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Decay of the high-spin isomers in ^{150,151,152}Ho

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The electron-capture decay properties of the high-spin isomers in ^{150,151,152}Ho were investigated. The nuclides were produced in ^{10}B bombardments of samarium and then transported to shielded areas with the use of gas-jet systems. Singles and coincidence γ-ray measurements were made. Each isomer decays primarily to one excited state in its dysprosium daughter by means of an allowed β transition (log*ft* values are ~ 4.5). The following explanations are proposed. For ^{150}Ho and ^{152}Ho the transitions connect $9^+(\pi h_{11/2},\nu f_{7/2})$ levels with $8^+(\nu h_{9/2},\nu f_{7/2})$ levels in ^{150}Dy(2401.8 keV) and ^{152}Dy(2437.6 keV). Deexcitation to the ground states then follows *via* a cascade of four $E2$ γ rays. In ^{151}Ho the β transition represents the changeover of an $h_{11/2}$ proton orbital to an $h_{9/2}$ neutron orbital in ^{151}Dy. This single neutron state lies at 527.4 keV and deexcites directly to the ground state. The α decay of ^{152}Ho was also investigated with the use of an on-line isotope separator. Its α-decay branching ratio was determined to be $10.5 \pm 3.0\%$.

[RADIOACTIVITY ^{150}Ho, ^{151}Ho, ^{152}Ho; measured $T_{1/2}$, E_γ, I_γ, $\gamma\gamma$ coin; ^{150}Dy, ^{151}Dy, ^{152}Dy deduced levels, J^π. ^{152}Ho; measured I_γ, I_α, deduced α-decay branching ratio; mass separation.]

I. INTRODUCTION

As part of our systematic study of low-lying states in nuclei around the $N = 82$ shell, we have recently identified[1] the new isotopes, ^{148}Ho and ^{149}Ho. Aiding in the identification was a concurrent investigation of the neighboring nuclides, ^{150}Ho, ^{151}Ho, and ^{152}Ho. Information available concerning the β^+/EC decay properties of these three isotopes is rather sparse and has been presented mainly in the form of unpublished results. The first data on ^{150}Ho decay were discussed briefly in a progress report[2]; the γ-ray energies and intensities were subsequently listed in Nuclear Data Sheets for $A = 150$ (Ref. 3) credited to a private communication.[4] The same experimental group was also the first to investigate[2,5] the β^+/EC decay of ^{152}Ho. A later singles γ-ray measurement[6] basically confirmed those results. In Ref. 6 an attempt was made to determine γ rays belonging to the decay ^{151}Ho.

In this paper we present data relating to the decay of high-spin isomers in ^{150}Ho, ^{151}Ho, and ^{152}Ho to levels in their respective dysprosium daughters. The information is compared with the earlier results mentioned above as well as with recent in-beam studies of these same dysprosium nuclei, i.e., ^{150}Dy (Refs. 7 and 8), ^{151}Dy (Ref. 9), and ^{152}Dy (Ref. 10).

II. EXPERIMENTAL METHOD

Most of the data reported herein were obtained by using gas-jet-capillary systems. Ions of ^{10}B^{3+}, accelerated both at the Oak Ridge and Texas A&M isochronous cyclotrons, were used to bombard targets of ^{144}Sm oxide. Product nuclei recoiling out of the thin targets were thermalized in helium gas and then pumped through Teflon capillaries to shielded areas where γ-ray measurements could be made. The recoils were collected on Mylar tapes which were attached to automated drive systems. These arrangements allowed radioactive nuclei to be collected for a preset time and then moved in front of two large-volume Ge(Li) detectors. At this time counting was started while a new source of activity was being collected. Singles and coincidence γ-ray measurements were made simultaneously. The coincidence data were accumulated in a three-word, γ-γ-τ, list mode with analog-to-digital converters interfaced to in-house computers. Singles spectra from one of the Ge(Li) detectors were stored in a spectrum multiscale mode for half-life information.

In the initial experiments at Oak Ridge, the target consisted of an ~300-μg/cm^2 layer of samarium oxide enriched in ^{144}Sm to 96.3%, electrodeposited onto a 12.7-μm beryllium foil. Incident energies on target of 60 and 75 MeV were used. At the latter energy, evidence was obtained that ^{149}Ho had been observed. Further experiments were performed at the Texas A&M cyclotron to take advantage of the availability of higher energy ^{10}B ions. Here, the energy was varied, with the use of aluminum absorbers, from 96 to 75 MeV. The target material consisted of samarium oxide enriched to only 85.6% in ^{144}Sm (see Table I for the isotopic composition). A layer of ~5 mg/cm^2 of the material, in the form of slurry, was evaporated on a 6.25-μm aluminum foil.

Some of the work on ^{152}Ho was done using the online isotope-separator facility at the Oak Ridge isochronous cyclotron. In this case the nuclide was produced in a ^{141}Pr (^{16}O, 5n) reaction as part of an ion-source development program.[11] Singles γ-ray and α-particle spectra were measured with Ge(Li) and Si(Au) detectors, respectively, placed in calibrated geometries to obtain information concerning the overall separation efficiency for rare earth nuclei.

III. RESULTS AND DISCUSSION

The discussion presented below deals mainly with data obtained at the Texas A&M cyclotron with 75-MeV ^{10}B ions. Bombardment and counting cycles at this incident energy were one minute in duration. Figure 1 shows a portion (~200–800 keV) of the singles spectrum accumulated during a large number of these cycles. With possibly one exception, all γ rays assigned to ^{150,151,152}Ho decay have energies that fall within the energy range displayed. In Fig. 1, γ-ray peaks whose nuclidic assignments were ascertained are labelled by isotope and energy.

TABLE I. Isotopic composition of the 85.6% enriched ^{144}Sm.

Mass number	Atomic %
144	85.6
147	4.0
148	2.2
149	2.2
150	1.0
152	2.9
154	2.1

A. ^{150}Ho decay

Because of the major closed shell at 82 neutrons, the maximum α-decay energy for a given element is reached at $N = 84$. As a result, α decay has not been observed for any rare earth nuclide with $N < 84$. It has been possible in some instances, however, to observe the radioactive decay of 83-neutron nuclides by noting a parent-daughter relationship between them and their α-decaying 84-neutron daughters. Indeed, ^{150}Ho was first identified in this manner by Macfarlane and Griffioen[12] who, in their studies of holmium α emitters, observed an initial growth period with a half-life of ~20 sec in the 4.23-MeV ^{150}Dy α group. They assigned this new activity to ^{150}Ho. In a later investigation,[13] also dealing with rare earth α emitters, an initial growth period was once again observed in the decay curve of the 4.23-MeV ^{150}Dy α group. From least-squares analyses a half-life of 30 ± 5 sec was determined for ^{150}Ho.

The β^+/EC decay of ^{150}Ho was first reported[2] as part of a short discussion of high-spin isomers in terbium, holmium, and thulium nuclei near the $N = 82$ shell. In a figure accompanying the text, ^{150}Ho was indicated to have a half-life of 20 sec and to populate primarily an 8^+ state at 2400 keV in ^{150}Dy which de-excited to the ground state via a cascade of four $E2$ γ rays. These four γ rays, i.e., 393.9, 551.1, 653.4, and 803.4 keV, can be seen in Fig. 1. From our multiscale data for these transitions we deduced a half-life of 28 ± 3 sec for ^{150}Ho. This value agrees with the one determined in Ref. 13 and is not in serious disagreement with the approximate half-life measured by Macfarlane and Griffioen.[12]

The assignment of the 28-sec activity to ^{150}Ho was further solidified by the following evidence obtained in the present investigation. Each of the four intense transitions was in coincidence with dysprosium K x rays. They had not been observed in studies[14-16] of dysprosium nuclides produced in ^{12}C + ^{142}Nd and ^{14}N + ^{141}Pr bombardments. Their intensities from 75 to 96 MeV varied with incident energy in the same manner as the 397.2-keV

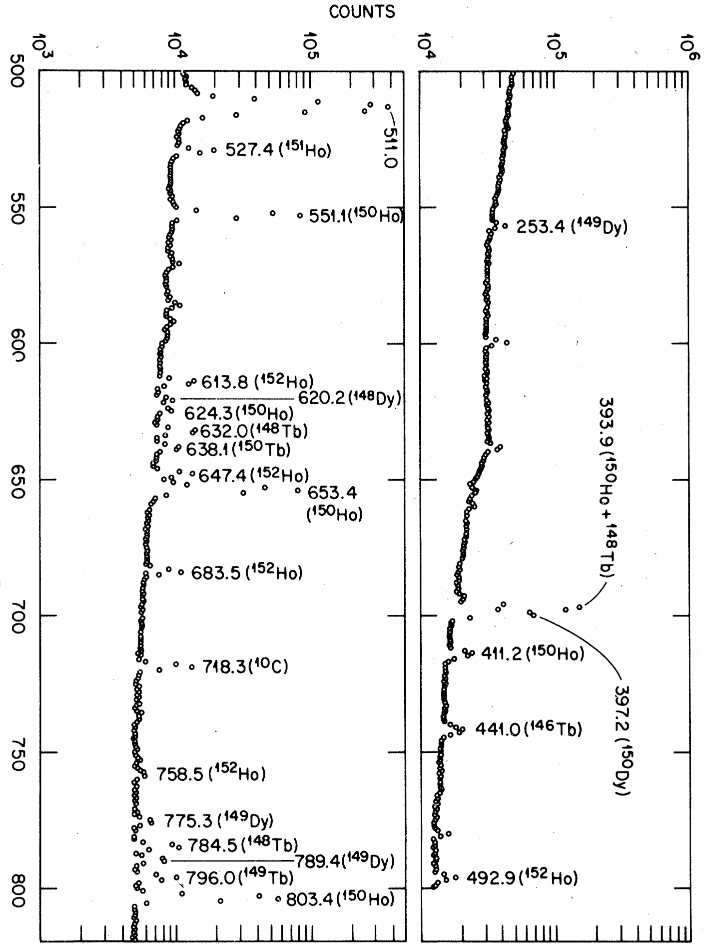

FIG. 1. Portion of a γ-ray spectrum obtained in 75-MeV ^{10}B bombardment of samarium oxide enriched in ^{144}Sm (isotopic composition is listed in Table I). It represents the accumulation of numerous 1-min irradiation and counting cycles. Peaks which could be identified are labelled by energy and nuclide. With the exception of ^{10}C they are terbium, dysprosium, and holmium isotopes.

γ ray known[14] to follow the decay of 7.2-min ^{150}Dy. In addition, this ^{150}Dy γ ray showed an initial growth period. While counting was done only out to one minute, the increase in ^{150}Dy activity was consistent with feeding from a parent whose half-life was about 30 sec.

In Table II our γ-ray energies and intensities are compared with those of Bowman *et al.*[2,4] as

TABLE II. Photon energies and intensities for transitions in ^{150}Dy.

^{150}Ho decay				In-beam	
(Present study)		(Refs. 3,4)		(Ref. 7)	(Ref. 8)
E_γ (keV)	I_γ [a]	E_γ (keV)	I_γ [b]	E_γ (keV)	E_γ (keV)
	<0.3			212.9	213.0
	<0.3			229.5	229.6
393.9 ± 0.1	93 ± 5	391.4 ± 0.5	100 ± 10	393.9	393.9
411.2 ± 0.2	7 ± 2			411.1	411.2
551.1 ± 0.1	88 ± 5	550.6 ± 0.5	85 ± 9	551.0	551.0
624.3 ± 0.2	3 ± 1			624.2	624.1
653.4 ± 0.1	100 ± 5	653.5 ± 0.5	100 ± 10	653.4	653.3
803.4 ± 0.1	100	804.4 ± 0.5	100 ± 10	803.7	803.3

[a] Relative intensities based on a value of 100 for the 803.4-keV transition.
[b] Relative intensities as listed in Ref. 3.

listed in Ref. 3. Included in the table are photon energies measured in-beam[7,8]; only transitions de-exciting ^{150}Dy levels up to spin of 10^+ are given in Table II. The next level observed[7,8] is 12^+ and would not be populated in the decay of ^{150}Ho whose spin, as we shall see, is very probably 9^+. Intensities for the observed transitions were not reported in either of the in-beam studies. In the case of the four strong transitions, seen in ^{150}Ho decay, our intensities agree with those of Bowman *et al.*[2,4] The energy values, however, are somewhat different particularly for the 393.9-keV transition where the discrepancy is 2.5 keV. Our energies agree with those measured in-beam though error limits are not indicated in the two studies. Additionally, γ rays of 411.2 and 624.3 keV, reported in Refs. 7 and 8, were observed for the first time in ^{150}Ho decay. The 393.4-, 411.2-, 551.1-, 653.4-, and 803.4-keV γ rays were in coincidence with one another. The assignment of the 624.3-keV transition to ^{150}Ho was made because its half-life was about 30 sec.

Figure 2 shows the decay scheme proposed for ^{150}Ho. It is based on coincidence data and photon intensities and on analogies with the decay schemes of neighboring odd-odd high-spin isomers. In particular, the decay pattern (see Ref. 17 for a more complete discussion) of its isotone, ^{148}Tb, is very similar. Here again, four strong $E2$ transitions are in coincidence with one another: 882 keV ($8^+ \rightarrow 6^+$), 395 keV ($6^+ \rightarrow 4^+$), 632 keV ($4^+ \rightarrow 2^+$), and 785 keV ($2^+ \rightarrow 0^+$). Note the similarity in energy to three of the ^{150}Ho γ rays, i.e., 394, 653, and 803 keV; this strongly suggests that they de-excite the 6^+, 4^+, and 2^+ levels in ^{150}Dy, respectively. Because the ^{150}Ho 551-keV γ ray is weaker than the other three, it must be located at the top of the cascade, as shown in Fig. 2. We should add that both in-beam studies have the same sequence for these four transitions. Piiparinen *et al.*[7] used a ^{12}C beam and observed the γ rays to have comparable strengths. They, therefore, based their

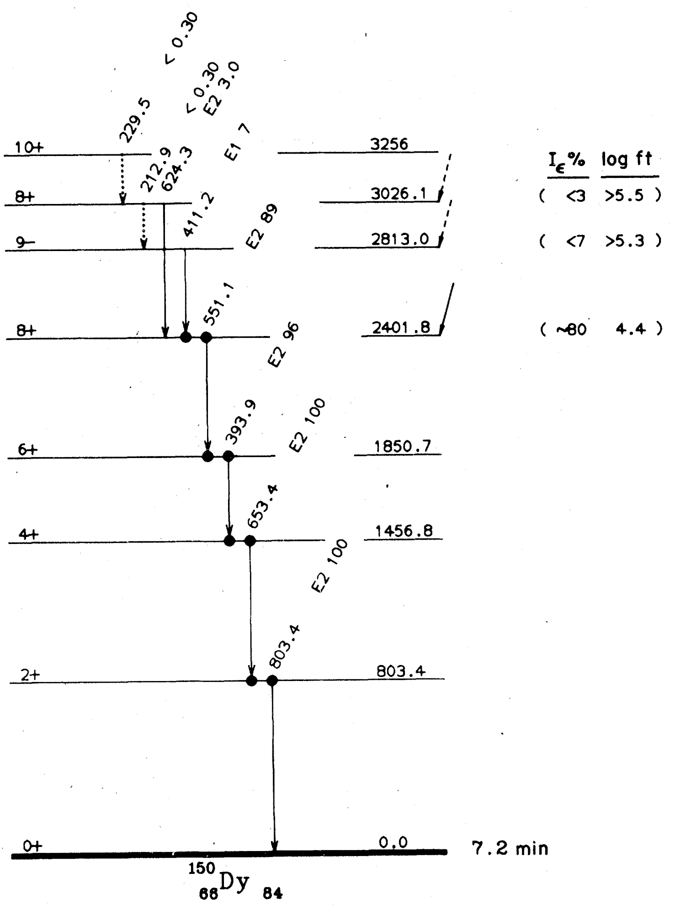

FIG. 2. Decay scheme of the 28-sec high-spin ^{150}Ho isomer ($Q_{\mathrm{EC}} \sim 7.1$ MeV). Dots indicate observed coincidences. Numbers following γ-ray energies and multipolarities represent total transition intensities calculated from photon intensities and theoretical conversion coefficients. Because of the transitions' high energies, the conversion coefficients are small, the largest one being ~3% for the 393.9-keV γ ray. The 10^+ level at 3256 keV is observed in-beam (Refs. 7 and 8).

level scheme on the work of Lunardi *et al.*[8] where the $(\alpha, 6n)$ reaction was used. As a result, according to Piiparinen *et al.*,[7] transition intensities observed in Ref. 8 decrease monotonically with increasing spin or excitation energy. While intensities are not given in Ref. 8, the statement appears to be correct, based on the widths of the arrows depicting the transitions in the accompanying level scheme.

Our data support the in-beam placement of the 411-keV transition, i.e., between the 2813- and 2402-keV levels. In-beam the 624-keV γ ray is observed as an intense transition; in agreement with Refs. 7 and 8, we place it between the 3026- and 2402-keV levels even though it was not seen in our coincidence spectra due to its weak intensity. A less intense 213-keV transition is seen in-beam also de-exciting the 3026-keV level. We can only set an upper limit for its intensity. Neither did we see the 230-keV transition which is shown in Refs. 7 and 8 as de-exciting at 10^+ level at 3256 keV.

About 80% of ^{150}Ho decay proceeds to the 2402-keV level. With an estimated[18] Q_{EC} of 7.1 MeV, one calculates a $\log ft$ value of ~4.4, indicating an allowed transition. This situation is once again similar to the decay of other neighboring high-spin isomers. In their decays much of the transition intensity occurs to a single level in the even-even daughters, with $\log ft$ values in the range 4.0–4.5. The interpretation offered (see Refs. 2 and 17, for example) is as follows. The isomers are due to the coupling of an $h_{11/2}$ proton orbital (available at $Z > 64$) and and $f_{7/2}$ neutron orbital (first one beyond $N = 82$) giving rise to a 9^+ spin. The level fed in the daughter then has to be 8^+. This spin and parity can be obtained by coupling the $f_{7/2}$ orbital to the next available neutron orbital, namely $h_{9/2}$. The allowed β transition would then connect states with the following configurations: $(\pi h_{11/2}, \nu f_{7/2}) \rightarrow (\nu h_{9/2}, \nu f_{7/2})$. The 0^+, 2^+, 4^+, and 6^+ levels can be understood in terms of coupling two $f_{7/2}$ neutrons.

Possible feedings are indicated in Fig. 2 for the 2813- (9^-) and 3026-keV (8^+) levels. Caution is expressed because the decay energy is high and there are very probably higher-lying, final states being fed by ^{150}Ho. Weak, unidentified transitions from these states could reduce the amount of direct decay to the 2813- and 3026-keV levels and increase significantly the $\log ft$ values. The same would not hold for the 2402-keV level because the 551-keV γ ray is so intense.

Finally, there is an indication of a slight intensity imbalance at the 6^+ 1851-keV level. Since β decay to this state would be extremely small, it apparently must be fed from a higher-lying state. One possibility would be a 7^- level, part of a negative-parity band built up on a 3^- state. A band of this nature does exist in ^{148}Gd. However, neither Refs. 7 nor 8 observed such a negative-parity band. We too were unable to identify any transitions in our spectra to propose additional levels in ^{150}Dy. A search was made for a 1175-keV transition which could connect the second 8^+ and the 6^+ levels. An upper limit of <0.4 (in terms of the units used in Table II) could be set for its intensity. Lunardi *et al.*[8] did not see this transition either.

B. ^{152}Ho decay

The high-spin isomer in ^{152}Ho was first identified by Macfarlane and Griffioen[12] via its α decay. This and subsequent studies (e.g., Ref. 19) established the mass assignment on the basis of excitation functions and α-decay systematics. Bowman *et al.*[5] were the first to report on the nuclide's β-decay properties. In a determination of its α-decay branching ratio, Schmidt-Ott *et al.*[6] also investigated its γ-ray spectrum. Table III summarizes transition energies and photon intensities obtained in the present gas-jet study and compares them with the data published in Refs. 5 and 6. The in-beam results[10] for the transitions seen in ^{152}Ho decay are also included in Table III.

TABLE III. Photon energies and intensities for transitions in ^{152}Dy.

		^{152}Ho decay				In-beam	
(Present study)		(Ref. 5)		(Ref. 6)		(Ref. 10)	
E_γ (keV)	I_γ [a]	E_γ (keV)	I_γ [a]	E_γ (keV)	I_γ [a]	E_γ (keV)	I_γ [a]
492.2 ± 0.1	59 ± 5	491	60	492.8 ± 0.1	70 ± 5	493.0	34
613.8 ± 0.1	100	613	100	614.0 ± 0.1	100	613.9	100
647.4 ± 0.1	100 ± 5	647	94	647.6 ± 0.1	104 ± 6	647.3	85
683.5 ± 0.1	86 ± 5	683	81	683.8 ± 0.1	102 ± 6	683.5	74
758.5 ± 0.2	11 ± 3			759.3 ± 0.3	15 ± 4	758.8	12

[a] Relative intensities based on a value of 100 for the 614-keV transition.

Our data show that the four intense $E2$ γ rays assigned to ^{152}Ho decay, i.e., 492.9, 613.8, 647.4, and 683.5 keV are in coincidence with one another. The weak 758.5-keV transition was observed in coincidence with the last three γ rays listed but not with the 492.9-keV γ ray. The four strong transitions were also found to be in coincidence with dysprosium K x rays. This information together with the fact that they were not seen in the studies[14-16] of dysprosium nuclides further solidifies their assignment. By combining their multiscale data a half-life of 54 ± 2 sec was determined, in agreement with previously reported values of 52.3 ± 0.5 sec (Ref. 12) and 50 ± 2 sec (Ref. 19) deduced from the isomer's α decay.

The ^{152}Ho decay scheme is shown in Fig. 3. It is based on coincidence relationships, γ-ray intensities, and on the fact that Schmidt-Ott *et al.*[6] observed the 614- and 647-keV transitions in the decay of the 2.4-min ^{152}Ho low-spin isomer. The placements also agree with the in-beam results where the intensities observed for the two transitions are different (see Table III). The ^{152}Ho electron-capture decay energy is given in Ref. 18 as 6410 ± 80 keV. By using this $Q_{\rm EC}$, a logft value of ~4.5 calculated for the β transition populating the 2438-keV level. Based on the arguments discussed in the previous section, we propose that this allowed transition connects $9^+(\pi h_{11/2}, \nu f_{7/2})$ and $8^+(\nu h_{9/2}, \nu f_{7/2})$ states in ^{152}Ho and ^{152}Dy, respectively. The 0^+, 2^+, 4^+, and 6^+ states can again be interpreted as being due to the coupling two $f_{7/2}$ neutron orbitals. A feed of ~11% is indicated for the 2703-keV level. As discussed earlier, this amount could be reduced by γ rays from higher-lying levels. The logft value of ~5.1, however, is consistent with the tentative 8^+ assignment.[10]

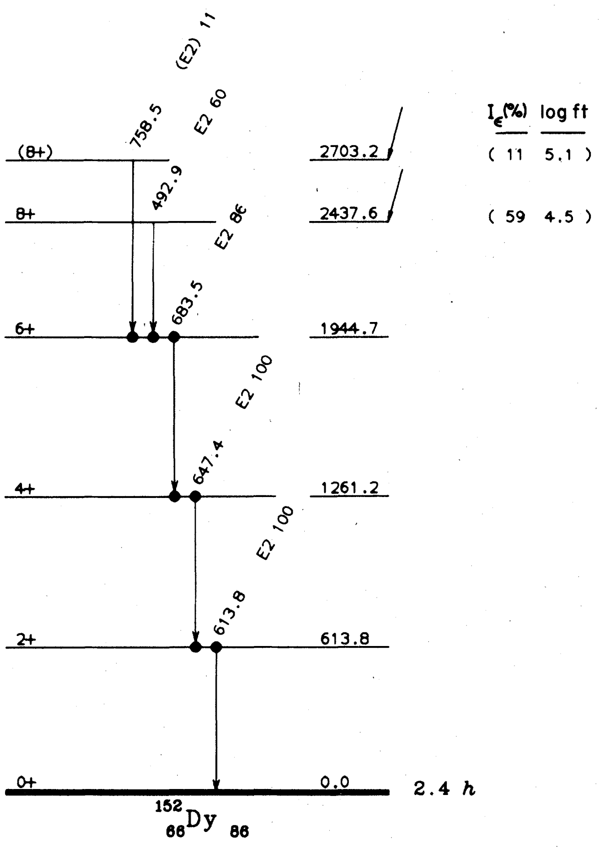

FIG. 3. Decay scheme of the 54-sec high-spin ^{152}Ho isomer ($Q_{\rm EC}$ = 6.41 MeV). Dots indicate observed coincidences. Numbers following γ-ray energies and multipolarities represent total transition intensities. However, because the conversion coefficients are small, only the 492.9-keV transition has any noticeable increase, ~1%, in intensity when internal conversion is taken into account.

The scheme shown in Fig. 3 has rather large imbalances at the 6^+ and 4^+ levels. The situation is particularly serious at the 4^+ level since it is improbable that states with spins ≤6, located at high excitations, would be fed by a 9^+ parent. An additional explanation of these imbalances may have to do with the fact that the ^{152}Dy level scheme is more complex than the one for ^{150}Dy. In contrast to ^{150}Dy, an odd-spin, negative parity, band up to a 9^- level at 2906 keV has been seen[10] in ^{152}Dy. Another complication is that the 614- and 647-keV transitions are proposed[10] to be doublets. This possibility could not be verified in our investigation, and only upper limits could be set for the intensities of transitions involving the odd-spin band. (See Table IV for a comparison of our limits with the intensities in Ref. 10.) Nevertheless, within the intensity limits for observed and unobserved γ rays, the three points discussed in this paragraph could account for the imbalance not only at the 6^+ but also the 4^+ level.

An ion-source development program,[11] designed to improve the ionization and extraction efficiency for rare earth nuclei, has been recently started at the University Isotope Separator at Oak Ridge (UNISOR). During one experiment in which 126-MeV ^{16}O ions bombarded a praseodymium foil it was possible to study the decay of ^{152}Ho for the first time with the aid of mass separation. Singles γ-ray and α-particle spectra were measured with detectors whose absolute efficiencies had been determined.

The four strong transitions were observed with approximately the same intensities listed in Table III. The 4.45-MeV α group (Refs. 12 and 19) was also observed. By assuming that the 614-keV

TABLE IV. Intensity limits for ^{152}Dy transitions observed in-beam.

	Reference 10		Present study
E_γ (keV)	Levels connected: J^π (keV)	I_γ [a]	I_γ [a]
203.0	$9^-(2906) \rightarrow 8^+(2703)$	4	<2
563.4	$\rightarrow 7^-(2343)$	30	<1
398.0	$7^-(2343) \rightarrow 6^+(1945)$	18	b
560.8	$\rightarrow 5^-(1782)$	16	<2
520.6	$5^-(1782) \rightarrow 4^+(1261)$	9	<4
553.8	$\rightarrow 3^-(1228)$	9	<2
~614	$3^-(1228) \rightarrow 2^+$ (614)	c	?

[a] Intensities based on a value of 100 for the 613.9-keV, $2^+ \rightarrow 0^+$, transition.

[b] Intensity not determined due to the proximity of the 397.2-keV ^{150}Dy transition (see Fig. 1).

[c] Intensity not given in Ref. 10.

transition encompasses all of the electron-capture strength, an α/total branching ratio of $(10.5 \pm 3.0)\%$ was deduced. This value is somewhat larger than those determined by Schmidt-Ott *et al.*[6] $(6.4 \pm 1.3)\%$, from K x-ray intensity, and $(4 \pm 1)\%$, from 614-keV γ-ray intensity. The three branches, however, lead to α-decay hindrance factors of only 2 to 5. (See Refs. 6 and 14 for a discussion of α-decay rates in this region.) Low hindrance factors strongly indicate that the α decay connects states with the same spin and parity. This would mean that the ^{152}Ho high-spin isomer probably α decays to the high-spin isomer in ^{148}Tb and that both have the proposed $9^+(\pi h_{11/2}, \nu f_{7/2})$ configurations.

C. ^{151}Ho decay

Macfarlane and Griffioen[12] first identified the high-spin isomer in ^{151}Ho on the basis of its α decay. Subsequent α-decay studies, such as Ref. 19, confirmed the assignment. The first investigation of its β decay was made by Schmidt-Ott *et al.*[6] in an effort to determine its α branch. A 527-keV γ ray was found to be the most intense transition associated with ^{151}Ho.

In the initial Oak Ridge experiments, utilizing the 96.3% enriched ^{144}Sm, a (527.4 ± 0.2)-keV γ ray was observed at an incident energy of 60 MeV to decay with a half-life of ~36 sec. Because of this half-life (see Refs. 12 and 19) and because the γ-ray's intensity decreased dramatically at 75 MeV, it was assigned to the ^{144}Sm(^{10}B, $3n$) product, i.e., ^{151}Ho. In later experiments at Texas A&M it was seen (Fig. 1) to decay with a half-life of 35 ± 2 sec. Thus the evidence accumulated in the present study supports the assignment[6] of this transition to the ^{151}Ho high-spin isomer. However, three of the ^{150}Ho γ rays, 551, 654, and 804 keV, were misassigned by Schmidt-Ott *et al.*[6] to ^{151}Ho, apparently because of their lesser intensities and the similarity in half-lives of the two nuclides.

The fact that only one intense ^{151}Ho γ ray has been identified is consistent with the decay properties of its isotone, ^{149}Tb. In the decay of the ^{149}Tb high-spin isomer a 796-keV transition represents[15] essentially all of the β-decay strength. This γ ray follows an allowed β transition, log*ft* of 4.2, corresponding to a change of an $h_{11/2}$ proton orbital in ^{149}Tb to an $h_{9/2}$ neutron state located at 796 keV in ^{149}Gd. A similar situation exists[17] in ^{147}Gd where the main $h_{9/2}$ state at 1397 keV receives a feeding of ~83%, log*ft* of ~4.1, from the high-spin isomer in ^{147}Tb. We, therefore, propose that the γ ray observed in the present study establishes the location of the $h_{9/2}$ neutron state in ^{151}Dy to be at 527 keV populated via an allowed transition, log*ft* of ~4.4, from the $h_{11/2}$ proton level in ^{151}Ho. As estimated[18] Q_{EC} of 5160 keV was used to calculate the log*ft* value. The decay scheme is shown in Fig. 4.

An in-beam study,[9] reported at a recent meeting, also proposes an $h_{9/2}$ neutron state at 527 keV in ^{151}Dy. In addition, the $i_{13/2}$ neutron orbital is said[9] to be at 968 keV. This state in ^{147}Gd and ^{149}Dy is known to be populated, albeit weakly, in the decay of ^{147}Tb (Ref. 17) and ^{149}Ho (Ref. 1). Our γ-ray spectrum was examined for a transition de-exciting this 968-keV level to the $f_{7/2}$ ground state. A weak γ ray was seen at 967.6 ± 0.3 keV. Its half-life could not be determined because of poor statistics. We do, however, show in Fig. 4 a tentative level at 968 keV with a feed of ~3% of that proceeding to the 527-keV level. The corresponding log*ft* of ~5.7 is similar to those deduced for the ^{147}Tb and ^{149}Ho transition feeding the $i_{13/2}$ states in their daughters. The competing $M2$ transition to the 527-keV level would have an energy of 440.2 keV. It would therefore be obscured by the 441-keV ^{146}Tb γ ray (see Fig. 1). The half-life of this peak was determined to be ~21 sec, in agreement with the 23 ± 2 sec ^{146}Tb half-life.[17]

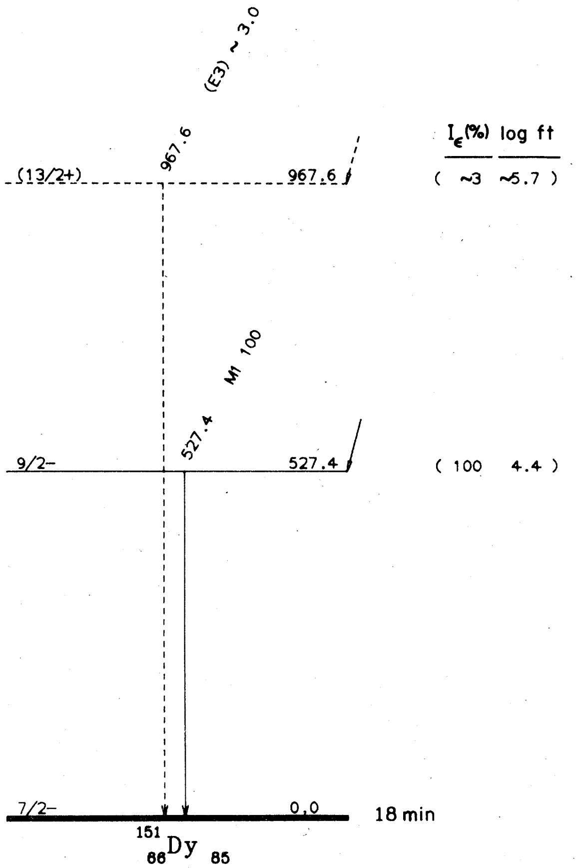

FIG. 4. Decay scheme of the 35-sec high-spin ^{151}Ho isomer ($Q_{EC} \sim 5.16$ MeV). Numbers following γ-ray energies and multipolarities represent relative intensities based on a value of 100 for the 527.4-keV transition. The level at 967.6 keV has been observed in-beam (Ref. 9).

There was no indication of a 35-sec component in the decay curve. On the basis of single-particle estimates one expects the 440-keV γ ray to be ~10 times more intense than the 967.6-keV γ ray. However, while $M2$ transitions are generally retarded, $E3$ transitions can be either enhanced or retarded. In particular, around $N=83$, $E3$ transitions have been found[20] to be enhanced by factors of 9 to 15. An enhancement of that order would make the two γ rays equal in intensity. The effect of the 440-keV γ ray on the half-life of the ^{146}Tb 441-keV transition would then be negligible.

IV. CONCLUSION

The decay properties of the high-spin isomers in ^{150,151,152}Ho were investigated. Previous results, available mostly in unpublished form, were in the main confirmed. However, only one of six γ rays assigned[6] to ^{151}Ho was observed in this study. In addition, three of the four ^{150}Ho transition energies listed in Nuclear Data Sheets were found to be somewhat off from the correct values. A comparison was made with recent in-beam investigations, as a result of which new decay information was deduced. The present study emphasizes the importance of the $h_{11/2}$ proton orbital in the high-spin isomers with $Z \geqslant 65$ and the fact that the main features of their decay schemes can be explained by invoking single-particle orbitals beyond $Z=64$ and $N=82$.

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