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New transitions and levels for ^{163}Tb obtained from β-decay studies

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Transitions in ^{163}Tb following β decay of ^{163}Gd were obtained as part of investigations of γ rays emitted following ^{163}Eu β decay to ^{163}Gd. Detailed analysis of the low-energy structure of ^{163}Tb has been carried out with these data to expand previous β-decay studies and reactions studies of levels in ^{163}Tb. Data were collected at the LeRIBSS station of the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory with an array of four Clover HPGe detectors for γ rays and two plastic scintillators for β detection. The γ rays were identified as belonging to ^{163}Gd and ^{163}Tb via mass selection and γ-γ-β, γ-γ, or γ-x-ray coincidence. In total, 38 new γ-ray transitions were observed in ^{163}Tb from 15 newly identified levels and 12 previously identified levels. Potential energy surface calculations were performed which support a rigid prolate deformation. Previously identified unplaced transitions in ^{163}Tb have been placed within the level scheme of ^{163}Tb and additional states and transitions have been identified.

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I. INTRODUCTION

Structural changes in neutron-rich nuclei following the rapid onset of deformation at 88 to 90 neutrons have instigated numerous investigations into the genesis and reach of this structural shift. Jones *et al.* [1] observed an aberration in the plot of the first 2^+ energy versus increasing neutron number from $N = 98$ to $N = 100$. To facilitate further study of this phenomenon, isotopes of mass 162–165 europium were produced for β-decay studies of levels in the daughter isotopes at the Holifield Radioactive Ion Beam Facility in Oak Ridge National Laboratory for observation of excited 162–165 gadolinium isotopes, neutron numbers 98 to 101. The data collection was optimized for observations of $^{162\text{–}165}$Gd; however, a large cohort of ^{163}Tb transitions were collected and analyzed as part of the study of ^{163}Gd recently published by Zachary *et al.* [2].

The structure of ^{163}Tb has previously been studied via the ^{164}Dy(d,^{3}He) reaction by Sugarbaker [3], γ spectroscopy following ^{163}Gd β^- decay by Gehrke *et al.* [4], and the ^{164}Dy(t,α) reaction by Garrett *et al.* [5]. The initial studies by Sugarbaker yielded a number of bands and levels within the structure of ^{163}Tb which were included in Dairiki *et al.*'s work [6]. However, the experiment had low resolution. Following Gehrke *et al.*'s [4] work, which studied transitions following ^{163}Gd β decay and identified 11 transitions, Burrows [7] placed the transitions observed without coincidence in Gehrke *et al.*'s [4] work into the structure observed by Sugarbaker [3]. However, findings from Garrett *et al.*'s [5] work were incompatible with the previously identified level scheme of ^{163}Tb, published in 1989 [7]. As a result, only three of the previously observed transitions were tentatively placed in the level scheme of ^{163}Tb.

This work has confirmed all 11 of the transitions previously observed by Gehrke *et al.* Furthermore, Garrett *et al.*'s [5] proposition that the 373.37-, 396.4-, 575.1-, 1167.7-, 1234.4-, and 1311.6-keV γ transitions were not correctly placed in the 1989 level scheme was also confirmed. In addition to the previous 11 transitions, 38 new transitions have been observed for ^{163}Tb, five of which are tentative. All transitions have been observed between 15 new levels, two of which

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are tentative, and 12 previously identified levels from reaction studies.

The three rotational bands observed are assigned spins and parities from earlier reaction studies and potential energy surface calculations were performed for the ground-state configuration of spin $\pi 3/2^+[411]$ and band heads of spin $\pi 5/2^+[413]$ and $\pi 7/2^-[523]$. The calculation results are consistent with ^{163}Tb being rigid and axially deformed.

II. EXPERIMENTAL METHODS

Data for this study were collected from isotopes produced via fission at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory. Isotopes were accelerated after fission and magnetically separated twice to produce an isotopically pure beam which was implanted onto a movable tape which was cycled to allow preferential observation of γ-ray emissions following β decay from ^{163}Eu to ^{163}Gd. A cycle of 30 s for source collection and 25 s with the beam off for decay observations was selected based upon half-life measurements for ^{163}Eu and ^{163}Gd. Following the accumulation and decay times, the tape was removed to behind a shield and the cycle repeated. For ^{163}Eu, the half-life was measured by Osa *et al.* [8] to be 7.7(4) s, by Sato *et al.* [9] to be 7.8(5) s, and by Wu *et al.* [10] to be 8.1(16) s. The half-life of ^{163}Gd was measured as 68(3) s by Gehrke *et al.* [4]. With the total cycle time of 55 s, significant data from decay to ^{163}Tb were obtained.

For a subset of the data, the intensities of the ^{163}Tb γ transitions were greatly enhanced relative to all other beam constituents as part of a 46-min saturation measurement where in the tape was not cycled. The discovery work on ^{163}Tb was primarily based on this data set combined with tape cycle data. Intensities and energy measurements were then performed with only tape cycle data to reduce the effect of contaminant transitions from decay products.

A Clover Array for Radioactive Decay Spectroscopy (CARDS) consisting of four high-purity germanium detectors and two plastic scintillators was implemented. Data acquisition was via digital pulse processing with Pixie16 modules according to methods detailed by Grzywacz [11]. This array collected data which allowed coincidence analysis to be carried out for γ-γ, x-ray-γ, γ-tape cycle, γ-β and associated coincidence projections. X-ray-γ, γ-tape cycle, and γ-β coincidences were implemented for identification of source isotope for given γ-ray observations. In turn, γ-γ coincidence was used for establishing the structure of ^{163}Tb. Further details of the experiment are found in the recent publication by Zachary *et al.* [2].

III. RESULTS

Gehrke *et al.* [4] previously performed γ-ray spectroscopy of ^{163}Tb following ^{163}Gd β^- decay, observing 11 transitions at the following energies: 214.0, 287.79, 373.37, 396.4, 575.1, 632.9, 1167.7, 1234.4, 1311.6, 1562.1, and 1684.5 keV. However, only the 214.0-, 287.79-, and 373.37-keV transitions were subsequently placed correctly within the structure of ^{163}Tb, as discussed by Garrett *et al.* [5]. These previously known transitions provided an excellent starting point for the present work, where they are observed as 213.8, 288.1, 373.5, 396.8, 574.9, 632.9, 1168.2, 1234.7, 1311.8, 1562.6, and 1685.1 keV respectively. Now all of these transitions have been placed in the level scheme as part of this work.

Figure 1 shows the level scheme for ^{163}Tb produced as part of this work. Each transition was placed based upon a variety of background-subtracted gates in addition to those gates shown here. Where separate gates did not agree, or where a gate on the transition in question yielded too few counts to confirm coincident transitions and the anticipated x-ray spectra, transitions have been placed tentatively according to level spacing or atop the strongest transition whose gate indicates the presence of the transition in question.

Table I lists every transition observed in ^{163}Tb. The relative intensities are referenced to the 288.1-keV transition with uncertainties of the last digit indicated in parentheses. To allow better approximation of feeding and outflow from levels in the structure, the internal conversion-corrected intensities, obtained by using coefficients from BrIcc [12], are also shown along with the multipolarities assumed for calculating the internal conversion corrections for those transitions with sufficient internal conversion; the displayed uncertainty is only the uncertainty in measurement of the γ-ray observations and does not account for possible multipolarity mixing of the internal conversion coefficient. The energies of the initial and final levels and the spins of the initial and final levels for those levels with spin assignments are shown in the final two columns.

Beginning from a gate on the 288.1-keV transition, shown in Fig. 2(f), four of the previously observed transitions, 574.9, 632.9, 1168.2, and 1562.6 keV, are found to be coincident with the 288.1 and 10 additional coincident transitions are observed at 82.2, 242.3, 394.7, 761.7, 768.6, (802.1), 929.5, 948.1, 1086.2, and 1480.9 keV. This gate and others are consistent with the previous tentative placement of the 213.8- and 288.1-keV transitions and they are thus listed here as confirmed transitions from the 341.8-keV $7/2^-$ level.

Figure 2(d) shows the gate on the 373.5-keV transition which reveals the coincidence relationship between the previously observed and placed 373.5-keV transition and the previously observed, but most recently unplaced [5], 1311.8-keV transition as well as the new 735.5-, 795.3-, and 1365.7-keV transitions. The 735.5- and 795.3-keV transitions are sequentially coincident with each other. This pair of transitions now forms a connection to the level previously observed in reaction studies at 1902(5) keV [5], observed in this study as 1904.6(5) keV, while the previously observed 1311.6(3)-keV transition from Gehrke *et al.*'s β^--decay study now originates from a new level at 1685.1(4) keV and is observed with an energy of 1311.8(2) keV.

In Fig. 2(e) is seen the gate on the 396.8-keV transition which yields observation of the previously identified 1234.7-keV transition and four new transitions of 541.2, 718.0, 735.5, 843.6, and 1059.6 keV. The coincidence between the 396.8-keV transition and the 1234.7-keV transition is confirmed by a gate on the 1234.7-keV transition, not shown. The presence of a weak 373.5-keV transition in the 1234.7-keV gate indicates there is a 77.6-keV transition from the 450.4-keV level to the 373.5-keV level. However, this is the only

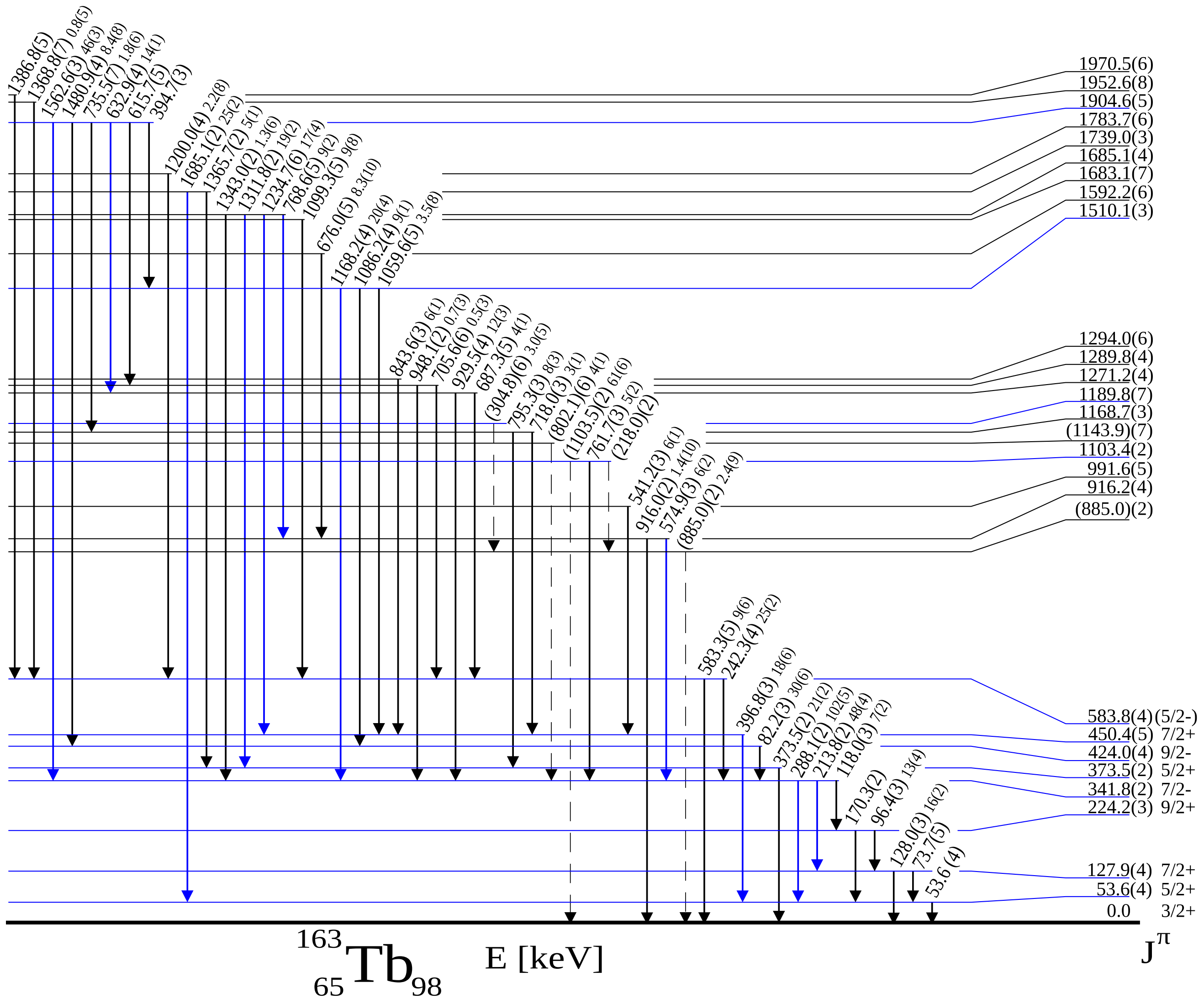

FIG. 1. Level scheme of ^{163}Tb. New transitions and levels are shown in black, while previously observed transitions and levels seen in reaction studies are in blue. Of the previously observed transitions, only the 213.8-, 288.1-, and 373.5-keV transitions were placed in the level scheme. Tentative transitions are dashed and tentative levels have labels in parentheses. Relative intensities corrected for internal conversion are detailed in Table I.

evidence for this transition and thus no such transition is listed or placed in the level scheme.

The gate on the 574.9-keV transition shown in Fig. 2(c) confirms the placement of the 574.9-keV transition feeding the 7/2$^-$ level at 341.8 keV and reveals two feeding transitions of 676.0 and 768.6 keV, the latter of which confirms the placement of the 1685.1-keV level. Gates on both the 676.0- and 768.6-keV transitions confirm these placements, not shown. The 414-, 666-, 695-, and 720-keV transitions are from ^{126}Te contamination from a previous experiment.

Shown in Fig. 2(b) is the gate on the (885.0)-keV transition which shows coincidences with two transitions, (218.0) and (304.8) keV. Both transitions have been assigned tentative locations within the level scheme. Gates on these transitions are observed in coincidence with terbium x rays. These are presently placed in the level scheme associated with the 1103.4- and 1189.8-keV levels. The (218.0)- and (304.8)-keV transitions are seen clearly in Fig. 2(b). The terbium x rays in the (885.0)-keV gate are observed weakly which supports the assignments of (885.0)-keV level feeding directly to ground with some feeding from above.

From the gate on the 1200.0-keV transition shown in Fig. 2(a), evidence is observed for the 583.3-keV transition feeding the ground state and the 242.3-keV transition feeding the 341.8-keV level from which the 213.8- and 288.1-keV transitions originate.

The (1103.5)- and 1685.1-keV transitions are observed in singles, with weak Tb x rays observed when gating on the 1685.1-keV transition. The 1685.1-keV transition has thus been included as feeding the 53.6-keV level as the 53.6-keV transition is greatly internally converted and results in coincidence predominantly observed with only the x rays from

TABLE I. Transitions in ^{163}Tb. Transition energy, intensity, internal conversion-corrected intensity obtained using coefficients from BrIcc [12], assumed multipolarity (uncertainties do not consider possible multipolarity mixing), energy, and J^π of initial and final levels. J^π assignments adopted from Refs. [3–5].

E_γ (keV)	I_γ (rel)	I_γ + ce	ICC multipolarity	E_i	E_f	J_i^π	J_f^π
53.6(4)				53.6(4)	0.0	$5/2^+$	$3/2^+$
73.7(5)				127.9(4)	53.6(4)	$7/2^+$	$5/2^+$
82.2(3)	6(1)	30(6)	3.86 $M1$	424.0(4)	341.8(2)	$9/2^-$	$7/2^-$
96.4(3)	4(1)	13(4)	2.44 $M1$	224.2(3)	127.9(4)	$9/2^+$	$7/2^+$
118.0(3)	6(2)	7(2)	0.19 $E1$	341.8(2)	224.2(3)	$7/2^-$	$9/2^+$
128.0(3)	8(1)	16(2)	1.07 $E2$	127.9(4)	0.0	$7/2^+$	$3/2^+$
170.3(2)				224.2(3)	53.6(4)	$9/2^+$	$5/2^+$
213.8(2)	46(4)	48(4)	0.04 $E1$	341.8(2)	127.9(4)	$7/2^-$	$7/2^+$
(218.0)(2)	4(2)			1103.4(2)	(885.0)(2)		
242.3(4)	21(2)	25(2)	0.18 $M1$	583.8(4)	341.8(2)	$(5/2^-)$	$7/2^-$
288.1(2)	100(5)	102(5)	0.02 $E1$	341.8(2)	53.6(4)	$7/2^-$	$5/2^+$
(304.8)(6)	3.0(5)			1189.8(7)	(885.0)(2)		
373.5(2)	21(2)			373.5(2)	0.0	$5/2^+$	$3/2^+$
394.7(3)				1904.6(5)	1510.1(3)		
396.8(3)	18(6)			450.4(5)	53.6(4)	$7/2^+$	$5/2^+$
541.2(3)	6(1)			991.6(5)	450.4(5)		$7/2^+$
574.9(3)	6(2)			916.2(4)	341.8(2)		$7/2^-$
583.3(5)	9(6)			583.8(4)	0.0	$(5/2^-)$	$3/2^+$
615.7(5)				1904.6(5)	1289.8(4)		
632.9(4)	14(1)			1904.6(5)	1271.2(4)		
676.0(5)	8(1)			1592.2(6)	916.2(4)		
687.3(5)	4(1)			1271.2(4)	583.8(4)		$(5/2^-)$
705.6(6)	0.5(3)			1289.8(4)	583.8(4)		$(5/2^-)$
718.0(3)	3(1)			1168.7(3)	450.4(5)		$7/2^+$
735.5(7)	1.8(6)			1904.6(5)	1168.7(3)		
761.7(3)	5(2)			1103.4(2)	341.8(2)		$7/2^-$
768.6(5)	9(2)			1685.1(4)	916.2(4)		
795.3(3)	8(3)			1168.7(3)	373.5(2)		$5/2^+$
(802.1)(6)	4(1)			(1143.9)(7)	341.8(2)		$7/2^-$
843.6(3)	6(1)			1294.0(6)	450.4(5)		$7/2^+$
(885.0)(2)	2.4(9)			(885.0)(2)	0.0		$3/2^+$
916.0(2)	1.4(10)			916.2(4)	0.0		$3/2^+$
929.5(4)	12(3)			1271.2(4)	341.8(2)		$7/2^-$
948.1(2)	0.7(3)			1289.8(4)	341.8(2)		$7/2^-$
1059.6(5)	3.5(8)			1510.1(3)	450.4(5)		$7/2^+$
1086.2(4)	9(1)			1510.1(3)	424.0(4)		$9/2^-$
1099.3(5)	9(8)			1683.1(7)	583.8(4)		$(5/2^-)$
(1103.5)(2)	61(6)			1103.4(2)	0.0		$3/2^+$
1168.2(4)	20(4)			1510.1(3)	341.8(2)		$7/2^-$
1200.0(4)	2.2(8)			1783.7(6)	583.8(4)		$(5/2^-)$
1234.7(6)	17(4)			1685.1(4)	450.4(5)		$7/2^+$
1311.8(2)	19(2)			1685.1(4)	373.5(2)		$5/2^+$
1343.0(2)	1.3(6)			1685.1(4)	341.8(2)		$7/2^-$
1365.7(2)	5(1)			1739.0(3)	373.5(2)		$5/2^+$
1368.8(7)	0.8(5)			1952.6(8)	583.8(4)		$(5/2^-)$
1386.8(5)				1970.5(6)	583.8(4)		$(5/2^-)$
1480.9(4)	8.4(8)			1904.6(5)	424.0(4)		$9/2^-$
1562.6(3)	46(3)			1904.6(5)	341.8(2)		$7/2^-$
1685.1(2)	25(2)			1739.0(3)	53.6(4)		$5/2^+$

Tb. The 1685.1-keV transition is presently assigned to be decaying from the 1739.0-keV level to the 53.6-keV level. This assignment is consistent with the observations from the gate on 1685.1 keV, not shown. A doublet transition from the 1685.1-keV level to the ground state is possible but not included in the present level scheme. The (1103.5)-keV transition is tentatively assigned as originating from the 1103.4-keV level to the ground state.

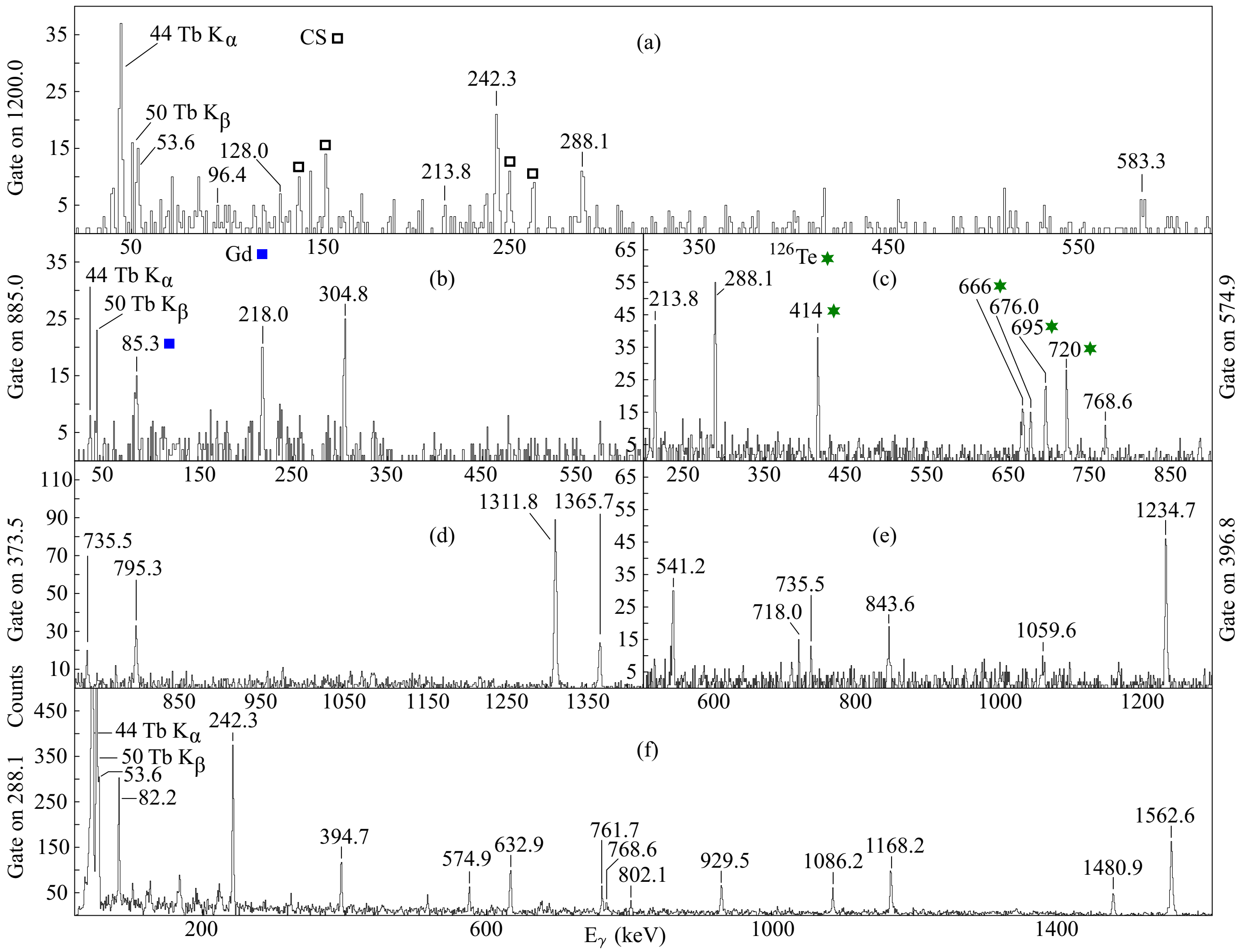

FIG. 2. Coincidence spectra for gates on ^{163}Tb transitions (a) 1200.0, (b) 885.0, (c) 574.9, (d) 373.5, (e) 396.8, and (f) 288.1 keV.

IV. DISCUSSION

Shown in Table II are the γ feeding and outflow values observed for ^{163}Tb. For known odd-parity states, there is limited observed β feeding, with limited observed γ outflow greater than observed γ feeding. This is consistent with the current proposed ground state for ^{163}Gd of $7/2^+$[2], especially as the states with the highest β feeding are the allowed spin $\Delta I = 0$ transition from a parent ground state of $7/2^+$ to a daughter state of $7/2^+$ and the $\Delta I = 1$ allowed β transitions to the $5/2^+$ and $9/2^+$ states.

A number of levels are observed to have more γ feeding than outflow. For all cases in ^{163}Tb, this difference in feeding compared to observed outflow is anticipated to be due to additional unobserved transitions. Lack of observation is likely due to strong internal conversion. For the 53.6-, 127.9-, and 224.2-keV levels, possibly strong depopulating transitions have been identified; however, accurate intensity measurements for these transitions are not possible due to background transitions.

In Fig. 1, levels have been indicated as previously observed for cases where the presently observed energies are within the previously published uncertainties and have depopulating transitions consistent with previous spin observations. The low-energy band structure of ^{163}Tb has already been well established and this work primarily fills in the previously unobserved transitions. For those previously observed states higher in the structure of ^{163}Tb, where the density of states is increased, it is possible that states of similar energy observed in this work are newly observed states. Table III lists the levels identified in reaction studies by Sugarbaker [3] and Garrett *et al.* [5] alongside the levels proposed in this work.

Sugarbaker [3] observed a level at 574(10) with a tentative spin assignment of $(7/2^-)$. A similar observation was made by Garrett *et al.* [5] on the shoulder of the 552-keV level, which was listed in their table without an independent energy listing and a tentative spin assignment of $(5/2^-)$ [532] band head. In the present work, a level is observed at 583.8(4) keV without any related band levels and is a candidate for the $(5/2^-)$ [532] band head as proposed by Garrett *et al.* [5].

Sugarbaker observed the 1110(15)- and 1512(15)-keV levels without spin assignments [3]. These are observed as 1103.4(2) and 1510.1(3) keV in this work. There are no observation of band excitations associated with these levels in the present work and have thus been included without spin assignment. The levels observed by Garrett *et al.* at 1186(5)

TABLE II. Internal conversion–corrected γ feeding and γ outflow in ^{163}Tb, including intensity observations of tentative transitions. J^π assignments adopted from Refs. [3–5].

E_{Level} (keV)	γ Feeding	γ Outflow	J^π
0.0[a]	112(9)		$3/2^+$
53.6(4)[†,a,b]	145(8)		$5/2^+$
127.9(4)[†,b]	60(6)	16(2)	$7/2^+$
224.2(3)	7(2)	13(4)	$9/2^+$
341.8(2)	151(9)	157(7)	$7/2^-$
373.5(2)[†]	32(4)	21(2)	$5/2^+$
424.0(4)	18(1)	30(6)	$9/2^-$
450.4(5)[†]	35(5)	18(6)	$7/2^+$
583.8(4)[a]	17(9)	34(6)	$(5/2^-)$
(885.0)(2)[a]	7(2)	2.4(9)	
916.2(4)[†]	17(2)	8(2)	
991.6(5)		6(1)	
1103.4(2)[b]		70(7)	
(1143.9)(7)		4(1)	
1168.7(3)	1.8(6)	11(4)	
1189.8(7)		3.0(5)	
1271.2(4)	14(1)	16(3)	
1289.8(4)[a]		1.2(4)	
1294.0(6)		6(1)	
1510.1(3)[a]		33(4)	
1592.2(6)		8(1)	
1683.1(7)		9(8)	
1685.1(4)		46(5)	
1739.0(3)		30(2)	
1783.7(6)		2.2(8)	
1904.6(5)[b]		70(4)	
1952.6(8)		0.8(5)	
1970.5(6)[b]			

[†] Apparent excess feeding due to lack of clear observation of depopulating transitions.

[a] These states have been observed populating transitions for which the intensity could not be fully quantified; the reported feeding is a lower limit.

[b] These states have been observed depopulating transitions for which the intensity could not be fully quantified; the reported outflow is a lower limit.

and 1902(5) keV [5] and by Sugarbaker at 1184(15) and 1910(15) keV [3], without spin assignment, are observed as 1189.8(7) and 1904.6(5) keV in the present work.

For the level observed by Sugarbaker [3] at 994(10) keV, a level of similar energy is observed within this work at 991.6(5) keV. However, Sugarbaker's proposed doublet of spins 1/2 and 3/2 is not consistent with observations in either the work of Garrett *et al.* or this work, and thus the 991.6(5)-keV level is listed as a new level without spin assignment. Similarly, Sugarbaker observed a level at 1292(15) with a spin assignment of $(5/2^+)$ in the $1/2^+[420]$ band. The 1289.8(4)- and 1294.0(6)-keV levels observed in this work do not have transitions depopulating the levels, consistent with being an excited state in the $1/2^+[420]$ band, and are proposed as a

TABLE III. Levels previously identified in ^{163}Tb via reaction studies by Garrett *et al.* [5] and Sugarbaker [3] as listed by Reich *et al.* [13] compared to present study.

E_{level} (keV) [5]	J^π	E_{level} (keV) [3]	J^π	E_{level} (keV)	J^π
0	$3/2^+$	0	$(3/2)^+$	0	$3/2^+$
54(2)	$5/2^+$	57(10)	$(5/2)^+$	53.6(4)	$5/2^+$
128(5)	$7/2^+$	122(10)	$(7/2^+)$	127.9(4)	$7/2^+$
223(2)	$9/2^+$	235(10)	$(9/2^+)$	224.2(3)	$9/2^+$
344(5)	$7/2^-$	343(10)	$(7/2)^-$	341.8(2)	$7/2^-$
373(5)	$5/2^+$	388(10)	$(5/2^+)$	373.5(2)	$5/2^+$

TABLE III. (*Continued*).

E_{level} (keV) [5]	J^π	E_{level} (keV) [3]	J^π	E_{level} (keV)	J^π
422(5)	$9/2^-$			424.0(4)	$9/2^-$
		437(10)	$(5/2^-)$		
452(2)	$7/2^+$	465(10)	$(7/2)^+$	450.4(5)	$7/2^+$
522(2)	$11/2^-$	537(10)	$(11/2)^-$		
(552)(5)	$9/2^+$				
(552)	$(5/2^-)$			583.8(4)[a]	$(5/2^-)$
		574(10)	$(7/2^-)$		
(640)(10)	$(3/2^+)$				
662(5)	$7/2^-$				
		674(10)	$(3/2^+)$ & $(1/2^+)$		
(678)(10)	$(5/2^+)$				
		709(10)	$(5/2^+)$		
771(5)	$9/2^-$				
		789(10)	$(7/2^+)$		
				(885.0)(2)	
890(2)	$11/2^-$	896(10)	$(11/2)^-$		
				916.2(4)	
960(5)	$(1/2^+)$				
987(2)	$(3/2)^+$	994(10)	$1/2^+$ & $3/2^+$		
				991.6(5)[a]	
1065(2)	$(5/2)^+$				
		1066(15)	$(3/2^-)$		
1112(5)	$(7/2)^+$				
		1110(15)		1103.4(2)	
				(1143.9)(7)	
				1168.7(3)	
1186(5)		1184(15)		1189.8(7)	
1219(2)	$(1/2^+)$	1226(15)	$(1/2^+)$ & $(7/2^-)$		
				1271.2(4)	
1281(2)	$3/2^+$ & $5/2^+$	1292(15)	$(5/2)^+$		
				1289.8(4)[a]	
				1294.0(6)	
1351(5)		1371(15)	$(9/2^+)$		
1428(2)	$7/2^+$ & $9/2^+$	1441(15)	$(7/2^+)$		
1498(5)					
		1512(15)		1510.1(3)	
1549(5)		1564(15)			
				1592.2(6)	
				1683.1(7)	
				1685.1(4)	
				1739.0(3)	
				1783.7(6)	
1815(2)	$(7/2)^-$	1818(15)			
1902(5)		(1910)(15)		1904.6(5)	
				1952.6(8)	
1982(2)	$(11/2)^-$				
		1983(15)	$(7/2)^+$		
				1970.5(6)[a]	
2204(5)					
2334(5)					
2432(5)					

[a] Level within the uncertainty of observations by Sugarbaker [3], however, transitions from level not consistent with spin assignment and level energy not consistent with observations from Garrett *et al.* [5].

new levels without spin assignment. Sugarbaker observed a level at 1983(15) with a tentative spin assignment of $(7/2)^+$. The 1970.5(6)-keV level observed in this work is within the uncertainty of this previous measurement but decays only to a $5/2^-$ state; thus it is not interpreted to be the level observed by Sugarbaker and has been included as a new level without spin assignment.

A. Potential energy surface calculations

The configuration-constrained potential-energy surface (PES) method [14], using a nonaxial deformed Woods-Saxon potential [15] and universal parameters, was implemented to generate single-particle levels. As the total energy of a nucleus is composed of a macroscopic part obtained from the standard liquid-drop model and a microscopic part computed with the shell-correction approach, including blocking effects, the deformation, excitation energy, and pairing property of a given state can be determined by minimizing the obtained PES. For these calculations, the Lipkin-Nogami method [16] was implemented, thereby avoiding the spurious transitions observed in the BCS approach.

A set of calculations were performed for the following configurations of the ^{163}Tb nucleus: $\pi 3/2^+[411]$, $\pi 5/2^+[413]$, and $\pi 7/2^-[523]$, which correspond to the ground state and two lowest band heads. Further calculations were done for the $\pi 1/2^+[411]$ and $\pi 5/2^-[532]$ configurations. Yet, no levels in the structure proposed here have been assigned these configurations. The deformations yielded by these calculations were consistent with a rigid deformed nucleus without any expected shape coexistence or triaxiality. Figure 3 is the plot of the $\pi 3/2^+[411]$ PES calculation.

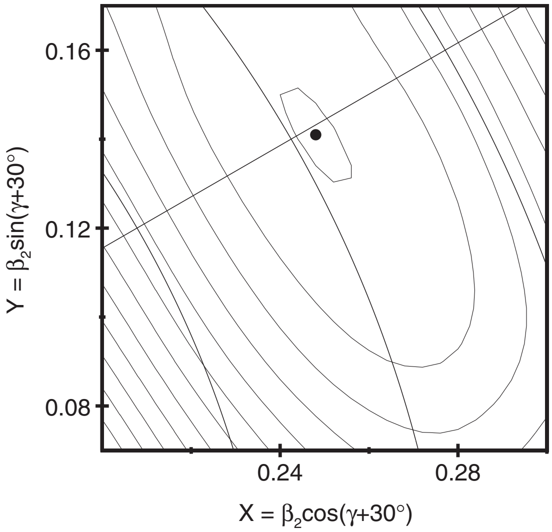

FIG. 3. PES calculation for $\pi 3/2^+$ [411]. $\beta_2 = 0.286$, $\gamma = 0$, and $\beta_4 = 0.028$.

V. SUMMARY

The low-energy level scheme of ^{163}Tb has now been rigorously examined across three previous studies [3–5] and this present one. Those transitions previously observed by Gehrke *et al.* [4], placed into a proposed structure by Burrows [7], and removed from the structure following publications by Garrett *et al.* [5] have been relocated within the structure of ^{163}Tb alongside 38 new γ transitions. Furthermore, the findings presented here have increased observations of the structure ^{163}Tb, adding 15 newly identified levels and improving the energy resolution of 12 previously identified levels. Potential energy surface calculations support ^{163}Tb being rigid and axially deformed.

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