Decay of the 6^- isomer of ^{164}Tm

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The decay of the 6^- isomer of ^{164}Tm has been studied by gamma-ray spectroscopy with large-volume high-resolution germanium detectors. Levels in ^{164}Er belonging to six different bands with $K^\pi=0^+$, 2^+, 0^-, 2^-, 5^-, and 7^- are observed in the 5.1 min ^{164}Tm decay. Two new levels at 1683.64 and 3302.8 keV and four levels at 1610.5, 1764.1, 1798.8, and 2163.65 keV known from reaction studies in ^{164}Er are observed to be populated in the decay. The revised decay scheme of the 5.1 min ^{164}Tm based on the present work shows 17 additional γ-ray transitions including eight new transitions with energies 73.0, 199.5, 486.0, 551.5, 624.6, 737.06, 1139.2, and 1317.6 keV, and nine other γ-ray transitions with energies 178.61, 251.0, 299.8, 347.2, 520.3, 1059.4, 1149.6, 1184.3, and 1499.3 keV, in agreement with the results of reaction studies. The results of the measurements are discussed in the light of the known band structure of ^{164}Er.

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I. INTRODUCTION

The decay of the 6^- isomer of ^{164}Tm with a half-life of 5.1 min has been reported by de Boer *et al.* [1] and Adam *et al.* [2]. They reported several levels and transitions in ^{164}Er from a study of the electron capture decay of the isomer. The nucleus ^{164}Er has also been studied in great detail by in-beam spectroscopy of γ rays following reactions [3–7]. Several bands of levels of both positive and negative parity have been established in ^{164}Er from these studies. Several γ-ray transitions observed from low-lying states in ^{164}Er from the in-beam studies, but not reported in Refs. [1,2], are expected to be seen in the electron capture decay of the 6^- isomer of ^{164}Tm. The decay scheme of the 5.1 min ^{164}Tm in Ref. [1] shows mismatch of γ-ray intensities at 4 levels of the γ-vibrational band in ^{164}Er. Only the depopulating γ-ray transitions are reported from the 3^+, 4^+, and 7^+ members of this band whereas the populating intensity at the 6^+ level is ~ 5 times the intensity of the depopulating transition. Many γ-ray transitions reported in Ref. [1] are not confirmed by coincidence relations due to poor counting statistics. The decay scheme reported in Ref. [2], on the other hand, gives widely different intensities for some of the γ rays, but does not show the above-mentioned 6^+ and 7^+ states of ^{164}Er to be populated in this decay. The in-beam studies [3–7] on ^{164}Er show multiple band crossings and mixing of different bands in this nucleus. Therefore, one can expect β decay from the 6^- ^{164}Tm to some new levels in ^{164}Er where the β decay is permitted by selection rules. The present work was undertaken to resolve the above-mentioned problems by investigating the decay scheme of the 5.1 min ^{164}Tm^m by γ-ray spectroscopy with large-volume high-resolution germanium detectors.

II. EXPERIMENTAL PROCEDURE

The 5.1 min activity of the 6^- isomer of ^{164}Tm was produced in the reaction ^{165}Ho$(\alpha,5n)^{164}$Tm at $E_\alpha=60$ MeV. The target used was a 25 μm foil of 99.9% pure holmium metal. The incident beam energy was decided on the basis of relative γ-ray excitation function measurements of ^{164}Tm^m with respect to other neighboring Tm isotopes, done in steps of 5 MeV from 50 to 65 MeV. The reaction products from the target were transported to a low background counting area, about 10 m away from the target using helium jet recoil transport system described earlier [8]. The recoils were collected on a 25 μm thick aluminum foil for γ-ray measurements. The collecting aluminum foil was periodically changed at intervals of about 30 min to avoid the buildup of unwanted long-lived activities.

The γ-ray singles and coincidence measurements were carried out with two HPGe detectors of $\sim 30\%$

efficiency, relative to 7.6 cm×7.6 cm NaI(Tl) at 25 cm distance. The energy resolution of the detectors was typically 2 keV at 1332 keV. The detectors were placed at a distance of about 10 cm from the collection foil to reduce the summing effects. For coincidence measurements the angle between the detectors was set to about 125° and a lead shield was interposed between the two to prevent detector-to-detector scattering. The data acquisition was carried out using a CAMAC based data acquisition system developed for ND-560 computer [9], suitably interfaced to Northern Scientific Nuclear ADC's. The data were recorded event by event on magnetic tape in a three-parameter ($E\gamma_1$–$E\gamma_2$–$t\gamma_1\gamma_2$) list mode configuration and sorted off-line to obtain gated spectra. The dead time of the ADC's was always kept below 10% during the measurements. The energy and efficiency calibration of the detectors was performed using radioactive sources of ^{133}Ba and ^{152}Eu under identical geometry.

III. MEASUREMENTS AND RESULTS

Gamma rays assigned to the 5.1 min ^{164}Tm decay are marked in Fig. 1, which shows a typical γ-ray spectrum measured with a 30% HPGe detector. The gamma rays belonging to the 2.0 min ^{164}Tm are also detected because a part of the decay of the 5.1 min ^{164}Tm proceeds via isomeric transition which feeds the 2.0 min ground state of ^{164}Tm. Contribution of interfering activities, namely, ^{166}Tm (7.7 h), ^{165}Tm (30 h), and ^{163}Tm (1.8 h), produced from other reaction channels, was relatively very small, owing to smaller reaction cross sections, longer half-lives, and the procedure of measurement outlined above, which reduced the buildup of longer-lived activities. The relative intensities of the γ rays assigned to the 5.1 min ^{164}Tm decay were corrected for the contributions arising from the 2.0 min ^{164}Tm(g.s.) decay taking the relative intensities of the γ rays belonging exclusively to the latter decay [1]. Similarly, small corrections for interfering activities were applied for a few γ rays where peaks overlapped. The energies and relative intensities of all the γ rays assigned to the 5.1 min ^{164}Tm decay, and placed in the level scheme of ^{164}Er in this work, are shown in Table I, along with the previous results from Ref. [1]. The results of Ref. [2], not shown in the table, are in fair overall agreement with Ref. [1] as well as the present work, except for the 386, 624, 663, and 855 keV γ rays for which the intensities quoted in Ref. [2] are 2 to 3 times higher.

The coincidence spectra, as mentioned before, were generated during off-line sorting of the list-mode data recorded on magnetic tape. Gates were set on 35 γ-ray peaks. For each γ-ray peak, Compton gates were set, partly on the left and partly on the right of the peak, and their projected spectra subtracted from the corresponding spectra obtained with gates on peaks. Width of the time window was typically 40 nsec. Figures 2 and 3 show some typical coincidence spectra involving the well established γ rays as well as the new ones. The coincident γ rays observed with all the gates are listed in Table II.

In the present work 13 new γ rays are observed to occur in the 5.1 min ^{164}Tm decay. In addition, 4 γ rays reported earlier [1] in this decay but not assigned to ^{164}Er (Table I) are also observed. The decay scheme of the 5.1

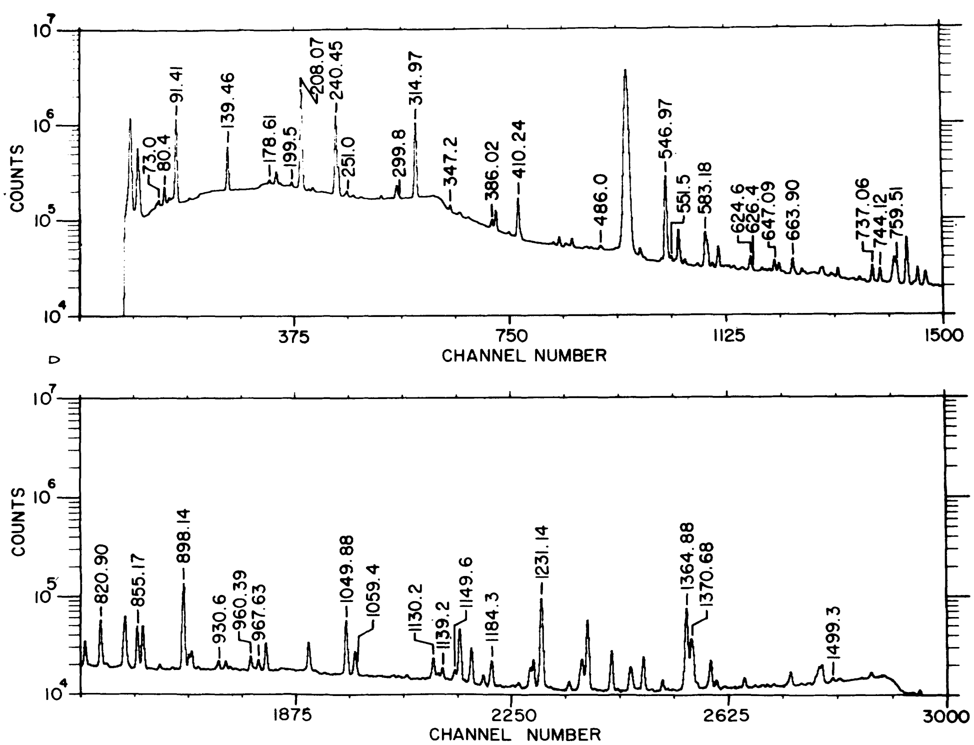

FIG. 1. Singles gamma-ray spectrum showing the gamma rays assigned to ^{164}Er from the decay of the 5.1 min ^{164}Tm. The energies are marked in keV.

min ^{164}Tm based on this work, showing levels and transitions of ^{164}Er occurring in this decay, is given in Fig. 4. The placement of the γ-ray transitions in the level scheme is based on their mutual coincidence relations, intensities in the coincidence spectra, intensity balance at levels and energy sums.

Besides the new γ rays, all the γ rays reported by de Boer *et al.* [1], in the 5.1 min ^{164}Tm decay and assigned to ^{164}Er, are observed in the present work, in fair overall agreement, with the exception of the 101.0 keV γ ray, which is not observed in this work. The limit of intensity of this γ ray deduced in the present work (Table I) is much less than its quoted value in Ref. [1]. The expected value 101.0 keV for the energy of this transition, given in the third column of Table I, is based on the difference of level energies determined from other transitions.

The level scheme of ^{164}Er, reported in Ref. [1], shows a γ-ray transition of energy 624.9±1.0 keV and relative intensity 2.7±0.3 units relative to 100 units for the 315 keV γ ray, and placed between states with $K;I^\pi=7;7^-$

TABLE I. Energies (E_γ) and relative intensities (I_γ) of γ rays of ^{164}Er observed in the decay of the 5.1 min isomer of ^{164}Tm. The placement of the γ rays in the present work is indicated by the energies of the initial and final states in the first two columns.

		Present		Previous[a]	
E_i (keV)	E_f (keV)	E_γ (keV)	I_γ	E_γ (keV)	I_γ
1683.64	1610.5	73.0±0.3	1.9±0.3		
1744.59	1664.35	80.4±0.1	7.9±0.8	80.32±0.05	6.2±0.6
91.41	0	91.41±0.04	38.2±5.7	91.39±0.03	43.4±6.0
1845.59	1744.59	101.0	<0.1	101.24±0.20	1.7±0.9
1985.04	1845.59	139.46±0.08	26.2±1.3	139.43±0.08	26.6±1.0
2163.65	1985.04	178.61±0.20	1.5±0.2		
1744.59	1545.0	199.5±0.2	1.9±0.2	199.2±0.3[b]	0.8±0.3
299.48	91.41	208.07±0.07	159.6±8.0	208.08±0.03	152.1±4.6
1985.04	1744.59	240.45±0.07	89.3±4.5	240.49±0.05	77.7±3.9
1197.62	946.58	251.0±0.2	2.2±0.2		
1358.57	1059.02	299.8±0.3	1.4±0.3		
614.45	299.48	314.97±0.07	100	314.93±0.05	100
1545.0	1197.62	347.2±0.6	0.8±0.2		
1744.59	1358.57	386.02±0.20	2.9±0.2	385.49±0.20	2.9±0.3
1024.69	614.45	410.24±0.10	15.3±0.9	410.20±0.10	14.7±1.1
1683.64	1197.62	486.0±0.08	0.7±0.2		
1545.0	1024.69	520.3±1.0	0.5±0.3		
1744.59	1197.62	546.97±0.10	49.5±2.5	547.00±0.10	46.2±2.6
1610.5	1059.02	551.5±0.5	0.5±0.1		
1197.62	614.45	583.18±0.10	8.6±0.8	583.23±0.10	7.4±0.5
1683.64	1059.02	624.6±0.2	2.5±0.3	624.9±1.0	2.7±0.3
1985.04	1358.57	626.4±0.8	0.5±0.3		
946.58	299.48	647.09±0.25	1.6±0.2	646.94±0.14	1.8±0.2
1610.5	946.58	663.90±0.20	3.1±0.2		
1683.64	946.58	737.06±0.20	3.0±0.2	736.7±0.3[b]	1.6±0.2
1358.57	614.45	744.12±0.20	2.2±0.2	743.9±0.3	1.1±0.1
1059.02	299.48	759.51±0.20	3.9±0.3	758.81±0.09	4.5±0.4
1845.59	1024.69	820.90±0.10	12.1±0.6	820.67±0.10	13.6±0.7
946.58	91.41	855.17±0.10	7.8±0.6	854.91±0.07	8.1±0.6
1197.62	299.48	898.14±0.10	42.6±2.1	897.91±0.05	44.3±2.0
1545.0	614.45	930.6±0.4	1.7±0.2	929.9±0.4	1.3±0.1
1985.04	1024.69	960.39±0.30	2.8±0.3	960.7±0.8	1.8±0.2
1059.02	91.41	967.63±0.30	2.0±0.2	967.4±0.3	1.1±0.1
1664.35	614.45	1049.88±0.10	17.5±0.9	1049.84±0.09	15.9±0.8
1358.57	299.48	1059.4±1.0	0.6±0.2		
1744.59	614.45	1130.2±0.2	3.6±0.4	1130.06±0.10	3.4±0.3
3302.8	2163.65	1139.2±0.3	2.1±0.2	1140.0±0.4[b]	1.7±0.2
1764.1	614.45	1149.6±0.4	1.6±0.2		
1798.8	614.45	1184.3±0.5	2.8±0.4		
1845.59	614.45	1231.14±0.10	44.0±2.2	1231.19±0.07	41.8±2.0
3302.8	1985.04	1317.6±1.0	0.5±0.3		
1664.35	299.48	1364.88±0.10	38.6±1.9	1364.60±0.06	42.5±2.1
1985.04	614.45	1370.68±0.20	8.8±0.7	1370.75±0.10	9.7±1.0
1798.8	299.48	1499.3±0.8	0.8±0.2	1498.0±0.2[b]	1.5±0.7

[a]Reference [1].
[b]Gamma ray not placed in the level scheme of Ref. [1].

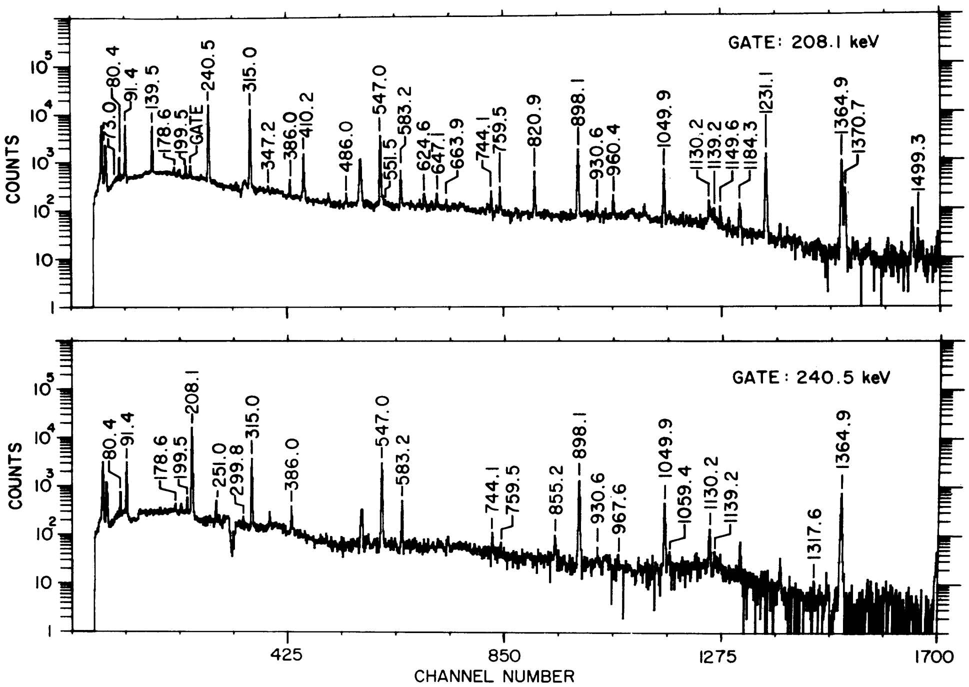

FIG. 2. Coincidence spectra of ^{164}Er gamma rays with gates set on 208.1 and 240.5 keV transitions.

and 2;6^+. The present work shows two close lying γ rays of energies 624.6±0.2 and 626.4±0.8 keV and relative intensities 2.5±0.3 and 0.5±0.3 units, respectively. If the 624.6 keV transition with relative intensity of 2.5 units is placed in the level scheme as stated above, one would expect to see comparable intensities of the 624.6 and 386.0 keV γ rays in the coincidence spectrum with the 744 keV gate. Contrary to this expectation, however, the 744 keV gate shows the weaker 626.4 keV γ ray with intensity about $\frac{1}{6}$ of that of the 386.0 keV γ ray. The reverse gate set on the 624.6 keV peak shows clear 759.5 and 967.6 keV γ rays with appropriate branching ratio for the 1059.02 keV state. With gates on 759.5 and 967.6 keV γ rays, the 299.8, 551.5, and 624.6 keV γ rays are observed with intensities expected according to the level scheme of Fig. 4. The 624.6 keV γ ray is also observed in the 208.1 and 91.4 keV gates. Therefore the 624.6 keV transition is shown to depopulate a new level at 1683.64 keV.

The 737.06 keV transition, which was not placed in the level scheme before, is observed in the 647.1 and 855.2 keV gates, and the reverse gate set on 737.1 keV shows the 647.1 and 855.2 keV γ rays with proper branching ratio. The 737.06 keV transition, therefore, connects the new level at 1683.64 keV and the 3^+ level of the γ-vibrational band.

Two new transitions, viz., 73.0 and 486.0 keV, are placed on similar considerations to depopulate the same level. The new level at 1683.64 keV is thus connected by four transitions to the four previously known levels of ^{164}Er. No γ transitions populating the 1683.64 keV level were found.

Another new level at 3302.8 keV is similarly observed to be connected by 1317.6 and 1139.2 keV transitions, to the 7^- and 8^- members of the $K=7$ band.

A new transition of 551.5 keV energy is shown in Fig. 4 to connect the 4^- state of the $K=2$ band and the 4^+ state of the γ-vibrational band on the basis of its coincidence relations with the 73.0, 91.4, 208.1, 759.5, and 967.6 keV γ rays.

Several γ rays reported [3–7] in ^{164}Er from $(\alpha,xn\gamma)$, $(n,n'\gamma)$, and (HI, $xn\gamma$) reactions but not reported in the decay of the 5.1 min ^{164}Tm are also observed. These are the 178.61, 251.0, 299.8, 347.2, 520.3, 1059.4, 1149.6, 1184.3, and 1499.3 keV γ rays. All these transitions are placed in the level scheme of Fig. 4 in accordance with their coincidence relations. The placement of these transitions involves previously [7] known levels of ^{164}Er, including three negative parity states with $K;I^\pi=0;7^-$, 2;5^-, and 7;8^-, not previously reported [1,2] to be populated in the 5.1 min ^{164}Tm decay.

As pointed out in the Introduction, there was mismatch of intensities at various levels of the γ-vibrational band in the earlier reported work by de Boer *et al.* [1]. In the present work this problem is considerably resolved by the observation of various transitions connecting the levels of this band. The change in the placement of the 624.6 keV transition, observation of the 486.0 and 737.06 keV transitions from the new level at 1683.64 keV, the 551.5 and 663.9 keV transitions from the 1610.5 keV level, 199.5 keV transition from the 1744.59 keV level, and 251.0, 299.8, 347.2, and 520.3 keV transitions from various levels of the γ- vibrational band, together account for most of the missing intensity in the earlier [1] work. In the level scheme of ^{164}Er based on the present work, the total populating and depopulating

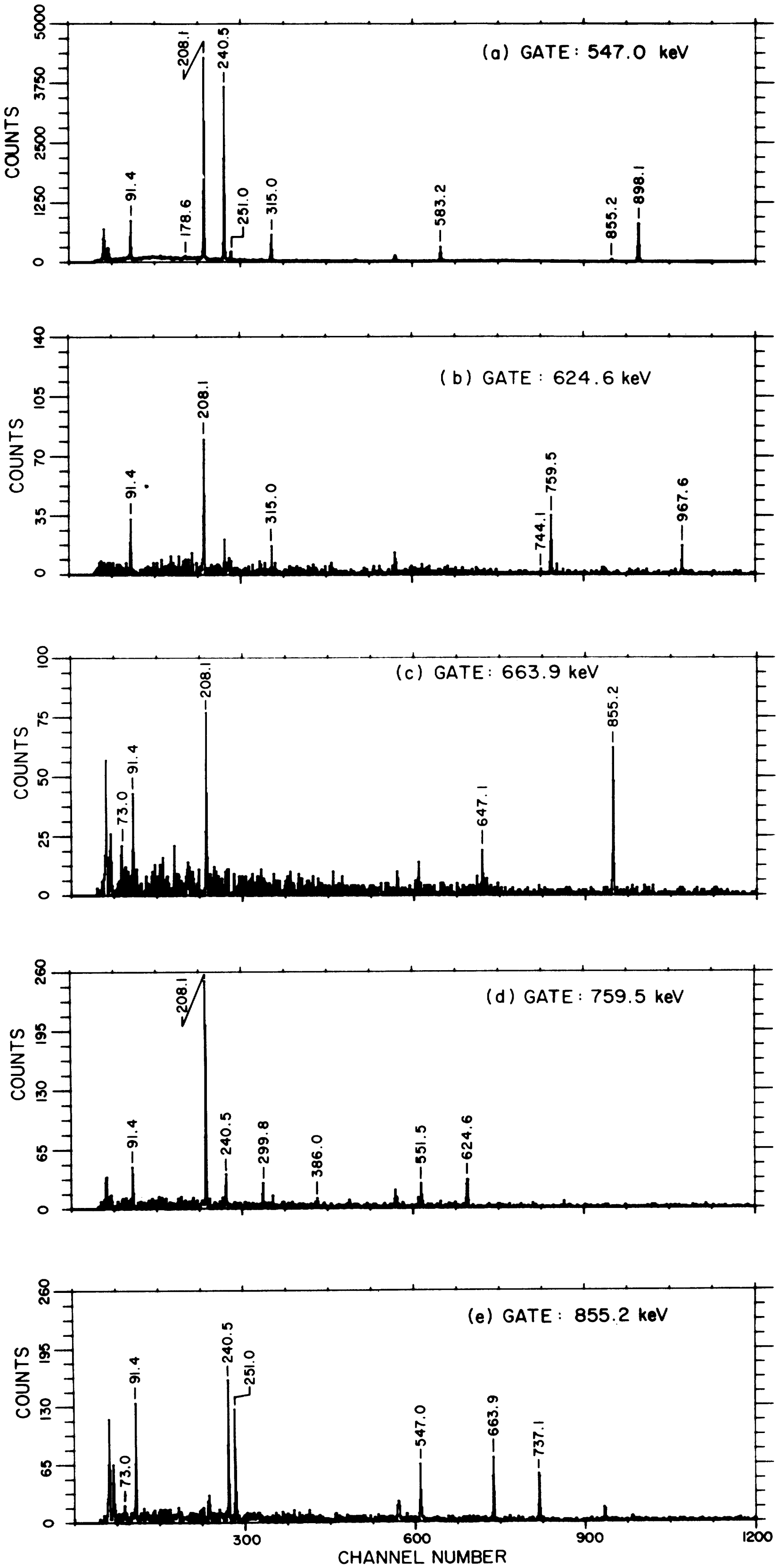

FIG. 3. Typical coincidence spectra showing gamma-ray transitions in ^{164}Er observed with gates on (a) 547.0, (b) 624.6, (c) 663.9, (d) 759.5, and (e) 855.2 keV gamma rays.

TABLE II. Results of $\gamma\gamma$ coincidence experiment. Numbers in parentheses indicate weak coincidences.

Gamma ray selected in gate (keV)	Gamma rays observed in coincidence (keV)
80.4	91.4, 208.1, 240.5, 315.0, 1049.9, 1364.9
91.4	80.4, 139.5, (178.6), 199.5, 208.1, 240.5, 251.0, (299.8), 315.0, 347.2, 386.0, 410.2, (486.0), 547.0, (551.5), 583.2, (624.6), 647.1, 663.9, 737.1, 744.1, 759.5, 820.9, 855.2, 898.1, 930.6, 960.4, 1049.9, 1059.4, 1130.2, (1139.2), (1149.6), 1184.3, 1231.1, 1364.9, 1370.7
139.5	91.4, 178.6, 208.1, 315.0, 410.2, 820.9, 1139.2, 1231.1, (1317.6)
178.6	80.4, 91.4, 139.5, 208.1, 240.5, 315.0, 410.2, 547.0, 626.4, (744.1), 820.9, 898.1, 1049.9, 1139.2, 1231.1, 1364.9, 1370.7
199.5	91.4, 208.1, 240.5, (251.0), 315.0, 347.2, 410.2, 520.3, 898.1, 930.6
208.1	73.0, 80.4, 91.4, 139.5, 178.6, 199.5, 240.5, 315.0, 347.2, 386.0, 410.2, 486.0, 547.0, 551.5, 583.2, 624.6, 647.1, 663.9, 744.1, 759.5, 820.9, 898.1, 930.6, 960.4, 1049.9, 1130.2, 1139.2, 1149.6, 1184.3, 1231.1, 1364.9, 1370.7, 1499.3
240.5	80.4, 91.4, 178.6, 199.5, 208.1, 251.0, 299.8, 315.0, 386.0, 547.0, 583.2, 744.1, 759.5, 855.2, 898.1, 930.6, 967.6, 1049.9, 1059.4, 1130.2, 1139.2, 1317.6, 1364.9
251.0	91.4, 208.1, 240.5, 486.0, 547.0, 647.1, 855.2
315.0	80.4, 91.4, 139.5, 178.6, 199.5, 208.1, 347.2, 386.0, 410.2, 486.0, 547.0, 583.2, 626.4, 744.1, 820.9, 930.6, 960.4, 1049.9, 1130.2, 1139.2, 1149.6, 1184.3, 1231.1, 1317.6, 1370.7
347.2	91.4, 199.5, 208.1, 240.5, 251.0, 315.0, (583.2), 898.1
386.0	91.4, 208.1, 240.5, 299.8, 315.0, 744.1, 759.5, 967.6, 1059.4
410.2	91.4, 139.5, 199.5, 208.1, 315.0, 520.3, 820.9, 960.4
486.0	91.4, 208.1, 315.0, 583.2, 898.1
547.0	91.4, 178.6, 208.1, 240.5, 251.0, 315.0, 583.2, 855.2, 898.1
551.5	73.0, 91.4, 208.1, 759.5, 967.6
624.6	91.4, 208.1, (315.0), (744.1), 759.5, 967.6
626.4	91.4, 208.1, 315.0, (744.1), (1059.4)
647.1	91.4, 208.1, 240.5, 251.0, 547.0, 663.9, 737.1
663.9	73.0, 91.4, 208.1, 647.1, 855.2
737.1	91.4, 208.1, 647.1, 855.2
744.1	91.4, 208.1, 240.5, 315.0, 386.0, 626.4
759.5	91.4, 208.1, 240.5, 299.8, 386.0, 551.5, 624.6
820.9	91.4, 139.5, 178.6, 208.1, 315.0, 410.2
855.2	73.0, 91.4, 240.5, 251.0, 547.0, 663.9, 737.1
898.1	91.4, 199.5, 208.1, 240.5, 347.2, 486.0, 547.0
960.4	91.4, 208.1, 315.0, 410.2
967.6	91.4, 240.5, 299.8, 386.0, 551.5, 624.6
1049.9	80.4, 91.4, 208.1, 240.5, 315.0
1139.2	91.4, 139.5, 178.6, 208.1, 240.5, 315.0, 547.0, 898.1
1184.3	91.4, 208.1, 315.0
1231.1	91.4, 139.5, 178.6, 208.1, 315.0
1317.6	(80.4), (91.4), 208.1, 240.5. 315.0, (410.2), 547.0, 898.1
1364.9	80.4, 91.4, 178.6, 208.1, 240.5
1370.7	91.4, 208.1, 315.0
1499.3	(91.4), 208.1

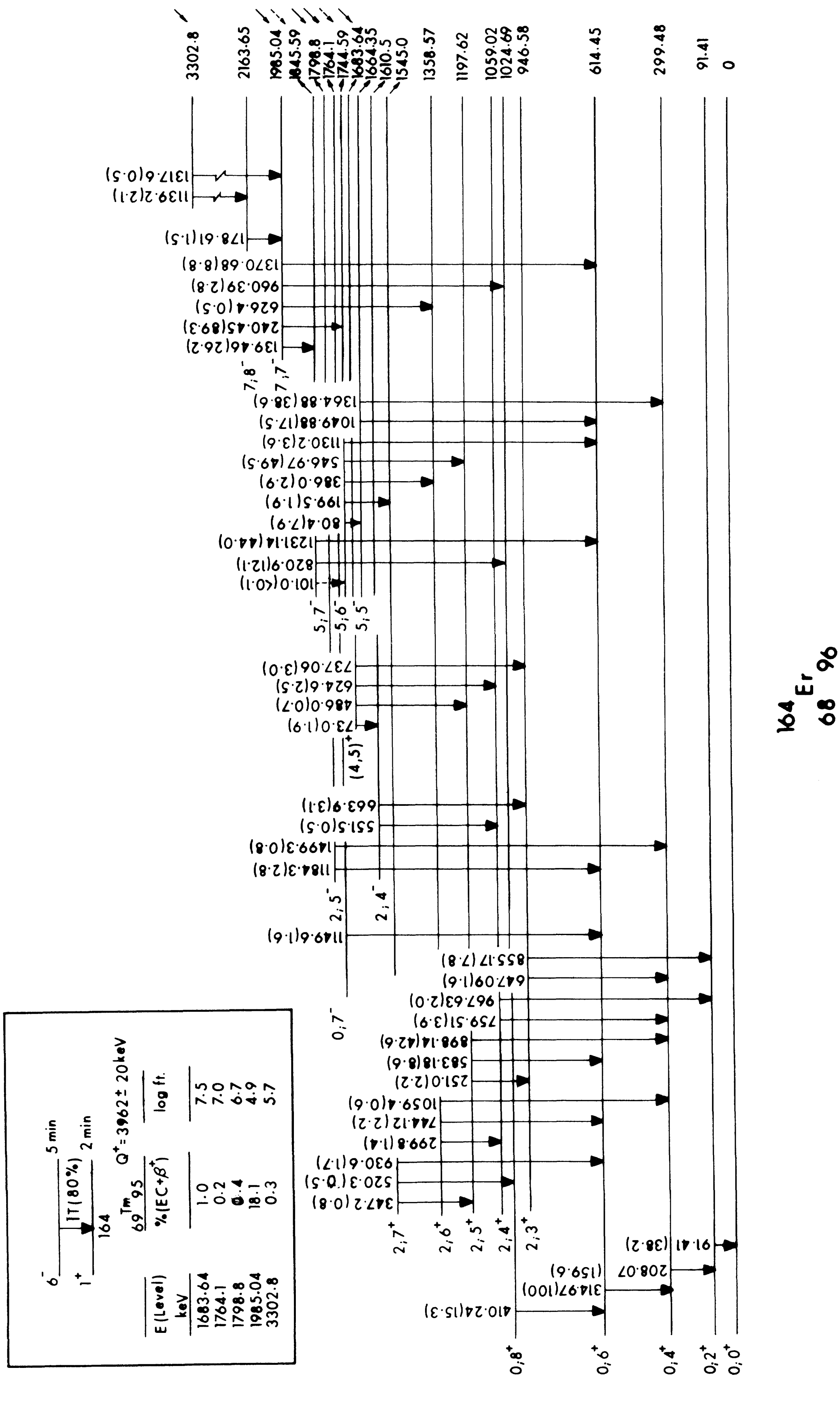

FIG. 4. Energy levels and transitions in ^{164}Er based on the present work. All energies are in keV. Relative gamma-ray intensity is given in parentheses for each transition. The inset on top left shows the isomeric transition in ^{164}Tm and the % (EC+β^+), logft values and energies of levels of ^{164}Er, to which β decay from the 5.1 min isomer of ^{164}Tm is deduced. Uncertain β feeding to the 1744.59 and 1845.59 keV states of ^{164}Er is indicated by broken arrows.

intensities of γ transitions including internal conversion, at the observed levels of the γ-vibrational band, agree within the error limits, except at the 4^+ and 7^+ levels where the depopulating intensity exceeds the populating intensity by about twice the standard deviation.

The new transition of energy 73.0 keV populates the 1610.5 keV state ($K;I^\pi=2;4^-$). The intensity balance at this state, assuming no β feeding, gives the following value for the total internal conversion coefficient of the 73.0 keV transition:

$$\alpha_{\rm tot}(73.0\ {\rm keV})=0.9\pm0.3\ .$$

The corresponding theoretical [10] values of $\alpha_{\rm tot}$ for $E1$, $E2$, $M1$, and $M2$ multipolarity are 0.75, 10.29, 7.33, and 91.34, respectively. If some β feeding is assumed to occur at the 1610.5 keV state, then the experimental value of $\alpha_{\rm tot}$ would be less than the value obtained. Hence it is concluded that the β feeding to the 1610.5 keV state is negligible and the 73.0 keV transition has $E1$ multipolarity.

The balance of total transition intensities at other levels gives the intensity of β feeding to those levels. Total transition intensities have been determined taking the experimental values [7] of total internal conversion coefficients wherever available or the theoretical values [10] in the absence of the experimental ones. Predominant β feeding is observed to the 1985.04 keV state in agreement with Refs. [1] and [2]. Weak β branches are deduced to four other levels of ^{164}Er. The intensities of various β branches and their logft values are given in Fig. 4.

IV. DISCUSSION

The 5.1 min isomer of ^{164}Tm decays via electron capture and β^+ emission as well as isomeric transition. The electron capture and β^+ decay, populating the levels of ^{164}Er, account for 20% disintegrations of the isomer [1]. The results of the present study show that five more levels of ^{164}Er are populated besides those observed earlier [1,2] in the decay of the 5.1 min isomer of ^{164}Tm. Two of these levels, viz., the 1683.64 and 3302.8 keV levels, are hitherto unreported, whereas the other three levels at 1764.1, 1798.8, and 2163.65 keV have been observed in in-beam studies [7]. Also 17 additional γ-ray transitions are placed in the level scheme of ^{164}Er, including eight new placements, viz., 73.0, 199.5, 486.0, 551.5, 624.6, 737.06, 1139.2, and 1317.6 keV. The placements of the other nine γ-ray transitions, viz., 178.61, 251.0, 299.8, 347.2, 520.3, 1059.4, 1149.6, 1184.3, and 1499.3 keV, are consistent with the results of (α,$xn\gamma$) and (HI,$xn\gamma$) reaction studies reported in the literature [7]. All the observed levels of ^{164}Er in this work, with the exception of the two new levels, can be identified as members of six different bands reported in the literature [7], two of which have positive parity, namely, the ground-state rotational band ($K^\pi=0^+$) and the γ-vibrational band ($K^\pi=2^+$), and the other four have negative parity with $K^\pi=0^-$, 2^-, 5^-, and 7^-. High spin states in all these bands have been studied extensively by (HI,$xn\gamma$) and (α,$xn\gamma$) reactions [7]. The present study of the levels and transitions in ^{164}Er from the decay of the 6^- isomer of ^{164}Tm provides details regarding the lower spin members of these bands.

The present study shows no transition connecting the 1845.59 and 1744.59 keV states. These states have been interpreted [5] as the 7^- and 6^- members of the $K^\pi=5^-$ band, with the 1664.35 keV state as the bandhead. The moment of inertia of this band has a relatively high value at $I=11$ and it shows markedly different trends above and below this spin. These irregularities have been explained in terms of mixing of the 5^- band with the octupole vibrational bands ($K^\pi=0^-$ and 2^-). The 5^- band is crossed by the 0^- band at $I=11$. The odd-spin states of the $K^\pi=5^-$ band in the neighborhood of $I=11$ are reported [7] to decay strongly to the ground-state band indicating significant $K=0$ strength in these states. The 11^- and 9^- states of this band are reported to decay only to the ground-state band and no intraband transitions have been observed from these states [7]. The results of the present work, regarding strong decay of the 7^- state of this band to the gound-state band and absence of the 101 keV intraband transition, are consistent with the above observations.

The 5^- band is crossed by the 2^- octupole vibrational band at $I=6$. The 6^- state of the $K^\pi=5^-$ band decays mainly to the γ-vibrational band ($K^\pi=2^+$). Besides the previously reported $6^-\to5^+$ and $6^-\to6^+$ transitions, a new $6^-\to7^+$ transition (199.5 keV) to the γ band is observed in this work. Predominant decay of the 6^- state to the γ-vibrational band indicates significant mixing of the $K^\pi=5^-$ and 2^-bands.

The negative parity levels belonging to the $K^\pi=0^-$ and 2^- bands observed in this work decay by $E1$ transitions to the positive parity bands. The occurrence of the $7^-\to6^+$ $E1$ transition from the $K^\pi=0^-$ to the ground-state band (g.s.b.) is consistent with the K assignment. The octupole-octupole mixing in the $K^\pi=2^-$ band has been predicted theoretically by Neergard and Vogel [11] and observed experimentally by Fields *et al.* [5]. Presence of significant $K=0$ components in the odd-spin states of the $K^\pi=2^-$ band has been inferred from their preferential decay by $E1$ transitions to the gound-state band. The even-spin states of this band, on the other hand, decay by $E1$ transitions to the γ band in preference to the g.s.b. [5]. New 551.5 keV $4^-\to4^+$ transition from the $K^\pi=2^-$ band to the γ band observed in this work is consistent with the known characteristics of the even-spin states of the $K^\pi=2^-$ band.

The new level at 1683.64 keV can be assigned positive parity because the multipolarity of the 73.0 keV transition to the 4^- state is deduced to be $E1$. Since three more transitions to the 3^+, 4^+, and 5^+ members of the γ band are also observed, the possible spin-parity assignments of the 1683.64 keV state are 3^+, 4^+, and 5^+. The assignment of 3^+ is nct favored by the logft value of the electron capture decay to this state. Hence 4^+ and 5^+ assignments are more likely. With similar arguments, the other proposed level at 3302.8 keV can be assigned likely spin values 6, 7, or 8.

The S band in ^{164}Er interpreted as $\nu(i_{13/2})^2$ excitation has been studied in detail from $I=8$ to 24 in (HI,$xn\gamma$)

and $(\alpha,xn\gamma)$ reactions [3–5]. It crosses the g.s.b., γ band, and β band at $I=16$, 12, and 8, respectively. Following the S band down from high spin one observes intraband transitions and then interband transitions to g.s.b., γ band, and β band. Existence of substantial mixing between the S band and the positive parity collective bands is demonstrated by significant energy level perturbations in all four bands and by occurrence of interband transitions. Extrapolation of the energy level sequence of the S band below $I=8$, taking the effects of mixing into account, predicts excitation energies 1.61, 1.66, 1.74, and 1.85 MeV, respectively, for the 0^+, 2^+, 4^+, and 6^+ states of this band [5]. On the basis of the deduced spin-parity, existence of interband transitions and excitation energy, the new level at 1683.64 keV appears to resemble the predicted 4^+ member of the S band. However, more experimental evidence would be needed to arrive at an acceptable interpretation of this level.

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