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THE DECAY OF ^{170}Lu TO LEVELS IN ^{170}Yb

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August 6, 1971

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Errata UCRL 72295

<u>Page</u>	<u>Line</u>	<u>Correction</u>
5	13	replace "6 ² " by "40"
6	last	delete everything from "...and later....Fig. 3"
10	16	replace "so" by "thus"
37	10	read "....to be directly populated by ¹⁷⁰ Lu β -decay...."
44	under 193.13	underline " <u>1641</u> " entry completely.
47	beside 461.20	intensity is "270" units not "70"
48	beside 656.25	intensity is "280" units not "80", add "e.b." in last column.
48	below 792.00	energy is "801.25" not "701.25"
48	beside 916.65	remove "1 +"
48	beside 916.90	add parenthesis, i.e. "(2-)"
49	beside 1050.40	add "(2-)"
49	beside 1069.4	remove + in next to the last column
50	beside 1290.9	delete "1+"
50	beside 1405.15	Multipolarity is "E1" not "E"
50	beside 1457.12	add parenthesis "(2-)"
51	beside 1531.30	add "1-" under I ₁ π column
	1549.92	add parenthesis "(0-)"
	1592.05	add "1-" under I ₁ π column.
	1610.70	add parenthesis "(0-)"
	1662.75	add parenthesis "(2-)"
52	entry 1983.09	Energy should read "1983.90" not "1983.09"
53	beside 2315.9	change respective entries to read "E1?" and "1-?"
53	beside 2344.9	delete "1+"
53	beside 2400.15	change entries to read "E1?" and "1-?"

53	beside 2429.0	delete "1+"
53	beside 2438.6	delete (1+) and 2 + entries
53	beside 2523.0	add "e.b." in last column
54	beside 2661.0	multipolarity should read "M1/E2"
	beside 2872.5	add "1-" under $I_1\pi$ column
	beside 2885.1	add parenthesis
55	under footnote e	delete entire last sentence of footnote e.
56	footnote i	change "of the observed" to "of <u>any</u> observed"
56	footnote k	change "to less than" to read "at"
57	between 1566.4 and 1634.8 levels	delete all column entries since there is no level
57	last	error is " ± 0.3 " and % entry is (0.02 ± 0.01)
63	heading, Col. 2 and table caption	should read $\frac{I_{n\pi} \xrightarrow{e^-} I_{m\pi}}{I_{n\pi} \xrightarrow{\gamma} I'_{m\pi}} \quad \text{and } (I_{n200}/I'_m)$
63	under 1069.4	change denominator subscript from " 0_2 " to " 0_1 "
63	Entry 1 column 4	$\frac{34 (3)}{1.2 \times 10^5}$
64	6th from bottom	"affect"
65	entry 3 column 2	$0 + 0_1 \rightarrow 2 + 0_0$
	entry 4, column 2	$0 + 0_2 \rightarrow 2 + 0_0$
66	Heading, col. 5	$ \rho $
	entry 1, col. 3	0.0049 ± 0.0005
	entry 3, col. 3	0.080 ± 0.009
	entry 3, col. 4	420 ± 80
	entry 3, col 5	0.13 ± 0.03
	footnote a	Add "Similar calculations could be listed for the other $e^-\gamma$ branches from this level (Table 5), but in view of the uncertainty in the $2 + 0_1 \rightarrow 2 + 0_0$ monopole conversion intensity these data provide no new information.

Figure Captions

68

- No. 1 "Relative reduced EO transition probabilities, $\rho^2(\text{EO})/\rho_0^2(\text{EO})$, from...."
- No. 2 Change "The low energy portion of ^{170}Lu" to read "A low energy portion of isotopically separated ^{170}Lu"
- No. 5 "Shown is the 544...." and change last sentence to read: "....energy suppressed and 'pair' spectra displayed....but statistical errors and residuals are shown on a CRT screen."

Figure 11

Delete the numbers 0.54 and 0.94 from the 84.3- and 277.4-keV levels above "Experiment".

Appendix A-1

Change Figs. "7 or 8" to read "6 or 7".

THE DECAY OF ^{170}Lu TO LEVELS IN $^{170}\text{Yb}^*$

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ABSTRACT

The locations of 70 energy levels in ^{170}Yb were deduced from Compton suppressed γ -ray singles, three-crystal γ -ray pair, conversion electron, and Ge(Li)-Ge(Li) γ - γ coincidence measurements on the EC- β^+ decay of ^{170}Lu . Both chemically separated and isotopically separated sources of ^{170}Lu were used in collecting the data. A total of 550 γ -ray transitions have been observed in the ^{170}Lu decay spectrum, 220 of which are definitely assigned to the ^{170}Yb -level scheme from 112 coincidence spectra. These definitive transitions account for 93% of the total observed γ -ray intensity. An additional 118 γ -ray transitions were placed on the basis of excited-state energy differences. Eight EO transitions were observed in the conversion electron data. Each of four excited 0+ states identified has less than 1% beta decay feeding from the 0+ parent. Spin and parity assignments are proposed for 46 levels in addition to the ground-state rotational band members. The ^{170}Yb level structure is compared with available theoretical calculations, and a preliminary interpretation of several features of the decay scheme is presented.

I. INTRODUCTION

The most complicated radioactive decay yet studied is the EC $-\beta^+$ decay of 2.15-day ^{170}Lu to the levels of ^{170}Yb . Early attempts to interpret the complex γ -ray spectrum from NaI(Tl) data were largely unsuccessful; and until recently, the best available data consisted primarily of conversion electron spectra.^{1,2,3} With the advent of germanium detectors, however, several groups⁴⁻⁸ renewed their efforts at unraveling this very complex decay. Hansen and coworkers⁹ established 0^+ as the ground-state spin and parity of ^{170}Lu . Paperiello et al.¹⁰ carried out directional correlation measurements on several of the more intense transition cascades in this decay and have definitely established the spins of 10 levels in ^{170}Yb . Concurrent with the work reported here were the recent studies reported by Bonch-Osmolovskaya and coworkers^{11,12} who employed Ge(Li) detectors, electron- γ , γ - γ , and electron-electron coincidences, in an effort to define the decay scheme. They placed some 177 transitions of 280 seen in the decay, thus accounting for almost 87% of the total γ -ray intensity.

In this work we report the results of extensive γ -ray singles, γ - γ coincidence, and conversion electron measurements. Compton suppression and three-crystal-pair spectrometer techniques were used to accurately define the energies and intensities of the ^{170}Lu γ -ray transitions. Measurements at lower energies (<1.2 MeV) were carried out with isotopically separated sources. An on-line computer and multiparameter data-acquisition system were used in conjunction with two Ge(Li) detectors and an isotopically separated ^{170}Lu source, to carry out a detailed study of the γ - γ coincidence spectra.

Conversion electron studies were carried out using chemically separated lutetium sources and a Si(Li) detector. On the basis of these data, we have constructed a level scheme for ^{170}Yb consisting of 70 excited states. Of 550 γ -ray transitions identified, over 200 have been placed on the basis of γ - γ coincidence data and another 118 were placed on the basis of energy differences; these two groups of γ rays account for 93 and 3% of the total γ -ray intensity, respectively. Significant differences exist between our decay scheme and that of Bonch-Osmolovskaya et al.,¹² and slight differences distinguish our decay scheme from the less-complete level scheme of Mihelich.¹³

II. EXPERIMENTAL

A. Target and Source Preparation

Sources of ^{170}Lu were prepared by the $^{169}\text{Tm}(\alpha, 3n)^{170}\text{Lu}$ reaction by irradiating 40-mg samples of Tm_2O_3 at the Lawrence Berkeley Laboratory 88-in. cyclotron with 40-MeV α particles. Three-hour irradiations at about 20- μA beam current produced about 2.0 mCi of ^{170}Lu activity for each experiment.

The lutetium activity was separated from other reaction products by ion-exchange chemistry. The target material was dissolved in 3-M HCl and placed on a 60-cm-long Dowex 50 $\times$ 8 (150-200 mesh) column; 0.05-M alpha-hydroxy isobutyric acid at pH 5.3 was used as the eluting agent. An 8-hr elution time allowed essentially complete separation of the lutetium activity from the thulium. The γ -ray sources were prepared by evaporating small amounts of the activity to dryness on aluminum or Teflon¹⁴ backings.

Conversion electron sources were prepared by liquid deposition of the activity

onto 0.25-mil gold-anodized Mylar. Source material for the isotope separator was prepared by adding 1 mg of Lu^{+3} carrier, precipitating the hydroxide with 8-hydroxy quinoline, and igniting to form Lu_2O_3 . Gamma-ray sources were obtained from the isotope separator on 5-mil aluminum foil. Counting was usually begun within 12 to 24 hr after the end of irradiation.

B. Experimental Apparatus

A number of different detector systems were used in this study, to obtain the spectral data. These systems include a Compton suppression and three-crystal-pair spectrometer, a small Ge(Li) x-ray detector, a γ - γ coincidence system, and a Si(Li) conversion electron detector system. In addition, ordinary singles Ge(Li) detector data were obtained for the interfering activities by counting isotopically separated sources of ^{169}Lu , ^{171}Lu , and ^{172}Lu .

The Compton suppression and three-crystal-pair spectrometer system used in this study is shown schematically in Fig. 1. The central Ge(Li) detector is a planar type, 2.0 by 3.0 cm (6 cm^2), with a 12-mm depletion depth (7 cm^3), oriented such that the 3.0-cm length is colinear with the γ -ray collimation axis. Cooled field-effect transistors in the preamplifier permit resolutions as low as 1.0, 2.0, and 3.0 keV FWHM at 122, 1332, and 2754 keV, respectively. Two 22.86-cm-diam $\times$ 11.43-cm-thick NaI(Tl) detectors machined to allow maximum enclosure surround the Ge(Li) detector housing. The entire system rests in a cylindrical lead shield with 10.16-cm-thick walls. A 1.9-cm-diam hole reduced to 1.27 cm by cadmium and copper lining collimates incoming γ rays. When the NaI(Tl) detectors are operated in anticoincidence with the Ge(Li) detector, those Compton events that scatter

out of the Ge(Li) detector and trigger the NaI(Tl) circuitry are eliminated. For ^{60}Co , the maximum 1.33-MeV full-energy peak-to-minimum continuum ratio observed with this system is 140:1 and for ^{137}Cs it is 640:1. When the NaI(Tl) detectors are operated independently, and single-channel windows are used to select 511-keV annihilation radiation, the system can also be simultaneously operated as a three-crystal-pair spectrometer.

The suppression and three-crystal-pair techniques offered by this spectrometer assembly have a number of significant advantages for the measurement of very complex γ -ray spectra such as that of ^{170}Lu . Many weaker radiations, which are ordinarily obscured by the Compton distribution, can be observed. Single and double escape peaks, which normally add complexity to the higher-energy portions of γ -ray spectra, are suppressed by factors of 6 and 6^2 , respectively. Thus, the precision obtainable for γ -ray intensities is improved at all energies. Finally, a pair spectrum unequivocally selects only those peaks that are due to γ -ray pair events and thus allows observation of weaker peaks than can be seen in the Compton suppressed data. A more detailed description of all aspects of this system appears in Ref. 15.

Data from the chemically and isotopically separated sources were also taken with the use of a low-energy photon Ge(Li) system 50 mm² in area and 5 mm in depletion depth. This system offers the advantage of very high resolution (600 eV FWHM at 100 keV) and is relatively insensitive to high-energy radiations. The energy region from 0 to 200 keV was observed in detail with this detector.

The γ - γ coincidence system¹⁶ consisted of a 10-cm³ planar Ge(Li) detector and a 35-cm³ coaxial Ge(Li) detector coupled with a multiparameter data-acquisition system interfaced to a PDP-7 computer. The 4096 $\times$ 4096 $\times$ 512 channel E_{γ_1} - E_{γ_2} -time coincidence distributions were digitized and stored serially on standard IBM magnetic tapes. These data were later sorted and processed, using computer codes developed for the LBL CDC 6600 computer.

Conversion electron data were obtained with a 3-mm-deep $\times$ 1-cm² Si(Li) detector operated at 650-V bias and at 110°K. The resolution of this system was about 2.5 keV FWHM for the 975.6-keV K conversion-electron line of ²⁰⁷Bi.

C. Experimental Data

1. Analysis of the ¹⁷⁰Lu γ -Ray Spectra

The γ -ray singles spectra from the ¹⁷⁰Lu decay are shown in Figs. 2 and 3. These data include spectra taken both with and without the benefit of isotope-separated sources. Attempts to perform the Lu isotope separation using LuF₃ were at first unsuccessful. In these early experiments, the higher-energy γ -ray data least affected by the interfering ¹⁶⁹Lu, ¹⁷¹Lu, and ¹⁷²Lu activities were obtained from sources not isotopically separated and are shown in Figs. 3 and 4. These data extend from 1200 to 3500 keV and include the Compton-suppressed singles and the "pair" spectra that were accumulated simultaneously with use of the Compton-suppression system. To identify the impurity activities in these early data, successive counts were taken at 2-day intervals and later added to get the counting statistics shown in Fig. 3.

The lower-energy data from the sources only chemically separated are not shown here because of the large number of interfering lines from ^{169}Lu and ^{171}Lu decay. Instead, Fig. 2 shows the data acquired from a later source that was isotopically separated. The Lu_2O_3 isotopic separation at that time allowed sufficient activity only for the acquisition of γ - γ coincidence data and the low-energy γ -ray singles data. The successful isotope separation also permitted data to be taken on the ^{169}Lu , ^{171}Lu , and, later, the ^{172}Lu decays, so positive identification of contaminant peaks and accurate removal of their relative intensities from the earlier mixed-isotope data was possible.

In the low-energy portion (70 keV to 1.2 MeV) of the ^{170}Lu γ -ray spectrum shown in Fig. 2, only some of the peaks have been labeled with their energies. Many others can be identified by comparing the tabulated γ -ray results with this figure. The excellent isotopic separation is shown by the trace amount of ^{171}Lu remaining. The 739.7-keV transition from the ^{171}Lu decay was the most prominent peak above 200 keV in the spectrum from the earlier chemically separated source. Trace amounts of ^{169}Lu and ^{169}Yb activity are also just visible in these data. The strongest indicators of these activities are transitions at 108.9 and 197.8 keV, which in the earlier data were almost half as intense as the 193.1-keV ^{170}Lu transition. Many of the weaker peaks seen in this spectrum and some not seen here at all were visible in the earlier mixed-isotope data, which had greater than 10^4 counts in the continuum over this same energy region.

Additional data from the isotopically separated source were obtained in the energy region from 10 to 205 keV with use of the small Ge(Li) x-ray

spectrometer. As the ^{170}Lu activity decayed, the trace amounts of ^{169}Lu and ^{171}Lu in this region were easily identified. Also, the higher-energy 119.9-keV component of the 118.8-keV peak was easily observed in these data.

In the higher-energy portion of the spectrum (Fig. 3), the spectral region from 2380 to 3210 keV was scaled down by one decade. Some of the peaks are labeled with their energies, and a few of the more prominent doublet and triplet components are indicated. The few single and double escape peaks remaining in this Compton suppressed spectrum have not been labeled; some are present but are not very prominent. Quantitative data reduction and comparison of these data with those from the "pair" spectrum in Fig. 4 allowed unequivocal identification of real γ -ray transitions. Again, here only some of the "pair" peaks are labeled with their corresponding transition energies. The energy deposited in the spectrometer by these events is 1022 keV lower than the labels on the peaks, so this spectrum exhibits better resolution than the high-energy Compton suppressed data (e.g., the weak 2046.5-keV component is resolved from the intense 2041.8-keV transition in the "pair" data but not in the suppressed data). The resolution in the high-energy suppressed data varies from 2.2 keV at 1.4 MeV to 4.0 keV at high energies, whereas in the "pair" data it varies from 1.5 to 3.3 keV.

All of the spectral data, including those shown in Figs. 2-4, were analyzed with use of the computer code SAMPO. This code is described in detail in Refs. 17 and 18. The code includes mathematical algorithms for automatically carrying out peak searches, peak fittings, line shape

determinations, and energy and efficiency calibrations. An example of part of the output from this code for the 544-keV multiplet is shown in Fig. 5. Data pertinent to the fit of each peak are tabulated below the graph. The column "INTENSITY (CTS)" is the area divided by the efficiency. At the end of the spectral printout is a result table summarizing all of the individual fitting data. Relative γ -ray intensities are also listed. All transition intensities from the ^{170}Lu decay were normalized to the very strong 1364.6-keV transition.

The spectral data shown in Figs. 3 and 4 were analyzed by an "on-line" interactive method of data reduction. The same code (SAMPO) was used, this time coupled with an interactive graphics system (VISTA)¹⁹ introduced between the user and the CDC-6600 computer.

The intensities from the pair data were first normalized to the Compton suppressed data, using an average normalization factor obtained from the 2040-keV doublet and 2126-keV transitions. A calibration curve defining the double escape to full-energy peak ratio for this detector had been established from other data (^{24}Na , ^{56}Co , ^{66}Ga). This curve is a very steep function of energy below 1.5 MeV; hence, the very strong 1280.3-, 1364.6-, and 1428.1-keV transitions were used as secondary normalization points. The intensities for these three transitions were derived from an average of the low- and high-energy (chemically separated) Compton suppressed data. Pair data for γ rays below 1250 keV were not used in determining final results.

Energy calibrations for all the data obtained in this study were carried out using one of the well-calibrated Ge(Li) detector (singles) systems

developed by Gunnink.²⁰ These systems are used to process many samples on a daily basis and operate continuously with gain stabilization. The nonlinearity function at various conversion gain settings has been precisely measured. The energies of the stronger peaks in the ^{170}Lu data were determined by using these precisely calibrated systems. These energies then served as internal standards in the Compton suppressed, "pair," and γ - γ coincidence data.

2. The ^{170}Lu γ - γ Coincidence Data

Extensive multiparameter γ - γ coincidence information was obtained at 90 and 180 deg with use of the ^{170}Lu isotopically separated source. The 90-deg data covered the entire energy region; at 180 deg, data from the 35-cm³ detector were accepted only above 800 keV. Some 70 separate coincidence spectra were sorted from the 90-deg data, and 40 from the 180-deg data. (Many, but not all, γ -ray gates in the 180-deg data were the same as in the 90-deg data.) Both the Compton background coincidences and random coincidences were subtracted by the computer during the sorting process, so the sorted coincidence spectra should represent only "valid" full energy-peak coincidences. The FWHM resolving time of the coincidence time amplitude curve was 20 nsec; for sorting prompt and random events, digital time gates of about 55 nsec (FWHM) were used.

The large quantity of these data does not allow the display of all of the coincidence spectra here; however, those γ rays observed in each coincidence gate are listed in Table I. A complete catalog of these coincidence spectra can be found in Appendix I of Ref. 21. Only several selected representative

gates are shown here. Figure 6 shows the gated coincidence spectra obtained at 90 deg for the two ^{170}Yb ground-band transitions observed at 84.26 and 193.13 keV. These two spectra are somewhat more complex than all of the others obtained. Perhaps more typical of the coincidence spectra are those shown in Fig. 7. These spectra were obtained at the 180-deg setting and show those γ rays in coincidence with the 152.6-688.0- and 1028.8-keV transitions. The Compton suppressed singles energy and intensity data had been carefully analyzed before the γ - γ coincidence sorting gates were set; hence, many of the close-lying lines were sorted with awareness of their multiplicity. Analysis of the coincidence data revealed the presence of many doublets that were otherwise unresolvable.

There remains one major unresolved problem in the coincidence relationships, that of the 706.5-keV transition in the 193.1-keV gate. According to the analysis of the singles data, there is a doublet with components at 706.5 and 707.1 keV and intensities of approximately 1650 and 3000 units, respectively. The 193-keV gate contains a peak of approximately 2300 ± 250 units at 707 keV (see Fig. 7). No other coincidence gate shows a 707-keV peak. If the 707-keV line feeds the 277.4-keV 4^+0 level directly, a level at 984.5 keV is indicated. Such a state would be below the 1069-keV level thought to be the first excited state above the ground band and would have a spin of at least two units. If part of the very intense 985-keV transition is really a ground-state transition from such a 984.5-keV level, then the level might be expected to feed the 84.26-keV 2^+0 level. No γ ray with an intensity greater than 300 units was observed either in the singles data or in the 84.26-keV gated spectrum at 900.2 keV. In addition, no strong

γ rays could be found decaying from other levels to a level at 984.5 keV. Therefore, such a placement of the 707-keV transition seems implausible at best.

Another possibility is that the 193-keV transition is a very closely spaced doublet. The only other evidence for such a possibility is the appearance of a 193-keV peak in the 999-keV gate. This transition was established from coincidence data to decay from the 2364-keV 1-1 level to the 1364-keV 1-0 level. This latter level does not decay to the 4+0 ground-band member. Therefore the presence of a 193-keV transition in the 999-keV gate remains puzzling. If indeed the 193-keV transition is a doublet, then the 707- and 999-keV transitions may very well be directly related to it. Such a 193-keV twin could not be very intense, since the net intensity balance for the 277.4-keV level is -400 ± 2400 units in 60,000, consistent with the expected negligible β -decay to the 4+ state.

3. The ^{170}Lu Conversion Electron Spectrum

In Fig. 8, portions of the conversion electron data taken with the 3-mm $\times$ 1-cm² Si(Li) detector are shown. The top two sections show the low-energy spectrum from 100 to 1500 keV, taken with a 4096-channel analyzer, and one of the chemically separated sources. These data were taken very soon after chemical separation so that contaminant peaks, denoted C, from ^{169}Lu and ^{171}Lu were minimal. Only some of the K- and L-conversion lines are identified. The 193.1-keV K-conversion peak is slightly asymmetric because of finite-source thickness effects. The bottom spectrum shows the high-energy portion, 1350 to 2800 keV, taken with a

1600-channel analyzer. Some of the prominent K-conversion peaks are identified as well as some of the double escape or "pair" peaks, D, produced by the more intense γ -ray transitions.

Although some information on transition multipolarities can be obtained from the Si(Li) data, the complexity of the γ -ray data limits the usefulness of such low-resolution electron data to only the more prominent conversion electron peaks. Conversion coefficients were determined by normalizing to the theoretical conversion coefficients of 1) the pure E2 ground-rotational band transition at 193.1 keV; 2) the 1138.8-, 1144.6-, 1145.9-, 1395.6-, and 1534.5-keV E2 transitions; and 3) the 1280- and 1364-keV E1 transitions. The multipolarities of all but the 193-keV E2 transition were determined from decay systematics and from the directional correlation measurements by Paperiello et al.¹⁰ It is worth noting that our low-energy conversion electron intensity data (<400 keV) disagree significantly with the data given in Ref. 2.

D. Experimental Results

1. γ -Ray Energies and Intensities

The energies and intensities for the 550 γ -ray transitions observed in the decay of ^{170}Lu are listed in Table II. Also given are K-conversion coefficients for the stronger lines obtained from the conversion electron data, as well as data for eight E0 transitions. Where multipole assignments can be made they are listed as well.

For those transitions placed in the decay scheme (see Section II.D.3, below), assignment was based either on coincidence data or energy balance, denoted c.d. and e.b., respectively, in the last column of Table II. There were 212 γ -ray and eight electron transitions assigned on the basis of coincidence data, and these account for 93% of the total γ -ray intensity observed. For these transitions, the initial and final energy levels are given; where well determined, the spins and parities of the levels are also listed.

An additional 118 transitions have been assigned on the basis of energy balance, that is, agreement between the γ -ray transition energies and the level energy differences for those levels established by coincidence data. Thirteen transitions can be placed in either of two locations, and these choices are listed under the columns labeled E_i and E_f . Three transitions having three possible placements and one transition having four possible placements are indicated under E_i . These 118 transitions account for another 3% of the γ -ray intensity. Therefore, only 4% of the total observed intensity remains unassigned, and this small percentage involves the remaining 210 γ -ray transitions.

2. Proposed ^{170}Yb -Level Scheme

The partial level scheme proposed for ^{170}Yb is shown in Fig. 9. The 61 levels shown are all based on γ - γ coincidence data. A few high-energy ground-state transitions whose energies agree very well with the established levels are also shown (those transitions lack the solid circles). The eight E0 transitions observed in the conversion electron data are shown as

dotted transitions. The 220 transitions shown account for 93% of the total observed γ -ray intensity. The electron capture and positron branching to each level, and the $\log ft$ values, have not been included in Fig. 9 but can be found in Table III. The bases for the spin, parity, and K quantum number assignments for each level are discussed in Section II.D.4, below.

Once these 61 levels were established, it was possible to compare all of the energy level differences with the unassigned transitions. Those transitions agreeing with only one energy-level difference were placed in another decay scheme, which is shown in Fig. 10. A total of 64 levels and 118 transitions is shown in this decay scheme. Many of the transitions shown are undoubtedly correctly assigned; however, a few may be misassigned because they really belong to one or several "unknown" levels not shown in either Fig. 9 or 10. An indication of the small percentage of incorrect assignments is given by those 17 transitions mentioned earlier that have either two, three, or four possible placements. These transitions represent only 5% of the 328 transitions not assigned on the basis of coincidence data. The 118 transitions placed in Fig. 10 were included in the calculation of the intensity balances and $\log ft$ values.

The position of the $6+$ ground-rotational-band member was calculated with the formalism outlined by Mariscotti et al.²² The $6+$ level is shown as a tentative (dashed) level in Fig. 10 at an energy of 572.28 keV. The 0.27-keV error in this level is based on the 4-eV error in the $2+ \rightarrow 0+$ transition and the 50-eV error in the $4+ \rightarrow 2+$ ground-band transitions. This is easily in agreement with the value observed in (d,t) and (d,d') experiments reported by Burke and Elbek.²³

The ^{170}Yb level scheme is so complex that a detailed discussion of differences between this work and that of Bonch-Osmolovskaya et al.¹² is not practical. Instead, only a few of the major differences are noted here. We do not see levels at 1757.6, 2113.2, 2533.1, 2883.6, and 3091.9 keV. A majority of the transitions issuing from these levels are placed elsewhere in our decay scheme by coincidence data. A comparison of transitions in the decay scheme of Ref. 12 and those in our Table II is relatively easy and will show which assignments differ. The 2521.3-keV level of Ref. 12 resembles our 2523.0-keV level only in the two transitions to the $2+0$ and $0+0$ levels of the ground band. Two additional transitions assigned to the 2523-keV level in Ref. 12 are placed elsewhere by our coincidence data. The 2641.4-keV level proposed in Ref. 12 may exist. We observe two transitions at 2642.1 and 2558.0 keV that suggest a level at 2642.2 keV, but such energy couplets seem too numerous to create levels without additional supporting evidence. The 884.1-keV transition proposed in Ref. 12 to deexcite this level is placed elsewhere by our coincidence data. The proposed 3148.3-keV level may correspond to the two levels at 3146.2 and 3149.2 keV established by our coincidence data. Several transitions issuing from these levels decay to the same level in both schemes, but the transition energies differ. The 3301.7-keV level of Ref. 12 may correspond to our 3302.6-keV level. Again, the ground-band transitions are placed by both groups, but with different energies. One of their transitions is placed elsewhere by our coincidence data, and two fit elsewhere by energy balance. Numerous other levels not discussed here have many associated transitions that are assigned differently in our level scheme on the basis of coincidence data.

3. EC- β^+ Decay, Logft's, and Q Value of ^{170}Lu

Table III lists a summary of the electron capture plus positron branching ratios and associated information for 70 excited states in ^{170}Yb . The first column lists the net γ -ray intensity out of each level in units that are 10^{-3} of the transition intensity units given in Table II. In some cases, a positive or negative balance occurs that is consistent with zero net feeding within the errors of the intensity balance. These cases are indicated by parentheses around the percentage of electron capture plus positron decay in column three of Table III.

The spin and parity of ^{170}Lu is $0+$, and Hansen et al.⁹ measured positron feeding to the ^{170}Yb ground state as $0.19 \pm 0.05\%$ with an end-point energy of 2390 ± 50 keV. Thus, a Q value of 3410 keV was adopted for the total available decay energy, and 99.36% was assumed to be the total EC+ β^+ feeding to the excited states of ^{170}Yb . The logft values in column four are derived from a nomogram²⁴ and assume a ^{170}Lu half-life of 51.8 hr.¹⁰ The spin, parity, and K quantum number assignments are listed in column five.

4. Spin and Parity Assignments

The data on which we base spin-parity assignments for levels in ^{170}Yb are primarily K-conversion coefficients, logft's, and γ -ray branching ratios, although the angular correlation data of Papierello et al.¹⁰ provide direct confirmation for a few of the assignments. The discussion of spin-parity assignments is divided into two parts, since a rather natural division is

apparent in the ^{170}Yb -level scheme. Most of the spin-2 and -3 states populated in the ^{170}Lu decay occur below the obvious gap in the level structure at 1800 keV. In fact, only one state with a probable spin greater than 1 is identified above this gap. Below the gap lie several states that would normally be considered to have substantial collective character. This lower group of states is considered first. Because of space limitations, no attempt is made to explain the disagreement between our spin assignments and those given by Bonch-Osmolovskaya¹² and Mihelich.¹³ In Table IV, our spin-parity assignments and those from these latter two references are summarized.

1069.4-, 1138.6-, 1145.6-, and 1224.5-keV Levels

The level at 1069.4 keV is assigned $I\pi K=0^+0$ (see also Ref. 23) primarily on the basis of a conversion electron line corresponding to an E0 transition from that energy level to ground. The E2 character of the 985.1-keV $0^+0 \rightarrow 2^+0_0$ transition is confirmed both by conversion-coefficient data and by the angular correlation data of Papierello et al.¹⁰

Energy spacing and other available decay data suggest that either the 1138.6- or 1145.6-keV state may be the 2^+ member of this first excited 0^+ band. Neither state displays the relative strength in the E2 branch to the 4^+0_0 ground-band member that would distinguish it as $K=0$ according to vector coupling rules. Moreover, the E0 strength from the 0^+ band-head at 1069.4-keV to ground is very small (cf. Table II), so that no enhancement of the 1054.3- or 1061.4-keV conversion coefficients is expected or measured.

Fortunately, the (d,d'), and (d,t) data of Burke and Elbek²³ serve to resolve the problem rather well. Though the absolute energy uncertainties in their data are substantial (5-10 keV), the relative energies can be related to those precisely known from decay work, and the conclusion that the 1138.6-keV state is the ^{170}Yb γ vibration seems fairly certain. On that basis then, and from elementary theoretical expectations, the K=0 assignment for the 1145.6-keV state is virtually required, and this state is then assigned as the 2+ rotation based on the 1069.4-keV 0+ state.

The first rotational excitation based on the γ -vibrational state is also observed at 1225.4 keV. The branching ratio to the 2+ and 4+ ground-band members, and the dominant E2 character of the 1141.3-keV $3+ \rightarrow 2+$ transition, both support the 3+2 assignment for this state.

1228.9- and 1306.4-keV States

The 1228.9- and 1306.4-keV levels form the second excited 0+ "band" to be observed in ^{170}Yb . The $0+0_2$ state is clearly indicated by the K-conversion electron line corresponding to an E0 transition of 1228.9 keV; and, in this case, the E0-enhanced conversion coefficient of the $2+ \rightarrow 2+$ transition at 1222.2 keV, together with the close agreement of branching into the ground band with Alaga's Rules, leaves little doubt that the assignment for the 1306.4-keV state is 2+0.

1364.6- and 1397.0-keV States

At 1364.6 keV is encountered the first of many 1-0 states observed in the ^{170}Yb -level structure. Branching from this state into the ground

band favors the 2^+ state by the 2:1 reduced intensity ratio expected for a $K=0$ state. Conversion data indicate E1 multipolarity for both the 1280- and 1364-keV γ rays. Angular correlation data from the work of Paperiello et al.¹⁰ further support the 1-0 assignment for this level.

The level at 1397 keV may be the spin-3 member of this lowest 1-0 band, but we are unable to confirm such an assignment. The energy spacing (32 keV) seems far too small, though such bands can be strongly perturbed; if indeed the $\log ft$ is 9.3, then the spin-3 assignment itself seems in doubt.

1425.3-keV State

The 286.6 and 1341.2-keV transitions out of the 1425.3-keV state are both identified as E1 from K-conversion coefficients. The absence of a 199.9-keV branch to the 3^+2 state at 1225.4 keV is puzzling (perhaps the 199.65-keV transition belongs here). If K is 2 for the 1425-keV state, one expects substantial feeding to both the spin-3 and spin-2 members of the low-lying $K=2^+$ band. Instead, only the $2 \rightarrow 2$ branch occurs. Similarly, the absence of branches to other than the 2^+ ground-band members seems to limit the spin to 2.

1479.9- and 1534.5-keV States

The 1479.9- and 1534.5-keV levels are the 0^+ and 2^+ band members of the third $K=0^+$ excitation. The 1479.9-, 410.5-, and 251.0-keV $E0$'s provide positive identification of the 1479.9-keV level as 0^+ ; and the

K-conversion coefficient data for transitions from the 1534.5-keV state, together with γ -ray branching ratios for transitions into the ground band, provide the necessary information for the $2+0_3$ assignment at 1534.5 keV.

1512.4-keV State

The E1 character of the 1512.5- and 1428.1-keV transitions to the ground band, and their 1:2 reduced intensity ratio, supports the 1-0 assignment for the 1512.4-keV state.

1566.4- and 1634.8-keV States

The 1566.4- and 1634.8-keV states form the beginning of the fourth low-lying $K=0+$ excited band. Again, the E0 branches to the ground, and the first two excited $0+$ bands make the assignment of $0+0_4$ to the 1566.4-keV level unambiguous. Although the 1357.4-keV transition to the $4+$ ground-band member is conspicuously absent from the 1634.8-keV level, the E2 character of the 1634.8 $2 \rightarrow 0$ transition and the apparent E0 enhancement of the 1550.6-keV conversion coefficient argue strongly for an assignment of $2+0_4$ for this state.

1658.0-keV Level

The 1658.0-keV level is the second state for which no definite spin and parity assignment is possible. Once again, as for the 1397.0-keV state, weak γ -ray branches to the $2+$ and $4+$ ground-band members are seen, but the conversion lines were not observed and little feeding occurs from

higher-lying levels. This level may decay to the ground state; but, unfortunately, a ^{169}Lu line occurs at the same energy, and a ground-state transition thus remains questionable. The $\log ft$ is quite large, so a relatively high spin seems justified on this basis.

1718.0-keV State

A trio of E1 transitions deexcites the 1718.0-keV state into the $K=2+\gamma$ -vibrational band and the apparently strongly-mixed $2+0_1$ state at 1145.7-keV. The γ -ray branching ratios do not provide convincing support for the $K=2$ assignment, and it is therefore based largely on the absence of any observable feeding into the ground band.

Levels Above 1800 keV

Beginning at 1985.6 keV, a multitude of low-spin states is populated by the ^{170}Lu decay. Most of these states appear to have 0 or 1 unit of angular momentum, and odd parity. Several exhibit the peculiar γ -ray branching characteristic of 0-0 states. Strangely enough (in view of the four lower-lying 0+ excitations already discussed), no conclusive evidence for further population of 0+ excited states is seen. Thus, with but four exceptions, all the remaining levels in ^{170}Yb for which sufficient data are available appear to be either 0- or 1-. Abbreviated arguments for the assignments proposed for the remaining ^{170}Yb states populated in ^{170}Lu decay follow. In general, the remaining assignments are based on γ -ray multipolarities from K-conversion coefficient data, selective feeding to lower-lying states of known $I\pi K$, and γ -ray-branching ratios. Most of

these higher-lying states must await considerable further information before any attempts can be made to understand their structure in detail.

States of $I\pi K=0-0$

We propose 0^- assignments for states at 2052.6, 2351.8, 2367.7, 2498.3, and 2819.8 keV. In every case, decay from these states picks out lower-lying $I\pi K=1-0$ and $1-1$ states, or, in a few instances, states with $I\pi K=2-2$. Decay to the ground band and other $K=0$ band members is strictly forbidden except for $M2$ or higher-order transitions that are not observed. The $0-0$ assignment is also supported in each case by conversion data that indicate $M1$ multipolarity for the deexciting γ rays.

States With $I\pi K=1-0$

In addition to the two low-lying $1-0$ states at 1364.6 and 1512.4 keV, other such states are assigned at 2126.1, 2275.4, 2667.4, 2929.6, 3115.2, 3149.2, 3195.5, and possibly 2116.0 and 2536.8 keV. In those cases where we make definite assignments, one or more transitions to the ground or excited 0^+ bands have been identified as $E1$, and the characteristic factor-of-two enhancement of the $1^- \rightarrow 2^+$ transition relative to the $1^- \rightarrow 0^+$ branch is observed. In the case of some of the higher-lying levels, assuming states of $I\pi K=1+0$ do not occur (not necessarily a valid assumption, as we note later), feeding to the 0^+ and 2^+ ground-band members with the "correct" reduced-intensity ratio is considered sufficient to support the $1-0$ assignment, even though the $E1$ character may not be established.

States With $I\pi K=1-1$

The 1-1 assignment is established for states at 2400.1, 2496.1, 2748.2, 2939.7, 2947.8, 3165.6, and possibly 2364.1 keV. The basis is rather similar to that just discussed for the 1-0 levels, except that the reduced branching ratio of 0+ band members is now reversed to 2:1 in favor of the 0+ spin state. Generally, a greater tendency to feed states with $I\pi K=2\pm 2$ is noted for the states assigned 1-1.

States With $I\pi K=1+1$

At least three states of this interesting class of excitation are thought to be identified in ^{170}Yb . The states at 2040.0, 2783.0, and 2965.6 keV seem well characterized; M1 transitions are observed to feed the 0+ and 2+ ground rotational band members, with some E2 mixture apparent in the $1+ \rightarrow 2+$ transitions.

It is noteworthy that we are unable to identify any states of the 1+0 configuration, such as those proposed by Gabrakov et al.²⁵ In particular, we fail to establish the existence of a state at 2533.1 keV previously proposed¹² to be the $I\pi K=1+0$ two-quasineutron state of configuration $\left[\frac{5}{2} (523) \downarrow \right] - \left[\frac{5}{2} (512) \uparrow \right]$.

States With $I\pi=2-$

Only one state with proposed spin of two units is definitely identified above 1800 keV, and the K-quantum number assigned for this state must be considered tentative. The state at 1985.6 keV is assigned on the basis

of the single γ ray of apparent E1 multipolarity leading to the ground-rotational-band $2+$ state.

III. DISCUSSION OF THE ^{170}Yb -LEVEL SCHEME

In the simplest sense, an overview of the level structure of the ^{170}Yb nucleus provides a graphical illustration of the distinction to be made between those excited states clearly influenced by coherent many-particle interactions and those whose structure may be dominated by essentially two or four quasiparticle configurations. Such a generalization is encouraged by the presumably fortuitous appearance of a distinct gap at about 1800 keV in the observed low-spin ^{170}Yb states. It is interesting to note that a similar phenomenon seems to occur in ^{176}Hf , another even-even deformed nucleus for which numerous low-spin states have been identified from radioactive decay.²⁶ In both nuclei, this dearth of at least low-spin states occurs near 2Δ , the upper limit of the pairing energy gap expected to be ~ 1.6 MeV for ^{176}Hf and ~ 1.7 MeV for ^{170}Yb . In both nuclei there also seems to be some evidence for a similar decrease in level density near the energy 4Δ .

At the present time, it is perhaps only for the lowest-lying group of excited states, those within the energy gap 2Δ , that one may hope for a degree of success in characterizing the exact nature of the observed states. This is particularly so in view of the uncertainty associated with the spin and parity assignments for many of the higher-lying levels. In the light of present understanding, we proceed to discuss the several

classes of "collective" states seen in the ^{170}Yb level scheme and then we provide a brief comparison with the few published quantitative calculations attempted for this nucleus.

A. $K=0+$ Excitations in ^{170}Yb

The observation in ^{170}Yb of four $0+$ excitations, all presumably within the pairing energy gap 2Δ , lends further interest to the lively discussion that already surrounds the occurrence of multiple low-lying $0+$ states in deformed nuclei. It is well-known that the simplest quadrupole vibrational mode allows for only one such low-energy $0+$ excitation, but it is also well-known by now that numerous deformed nuclei exhibit multiple low-lying $0+$ excitations. Various explanations for this phenomenon have been made by invoking the quadrupole-quadrupole, pairing, and spin-quadrupole interactions, and combinations and variations of all three phenomena.^{26,27} On the basis of the considerable volume of literature treating the subject from the standpoint of both experiment and theory, the picture now seems to be developing that the low-lying $0+$ states in the deformed regions are not so much pure states of any single type, but rather consist of mixed-mode excitations where the quadrupole vibrational strength in particular may often be spread over several close-lying states.

One of the more useful properties of $K=0+$ excitations that may be extracted from decay data is the ratio of monopole to quadrupole decay into other $0+$ bands. The usual expression is that proposed by Rasmussen:²⁸

$$X \left[\frac{B(E0; 0^+ \rightarrow 0^+_{g})}{B(E2; 0^+ \rightarrow 2^+_{g})} \right] = \frac{\rho^2 e^2 R_0^4}{B(E2; 0^+ \rightarrow 2^+_{g})} \quad (1)$$

Similar expressions, including the applicable angular-momentum coupling coefficients, may be written for transitions from higher-spin members of the $K=0+$ bands to the ground band, and for interband transitions between excited $0+$ band members. Table V displays the X -parameters deduced for ^{170}Yb . Perhaps the most notable departure from the theoretical values allowable for a "good" β vibration, $0.15 \leq X \leq 0.80$,²⁸ is the very small $X=0.005$ observed for the lowest $0+$ excitation. It is also for this state that the isospin forbidden Fermi β -decay is most highly hindered.

The quadrupole vibrational strength of $0+$ excitations may be sensed by Coulomb excitation, and in the case of ^{170}Yb we are fortunate to have preliminary results from the (^{16}O , $^{16}\text{O}'\gamma$) work of Riedinger et al.,³⁰ as shown in Table VI. On the basis of these data, one would conclude that there is little β -vibrational character in the first ^{170}Yb $0+$ excitation at 1069 keV, and considerably more in the second, at 1229 keV. It is most remarkable that the $2+0_1$ state apparently has a large $E2$ transition moment to the ground state, while the $0+0_1 \rightarrow 2+0_0$ moment to ground is at least an order of magnitude smaller. This is again consistent with the picture already suggested that the $2+2_\gamma$ and $2+0_1$ states are strongly mixed.

With the aid of the $B(E2)$ data of Riedinger et al., it is also possible to calculate the values $\rho(E0)$, the nuclear $E0$ matrix elements, for the first two $0+$ excited states in ^{170}Yb . With use of Eq. (1), we

obtain the results shown in Table VII. It should be noted that in deriving the values for ρ in Table VII, we have made the assumption

$$B(E2; 0_n \rightarrow 2_0) = B(E2; 0_0 \rightarrow 2_n).$$

If in fact a simple first-order correction to the reduced E2 transition moment is allowed, then one has²⁷

$$B(E2; 0_n \rightarrow 2_0) = B(E2; 0_0 \rightarrow 2_n) \left[\frac{1 + 6z_0}{1 - 6z_0} \right]^2, \quad (2)$$

where $z_0 = \frac{M_2}{M_1}$, according to the first-order expansion of Mikhailov³¹:

$$B(E2; I\pi 0_n \rightarrow I'\pi 0_0) = (I200|I'0)^2 \left\{ M_1 + M_2 [I'(I'+1) - I(I+1)] \right\}^2. \quad (3)$$

The relation (2) should be valid if a consistent value of the parameter z_0 is found to adequately describe the branching from the members of a given " β -vibrational" band. Table VIII shows that, in ^{170}Yb , except for the second excited $0+$ band, the various derived z_0 parameters are not consistent for branching from the $2+0$ excited states into the ground band. In several cases, the $2 \rightarrow 2$ transition is assumed to be pure E2. It would be most surprising if this assumption were eventually shown to be valid for all $2+0$ states in ^{170}Yb .

In the case of the second excited $0+$ band, a single value of z_0 [i.e., consistent values of M_1 and M_2 in Eq. (3)] is found to fit the limited data nearly perfectly, so we may be justified in using Eq. (2) to modify the calculated value of ρ . This correction is only 27% for ρ^2 , so that ρ_{corr} is 0.15. The fact that a single mixing parameter seems to describe the γ -ray branching from the $2+0_2$ state and that one deduces the relatively large value of $\rho \approx 0.15$ for this band argues further for the

characterization of the second excited $K=0+$ state as predominantly quadrupole vibrational in nature. One notes in Pyatov's tabulation of experimental data²⁷ that the presumed "good" β -vibrational states in ^{150}Sm , ^{152}Sm , ^{154}Sm , ^{154}Gd , and ^{156}Gd all have values of $\rho(E0)$ in the range 0.2 to 0.5.

The early work of Reiner³² considered the collective monopole transition moment arising from quadrupole surface oscillations of an incompressible uniformly charged spheroid and predicted values of $\rho(E0)$ in the range 0.2 to 0.6 for the β -vibrational states in deformed nuclei. The more general calculations of Bès³³ and, most recently, of Kuliev and Pyatov³⁴ have not changed the expectation that excited $0+$ states that may be characterized as β vibrations should exhibit relatively large $E0$ moments as well as large $E2$ transition moments.

It is unusual that in ^{170}Yb one is also able to see $E0$ transitions between excited $0+$ states. In Table IX the monopole transition matrix elements for transitions between the excited $0+$ states and the ground-band $0+$ state are compared. There appears to be little difference in the monopole matrix elements between the various $0+$ states in the cases where the $E0$'s could be observed. The greatest departure of the value ρ^2 is shown for the $0_3 \rightarrow 0_1$ transition, where the $E0$ strength is about one-fifth that to ground.

Finally, it is worth noting that the $0+$ bands higher in energy exhibit larger moments of inertia, perhaps indicating their greater two-particle character as compared with the lower $0+$ bands; the 1479.9-keV $0+$ band, for example, exhibits a moment of inertia some 50% greater than that of the ground band.

One of the most useful probes of the nature of excited $0+$ states is provided by the transfer of a single nucleon or pair of nucleons to populate excited $0+$ bands in the residual nucleus. The (p,t) , $(^3\text{He},d)$, (α,t) , (p,d) , and similar reactions can be particularly useful in this regard. Preliminary $^{172}\text{Yb}(p,t)^{170}\text{Yb}$ pickup reaction data from Oothoudt et al.³⁵ have shown only that the two-neutron-transfer reaction drops off sharply as one moves toward lighter Yb isotopes, until in ^{170}Yb only tentative identification can be made of the 1069.3-keV $0+$ state. This state appears to be populated with a cross section only 1% that of the ground $0+$ state. These data seem to argue against the presence of much neutron pairing-vibrational character in the $0+0_1$ state of ^{170}Yb , at least.

Recent data from $^{169}\text{Tm}(\alpha,t)^{170}\text{Yb}$ reaction studies carried out at the Michigan State Cyclotron Laboratory³⁶ indicate strong $l=2$ proton transfer into the same 1228.9-keV $2+0_2$ excited state we have tentatively identified as the best candidate for a ^{170}Yb β -vibrational state. Since the (α,t) reaction in this case should predominantly involve transfer of a proton into the $1/2+[411]^{169}\text{Tm}$ ground-state orbital, this result seems difficult to harmonize with the supposed collective nature of the state in question. Transfer-reaction studies aimed at further elucidating the $0+$ states in ^{170}Yb are continuing.

As the experimental data on $0+$ states in deformed nuclei have become more complete in recent years, some attempts have been made to develop a theoretical understanding for them. In most cases,

however, little is known about absolute E0 transition probabilities or the details of the nuclear wave functions associated with excited 0+ states, and it seems rather futile to attempt to further characterize the different 0+ levels in ^{170}Yb on the basis of the still rather limited experimental data. Some workers have published theoretical calculations for the ^{170}Yb 0+ states, and in Fig. 11 the results of Kuliev and Pyatov³⁴ are displayed. Kuliev and Pyatov invoked the spin-quadrupole residual force and investigated the effect of coupling β -vibrations with excitations of the spin-quadrupole type. They also included estimates of the X parameters, which are shown with the associated levels in Fig. 11, but it should be noted that these calculations are very sensitive to interference between the different 0+ excitation modes. The X parameters also depend on the effective charge used for calculating the E0 and E2 moments, so it is difficult to distinguish between the ^{170}Yb 0+ states on the basis of these parameters alone. Kuliev and Pyatov also show results for 0+ states induced by coupling proton- and neutron-pairing vibrational modes with the quadrupole mode. The lowest roots of these calculations are shown as dashed lines in Fig. 11. It is noteworthy that addition to their calculations of both the pairing and spin-quadrupole interactions succeeds in lowering one 0+ state to an energy near that of the β -vibrational state as calculated by Bès,³³ but this refinement still fails to reproduce the observed four low-lying 0+ states. Kuliev and Pyatov do, however, predict $B(E2) = 1.3$ spu. and $\rho(E0) = 0.16$ for the lowest (1240 keV) 0+ excitation. This state may correspond to that seen experimentally at 1229 keV.

Mikoshiba et al.³⁷ also carried out calculations for 0+ excitations in rare-earth nuclei. These authors considered the effects of coupling the quadrupole and pairing field fluctuations to generate mixed-mode 0+ excitations. They show no explicit results of 0+ level calculations for the ^{170}Yb case, but the general pattern of their results for other nuclei seems to predict a single lower-lying 0+ state that does not in every case carry the bulk of the quadrupole collectivity. A series of higher-lying 0+ states, near or above the upper limit of the pairing gap 2Δ , is normally expected, then, according to their results. For ^{170}Yb , as for most other nuclei near the middle of the rare-earth region of deformation, Mikoshiba et al.³⁷ note that the quadrupole sum rule is far from exhausted on the " β -vibrational" state, which carries no more than 60% of the collective quadrupole strength.

Bernthal et al.²⁶ also reported attempts at calculating the 0+ excited levels for the single case of ^{176}Hf by means of an exact diagonalization of the pairing and quadrupole interaction matrix in a seniority-zero subspace of 9-proton and 9-neutron Nilsson orbitals nearest the Fermi surface. The results of these preliminary calculations for ^{176}Hf seemed to explain a very large value of the X parameter for one of two low-lying 0+ states in that nucleus; but the theory could not account for another 0+ state at still lower energy, relative to the first. Similar calculations have now been attempted for ^{170}Yb ; but in this case the results are even more difficult to interpret in the absence of detailed $B(E2)$, $\rho(E0)$, and transfer-reaction data, or of unusual β - or γ -decay patterns that might

label any of the ^{170}Yb 0+ states as being of one particular type or another.

In summary, it can be said that data of the kind required to resolve the problem of the multiple low-lying 0+ states in deformed nuclei are now becoming available, but much more work will be required before these states in ^{170}Yb and other deformed nuclei can be characterized in detail.

B. The 2+2 γ -Vibrational Band

The experimental location of the γ -vibrational bandhead in ^{170}Yb is very close to that predicted by Bès.³⁸ It should be noted that some ambiguity still exists regarding the assignment of the 1138.6- or 1145.6-keV state as the γ -vibrational state, because of the failure of Alaga's branching rules to dictate one choice or the other. The breakdown of the geometrical branching relations for the transitions from these two states into the ground band may well indicate very strong mixing between the close-lying $2+0_1$ and $2+2$ excited states. It is fashionable to gauge the degree of first-order mixing of the ground band into the γ -vibrational band by calculating the so-called z_2 -parameter. The appropriate first-order expansion of the reduced E2 moment is similar to that written earlier for mixing between ground and excited 0+ bands³¹:

$$B(E2; I\pi 2_\gamma \rightarrow I'\pi 0) = 2(I22 - 2|I'0)^2 [M_1 + M_2 [I'(I'+1) - I(I+1)]]^2, \quad (4)$$

where M_1 and M_2 are proportional to the principal and first-order E2 transition matrix elements. The z_2 parameter is then defined as

$$z_2 = [2M_2 / (M_1 - 4M_2)].$$

For ^{170}Yb , we find $z_2 = 0.052$ for transitions from the 2+2 state into the ground-rotational band, and $z_2 = 0.054$ for transitions from the 3+2 state. The expression of Mikhailov et al. and equivalent earlier relations involving the z-parameter assume that the intrinsic quadrupole moments of the ground and γ -vibrational bands are equal. Reich and Cline³⁹ worked out the expressions whereby one may compare $z_2(0)$ with $z_2(2)$ for the presumed first-order mixing into the γ -vibrational band, where

$$z_2(0) \propto (Q_{00}/Q_{20})$$

and

$$z_2(2) \propto (Q_{22}/Q_{20}),$$

with Q_{00} and Q_{22} representing the intrinsic quadrupole moments of the ground and γ -vibrational bands, respectively, and Q_{20} the E2 transition moment between the two bands. Within the precision of the experimental data, no difference is found between $z_2(0)$ and $z_2(2)$ for the ^{170}Yb γ -vibrational band. Still, it is noteworthy that the simple first-order mixing theory predicts an intensity of 3500 units for the unseen 861.6-keV (2+2) $\rightarrow$ (4+0) transition, a factor of six greater than the experimental upper limit for the intensity. The intensity of this unseen transition is in serious disagreement with Alaga's branching rules, and it is evident that the first-order mixing theory does not explain the discrepancy.

C. Low-Lying States of Odd Parity

Of the numerous odd-parity states excited in ^{170}Yb by ^{170}Lu decay, those states within or slightly above the energy gap 2Δ and thought to be influenced by the octupole-octupole interaction lend themselves most readily to interpretation. Neergård and Vogel⁴⁰ carried out extensive collective model calculations for the octupole states in deformed even-even nuclei. They used a pairing and octupole-octupole residual force and solved the random-phase equations for quasiparticles in a Nilsson deformed potential well. With use of the intrinsic wave functions thus obtained, they also calculated the Coriolis interaction matrix elements and diagonalized the interaction matrix for the lowest-lying multiplet of octupole states: $K\pi=0-, 1-, 2-, \text{ and } 3-$. Their calculated energies for the members of this quartet of states in ^{170}Yb are shown in Fig. 11.

Perhaps the most puzzling feature of the ^{170}Yb -level scheme in comparison with the calculations of Neergård and Vogel is the apparent presence of two states of $I\pi K=1-0$, quite low in energy, at 1364 and 1512 keV. Such states are not particularly collective in this region, however, and Neergård and Vogel emphasize the extreme sensitivity of their calculations to the two-quasiparticle energies for single-particle states near the Fermi surface. This explanation may account for the 500-keV discrepancy between the calculated and the experimental location of the lowest $1-0$ state in ^{170}Yb . The remaining anomaly, the apparent presence of a second $1-0$ state at low energy, might be explained as resulting from strong mixing between the several low-lying odd-parity states in this region. The experimental assignment of zero K-quantum

numbers to the two states in question depends largely on γ -ray-branching ratio data. In the case of the 1364-keV state, the data seem unassailable—the expected 2:1 favored feeding to the 2+0 ground-rotational-band member is very clear. In the case of the 1512-keV state, however, there is some room for doubt, though the $1 \rightarrow 2+$ reduced transition strength is still 60% greater than the $1 \rightarrow 0+$ strength, and far from the 50% smaller value that would imply a $K=1$ assignment. The inclination to identify this state with the 1-1 octupole branch is further strengthened by our failure to identify any other 1-1 state below 2400 keV.

The lowest 2-2 root in ^{170}Yb is predicted in Ref. 39 to lie at 1730 keV; we observe 2-2 states at both 1425 and 1718 keV. Finally, it seems unlikely that we could identify the 3-3 octupole branch as being either of the two spin-3 states tentatively proposed at 1397 and 1658 keV, since both states decay primarily into the $K=0$ ground rotational band.

D. States of $I\pi=1+$

We have already noted the recent work of Gabrakov et al.,²⁵ wherein the properties of excited states of the type of $I\pi=1+$ with $K=0$ or 1 are calculated. These authors show predicted energies of numerous states with $I\pi K=1+1$ in ^{170}Yb ; and, although all of these states are predicted to be predominantly two-quasiparticle structures, in many cases they may also possess a weak collectivity proposed to arise from oscillations of the spin part of the nuclear magnetic dipole moment. The bulk of the strength of these collective oscillations is predicted to lie near 10 MeV,

but smaller influences are expected at lower energies and would be evidenced primarily by enhanced M1 moments and hindered β -feeding.²⁵

Shown in Fig. 11 are only the lowest few 1^+ states predicted by Gabrakov et al. to exist in ^{170}Yb . Others are proposed to lie at 2930, 2990, 3030, 3200, 3330, 3350, 3500, and 3520 keV. Only two of these states are predicted to have $K=0$ quantum numbers: one at 2500 keV and the other at 3520 keV.

In comparing the calculations of Gabrakov et al. with our experimental results, we can draw at least two conclusions: 1) Very few states of even parity appear to be populated by ^{170}Lu decay. In fact, only four such states are identified in our work. This would appear to bear out the expectation that β decay to such states will be highly hindered.²⁵ 2) Bonch-Osmolovskaya et al.¹² propose a state at 2533.1 keV and assign to it the $1^+0 \left[\frac{5}{2} (523)_n^\downarrow - \frac{5}{2} (512)_n^\uparrow \right]$ two-neutron configuration proposed by Gabrakov et al.²⁵ We fail to observe any state at 2533.1 keV, thus negating the earlier-suggested experimental identification of a state $I\pi K=1^+0$ in this nucleus. Such a state would be expected to be part of a rotational sequence $1, 3, 5, \dots$ with even parity.²⁵

CONCLUSIONS

The staggering complexity of the ^{170}Yb -level scheme raises the question of the feasibility and even the necessity of experimentally detailing the structure of the myriad excited states in this and other similarly complex nuclei. The objective of an increased understanding of structure

in such nuclei is perhaps best achieved by concentrating further study on a few of the states most representative and perhaps least understood of a particular type of excitation or interaction. In ^{170}Yb , the best candidates for such detailed further investigations are those states lying within the energy gap 2Δ . High-resolution direct-reaction particle spectroscopy can reveal much about the exact nature of the four low-lying 0^+ states. Coulomb-excitation studies with ions heavier than ^{16}O may shed still more light on the structure of these interesting states. It is also of interest to further detail the nature of the low-lying negative-parity states, in order to better define the structure of the various octupole collective-vibrational modes. Higher-lying states meriting additional study include the $1+1$ and $1+0$ excitations. It would be of considerable interest to be able to document the proposed collective properties of these states. Finally, one must note again the curious gaps in the level structures of both ^{170}Yb and ^{176}Hf that seem to occur near the energies 2Δ and perhaps also 4Δ . It is important to determine from further study in ^{170}Yb and other nuclei whether this feature is indeed fortuitous, a result only of selective β -decay feeding, perhaps, or whether it represents a more general phenomenon that may provide new insight into the pairing interaction in nuclei.

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Table I. Gamma rays observed in selected coincidence gates at 90 deg
and 180 deg.

Gated E_γ keV	Angle		γ rays observed in coincidence gate ^a
	90°	180°	
84.26	X	X	<u>152, 193, 241, 283, 286, 323, 419, 492, 544, 572, 579, 829, 839, 855, 868, 884, 938, 985, 999, 1003, 1028, 1054, 1061, 1101, 1133, 1141, 1144, 1218, 1222, 1225, 1257, 1280, 1294, 1307, 1312, 1341, 1395, 1405, 1428, 1450, 1455, 1459, 1482, 1514, 1550, 1565, 1574, 1610, 1641, 1678, 1719, 1757, 1776, 1809, 1860, 1878, 1901, 1955, 2031, 2041, 2116, 2191, 2205, 2279, 2316, 2411, 2452, 2582, 2664, 2691, 2698, 2845, 2855, 2881, 2885, 2923, 2983, 3015, 3031, 3062, 3065, 3095, 3111</u>
118.8		X	<u>850, 926, 938, 943, 1028, 1222, 1306</u>
152.1	X	X	<u>84, 193, 511, 485, 1028, 1054, 1133, 1144, 1187, 1222, 1242, 1280, 1306, 1341, 1361, 1395, 1438, 1521, 1529, 1597, 2582, 2667</u>
193.13	X	X	<u>84, 118, 152, 228, 283, 419, 455, 479, 492, 544, 572, 572, 706, 741, 819, 829, 868, 947, 966, 980, 1028, 1050, 1057, 1101, 1119, 1218, 1230, 1257, 1350, 1361, 1380, 1395, 1405, 1413, 1469, 1565, 1614, 1630, 1641, 1662, 1759, 1793, 1802, 1842, 1859, 1954</u>
221-4	X		<u>84, 865, 999, 1395, 2191</u>
228.0	X		<u>193, 829, 1028, 1306, 1405</u>
235.6	X		<u>981, 1102, 1222, 1280, 1352, 1428, 1512</u>
241.5	X	X	<u>84, 2041, 2126</u>
251.8	X		<u>193, 2031</u>
283.0	X	X	<u>84, 193, 985, 1002, 1028, 1054, 1138, 1144, 1172, 1222, 1230, 1306+8, 1391, 1398, 1467, 2452, 2536</u>
286.6	X	X	<u>84, 850, 926, 938, 1054, 1138, 1323, 1514, 1531, 1540, 1706</u>
323.6	X	X	<u>84, 511, 983, 1054, 1070, 1138, 1144, 1426+8, 2411, 2496</u>
395.9	X	X	<u>84, 829, 1054, 1138, 1405, 1413</u>
419.6	X	X	<u>84, 193, 1380, 2315, 2400</u>
455.5		X	<u>1057, 1138, 1218, 1225, 1280, 1341, 1428, 1512</u>
447.6	X		<u>84, 576, 741, 1003, 1061, 1222, 1428</u>
479.0	X		<u>84, 96?, 193, 385</u>
492.6	X	X	<u>84, 193, 947, 1050, 1101, 1141</u>
530.5	X		<u>193, 329</u>
544.2	X		<u>84, 850, 910, 985, 1054, 1137, 1206, 1280, 1306, 2191, 2275</u>
572.2	X	X	<u>84, 193, 868, 1050, 1061, 1101, 1145</u>
579.4	X	X	<u>84, 1050, 1054, 1101, 1138</u>
612.1	X		<u>222</u>
688.0	X	X	<u>(84), 916, 1280, 1364</u>
706-8	X		<u>193</u>
829.3	X		<u>193, 1257, 1450, 1534</u>
839.3	X		<u>1428, 1512</u>
855.2	X		<u>84, 1428, 1512</u>
868.1	X		<u>193, 323, 511</u>
938.7	X		<u>84, 118, 193, 286, 1054, 1341</u>
947.8	X		<u>193, 492</u>

Table I (Continued).

Gated E_γ keV	90°	180°	γ rays observed in coincidence gate ^a
983.7	X	X	<u>84</u> , (323), 1428
985.1	X	X	<u>84</u> , <u>1206</u> , <u>1294</u> , 1678, 1860, 1878, <u>1995</u> , 2030, 2096
987.3	X		<u>84</u> , <u>1280</u> , <u>1364</u>
999.6	X		84, 193?, 1280, 1364
1003.2	X	X	<u>1054</u> , <u>1145</u> , 1280, 1364
1028.8	X	X	84, 152, <u>193</u> , 1057, 1361, <u>1641</u> , 1793, 1842, <u>1859</u>
1050.4	X	X	84, 193, 492, <u>572</u> , 579, 1054, <u>1061</u> , 1138, 1141, 1145
1054.3	X	X	<u>84</u> , <u>286</u> , 396, 455, 579, 938, 980, 1002, 1050, 1101, 1137, <u>1225</u> , 1405, 1529, 1609, <u>1809</u> , 1960, 2027
1061.4	X	X	<u>84</u> , 152, 388, 572, 819, 829, 980, 988, 1002, 1050, <u>1055</u> , 1101, 1132, <u>1218</u> , 1405, 1602, 1802, 2041, 2126
1101.7	X	X	193, 492, <u>572</u> , 579, <u>1054</u> , <u>1061</u> , <u>1138</u> , 1141, <u>1145</u>
1119.4	X		<u>193</u>
1133.6	X		84, 1280, 1364
1138.6	X		286, 579, 1137, <u>1225</u> , <u>1398</u> , <u>1529</u> , <u>1609</u> , <u>1809</u> , 1960, <u>2027</u>
1144.6	X	X	84, <u>152</u> , 1135, 1438, 1700, 1719, 1936
1145.8	X	X	<u>572</u> , 1050, 1101, 1132, <u>1218</u> , <u>1521</u> , 1802
1218.5	X		84, 193, 1061, 1145
1225.6	X		<u>84</u> , 1054, 1138
1257.2	X	X	84, <u>193</u> , <u>829</u> , <u>1395</u> , <u>1405</u> , <u>1413</u> , <u>1507</u> , 1564
1280.3	X	X	84, 688, 910, 987, 999, <u>1003</u> , <u>1133</u> , 1383, 1403, <u>1455</u> , <u>1565</u> , 1575, <u>1601</u> , <u>1610</u> , 1776
1294.7	X		<u>84</u> , <u>985</u>
1307.5	X		84, 283, 1428, 1512
1341.2	X	X	<u>84</u> , 926, <u>938</u> , 942, <u>1070</u> , 1323, <u>1514</u> , 1531, 1540, 1549
1364.6	X		[84, 152, 193 - via 1361], <u>987</u> , 999, <u>1003</u> , <u>1133</u> , <u>1455</u> , 1575, 1610, 1776
1380.8	X		193, <u>419</u>
1395.6	X	X	84, <u>193</u> , <u>884</u> , 1268, 1449, <u>1459</u> , 1467, 1619, 1685
1405.1	X		84, <u>193</u> , 388, 395, <u>1257</u> , <u>1450</u> , <u>1534</u>
1428.1	X	X	<u>84</u> , <u>540</u> , <u>839</u> , <u>855</u> , 983, 1235, 1263, <u>1307</u> , 1427, 1435, <u>1457</u> , 1674
1450.2	X		<u>84</u> , 829, <u>1132</u> , 1395, <u>1405</u>
1455.3	X		84, <u>1280</u> , <u>1364</u>
1459.9	X	X	<u>84</u> , <u>1395</u>
1512.5	X		839, 855, 983, 1263, 1307
1514.6	X		<u>84</u> , <u>286</u> , 1138, 1341
1550.5		X	1113, 1294, 1304, 1313, 1341
1860	X		<u>84</u> , <u>193</u> , <u>511</u> , <u>985</u> , 1028, 1222
2041.9	X		<u>84</u> , 241, 511
2116.6			84

^a A qualitative indication of the relative strengths of the gamma rays appearing in each coincidence gate is shown by: the strongest lines are underlined, e.g. 193; the medium strength lines are written normally, e.g. 193; the weak lines are underlined partially, e.g. 193; and very weak lines of questionable existence are parenthetically enclosed. A question mark following an entry indicates that line was observed, but its presence is not understood in that particular gate. Single and double escape peaks are not entered.

Table II. Gamma-ray transitions, energies, intensities, multiplicities and level assignments for all transitions observed in the decay of ^{170}Lu .

E_γ^a keV	ΔE_γ^b keV	I_γ^c % $\times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
84.262	± 0.004	195,000	$\pm 10,000$		E2	2+	0+	84	0	c.d.
118.80	0.15	720	70			2-	2+	1425	1306	c.d.
119.90	0.20	150	15					2939	2819	e.b.
134.05	0.15	280	30					3099	2965	e.b.
142.50	0.15	210	20							
152.60	0.03	6,100	200			0-	1-	2819	2667	c.d.
166.70	0.20	135	15					2367	2200	e.b.
170.80	0.20	70	10					3146	2975	e.b.
193.13	0.05	46,250	1,500	1,790	E2	4+	2+	277	84	c.d.
199.65	0.15	200	20							
201.75	0.15	350	30					1566	1364	e.b.
205.55	0.20	175	15					1717	1512	e.b.
209.90	0.20	165	15							
220.90	0.15	425	15	$\leq 2,100$	M1(E2)	1-	1-	2496	2275	c.d.
222.40	0.15	900	30	2,670	M1(E2)					
223.40	0.15	450	15	3,320	M1					
225.45	0.20	130	20					2351	2126	e.b.
228.05	0.15	800	50	5,420	E0+E2	2+	2+	1534	1306	c.d.
231.15	0.20	130	15					2768	2536	e.b.
235.55	0.15	880	80	1,920	M1E2			2351	2116	e.b.
238.25	0.15	370	35					2667	2429	e.b.
241.50	0.05	5,100	150	2,380	M1	0-	1-	2367	2126	c.d.
249.95	0.20	85	25					2748	2498	e.b.
251.0	—	≤ 100	—	$\geq 25,000$	E0	0+	0+	1479	1228	e.b.
251.75	0.10	1,050	50					2367	2116	e.b.
272.40	0.15	205	20					2939	2667	e.b.
275.40	0.20	100	10							
279.40	0.15	470	30					2775	2496	e.b.
283.05	0.10	4,450	150	1,240	M1	0-	1-	2819	2536	c.d.
286.60	0.05	10,100	300	180	E1	2-	2+	1425	1138	c.d.
292.55	0.20	110	10					1717	1425	e.b.
295.15	0.20	100	10					(4)		
296.70	0.20	170	15					(3)		
297.70	0.20	85	10							
300.60	0.20	100	10	2,640	M1					
301.85	0.20	130	15	2,050	M1					
303.20	0.20	90	10					2429	2126	
								2667	2364	
311.80	0.20	160	15					2351	2040	e.b.
323.57	0.05	7,700	250	850	M1	0-	1-	2819	2496	c.d.
329.3	0.2	250	20			1-	1-	3149	2819	c.d.
337.5	—	≤ 100	—	$\geq 1,500$	E0	0+	0+	1566	1228	e.b.
339.45	0.20	70	10					2768	2429	
								3115	2775	
340.90	0.15	340	15							
366.35	0.15	540	20					3149	2783	
								2351	1985	
368.30	0.20	200	10					2768	2400	e.b.
369.80	0.15	580	30							
371.90	0.15	680	40	$< 2,100$	M1	0-	1-	2498	2126	c.d.
374.55	0.20	100	10							
382.35	0.10	1,300	50	$< 1,300$				2498	2116	e.b.
384.85	0.15	320	15							
386.45	0.20	200	15					3169	2783	e.b.
388.80	0.10	2,000	60	600	M1	2+	2+	1534	1145	c.d.
390.40	0.15	1,250	50							
395.95	0.10	4,200	120	600	M1	2+	2+	1534	1138	c.d.
401.30	0.20	190	60					3169	2768	e.b.
404.00	0.15	320	15	680	M1			3179	2775	
								3065	2661	

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c % $\times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via h
406.25	0.15	520	30							
407.55	0.20	200	10							
410.5	—	(i)	—	$\geq 2,300$	E0	0+	0+	1479	1069	e.b.
410.55	0.15	220	50							
416.50	0.20	135	15							
419.65	0.05	11,200	300	430	M1	0-	1-	2768	2351	e.b.
427.20	0.20	190	30					2819	2400	c.d.
443.40	0.15	910	30	240	M1E2			3195	2768	e.b.
447.65	0.10	1,575	50	475	M1			(3)		
449.25	0.20	160	15							
455.50	0.10	2,900	100	≤ 465	M1	0-	1-	2819	2364	c.d.
457.90	0.15	480	40					2116	1658	e.b.
461.20	0.15	70	40	500	M1					
465.50	0.15	240	20							
467.35	0.15	490	25	475	M1			2965	2498	e.b.
472.50	0.15	250	10							
478.80	0.10	1,250	140	≤ 500	$\leq M1$			3146	2667	e.b.
479.50	0.15	670	30					3140	2661	e.b.
480.50	0.15	440	20							
486.80	0.15	420	20							
490.95	0.15	500	15							
492.58	0.05	12,700	400	56	E1	2-	3+	1717	1225	c.d.
497.0	—	(i)	—	$\geq 1,400$	E0	0+	0+	1566	1069	e.b.
497.50	0.15	310	10							
500.50	0.15	220	10							
518.90	0.15	220	10					2929	2429	e.b.
525.05	0.15	250	30							
530.50	0.10	2,100	100	145	E2	0-	(2-)	2819	2289	c.d.
534.65	0.15	220	10	210						
535.95	0.15	210	10							
539.05	0.15	540	50							
540.15	0.10	4,600	200	270	M1	0-	1-	2052	1512	c.d.
544.24	0.05	18,500	500	≤ 230	M1	0-	1-	2819	2275	c.d.
547.25	0.15	860	40					2748	2200	e.b.
558.90	0.15	350	35	80	E1					
560.55	0.15	370	50	325	M1					
563.00	0.15	960	30	≤ 210	M1E2					
565.80	0.15	280	15					3314	2748	e.b.
572.20	0.05	28,000	750	33	E1	2-	2+	1717	1145	c.d.
575.95	0.25	435	20	≤ 800	$\leq M2$					
579.40	0.05	10,000	300	44	E1	2-	2+	1717	1138	c.d.
584.35	0.15	265	15							
585.80	0.15	340	20							
587.15	0.15	660	120	180	M1E2					
590.85	0.15	810	25							
595.70	0.15	700	20							
598.15	0.15	720	30							
612.15	0.15	930	30	78	E2			3149	2536	e.b.
614.00	0.20	200	10					2965	2351	e.b.
618.95	0.10	1,650	50	110	M1E2			2819	2200	e.b.
621.40	0.15	970	100	230	M1					
622.75	0.20	550	35							
633.75	0.25	200	10					2351	1717	e.b.
636.80	0.20	500	80							
645.80	0.20	300	15							
649.60	0.15	1,000	60					2775	2126	
								2367	1717	
652.65	0.20	370	30							
655.10	0.20	225	10							

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c % $\times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
656.65	0.20	80	15					3179	2522	
658.20	0.20	220	15							
659.70	0.20	240	15					2775	2116	e.b.
670.35	0.20	840	40					3099	2429	e.b.
675.45	0.20	240	15					2040	1364	
								2661	1985	
681.50	0.25	175	10					3179	2498	e.b.
688.00	0.08	4,400	150	150	M1	0-	1-	2052	1364	c.d.
691.75	0.20	370	15							
693.55	0.20	530	50					2819	2126	e.b.
700.15	0.20	465	15	200	M1					
700.80	0.20	700	20					2126	1425	e.b.
703.85	0.15	1,700	50	160	M1			2819	2116	e.b.
706.50	0.45	1,650	150	27	E1					
707.10	0.15	3,000	100							
711.65	0.15	1,600	50	190	M1			3140	2429	e.b.
723.05	0.20	440	20					2775	2052	e.b.
728.85	0.20	950	200					2929	2200	e.b.
741.50	0.20	970	30			1-		2400	1658	c.d.
746.90	0.20	680	20					2947	2200	e.b.
750.95	0.20	830	30					3115	2364	e.b.
756.15	0.20	450	20							
757.60	0.15	2,550	100					3186	2429	e.b.
762.55	0.15	620	20					2748	1985	e.b.
785.75	0.20	620	70							
787.60	0.15	1,200	80							
792.00	0.15	2,350	120					3067	2275	e.b.
701.25	0.20	800	40							
802.40	0.20	730	35							
805.85	0.25	400	100							
809.25	0.20	620	30							
813.55	0.20	900	90					2929	2116	
								2939	2126	
815.70	0.20	520	25					3179	2364	
								3314	2498	
819.50	0.20	700	20			1-	2+	2126	1306	c.d.
822.30	0.15	2,450	100							
829.30	0.10	10,850	300			1-	2+	2364	1534	c.d.
834.45	0.10	2,230	75	30						
839.30	0.10	15,700	450	≤ 106	M1	0-	1-	2351	1512	c.d.
850.05	0.15	1,050	50			1-	2-	2275	1425	c.d.
851.45	0.20	1,800	100					2364	1512	e.b.
855.15	0.15	21,400	600	75	M1	0-	1-	2367	1512	c.d.
859.45	0.20	1,300	100					2975	2116	e.b.
864.85	0.25	800	40					2522	1658	e.b.
868.10	0.20	1,700	200			2+	4+	1145	277	c.d.
873.85	0.25	300	30					3149	2275	e.b.
876.80	0.25	600	30					2929	2052	e.b.
879.65	0.25	500	25							
884.10	0.15	7,700	450			1-	0+	2364	1479	c.d.
895.00	0.25	540	30					2947	2052	e.b.
901.40	0.20	1,500	70					2040	1138	
								3169	2268	
910.8	0.30	920	50			1-	1-	2275	1364	c.d.
916.65		2,200	200	42		1+	1-	2429	1512	c.d.
916.90		1,500	150			2-	0-	2969	2052	c.d.
926.40	0.15	5,800	180	28	E2	0-	2-	2351	1425	c.d.
938.75	0.08	35,200	1,000	68	M1	1-	2-	2364	1425	c.d.
942.45	0.15	4,700	150			0-	2-	2367	1425	c.d.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c $\% \times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
947.80	0.15	3,500	100			3+	4+	1225	277	c.d.
952.55	0.25	930	50							
954.30	0.15	5,000	150	75	M1			2939	1985	e.b.
962.85	0.25	170	20							
966.85	0.20	3,200	100					2364	1397	e.b.
969.05	0.20	1,300	60					2275	1306	e.b.
970.20	0.20	2,500	80					2116	1145	e.b.
980.30	0.20	2,900	300	≤ 64	M1	1-	2+	2126	1145	c.d.
983.67	0.20	7,000	500			1-	1-	2496	1512	c.d.
985.10	0.10	120,000	4,000	29	E2	0+	2+	1069	84	c.d.
987.25	0.10	37,000	1,200	75	M1	0-	1-	2351	1364	c.d.
988.5	(j)	3,000	300					2126	1138	c.d.
999.60	0.10	34,000	1,000	56	M1	1-	1-	2364	1364	c.d.
1002.3	(j)	3,000	300					2536	1534	c.d.
1003.20	0.10	77,000	2,400	55	M1	0-	1-	2367	1364	c.d.
1009.50	0.30	880	50					2667	1658	e.b.
1012.30	0.30	290	30					3065	2052	e.b.
1028.80	0.10	18,000	600	31	E2	2+	4+	1306	277	c.d.
1034.20	0.30	600	200							
1046.60	0.25	1,950	100					2275	1228	e.b.
1050.40	0.10	22,000	700	≤ 34	M1E2	2-	2-	2768	1717	c.d.
1053.7	(i)	2,500	500				1-	3179	2126	c.d.
1054.28	0.05	103,000	3,300	≤ 24	E2	2+	2+	1138	84	c.d.
1055.23	(i)	5,000	1,000				2+	2200	1145	c.d.
1057.70	0.15	4,750	150			1-	2+	2364	1306	c.d.
1060.58	0.20	5,500	500				1-	3186	2126	c.d.
1061.35	(i)	5,000	1,000			0-	2+	2367	1306	c.d.
1061.39	0.10	47,000	1,500	29	E2	2+	2+	1145	84	c.d.
1068.80	0.40	120	10	$\geq 2,800$						
1069.4	—	(i)	—		E0	0+	0+	1069	0+	e.b.
1070.90	0.30	1,170	40			1-	2-	2496	1425	c.d.
1078.3	0.40	750	200					3131	2052	e.b.
1082.10	0.30	570	60							
1086.9	0.30	750	30							
1101.70	0.10	21,300	600	34	E2	0-	2-	2819	1717	c.d.
1110.65	0.30	270	15					2768	1658	e.b.
1113.10	0.20	2,250	100	≤ 150		1-	2+	2748	1634	c.d.
1119.40	0.20	4,000	120				4+	1397	277	c.d.
1122.5	0.30	350	10					2268	1145	e.b.
1124.65	0.30	850	25							
1132.86	(j)	1,500	150			1-	2+	2667	1534	c.d.
1133.60	0.10	23,000	750	40	M1	0-	1-	2498	1364	c.d.
1135.1	(j)					1-	0+	2364	1228	c.d.
1137.05	0.30	3,500	100			1-	2+	2275	1138	c.d.
1138.65	0.10	78,000	2,400	24	E2	2+	0+	1138	0	c.d.
1141.30	0.20	11,400	350	22	E2	3+	2+	1225	84	c.d.
1144.65	0.20	37,200	1,200	22	E2	0+	2+	1228	84	c.d.
1145.80	0.20	39,100	1,500	23	E2	2+	0+	1145	0	c.d.
1155.25	0.30	750	50					(3)		
1158.45	0.30	460	25					2522	1364	
								3274	2116	
1162.35	0.30	900	50							
1173.20	0.40	700	300			1-	1-	2536	1364	c.d.
1180.75	0.30	250	25							
1181.5	0.30	1,000	200					2748	1566	e.b.
1187.50	0.30	1,000	50			1-	0+	2667	1479	c.d.
1202.95	0.30	450	25							
1204.80	0.30	400	20							
1206.30	0.20	3,000	150			1-	0+	2275	1069	c.d.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c % $\times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{+4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
1211.20	0.30	800	40							
1213.65	0.20	1,150	60					2748	1534	e.b.
1217.30	0.20	4,500	150	30	M1E2					
1218.50	0.20	30,400	1,000	6.5	E1	1-	2+	2364	1145	c.d.
1222.25	0.30	14,300	500	103	E0+E2	2+	2+	1306	84	c.d.
1225.65	0.10	108,000	3,200	9.2	E1	1-	2+	2364	1138	c.d.
1228.9	—	(k)	—	≥ 500	E0	0+	0+	1228	0	e.b.
1230.20	0.30	2,500	100	≤ 115		1-	2+	2536	1306	c.d.
1234.50	0.30	500	25					3274	2040	e.b.
1235.90	0.10	5,100	150	50	M1	1-	1-	2748	1512	c.d.
1240.65	0.30	370	20							
1241.95	0.20	1,100	50			1-	2-	2667	1425	c.d.
1257.20	0.10	30,500	1,000	21	E2	2+	4+	1534	277	c.d.
1263.45	0.20	6,900	200	45	M1	1-	1-	2775	1512	c.d.
1268.30	0.20	2,600	100			1-	0+	2748	1479	c.d.
1280.25	0.10	177,000	5,000	8.7	E1	1-	2+	1364	84	c.d.
1290.9	0.40	1,900	350			1+	2+	2429	1138	c.d.
1294.70	0.10	63,500	2,000	9.5	E1	1-	0+	2364	1069	c.d.
1294.74	(j)	1,000	100			1-	2+	2929	1634	c.d.
1304.85	0.20	2,200	80			1-	2+	2939	1634	c.d.
1306.30	0.20	11,000	500	≤ 42	E2	2+	0	1306	0	c.d.
1307.55	0.10	24,000	1,000	≤ 22	M1	0-	1-	2819	1512	c.d.
1307.97	(j)	2,600	300			1-	0+	2536	1228	c.d.
1312.90	0.30	7,000	400				2+	1397	84	c.d.
1313.03	(j)	1,000	100			1-	2+	2947	1634	c.d.
1323.00	0.20	3,900	300			1-	2-	2748	1425	c.d.
1330.65	0.30	800	40					2400	1069	
1341.20	0.10	70,500	2,000	9.5	E1	2-	2+	2965	1634	
1350.45	0.30	1,280	60			1-	2-	1425	84	c.d.
1361.10	0.30	2,500	250			1-	2+	2775	1425	c.d.
1364.60	0.10	100,000	—	7.9	E1	1-	0+	2667	1306	c.d.
1370.40	0.30	520	25					1364	0	c.d.
1373.50	0.20	3,700	350					2939	1566	e.b.
1380.80	0.20	2,700	350				4+	1658	277	c.d.
1383.60	0.20	4,200	150			1-	1-	2748	1364	c.d.
1385.50	0.30	1,000	50							
1395.03	(j)	9,000	1,000			1-	2+	2929	1534	c.d.
1395.65	0.10	49,000	1,500	16	E2	0+	2+	1479	84	c.d.
1398.30	0.20	1,500	300			1-	2+	2536	1138	c.d.
1403.79	(i)	4,500	500			2-	1-	2768	1364	c.d.
1405.15	0.10	56,500	1,800	≤ 11.6	E	1-	2+	2939	1534	c.d.
1410.35	0.40	2,850	300							
1413.20	0.20	4,900	350			1-	2+	2947	1534	c.d.
1418.65	0.30	700	35					2783	1364	e.b.
1426.72	(j)	10,000	1,000			1-	0+	2496	1069	c.d.
1427.27	(j)	7,300	800	9.1	E1	1-	1-	2939	1512	c.d.
1428.08	0.10	75,500	2,500			1-	2+	1512	84	c.d.
1435.40	0.20	5,500	200			1-	1-	2947	1512	c.d.
1438.10	0.30	1,100	50			1-	0+	2667	1228	c.d.
1445.10	0.30	800	40							
1449.64	(j)	3,000	400							
1450.20	0.10	35,000	1,000	275	E0+E2	1-	0+	2929	1479	c.d.
1455.25	0.10	25,500	750	≤ 25	M1	2+	2+	1534	84	c.d.
1457.12	0.15	3,800	400			0-	1-	2819	1364	c.d.
1459.85	0.10	23,500	750			2-	1-	2969	1512	c.d.
1463.25	0.30	1,600	200			1-	0+	2939	1479	c.d.
1467.50	(j)	1,500	150					2975	1512	e.b.
1467.93	(j)	2,000	200			1-	0+	2536	1069	c.d.
						1-	0+	2947	1479	c.d.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c $\% \times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
1469.10	0.20	2,000	100			1-	2+	2775	1306	c.d.
1479.9	—	≤ 200	—	$\geq 32,600$	E0	0+	0+	1479	0	e.b.
1482.15	0.10	13,500	500			0+	2+	1566	84	c.d.
1486.00	0.30	1,000	50					2965	1479	e.b.
1490.45	0.30	530	30							
1498.75	0.30	760	40					3065	1566	e.b.
1503.85	0.40	200	20					2929	1425	e.b.
1507.80	0.20	1,000	150	≤ 290			2+	3042	1534	c.d.
1512.50	0.10	55,300	1,500	8.2	E1	1-	0+	1512	0	c.d.
1514.60	0.20	12,200	500	31	M1	1-	2-	2939	1425	c.d.
1518.85	0.30	1,300	50					2748	1228	e.b.
1521.7	0.30	800	200			1-	2+	2667	1145	c.d.
1529.00	0.30	1,600	150	39		1-	2+	2667	1138	c.d.
1531.30	0.20	4,000	150	37	M1?		2-	2956	1425	c.d.
1534.55	0.10	20,400	600	13.5	E2	2+	0+	1534	0	c.d.
1540.35	0.30	1,900	100			1+	2-	2965	1425	c.d.
1549.92 (j)		2,500	250			0-	2-	2975	1425	c.d.
1550.55	0.10	{ 4,300 } { 10,000 }	(2) 300	{ 106 } { 45 }	E0+E2	2+	2+	1634	84	c.d.
1560.25	0.30	285	25							
1564.97 (j)		2,000	200			1-	1-	2929	1364	c.d.
1565.08 (j)		4,500	200				2+	3099	1534	c.d.
1566.4	—	≤ 500 (m)	—	$\geq 1,660$	E0	0+	0+	1566	0	e.b.
1573.60	0.25	2,000	100				2+	1658	84	c.d.
1575.10	0.20	11,200	300	17	M1	1-	1-	2939	1364	c.d.
1583.30	0.30	1,300	50			1-	1-	2947	1364	c.d.
1585.80	0.40	200	20							
1592.05	0.20	3,100	100				1-	2956	1364	c.d.
1597.55	0.30	1,600	100			1-	0+	2667	1069	c.d.
1601.20	0.30	2,600	100			1+	1-	2965	1364	c.d.
1602.20	0.30	2,300	100			1-	2+	2748	1145	c.d.
1609.40	0.20	4,800	250			1-	2+	2748	1138	c.d.
1610.70	0.15	9,600	500	12	{ E1 M1 }	0-	1-	2975	1364	c.d.
1614.70	0.30	820	40					3149	1534	e.b.
1619.65	0.30	2,000	100				0+	3099	1479	c.d.
1630.50	0.30	2,200	50				2+	3165	1534	c.d.
1633.30	0.30	1,150	200					2939	1306	e.b.
1634.80	0.30	2,100	75	6.2	E2	2+	0+	1634	0	e.b.
1636.85	0.30	1,200	40					3149	1512	e.b.
1641.30	0.20	6,900	200			1-	2+	2947	1306	c.d.
1645.40	0.40	430	15					3179	1534	e.b.
1648.7	0.3	330	25							
1651.40	0.40	680	25					3131	1479	e.b.
1653.2	0.40	470	25					3165	1512	e.b.
1662.75	0.30	1,425	75			2-	2+	2969	1306	c.d.
1667.10	0.40	690	35					3179	1512	e.b.
1674.20	0.30	3,500	100				1-	3186	1512	c.d.
1678.60	0.20	5,000	150			1-	0+	2748	1069	c.d.
1682.70	0.30	1,200	400					3195	1512	e.b.
1685.55	0.30	1,300	150				0+	3165	1479	c.d.
1687.90	0.40	500	50							
1700.90	0.20	3,000	100			1-	0+	2929	1228	c.d.
1703.30	0.30	1,900	60							
1706.0	0.30	1,050	150				2-	3131	1425	c.d.
1714.35	0.40	400	80					2939	1225	e.b.
1719.10	0.20	3,250	100			1-	0+	2947	1228	c.d.
1723.75	0.30	600	40					2947	1225	
								3149	1425	
1731.30	0.40	210	20					2956	1225	e.b.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c $\% \times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
1736.60	0.30	870	120					2965	1228	e.b.
1740.65	0.30	1,800	60				2-	3165	1425	c.d.
1746.30	0.30	675	35					2975	1228	e.b.
1747.75	0.40	250	25					3314	1566	e.b.
1753.85	0.30	1,000	50							
1758.95	0.20	1,800	60				2+	3065	1306	c.d.
1761.35	0.30	930	120					3186	1425	e.b.
1767.15	0.30	1,800	100							
1770.35	0.40	250	25					3195	1425	e.b.
1776.10	0.30	5,750	200				1-	3140	1364	c.d.
1778.80	0.40	540	50					3007	1228	e.b.
1783.30	0.40	540	50							
1784.70	0.40	880	150					3149	1364	e.b.
1791.70	0.4	780	20							
1793.75	0.3	2,000	100				2+	3099	1306	c.d.
1796.30	0.5	400	20							
1799.25	0.5	285	20							
1802.25	0.15	3,500	100			1-	2+	2947	1145	c.d.
1809.50	0.15	17,200	500	2.5	E1	1-	2+	2947	1138	c.d.
1818.75	0.45	470	45							
1820.65	0.45	350	35							
1824.60	0.45	680	65					3131	1306	e.b.
1830.10	0.45	430	40							
1832.40	0.40	530	20							
1836.65	0.45	1,300	130					2975	1138	e.b.
1838.15	0.45	940	30					3067	1228	e.b.
1842.75	0.45	1,150	70			1-	2+	3149	1306	c.d.
1843.30	0.30	2,600	300							
1855.00	0.45	350	35							
1859.20	0.20	4,500	700	8.7	E2		2+	3165	1306	c.d.
1860.30	0.15	12,100	500	3.6	E1	1-	0+	2929	1069	c.d.
1870.80	0.30	1,300	150							
1874.75	0.45	610	30							
1876.15	0.30	3,250	200							
1878.65	0.15	12,300	400			1-	0+	2947	1069	c.d.
1887.10	0.45	750	100							
1888.70	0.45	800	40							
1893.70	0.45	950	50							
1896.50	0.30	1,230	60							
1901.35	0.15	13,200	500			2-	0+	1985	84	c.d.
1904.55	0.45	440	20							
1909.70	0.45	450	25							
1917.70	0.45	500	25							
1920.70	0.30	2,100	75					3146	1225	e.b.
1936.90	0.30	4,750	150				0+	3165	1228	c.d.
1954.00	0.30	3,600	200	≤ 42			2+	3099	1145	c.d.
1955.65	0.15	29,800	1,000	6.5	E2	1+	2+	2040	84	c.d.
1960.80	0.30	6,400	200				2+	3099	1138	c.d.
1962.45	0.30	2,150	70							
1966.80	0.45	650	50					3195	1228	e.b.
1974.00	0.30	1,200	40							
1977.40	0.45	700	150							
1983.09	0.45	570	30							
1985.50	0.30	1,700	60					3131	1145	e.b.
1992.70	0.45	400	20					3131	1138	e.b.
1995.75	0.30	1,800	70				0+	3065	1069	c.d.
1998.40	0.45	400	100							
2007.30	0.45	280	40					3146	1138	
								3314	1306	
2019.70	0.30	1,350	100				2+	3165	1145	c.d.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c $\% \times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{+4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
2025.75	0.30	1,250	50							
2027.20	0.30	3,650	150							
2030.15	0.20	6,400	400				2+	3165	1138	c.d.
2031.70	0.20	8,150	250				0+	3099	1069	c.d.
2040.00	0.15	56,800	2,000	≥ 7.1	M1	1-	2+	2116	84	c.d.
2041.88	0.10	132,000	4,000	3.0	E1	1+	0+	2040	0	c.d.
2046.5	0.5	580	30			1-	2+	2126	84	c.d.
2054.35	0.3	2,800	100							
2057.1	0.4	860	25					3195	1138	e.b.
2061.3	0.5	310	15					3131	1069	e.b.
2063.2	0.3	1,580	50							
2086.4	0.5	450	20							
2094.5	0.5	615	30							
2096.3	0.2	3,100	100			1-	0+	3165	1069	c.d.
2116.0	(j)	3,500	400	2.5	E1	1-	0+	2116	0	c.d.
2116.60	0.15	11,000	400				2+	2200	84	c.d.
2126.11	0.10	111,000	3,500	2.4	E1	1-	0+	2126	0	c.d.
2143.5	0.3	1,600	60							
2148.5	0.5	750	25							
2152.9	0.5	430	20							
2157.7	0.5	220	10							
2165.7	0.5	290	15							
2178.0	0.5	420	20							
2183.9	0.5	880	50				2+	2268	84	c.d.
2191.15	0.15	35,500	1,000	2.6	E1	1-	2+	2275	84	c.d.
2200.9	0.3	1,200	50							
2205.3	0.4	760	30				2+	2289	84	c.d.
2223.9	0.5	350	40							
2232.7	0.5	350	15							
2243.7	0.4	720	50							
2246.8	0.5	250	15							
2255.4	0.6	175	15							
2257.4	0.4	700	25							
2266.8	0.5	360	20							
2268.15	0.30	4,200	120				0+	2268	0	e.b.
2275.40	0.10	19,400	600	1.6	E1	1-	0+	2275	0	c.d.
2279.9	0.2	4,250	150			1-	2+	2364	84	c.d.
2284.2	0.5	320	100							
2289.2	0.4	950	50				0+	2289	0	c.d.
2315.1	0.4	800	40							
2315.9	0.2	4,600	150	5.1	E1	1-	2+	2400	84	c.d.
2325.0	0.4	700	50							
2330.6	0.6	130	15							
2333.9	0.5	240	20							
2344.9	0.5	1,000	40							
2352.3	0.5	1,100	40			1+	2+	2429	84	e.b.
2364.10	0.15	32,400	1,000	1.7	E1	1-	0+	2364	0	c.d.
2398.1	0.30	1,000	200							
2400.15	0.20	9,050	300	3.0	E2?	1-	0+	2400	0	c.d.
2411.90	0.15	17,900	600	1.6	E1	1-	2+	2496	84	c.d.
2419.9	0.50	430	70							
2424.4	0.30	2,700	100							
2429.0	0.40	1,050	100			1+	0+	2429	0	e.b.
2438.6	0.30	2,300	100	7.6	M1	(1+)	2+	2522	84	e.b.
2452.7	0.30	3,000	100			1-	2+	2536	84	c.d.
2459.9	0.50	270	25							
2496.15	0.15	16,500	500	1.4	E1	1-	0+	2496	0	c.d.
2523.0	0.3	3,000	100					2522	0	
2534.0	0.6	180	60							
2536.9	0.4	1,400	100			1-	0+	2536	0	c.d.

Table II (Continued).

E_γ^a keV	ΔE_γ^b keV	I_γ^c $\% \times 10^3$	ΔI_γ^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
2542.8	0.6	250	25							
2546.1	0.6	150	15							
2558.0	0.5	800	50							
2561.1	0.6	300	30							
2575.3	0.7	600	300							
2576.8	0.4	1,700	300					2661	84	e.b.
2582.9	0.3	3,100	100			1-	2+	2667	84	c.d.
2599.0	0.5	700	70							
2637.0	0.6	190	20							
2642.1	0.4	1,900	100							
2652.0	0.4	450	50							
2653.0	0.6	800	80							
2661.0	0.30	5,000	300	3.7	M1E2			2661	0	e.b.
2663.95	0.20	27,300	1,000	1.4	E1	1-	2+	2748	84	c.d.
2667.4	0.5	1,800	120	6.0	M1	1-	0+	2667	0	c.d.
2677.3	0.7	150	15							
2680.3	0.7	170	17							
2691.45	0.20	49,500	2,000	1.1	E1	1-	2+	2775	84	c.d.
2698.80	0.30	13,200	500	3.2	M1E2	1+	2+	2783	84	c.d.
2718.3	0.6	350	35							
2720.9	0.5	950	50							
2726.6	0.6	250	25							
2729.3	0.7	200	20							
2735.6	0.6	550	50					2819	84	e.b.
2737.2	0.4	1,250	200							
2748.15	0.20	46,300	2,000	1.5	E1	1-	0+	2748	0	e.b.
2775.7	0.3	2,450	100							
2783.00	0.20	22,400	1,000	3.2	M1	1+	0+	2783	0	e.b.
2793.1	0.7	260	25							
2805.0	0.6	650	25							
2813.7	0.6	450	50							
2845.30	0.20	37,200	2,000	1.4	E1	1-	2+	2929	84	c.d.
2849.5	0.30	4,600	400	2.7	E2					
2855.4	0.30	7,100	300	1.4	E1	1-	2+	2939	84	c.d.
2863.6	0.30	2,870	100			1-	2+	2947	84	c.d.
2872.5	0.40	1,680	80				0+	2956	0	c.d.
2881.40	0.20	16,300	750			1+	2+	2965	84	c.d.
2885.1	0.30	6,500	250			2-	2+	2969	84	c.d.
2897.6	0.50	1,000	70							
2923.3	0.3	4,000	200				2+	3007	84	c.d.
2929.50	0.20	13,000	650			1-	0+	2929	0	e.b.
2939.65	0.20	33,500	2,000			1-	0+	2939	0	e.b.
2947.80	0.20	12,900	650			1-	0+	2947	0	e.b.
2953.1	0.5	750	150							
2956.6	0.4	1,900	60				0+	2956	0	e.b.
2958.1	0.4	1,000	50				2+	3042	84	c.d.
2965.6	0.20	27,900	1,500				0+	2965	0	e.b.
2969.7	0.5	600	70							
2981.5	0.5	700	70							
2983.1	0.4	1,700	100				2+	3067	84	c.d.
2985.9	0.4	1,200	80							
3007.5	0.3	3,050	150				0+	3007	0	e.b.
3015.10	0.3	5,500	250				2+	3099	84	c.d.
3018.5	0.6	320	30							
3030.95	0.20	28,600	1,500			1-	2+	3115	84	c.d.
3036.90	0.3	4,600	200							
3042.8	0.4	1,500	75				0+	3042	0	e.b.
3046.9	0.5	750	75				2+	3131	84	e.b.
3053.1	0.3	2,400	200							
3062.1	0.3	2,300	200					3146	84	e.b.

Table II (Continued).

E_{γ}^a keV	ΔE_{γ}^b keV	I_{γ}^c $\% \times 10^3$	ΔI_{γ}^d	α_k^e ($\times 10^{-4}$)	Multi- polarity	I_i^f	I_f^f	E_i^g keV	E_f^g keV	Assign- ment via ^h
3064.8	0.3	5,600	250			1-	2+	3149	84	c.d.
3067.0	0.3	2,600	200				0+	3067	0	e.b.
3085.4	0.6	330	20					3169	84	e.b.
3091.9	0.3	3,400	200							
3095.50	0.20	7,200	400				2+	3179	84	c.d.
3099.55	0.25	4,300	250				0+	3099	0	e.b.
3102.1	0.6	330	30					3186	84	e.b.
3111.5	0.3	3,900	200			1-	2+	3195	84	c.d.
3115.20	0.25	16,200	800			1-	0+	3115	0	e.b.
3119.2	0.6	450	150							
3123.0	0.6	420	40							
3128.1	0.5	900	90							
3130.9	0.7	250	40				0+	3131	0	e.b.
3139.6	0.8	65	15							
3146.1	0.4	2,500	200					3146	0	e.b.
3149.4	0.4	2,250	200			1-	0+	3149	0	e.b.
3157.0	0.8	90	10							
3161.1	0.5	1,000	100							
3165.3	0.4	2,200	200					3165	0	e.b.
3169.6	0.8	100	15					3169	0	e.b.
3173.4	0.7	300	30							
3179.8	0.7	375	40							
3183.6	0.5	1,400	140							
3190.3	0.5	1,250	120					3274	84	e.b.
3195.3	0.4	2,000	200					3195	0	e.b.
3202.4	0.5	1,500	150							
3206.8	0.8	300	30							
3212.2	0.8	150	15							
3218.4	0.9	50	10					3302	84	e.b.
3229.5	0.8	150	15					3314	84	e.b.
3255.9	0.7	300	30							
3258.2	0.8	250	25							
3274.2	0.5	1,000	100					3274	0	e.b.
3282.1	0.8	50	10							
3291.4	0.7	100	10							
3302.4	0.7	260	25					3302	0	e.b.
3314.1	0.7	280	30					3314	0	e.b.
3338.9	0.8	40	10							
3385.0	0.8	40	10							

^aThe γ -ray energies have been rounded off in most cases to the nearest multiple of 50 eV.

^bThe final energy errors are adopted on the basis of the strength and multiplicity of the gamma rays. For the strongest transitions the errors range from ± 50 eV at low energy to ± 250 eV above 3.1 MeV, while the weakest transitions have been assigned errors from ± 200 eV at low energy to ± 1.0 keV above 3.1 MeV.

^cSee text for a discussion of the method of intensity determinations. The 1364.6 keV transition intensity was adopted as 100,000 units ($100\% \times 10^3$).

^dThe intensity errors have the same units ($\% \times 10^3$) and include both the error in the Ge(Li) detector efficiency curve ($\pm 5\% < 100$ keV; $\pm 3\% 100$ keV to 2.5 MeV; $\pm 5\% \leq 3.1$ MeV; and $\pm 10\% > 3.1$ MeV) and the systematic error arising from differing results from different runs.

^eThose conversion coefficients preceded by a $\leq$ sign indicate that the conversion line contained additional strong components from either ^{169}Lu or ^{171}Lu impurities or ^{170}Lu L or M conversion lines from strong ^{170}Lu K lines. Those entries enclosed in parentheses, are for E0 transitions and give the measured relative conversion line strengths based on $I_K = 100.0$ for the 1450 keV line.

^fNo spin and parity information is entered unless the transition is believed to be firmly placed—i.e. appears on the coincidence γ -ray decay scheme.

Table II (Continued).

^gInitial and final excited state energies are given to aid in identifying placement. Where two possibilities exist, both are shown, otherwise the number of possible placements appears in parentheses (n).

^hThe level assignments are based either on gamma-gamma coincidence data denoted c.d.; or from energy differences or energy balance denoted e.b.

ⁱIn calculating the lower limit to α_K , the intensity of the observed gamma-ray is assumed.

^jAn unresolvable multiplet, hence energies and intensities are determined from the level scheme and coincidence data respectively.

^kThe nearby intense 1225.65 keV γ -ray sets the upper limit for an observable 1228.9 keV γ -ray to less than 2000 units, thus the low α_K limit.

^lThis line is apparently at least a doublet with all 10,000 units in coincidence with the 84.26 keV transition. If the 1634 keV level is $2+K=0$, then a 1550 keV γ -ray has theoretically twice the intensity of the 1634 keV ground state transition intensity (2100), thus the uncertainty in α_K .

^mA doublet at 1565 keV sets the observable intensity for a 1566.4 keV transition at 500 units, thus the α_K limit.

Table III. Net γ -ray intensity out, total EC + β^+ feeding, $\log ft$ values, and $1\pi K$'s of all levels proposed in ^{170}Yb .

$(0 - I)_{10}^{-3}$	Level	$\%(EC + \beta^+)$	$\log ft$	$1\pi K$
	0	0.64	9.72	0+0
23 $\pm$ 70	84.262 $\pm$ 0.004	(1.08 $\pm$ 3.34)	>10	2+0
-0.4 $\pm$ 2.4	277.39 $\pm$ 0.03	(0.02 $\pm$ 0.11)	>11	4+0
	572.28 $\pm$ 0.27	0	>12	6+0
-0.7 $\pm$ 6.0	1069.40 $\pm$ 0.05	(0.03 $\pm$ 0.25)	>9.6	0+0
5.6 $\pm$ 8.2	1138.58 $\pm$ 0.03	(0.27 $\pm$ 0.39)	>9.6	2+2
4.2 $\pm$ 5.0	1145.65 $\pm$ 0.05	(0.20 $\pm$ 0.24)	>9.7	2+0
-0.5 $\pm$ 0.6	1225.4 $\pm$ 0.10	(0.02 $\pm$ 0.03)	>10.6	3+2
14.0 $\pm$ 1.7	1228.9 $\pm$ 0.1	0.67 $\pm$ 0.08	9.11	0+0
3.4 $\pm$ 3.6	1306.35 $\pm$ 0.10	(0.16 $\pm$ 0.17)	>9.7	2+0
28.0 $\pm$ 10.0	1364.55 $\pm$ 0.05	1.33 $\pm$ 0.48	8.77	1-0
7.8 $\pm$ 0.6	1397.0 $\pm$ 0.2	0.37 $\pm$ 0.03	9.32	?
2.3 $\pm$ 4.0	1425.30 $\pm$ 0.10	0.11 $\pm$ 0.19	$\geq$ 9.8	2-2
4.4 $\pm$ 2.6	1479.90 $\pm$ 0.10	0.21 $\pm$ 0.12	9.55	0+0
16.0 $\pm$ 7.0	1512.4 $\pm$ 0.10	0.75 $\pm$ 0.33	8.98	1-0
1.0 $\pm$ 5.0	1534.53 $\pm$ 0.05	(0.05 $\pm$ 0.24)	>10.1	2+0
8.3 $\pm$ 0.8	1566.4 $\pm$ 0.1	0.40 $\pm$ 0.04	9.23	0+0
0 $\pm$ 0.9		(0 $\pm$ 0.04)	>10.2	
5.7 $\pm$ 0.9	1634.8 $\pm$ 0.1	0.27 $\pm$ 0.04	9.36	2+0
1.3 $\pm$ 0.5	1658.0 $\pm$ 0.1	0.06 $\pm$ 0.02	10.0	?
7.5 $\pm$ 2.0	1717.95 $\pm$ 0.05	0.36 $\pm$ 0.09	9.19	2-2
7.6 $\pm$ 0.6	1985.6 $\pm$ 0.1	0.36 $\pm$ 0.03	9.05	2-(2)
86.4 $\pm$ 3.0	2040.0 $\pm$ 0.05	4.09 $\pm$ 0.14	7.95	1+1
6.4 $\pm$ 0.4	2052.6 $\pm$ 0.05	0.31 $\pm$ 0.02	9.07	0-0
8.2 $\pm$ 0.9	2116.0 $\pm$ 0.10	0.39 $\pm$ 0.04	8.94	1-0
233.0 $\pm$ 8.0	2126.10 $\pm$ 0.05	11.04 $\pm$ 0.38	7.47	1-0
11.7 $\pm$ 1.5	2200.8 $\pm$ 0.1	0.56 $\pm$ 0.07	8.71	
5.4 $\pm$ 0.2	2268.1 $\pm$ 0.1	0.26 $\pm$ 0.01	9.00	
44.1 $\pm$ 2.2	2275.4 $\pm$ 0.1	2.08 $\pm$ 0.10	8.09	1-0
-0.4 $\pm$ 0.2	2289.3 $\pm$ 0	0	>10	

Table III (Continued).

$(0 - 1)_{10}^{-3}$	Level	$\%(EC + \beta^+)$	Logft	$I\pi K$
62.5 $\pm$ 2.0	2351.8 $\pm$ 0.05	2.96 $\pm$ 0.09	7.66	0-0
332.3 $\pm$ 10.5	2364.05 $\pm$ 0.05	15.75 $\pm$ 0.50	7.13	1-1
117.4 $\pm$ 4.4	2367.70 $\pm$ 0.05	5.56 $\pm$ 0.20	7.50	0-0
3.2 $\pm$ 0.6	2400.15 $\pm$ 0.10	0.15 $\pm$ 0.03	9.11	1-1
0.8 $\pm$ 0.8	2429.1 $\pm$ 0.1	(0.04 $\pm$ 0.04)	>9.7	
44.4 $\pm$ 2.7	2496.15 $\pm$ 0.10	2.10 $\pm$ 0.13	7.86	1-1
24.3 $\pm$ 0.9	2498.3 $\pm$ 0.1	1.15 $\pm$ 0.04	8.13	(0-0)
5.8 $\pm$ 0.3	2522.9 $\pm$ 0.1	0.28 $\pm$ 0.01	8.72	(1+)
7.0 $\pm$ 1.1	2536.8 $\pm$ 0.1	0.33 $\pm$ 0.05	8.64	1-(0)
6.0 $\pm$ 0.6	2661.0 $\pm$ 0.1	0.29 $\pm$ 0.03	8.57	
9.0 $\pm$ 1.1	2667.38 $\pm$ 0.05	0.43 $\pm$ 0.05	8.38	1-0
108.5 $\pm$ 4.7	2748.15 $\pm$ 0.05	5.14 $\pm$ 0.22	7.21	1-1
26.9 $\pm$ 1.2	2768.3 $\pm$ 0.2	1.27 $\pm$ 0.06	7.79	
60.8 $\pm$ 2.4	2775.7 $\pm$ 0.1	2.88 $\pm$ 0.11	7.43	1-
36.1 $\pm$ 1.5	2783.0 $\pm$ 0.2	1.71 $\pm$ 0.07	7.64	1+1
128.0 $\pm$ 4.0	2819.80 $\pm$ 0.10	6.07 $\pm$ 0.19	7.05	0-0
82.3 $\pm$ 5.2	2929.55 $\pm$ 0.10	3.90 $\pm$ 0.25	7.07	1-0
164.0 $\pm$ 7.5	2939.70 $\pm$ 0.10	7.80 $\pm$ 0.36	6.75	1-1
73.5 $\pm$ 3.0	2947.85 $\pm$ 0.10	3.48 $\pm$ 0.14	7.08	1-1
10.9 $\pm$ 0.4	2956.7 $\pm$ 0.2	0.52 $\pm$ 0.02	7.88	1-
48.4 $\pm$ 2.5	2965.6 $\pm$ 0.2	2.29 $\pm$ 0.12	7.22	1+1
13.2 $\pm$ 0.9	2969.5 $\pm$ 0.2	0.63 $\pm$ 0.04	7.77	
16.9 $\pm$ 1.2	2975.2 $\pm$ 0.2	0.80 $\pm$ 0.06	7.65	(0,1-)
7.6 $\pm$ 0.4	3007.2 $\pm$ 0.2	0.36 $\pm$ 0.02	7.96	
3.5 $\pm$ 0.3	3042.6 $\pm$ 0.2	0.17 $\pm$ 0.01	8.19	
4.6 $\pm$ 0.2	3065.1 $\pm$ 0.2	0.22 $\pm$ 0.01	8.02	
7.6 $\pm$ 0.5	3067.2 $\pm$ 0.2	0.36 $\pm$ 0.02	7.81	
35.8 $\pm$ 1.8	3099.6 $\pm$ 0.1	1.70 $\pm$ 0.09	7.05	
45.6 $\pm$ 2.3	3115.2 $\pm$ 0.2	2.16 $\pm$ 0.11	6.90	1-0
6.4 $\pm$ 0.7	3131.0 $\pm$ 0.2	0.31 $\pm$ 0.03	7.66	

Table III (Continued).

$(0 - I)_{10}^{-3}$	Level	$\%(EC + \beta^+)$	$\log ft$	$l\pi K$
8.0 ± 0.3	3140.6 ± 0.3	0.38 ± 0.01	7.54	
8.2 ± 0.6	3146.2 ± 0.2	0.39 ± 0.03	7.51	
13.1 ± 0.8	3149.2 ± 0.2	0.62 ± 0.04	7.30	(1-0)
25.3 ± 1.7	3165.6 ± 0.10	1.20 ± 0.08	6.96	1-1
0.8 ± 0.1	3169.6 ± 0.3	0.04 ± 0.005	8.43	
11.3 ± 1.0	3179.8 ± 0.2	0.54 ± 0.05	7.27	
12.8 ± 0.8	3186.7 ± 0.2	0.61 ± 0.04	7.20	
9.0 ± 0.9	3195.5 ± 0.2	0.43 ± 0.04	7.32	(1-0)
1.0 ± 0.1	3212.2 ± 0.3	0.05 ± 0.005	8.19	
2.2 ± 0.2	3274.4 ± 0.4	0.10 ± 0.01	7.64	
0.8 ± 0.1	3302.6 ± 0.4	0.04 ± 0.005	7.74	
1.0 ± 0.1	3314.1 ± 0.4	0.05 ± 0.005	7.59	

Table IV. Comparison of levels and $I\pi K$ values found in this work with two other references.

This work	Mihelich (Ref. 13)	Bonch- Osmolovskaya (Ref. 12)	Our $I\pi K$	Mihelich $I\pi K$	Bonch- Osmolovskaya $I\pi K$
0	0	0	0+0	0+0	0+0
84.262	84.3	84.26	2+0	2+0	2+0
277.39	277.6	277.8	4+0	4+0	4+0
572.28			6+0		
1069.40	1069.6	1069.1	0+0	0+0	0+0
1138.58	1138.5	1138.25	2+2	2+2	2+2
1145.65	1145.7	1145.5	2+0	2+0	2+0
1225.4	1225.2		3+2	3+2	
1228.9	1228.5	1228.4	0+0	0+0	0+0
1306.35	1306.3	1306.2	2+0	2+0	2+0
1364.55	1364.5	1364.2	1-0	1-0	1-0
1397.0					
1425.30	1425.5		2-2	2-(2)	
1479.90	1480.0	1479.6	0+0	0+0	0+0
1512.4	1512.0	1511.6	1-0	1-0	1-0
1534.53	1534.6	1534.2	2+0	2+0	2+0
1566.4	1566.3	1565.9	0+0	0+0	0+0
1634.8	1635.1	1634.8	(2+0)	0-0	2+0
1658.0					
1717.95	1717.9		2-2	2-(1)	
		1757.6			2+(2)
		1961.4			1-0
1985.6	1985.4		2-(2)	(1-)	
2040.0	2040.2	2039.6	1+1	1+1	1+1
2052.6			0-0		
		2113.2			(2+)
2116.0			1-0		
2126.10	2126.2	2125.6	1-0	1-0	1-0
2200.8					
2268.1					

Table IV (Continued).

This work	Mihelich (Ref. 13)	Bonch- Osmolovskaya (Ref. 12)	Our [π K	Mihelich [π K	Bonch- Osmolovskaya [π K
2275.4	2275.5	2275.1	1-0	1-0	1-0
2289.3					
2351.8			0-0		
	2352.3			1-2-	
2364.05	2364.2	2363.4	1-1	1-(0)	1-(1)
2367.70	2367.8	2367.2	0-0	1-2-	1-
2400.15	2400.2	2399.1	1-1	1-1	1-1
2429.1			2+		
2496.15	2496.3	2496.0	1-1	1-	1-(0)
2498.3	2498.0		(0-0)	1-2-	
		2521.3			(2+)
2522.9			(1+)		
		2533.1			1+0
2536.8			1-(0)		
	2584.5			1+0+	
		2641.4			1+
2661.0					
2667.38			1-0		
2748.15	2748.2	2747.8	1-1	1-1	1-1
2768.3	2768.7			1-2-	
2775.7	2775.8	2775.3	1-	2-	2-
2783.0	2783.1	2782.6	1+1	1+1	1+1
2819.80	2819.8	2819.3	0-0	1-2-	1-
		2883.6			1+
2929.55	2929.9	2929.6	1-0	1-0	1-0
2939.70	2940.0	2939.2	1-1	1-	1-(0)
2947.85	2948.1	2947.5	1-1	1-	1-(1)
2956.7			1-		
2965.6	2966.2	2965.3	1+1	1+	1+1
2969.5					
2975.2			0-		

Table IV (Continued).

This work	Mihelich (Ref. 13)	Bonch- Osmolovskaya (Ref. 12)	Our I π K	Mihelich I π K	Bonch- Osmolovskaya I π K
3007.2					
3042.6					
3065.1					
3067.2		3067.6			1-2-
	3092.5	3091.9		(1-)	1+1
3099.6	3100.0	3099.4		1+	1-
3115.2	3115.6	3114.7	1-0	1-0	1-0
3131.0					
3140.6					
3146.2	3149.4	3148.3			1+
3149.2			1-0	1+	
3165.6			1-1		
3169.6					
3179.8					
		3184.1			1+
3186.7					
3195.5	3195.7	3196	(1-0)	1+	1-0
3212.2					
3274.4	3274.8	3274.9		1-	1-
	3287			(0-)	
3302.6		3301.7			1+
3314.1					
		3336.5			1-
		3432.6			1-

Table V. Derived values of the E0-E2 branching parameter

$$X = \rho^2 R_0^4 e^2 (I_n' 200 | I_0' 0) / B(E2)$$

for decay of K=0+ states in ^{170}Yb .

Level (keV)	$I_n' \pi \xrightarrow{e^-} I_2' \pi$ $I_n' \pi \xrightarrow{\gamma} I_1' \pi$	E_{e^-} (keV) E_{γ} (keV) Transition energies	I_{e^-} I_{γ}	X^a
1069.4	$0_1^+ \rightarrow 0_0^+$ $0_2^+ \rightarrow 2_0^+$	1069.4 985.1	$\frac{34 (3)}{1.2 \times 10^4}$	0.0049 (5)
1145.6	$2_1^+ \rightarrow 2_0^+$ $2_1^+ \rightarrow 0_0^+$	1061.4 1145.8	$\frac{\leq 10}{3.9 \times 10^4}$	$\leq 0.0021^b$
	$2_1^+ \rightarrow 2_0^+$ $2_1^+ \rightarrow 2_0^+$	1061.4 1061.4	$\frac{\leq 10}{4.7 \times 10^4}$	$\leq 0.0017^b$
	$2_1^+ \rightarrow 2_0^+$ $2_1^+ \rightarrow 4_0^+$	1061.4 868.1	$\frac{\leq 10}{1.7 \times 10^3}$	$\leq 0.032^b$
1228.9	$0_2^+ \rightarrow 0_0^+$ $0_2^+ \rightarrow 2_0^+$	1228.9 1144.6	$\frac{94 (9)}{3.7 \times 10^4}$	0.080 (9)
1306.4	$2_2^+ \rightarrow 2_0^+$ $2_2^+ \rightarrow 0_0^+$	1222.2 1306.3	$\frac{86 \leq I_{e^-} \leq 114}{1.1 \times 10^4}$	$0.085 \leq X \leq 0.14^c$
	$2_2^+ \rightarrow 2_0^+$ $2_2^+ \rightarrow 2_0^+$	1222.2 1222.2	$\frac{114 (12)}{1.4 \times 10^4}$	$0.100 (12)^b$
	$2_2^+ \rightarrow 2_0^+$ $2_2^+ \rightarrow 4_0^+$	1222.2 1028.8	$\frac{86 \leq I_{e^-} \leq 114}{1.8 \times 10^4}$	$0.041 \leq X \leq 0.068^c$
1479.9	$0_3^+ \rightarrow 0_0^+$ $0_3^+ \rightarrow 2_0^+$	1479.9 1395.6	$\frac{650 (70)}{4.9 \times 10^4}$	0.94 (11)

Table V (Continued).

Level (keV)	$I_n \pi \xrightarrow{e^-} I_2 \pi$ $I_n' \pi \xrightarrow{\gamma} I_1' \pi$	E_- (keV) E_γ (keV) Transition energies	I_- I_γ	X^a
1534.5	$2_3^+ \rightarrow 2_0^+$	1450.2	$870 \leq I_- \leq 910$	$0.86 \leq X \leq 1.2^c$
	$2_3^+ \rightarrow 0_0^+$	1534.6	$\frac{e^-}{2.0 \times 10^4}$	
	$2_3^+ \rightarrow 2_0^+$	1450.2	$\frac{910 (100)}{3.5 \times 10^4}$	$0.64 (8)^b$
	$2_3^+ \rightarrow 2_0^+$	1450.2	$870 \leq I_- \leq 910$	
	$2_3^+ \rightarrow 4_0^+$	1450.2	$\frac{e^-}{3.0 \times 10^4}$	$0.55 \leq X \leq 0.77^c$
	$2_3^+ \rightarrow 2_1^+$	1257.2	$53 (6)$	
1566.4	$2_3^+ \rightarrow 2_1^+$	388.8	$\frac{2.0 \times 10^3}{2.0 \times 10^3}$	$0.0031 (3)^b$
	$2_3^+ \rightarrow 2_1^+$	388.8	$290 (80)$	
	$2_3^+ \rightarrow 2_2^+$	228.0	$\frac{800}{800}$	$0.0039 (5)^b$
	$2_3^+ \rightarrow 2_2^+$	228.0	$83 (13)$	
	$0_4^+ \rightarrow 0_0^+$	1566.4	$\frac{1.4 \times 10^4}{1.4 \times 10^4}$	$0.54 (9)$
	$0_4^+ \rightarrow 2_0^+$	1482.2	$24 \leq I_- \leq 31$	
1634.8	$2_4^+ \rightarrow 2_0^+$	1550.6	$\frac{e^-}{2100}$	$0.30 \leq X \leq 0.50^c$
	$2_4^+ \rightarrow 0_0^+$	1634.8	$31 (4)$	
	$2_4^+ \rightarrow 2_0^+$	1550.6	$\frac{1.0 \times 10^4}{1.0 \times 10^4}$	$0.101 (13)^b$

^aThe error limits placed on X are based only on the assigned γ -ray and electron relative intensities. It should be noted that most authors extract values for the electronic factor, Ω_K in the expression for the nuclear monopole transition strength parameter $\rho^2 = W/\Omega_K$ from the graph (or a poor reproduction thereof) of W/ρ^2 in Ref. 29 (where W is the E0 transition probability). The inaccuracy of such a procedure (and an unfortunate misprint for the Z=85 line that should not effect any published results for Z=70) probably requires that a reading error of at least 10% also be assigned to the values Ω_K used in the calculation of X. For example, we read $\Omega_K = 1.3 \times 10^{11} \text{ sec}^{-1}$ for 1069 keV, while the authors of Ref. 12 read 1.1×10^{11} .

^bAssumes the $2 \rightarrow 2'$ γ -ray transition is pure E2.

^cLimits based on assumptions of pure M1 or pure E2 for $2 \rightarrow 2'$ transitions.

Table VI. B(E2) data for K=0+ states in ^{170}Yb (from Ref. 30).

$E_i \rightarrow E_f$	$I_i \pi K_i \rightarrow I_f \pi K_f$	B(E2)	
		$e^2 \text{ fm}^4$	spu
Gnd $\rightarrow$ 1138.5	$0+0_0 \rightarrow 2+2_\gamma$	~ 440	1.5
Gnd $\rightarrow$ 1145.6	$0+0_0 \rightarrow 2+0_1$	~ 440	1.5
1069.4 $\rightarrow$ 84.3	$0+0_1 \rightarrow 0_0$	< 30	< 0.1
1228.9 $\rightarrow$ 84.3	$0+0_2 \rightarrow 0_0$	420 ± 80	1.44

Table VII. E0 matrix elements in ^{170}Yb .

Level	Energy (keV)	X	B(E2; $0 \rightarrow 2$)	
			$e^2 \text{ fm}^4$	ρ
$0+0_1$	1069.4	0.0049	<30	<0.009
$2+0_0$	1145.6	$\leq 0.0021^a$	440	≤ 0.01
$0+0_2$	1228.9	0.080	420	0.13

^a Assumes the $2+0_1 \rightarrow 2+0_0$ transition is pure E2. If this transition has M1 admixture, then ρ is still smaller.

Table VIII. z_0 -parameters for γ -ray branching from excited $K=0+$ bands in ^{170}Yb .

Transitions	Energies (keV)	$\frac{B'(E2)}{B(E2)}$	Alaga's rule	z_0
<u>1145.8-keV $2+0_1$ state</u>				
$2+0_1 \rightarrow 0+0_0$	1145.8	0.566	0.699	0.016
$2+0_1 \rightarrow 2+0_0$	1061.4			
$2+0_1 \rightarrow 4+0_0$	868.1	0.099	1.80	-0.60
$2+0_1 \rightarrow 2+0_0$	1061.4			
$2+0_1 \rightarrow 0+0_0$	1145.8	5.71	0.388	-0.048
$2+0_1 \rightarrow 4+0_0$	868.1			
<u>1306.3 $2+0_2$ state</u>				
$2+0_2 \rightarrow 0+0_0$	1306.3	0.549	0.699	0.020
$2+0_2 \rightarrow 2+0_0$	1222.2			
$2+0_2 \rightarrow 4+0_0$	1028.8	2.97	1.80	0.020
$2+0_2 \rightarrow 2+0_0$	1222.2			
$2+0_1 \rightarrow 0+0_0$	1306.3	0.185	0.388	0.020
$2+0_1 \rightarrow 4+0_0$	1028.8			
<u>1534.5 $2+0_3$ state</u>				
$2+0_3 \rightarrow 2+0_0$	1534.5	0.440	0.699	0.034
$2+0_3 \rightarrow 2+0_0$	1450.2			
$2+0_3 \rightarrow 4+0_0$	1257.3	1.78	1.80	-0.0005
$2+0_3 \rightarrow 2+0_0$	1450.2			
$2+0_3 \rightarrow 0+0_0$	1534.5	0.247	0.388	0.012
$2+0_3 \rightarrow 4+0_0$	1257.3			
<u>1634.8 $2+0_4$ state</u>				
$2+0_4 \rightarrow 0+0_0$	1634.8	0.160	0.699	0.087
$2+0_4 \rightarrow 2+0_0$	1550.6			
$2+0_4 \rightarrow 4+0_0$	(1357.4)	<0.384	1.80	<-0.038 $ z_0 > 0.038$
$2+0_4 \rightarrow 2+0_0$	1550.6			
$2+0_4 \rightarrow 0+0_0$	1634.8	>0.416	0.388	<-0.002 $ z_0 > 0.002$
$2+0_4 \rightarrow 4+0_0$	(1357.4)			

Table IX. Relative E0 matrix elements, $\rho^2(E0)$, from $K=0+$ states with multiple E0's.

Level	Transitions	Transition energies	Relative e^- intensity	$R(E0) = \frac{\rho^2(E0)}{\rho_0^2(E0)}$
1479.9	$0_3^+ \rightarrow 0_1^+$	410.5	$35 \leq I_- \leq 48$	$0.18 \leq R \leq 0.24^a$
	$0_3^+ \rightarrow 0_0^+$	1479.9	$\frac{e^-}{652}$	
	$0_3^+ \rightarrow 0_2^+$	251.0	$\frac{247}{652}$	1.7
	$0_3^+ \rightarrow 0_0^+$	1479.9		
1566.4	$0_4^+ \rightarrow 0_1^+$	497.1	$31 \leq I_- \leq 43$	$1.2 \leq R \leq 1.6^a$
	$0_4^+ \rightarrow 0_0^+$	1566.4	$\frac{e^-}{83}$	
	$0_4^+ \rightarrow 0_2^+$	338.0	$\frac{15}{83}$	0.73
	$0_4^+ \rightarrow 0_0^+$	1566.4		

^aA weak γ ray was observed at this same energy. The limits correspond to an assumed E1 or M1 multipolarity for the γ ray.

FIGURE CAPTIONS

- Figure 1. A schematic drawing of the NaI(Tl) Compton suppression and three-crystal pair spectrometer used in this work.
- Figure 2. The low-energy portion of the ^{170}Lu γ -ray spectrum taken with the Compton suppression system shown in Fig. 1. A lower-case d shows the presence of a doublet component; an upper-case D indicates the presence of a double escape peak. Only some of the many transitions observed have been identified.
- Figure 3. The high-energy portion of the ^{170}Lu γ -ray spectrum taken with the Compton suppression system. The spectral region from 2380 to 3220 keV has been lowered one decade for clarity of display.
- Figure 4. The "pair" spectrum of ^{170}Lu taken with the system shown in Fig. 1 operated as a three-crystal spectrometer. The spectral region shown as 2350 to 3220 keV has been lowered one decade for clarity of display. Peaks are labeled with their transition energy, not their actual escape peak energy.
- Figure 5. An example of the output from the Computer Code SAMPO used to analyze the ^{170}Lu low-energy data. Shown in the 544-keV region. The interactive graphics system used to analyze the high-energy and "pair" data displayed data similar to this but with more detail on a CRT screen.
- Figure 6. Two examples of the more than 100 γ - γ coincidence spectra obtained. Shown here are 90-deg data for those gamma rays in coincidence with the 84.26-keV $2+$ to $0+$ and the 193.13-keV $4+$ to $2+$ ground band transitions. Many, but not all, of the γ rays identified in these two gates are labeled.

- Figure 7. Three examples of the forty 180-deg γ - γ coincidence gates sorted. Shown here are the 152.6-, 688.0-, and 1028.8-keV gates. A small "i" in the top spectrum identifies those transitions that are indirect, i.e., those that follow the labeled transitions. The S and D identify single and double escape peaks.
- Figure 8. A plot of the conversion electron data obtained with a 3-mm-depletion-depth Si(Li) detector. Contaminant activities are indicated by an upper-case C, while D represents double escape peaks from strong higher-energy transitions. Only some of the many conversion lines analyzed are identified.
- Figure 9. A partial-level scheme for ^{170}Lu , showing only those levels firmly established from coincidence data. The eight E0 transitions observed are indicated by "dotted" lines. See Table II for EC branching ratios and $\log ft$ values.
- Figure 10. A partial-level scheme of ^{170}Lu , showing additional transitions that were placed on the basis of energy sums and differences alone.
- Figure 11. Comparison of ^{170}Yb levels with theory from Kuliev and Pyatov,³⁴ Bès,^{33,38} Neergård and Vogel,⁴⁰ and Grabakov et al.²⁵

Camp - Fig. 1

Camp - Fig. 2

Camp - Fig. 3

Camp - Fig. 4

1 ISEPL: FROM CH 1727, BKGR CENTROID CH 1780, FITTING PEAKS AT CH 1753 1744 1747 1760 1771									
BKGR	DATA	FIT	CHANE	712-CHIN	SEMI-LOG PLOT	MAX	46975	910	
735	772	735	1727	5					.25
741	756	741	1728	6					-.53
777	774	777	1729	5					-.09
773	771	773	1735	5					-.10
759	643	759	1731	6					1.21
745	773	745	1732	5					.42
751	751	751	1733	6					.68
738	730	738	1734	6					-1.08
734	728	734	1735	6					-1.17
731	741	731	1736	6					-.61
748	775	748	1737	6					.48
745	750	745	1739	1					-.86
742	820	742	1739	1					.63
739	851	739	1740	1					-.07
737	933	737	1741	1					.20
734	1521	734	1742	1					-.31
732	1198	732	1743	1					.15
730	1477	730	1744	1					-.17
728	1626	728	1745	1					.01
726	1755	726	1746	1					.79
724	1626	724	1747	1					-.90
722	1453	722	1748	1					.92
721	1142	721	1749	1					-.98
719	941	719	1750	1					-.54
718	918	718	1751	1					2.89
717	831	717	1752	1					1.51
716	856	716	1753	1					.37
715	835	715	1754	1					-.63
714	1122	714	1755	1					.33
713	1291	713	1756	1					.02
713	1900	713	1757	1					-.29
712	2942	712	1758	1					.63
712	3988	712	1759	1					-1.20
712	4617	712	1760	1					-.92
712	4627	712	1761	1					.99
712	4720	712	1762	1					2.61
712	2710	712	1763	1					-1.21
713	1651	713	1764	1					-.28
713	1155	713	1765	1					-1.36
714	831	714	1766	1					-1.72
715	785	715	1767	1					-1.77
716	638	716	1768	1					.47
717	856	717	1769	1					.37
718	925	718	1770	1					1.05
719	631	719	1771	1					-.97
720	913	720	1772	1					.70
722	829	722	1773	1					-.66
724	797	724	1774	1					-.08
725	731	725	1775	1					-.42
727	737	727	1776	1					.87
729	722	729	1777	6					1.99
732	735	732	1778	5					-.06
734	733	734	1779	5					-.08
736	715	736	1780	6					-.71
BKGR DATA FIT CHANE (=BKGR,=DATA,=FIT)=BKGR,DATA (=BKGR,FIT,=DATA,FIT) S=SIGMA(D-F)/SQRT(D)									
10153=30 (D-F) S=SIGMA(D-F)/SQRT(D)									
RESULTS OF THE ABOVE FITTING. CHECK THE PLOT FOR MISSING PEAKS.									
BE CRITICAL OF THE ERROR ESTIMATES. REJECT IF CHI SQUARE (4.991E+01) OR SIGMA (1.077) IS UNACCEPTABLE									
CHANNEL--FIT,ERR(C)	ENERGY----	CAL.ERR-EN,ERR(KEV)	AREA--(CTS)---	FIT,ERR%	INTENSITY--(CTS)---	CAL.ERR%INT,ERR%			
1742.3964	.5528	539.0362	.0289	.1611	789.408	22.9163	119.113	2.0000	23.0034
1746.2582	.5894	540.1452	.0289	.0387	5477.394	3.3832	829.282	2.0000	3.9302
1760.4377	.5155	544.2108	.0291	.0294	22774.801	.6855	3492.950	2.0000	2.1142
1771.0131	.1612	547.2430	.0292	.0596	1061.122	7.9227	164.378	2.0000	6.1712

Camp - Fig. 5

Camp - Fig. 6

Camp - Fig. 7

Camp - Fig. 8

Camp - Fig. 9b

E.C. + β^+

$1+1$ — 2783.0 $0-0$ — 2819.8
 $1-1$ — 2748.2
 $1-0$ — 2667.4
 $1-(0)$ — 2536.8
 $1-1$ — 2400.1
 $0-0$ — 2367.7
 $0-0$ — 2351.8
 $1-0$ — 2275.4
 $1-0$ — 2126.1
 $1-0$ — 2116.0
 $0-0$ — 2052.6
 $2-(2)$ — 1985.6
 $1+1$ — 2040.0

$2-2$ — 1718.0
 $0+0$ $\frac{0.54}{0.94}$ 1566.4
 $0+0$ — 1479.9
 $1-0$ — 1512.4
 $2-2$ — 1425.3
 $1-0$ — 1364.5

$0+0$ $\frac{0.080}{0.005}$ 1228.9
 $2+2$ — 1145.6
 $0+0$ — 1069.3

$4+0$ $\frac{0.54}{0.94}$ 277.4

$2+0$ — 84.3
 $0+0$ — Ground
 170_{Yb}
 Experiment

$0+0$ — — — 1820

$x = 0.05$
 $0+0$ — 1630
 $0+0$ — 1610
 $0+0$ — 1530
 $x = 0.29$

$0+0$ — — — 1340
 $0+0$ — 1240
 $x = 0.14$

Theory
 Kuliev and Pyatov

$0+0_{\beta}$ — 1344
 $2+2$ — 1170

Theory
 Bes

$1-0$ — 1870

$2-2$ — 1730

$3-3$ — 1490
 $1-1$ — 1470

Theory
 Neergård and Vogel

$1+1$ — 2810
 $1+1$ — 2720
 $1+1$ — 2610
 $1+0$ — 2500
 $1+1$ — 2430
 $1+1$ — 2350

Theory
 Gabrakov et al.

Camp — Fig. 11

APPENDIX

The following figures comprise the remainder of the coincidence spectra that do not appear in the main text. These spectra were all obtained using the isotopically separated ^{170}Lu source, the multiparameter coincidence equipment, and a computer sorting program. In all cases the graphs are three-cycle semi-log plots. It will be noted that some of the spectra appear on a white background while others appear on a regular graph-paper-type background. Those in this latter category were all spectra contained on several magnetic tapes that were inadvertently lost or misplaced, hence not available for replotting on white paper. Therefore, what appears are photographs of the original working spectra. In many cases there were 4096 channels of data plotted, but those channels not shown contained no counts greater than 1.

Those spectra appearing on white backgrounds have all been averaged, with the exception of the 84.26- and 193.13-keV ground-band transition gates. For the averaged spectra, the data plotted are an average of the data in channels $(n-1)$, n , and $(n+1)$, where n runs from channel 1 to 4094. Almost all peaks observed in each gate have been identified.

An index to the spectra contained in this appendix is given on the following page. Five entries contain the code "text," which indicates that these spectra can be found in either Figs. 7 or 8 of the main text. Sixteen additional gates were taken that are not shown. These either contained no information or information already shown.

Index to Coincidence Gate Spectra

E(keV)	90°	180°	Appendix page	E(keV)	90°	180°	Appendix page
84.26	text	X	3	987.3	X	X	19
118.60		X	4	999.6	X		20
152.60	X	text	4	1003.2	X	X	20
193.13	text	X	3	1028.8	X	text	21
221.4	X		5	1050.4	X	X	21
228.0	X		5	1054.3	X	X	22
235.6	X		5	1061.4	X		22
241.5	X		6	1061.4		X	23
251.8	X		6	1101.7	X	X	23
283.0	X		6	1119.4	X		24
283.0		X	7	1133.5	X		24
286.6	X	X	7	1138.6	X		24
323.6	X	X	8	1138.6		X	25
395.9	X		8	1144.6	X		26
395.9		X	9	1144.6		X	25
419.6	X	X	9	1145.8	X		26
447.6	X		10	1145.8		X	25
455.5		X	10	1218.5	X		26
479.0	X		10	1225.6	X		27
492.6	X	X	11	1257.2	X	X	27
530.5	X		11	1280.3	X	X	28
544.2	X	X	12	1294.7	X		28
572.2	X		12	1307.5	X		29
572.2		X	13	1341.2	X	X	29
579.4	X	X	13	1364.6	X		30
612.1	X		14	1380.8	X		30
619.0	X		14	1395.6	X	X	31
688.0	X	text	14	1405.1	X		31
706.8	X		15	1428.1	X	X	34
829.3	X	X	15	1450.2	X		32
839.3	X	X	16	1455.3	X		32
855.2	X		16	1459.9	X		32
868.1	X		17	1459.9		X	33
938.7	X		17	1512.5	X		33
947.8	X		17	1514.6	X		33
966.8	X		18	1550.5		X	34
983.7	X		19	1860.0	X		30
983.7		X	18	2040.0	X		35
985.1	X		19	2041.9	X		35
985.1		X	18	2116.6	X		35

-A-4-

11
100

11
100

11
100

8/ 181a

8/ 181a

8/ 181a

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