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Level structure of ^{175}Yb and ^{177}Yb via the ^{174,176}Yb$(d,p)^{175,177}$Yb and ^{176}Yb$(d,t)^{175}$Yb reaction

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We studied ^{175}Yb with the ^{176}Yb (d,t) and ^{174}Yb (d,p) reactions and ^{177}Yb with the ^{176}Yb (d,p) reaction. We report 129 levels below 2550 keV in ^{175}Yb, 63 of which are previously unreported and 71 levels below 2700 keV in ^{177}Yb, 19 of which are new. We identified a few of these levels as possibly assigned to the wrong isotope because of isotopic contamination of the targets. The adopted 1104- and 1167-keV states in ^{177}Yb are among these identifications. We took angular distributions on all three reactions and compared the data to distorted-wave Born-approximation theory to extract l values. The (d,t) distributions yield a few cases of anomalously shaped distributions, especially in the case of the 603.3-keV state in ^{175}Yb. The distribution data contradict a few tentative assignments and we can make several new l assignments. Extensions of the proposed band structures of these nuclei suggest possible placements and spin assignments for a few additional states. We also show how the revised level schemes can be used to interpret data already in the literature.

[NUCLEAR REACTIONS ^{174}Yb (d,p), ^{176}Yb(d,t), ^{176}Yb(d,p), $E(d)=14$ MeV; measured excitation energies, $\sigma(p,\theta)$, $\sigma(t,\theta)$, $\theta=16-120°$, ^{175}Yb and ^{177}Yb deduced l, J, π, S; enriched targets, DWBA analysis, magnetic spectrograph.]

The ytterbium nuclei provide a testing ground for collective and unified models in the region of large deformations, and as such one can characterize their low lying levels as members of rotational and vibrational bands built on various Nilsson orbits. As discussed in our previous work on ^{173}Yb[1] the accuracy and completeness of some of the adopted level schemes suffer from a lack of particle reaction studies using detectors of high resolution and good energy accuracy. A number of studies[2-5] have been published recently in which the applicability of spherical distorted wave Born approximation (DWBA) theory to the deformed rare earth nuclei was investigated, but angular distribution data for ytterbium are scarce. ^{175}Yb has been studied extensively in β decay and (n,γ) experiments and the energies of many levels have been measured to very high accuracy[6]; however, several low lying levels are not excited in these accurate experiments and thus when they have been reported, the energies are not very accurate. In ^{177}Yb a large number of adopted levels are poorly defined in energy.[7] Our previous work suggests the likelihood of finding several new levels below 2 MeV in excitation and the possibility of extracting spectroscopic information from straightforward DWBA analyses.

The Notre Dame broad range magnetic spectrograph[8] is suitable for accurate excitation energy and angular distribution measurements on nuclei with high level densities. The absolute calibration permits measurements of excitation energies to within 1–2 keV for states up to 3 MeV in excitation. The dispersion characteristics yield a resolution as good as 1 part in 1500–2500 or 5–10 keV for the range of energies studied. Thus this device can handle the high level densities of these nuclei with good accuracy at least below 3.0 MeV in excitation. The chief drawback to the spectrograph is its small solid angle (0.3 msr) which coupled with the low cross sections of the (d,p) and (d,t) reaction (1–1000 μb/sr), the thin targets (80–300 μg/cm^2) necessary to maintain decent resolution, and typical input beam intensities of 1–2 μA makes data collection, especially angular distributions, quite time consuming.

We prepared targets of 96.2% isotopically enriched ^{176}Yb and 95.8% enriched ^{174}Yb by reducing the oxides with lanthanum and then evaporating the ytterbium onto 20 μg/cm^2 carbon foils. The ^{176}Yb targets were 300 μg/cm^2 thick and the ^{174}Yb targets were 80 μg/cm^2 thick.

We extracted 14 MeV deuteron beams from the Notre Dame FN tandem accelerator and momentum analyzed the reaction products in the 100-cm spectrograph using photographic plates as the detectors in all the excitation work. We show typical spectra in Figs. 1–3.

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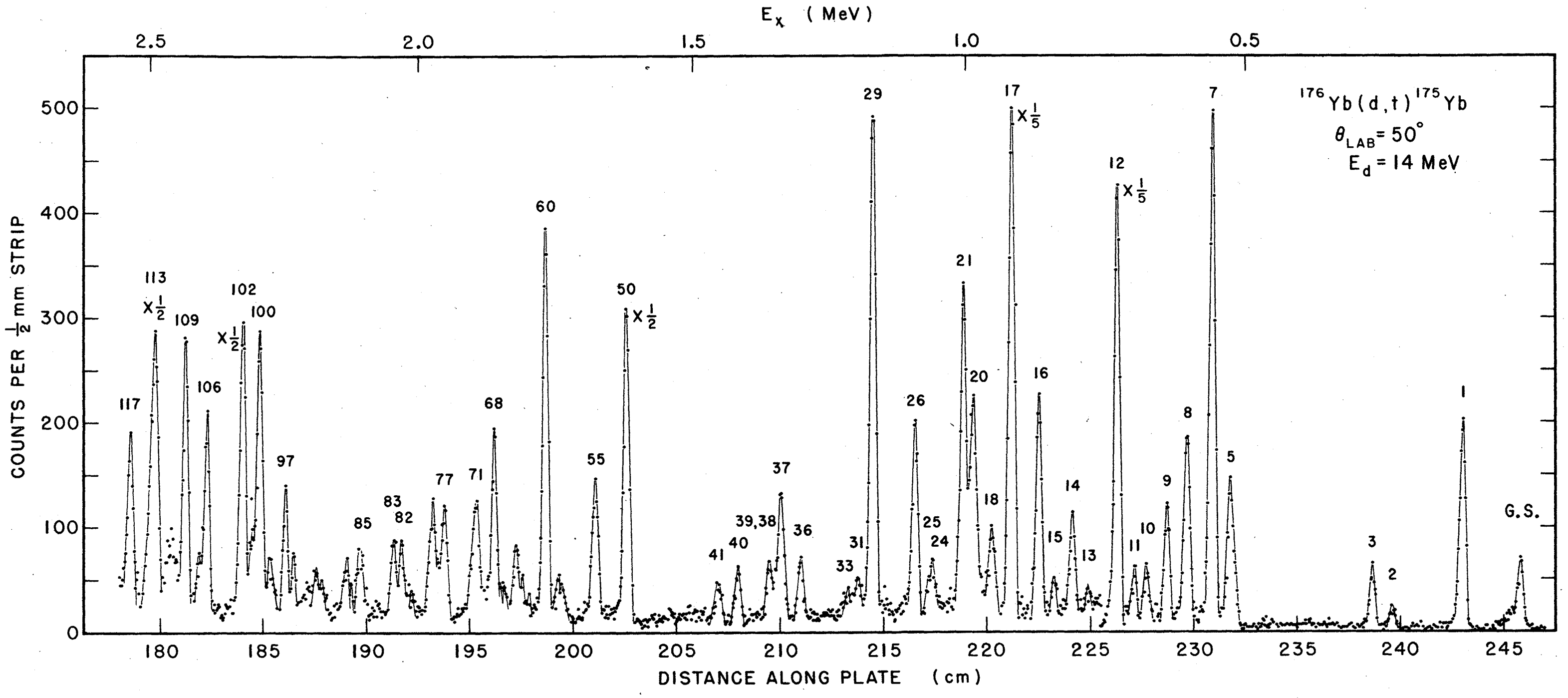

FIG. 1. Spectrum of tritons observed at 50° from a ^{176}Yb target bombarded with 14-MeV deuterons. The group numbers correspond to the level numbers in Table I. The E_x scale gives excitation energies in ^{175}Yb.

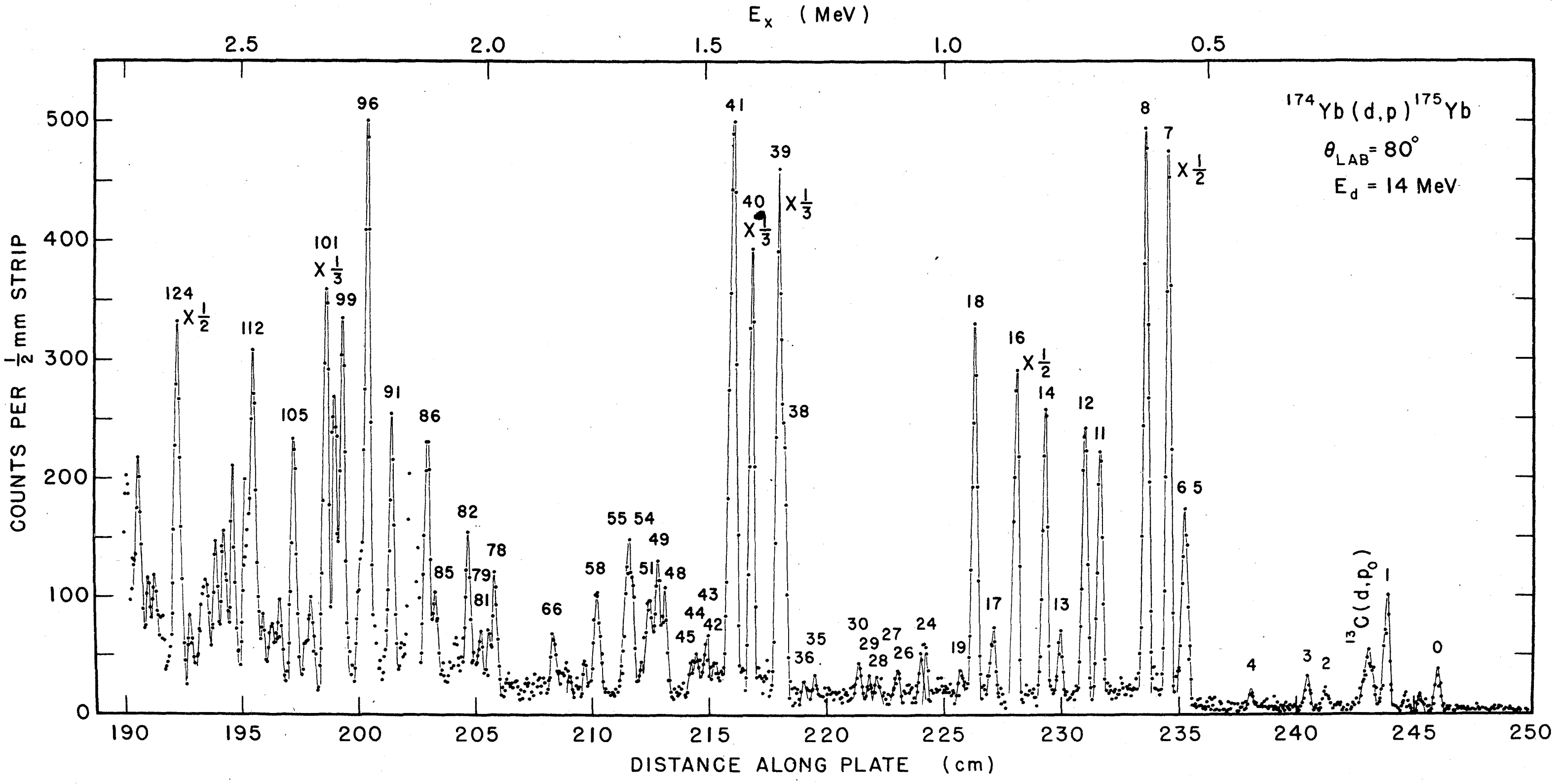

FIG. 2. Spectrum of protons observed at 80° from a ^{174}Yb target bombarded with 14 MeV deuterons. The group numbers correspond to the level numbers in Table I. The E_x scale gives excitation energies in ^{175}Yb. A group from ^{13}C is labeled with the reaction symbols.

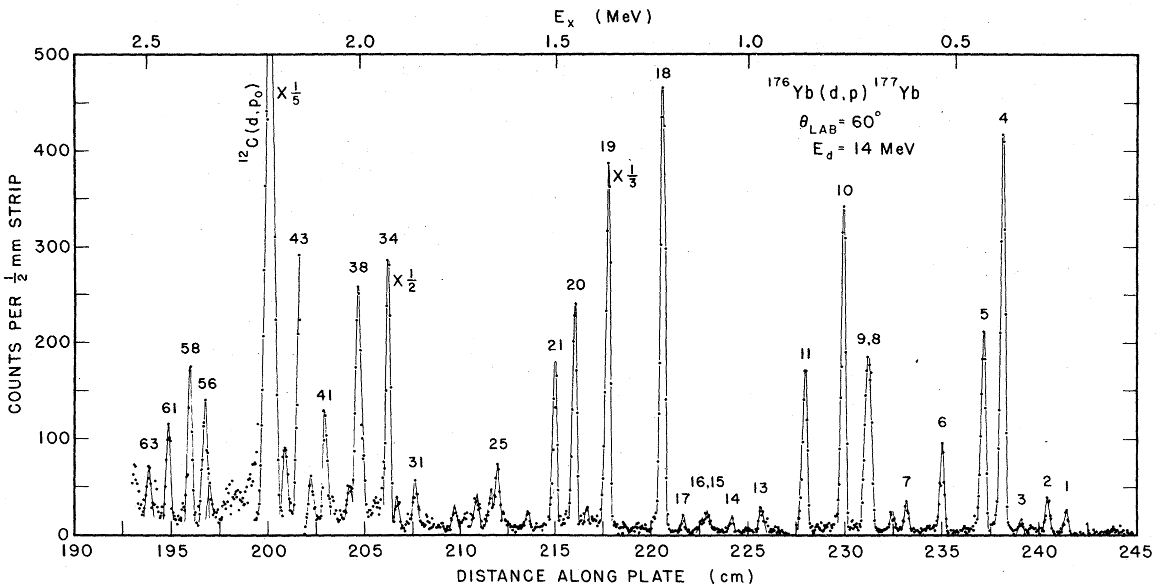

FIG. 3. Spectrum of protons observed at 60° from a ^{176}Yb target bombarded with 14-MeV deuterons. The group numbers correspond to the level numbers in Table I. The E_x scale gives excitation energies in ^{177}Yb. A group from ^{12}C is labeled with the reaction symbols.

^{175}Yb

We took exposures at 40, 50, and 60° for the ^{176}Yb (d,t) ^{175}Yb reaction and at 40, 60, 80, and two at 90° for the ^{174}Yb (d,p) ^{175}Yb reaction. The multiangle exposures allow the identification of contaminant groups through kinematic differences, at least for contaminants significantly different in mass from ytterbium. Isotopic contamination does not cause enough kinematic shift to be identified in this manner, and it is important to identify such contamination in light of the wide variation in cross sections (three orders of magnitude) for the states of interest. We must know the energies and cross sections of all strong states populated in the isotopic contaminant reactions so that the expected particle groups can be compared to the weak groups in the spectra of interest. The high level densities add to the difficulties, as many of the expected contaminant groups are masked by strong groups in the spectra of interest. Uncertainties are large in this process especially when there are few isolated contaminant groups with which to calibrate the intensities. The group strengths have uncertainties ranging from 3–30% depending on their magnitudes and proximities to other strong groups. Target thickness and uniformity is uncertain to at least 20% and cross sections from previous experiments carry 50–100% absolute and 10–20% relative uncertainties. Within these uncertainties a weak state of interest may be overlapped by a contaminant group, therefore in the list of all the levels we measured, given in Table I, we identify those for which the particle group is suspected of actually arising from an isotopic contaminant. For easy reference, in Table I we have numbered the levels of ^{175}Yb and ^{177}Yb measured in our work. We show the number of experimental measurements made for each level with the reaction used indicated in the case of ^{175}Yb. The next two columns give the excitation energy determined from these measurments and the uncertainty calculated as in Ref. 1. The columns marked l and S give information concerning our angular distribution work and we present the energy, uncertainty (when given), and the J^{π} values from the Nuclear Data Sheet compilations for each state.

We can point out several examples of possible isotopic contamination in the case of ^{175}Yb. Levels 6 and 10 are most likely the 1074- and 78-keV states in ^{173}Yb. The strengths of the groups are greater than those calculated using the chemical analysis sheets and the ^{173}Yb cross section measured in Ref. 1, but we can understand a factor of 2–3 in terms of the uncertainties involved. Levels 25, 32, and 33 on the other hand are much stronger (6–10 times) than the expected contaminant states and thus appear to be ^{175}Yb states. In addition we see state 33 in both reactions whereas the possible contaminant state only appears in (d,t). States 28 and 63 are closer to the expected

TABLE I. Energy levels of ^{175}Yb and ^{175}Yb. The weighted average excitation energy (from both reactions for ^{175}Yb) is shown. Information from our angular distributions and our DWBA analysis is shown as well as the excitation energies and J^π values taken from the latest compilation.

				^{175}Yb via ^{176}Yb$(d,t)^{175}$Yb and ^{174}Yb$(d,p)^{175}$Yb				
					This exp		Nuclear data sheets	
Level number	Total runs	(d,t) runs	(d,p) runs	$E_x+\Delta E_x$	$l(t)=(d,t)$ $l(p)=(d,p)$	$S(J^\pi)$	E_x (keV)	J^π
0	3	3		0.0 ± 1.1			0.00	$\frac{7}{2}^-$
1	8	3	5	104.1 ± 0.7	5(t)	0.472($\frac{9}{2}^-$)	104.526 ± 0.002	$\frac{9}{2}^-$
2	7	3	4	231.8 ± 1.3			231.502 ± 0.006	$\frac{11}{2}^-$
3	7	3	4	266.8 ± 0.9			267.541 ± 0.003	($\frac{9}{2}^+$)
4	4		4	385.5 ± 1.7			384.775 ± 0.007	($\frac{11}{2}^+$)
5	8	3	5	522.2 ± 1.0	6(t)	0.434($\frac{13}{2}^+$)	520 ± 3	($\frac{13}{2}^+$)
6	3		3	531.5 ± 2.7 [1075 keV in ^{173}Yb]				
7	8	3	5	557.0 ± 0.7	1(t)	0.042($\frac{3}{2}^-$)	556.085 ± 0.007	$\frac{3}{2}^-$
					1(p)	0.226($\frac{3}{2}^-$)		
8	8	3	5	603.3 ± 0.7	3(t)	0.060($\frac{5}{2}^-$)	602.836 ± 0.007	$\frac{5}{2}^-$
					3(p)	0.398($\frac{5}{2}^-$)		
9	3	3		639.2 ± 1.1	3(t)	0.038($\frac{5}{2}^-$)	639.256 ± 0.007	($\frac{5}{2}^-$)
10	3	3		676.1 ± 1.3 [78 keV in ^{173}Yb]				
11	7	3	4	698.0 ± 0.8	3(p)	0.045($\frac{7}{2}^-$)	698.109 ± 0.007	$\frac{7}{2}^-$
12	8	3	5	729.4 ± 0.7	3(t)	0.726($\frac{7}{2}^-$)	729.213 ± 0.007	($\frac{7}{2}^-$)
					3(p)	0.055($\frac{7}{2}^-$)		
13	4	3	1	781.3 ± 1.4			773 ± 3	($\frac{9}{2}^-$)
14	8	3	5	811.2 ± 0.7	1(p)	0.054($\frac{3}{2}^-$)	811.425 ± 0.008	($\frac{3}{2}^-$)
15	3	3		844.1 ± 1.4			844.18 ± 0.01	($\frac{9}{2}^-$)
16	8	3	5	872.3 ± 0.7	3(t)	0.064($\frac{5}{2}^-$)	871.69 ± 0.008	($\frac{5}{2}^-$)
					3(p)	0.258($\frac{5}{2}^-$)		
17	7	3	4	919.1 ± 1.3	1(t)	0.282($\frac{1}{2}^-$)	920.030 ± 0.009	$\frac{1}{2}^{(-)}$
18	7	3	4	957.4 ± 0.8	3(p)	0.051($\frac{7}{2}^-$)	957.47 ± 0.02	($\frac{7}{2}^-$)
19	3		3	983.0 ± 1.5			≈977 ± 3	($\frac{11}{2}^-$)
20	3	3		991.1 ± 1.3	1(t)	0.020($\frac{3}{2}^-$)	992.263 ± 0.008	$\frac{3}{2}^{(-)}$
							1009.1	($\frac{7}{2}^+$)
21	5	3	2	1008.2 ± 1.2	2(t)	0.033($\frac{5}{2}^+$)	1009.386 ± 0.009	$\frac{5}{2}^{(-)}$
					3(t)	0.129($\frac{5}{2}^-$)		
22	2		2	1021.5 ± 2.3				
23	2		2	1035.0 ± 2.1				
24	7	3	4	1062.2 ± 1.0				
							1067.87 ± 0.01	($\frac{3}{2}^+$)
25	3	3		1073.3 ± 1.7 [482 keV in ^{173}Yb]				
26	7	3	4	1097.3 ± 0.9	3(t)	0.077($\frac{5}{2}^-$)	1090	($\frac{9}{2}^+$)
						0.059($\frac{7}{2}^-$)		
27	4		4	1117.6 ± 1.3			1121.327 ± 0.009	($\frac{5}{2}^+$)

TABLE I. *(Continued)*.

				^{175}Yb via ^{176}Yb$(d,t)^{175}$Yb and ^{174}Yb$(d,p)^{175}$Yb	This exp		Nuclear data sheets	
Level number	Total runs	(d,t) runs	(d,p) runs	$E_x \pm \Delta E_x$	$l(t)=(d,t)$ $l(p)=(d,p)$	$S(J^\pi)$	E_x (keV)	J^π
28	4		4	1156.5 ± 1.6[1707 keV in ^{173}Yb]				
29	7	3	4	1174.8 ± 0.9	3(t)	0.164($\frac{7}{2}^-$)	1174.759 ± 0.009	$\frac{7}{2}^{(-)}$
30	4		4	1195.2 ± 1.5			1197.29 ± 0.02	($\frac{7}{2}^+$)
31	3	3		1204.2 ± 1.3			1200	
32	4		4	1210.3 ± 1.4[1760 keV in ^{173}Yb]				
33	6	3	3	1222.9 ± 1.4[(d,t)627 keV in ^{173}Yb]				
34	4		4	1262.0 ± 1.5			~1259	
35	4		4	1290.0 ± 1.2			(1300)	
36	7	3	4	1308.4 ± 1.0			1309.3	
37	3	3		1346.4 ± 1.1	6(t)	0.979($\frac{13}{2}^+$)	1336	($\frac{13}{2}^+$)
38	8	3	5	1355.9 ± 0.8			1356.49 ± 0.01	($\frac{1}{2}^+$)
					0(p)	0.793($\frac{1}{2}^+$)		
					1(p)	0.488($\frac{5}{2}^+$)		
39	8	3	5	1367.4 ± 0.8			1368.111 ± 0.009	($\frac{5}{2}^+$)
40	8	3	5	1424.9 ± 0.8	4(p)	1.509($\frac{7}{2}^+$) 1.207($\frac{9}{2}^+$)	1420 ± 3	
41	8	3	5	1461.1 ± 0.9 [a]	2(p)	0.202($\frac{3}{2}^+$)	1456.3	($\frac{5}{2}^+$)
						0.135($\frac{5}{2}^+$)	1468.87 ± 0.1	($\frac{3}{2}^+$)
42	4		4	1497.4 ± 1.2			1497.33	($\frac{3}{2}^+$)
43	4		4	1517.1 ± 1.3				
44	4		4	1536.0 ± 1.4				
45	3		3	1549.5 ± 1.6			1550	
46	3		3	1566.6 ± 1.9				
47	4		4	1581.4 ± 2.6				
48	4		4	1604.2 ± 1.4			1605 ± 6	
49	4		4	1620.6 ± 1.2			1620	
50	3	3		1628.2 ± 1.1	1(t)	0.098($\frac{1}{2}^-$)	1627.49	
						0.089($\frac{3}{2}^-$)		
51	4		4	1636.4 ± 1.4			1632 ± 6	
52	3	3		1642.2 ± 1.5				
53	4		4	1650.4 ± 1.4			1647.9	
							1661	
54	3	3		1671.5 ± 1.5			1672 ± 6	
55	5	3	2	1685.8 ± 1.0	1(t)	0.017($\frac{1}{2}^-$)	1682.6	
						0.016($\frac{3}{2}^-$)	1691.0	
56	3	3		1743.4 ± 1.2			1745	
57	4		4	1749.7 ± 1.1				
58	3	3		1754.3 ± 1.6			1752 ± 6	
59	7	3	4	1775.5 ± 1.7	2(t)	0.056($\frac{3}{2}^+$)	1774 ± 3	
						0.048($\frac{5}{2}^+$)		
					3(t)	0.203($\frac{5}{2}^-$)		
						0.154($\frac{7}{2}^-$)		
60	4		4	1802.2 ± 1.8				
61	3	3		1808.7 ± 1.8			(~1812)	

TABLE I. *(Continued).*

^{175}Yb via ^{176}Yb$(d,t)^{175}$Yb and ^{174}Yb$(d,p)^{175}$Yb

Level number	Total runs	(d,t) runs	(d,p) runs	This exp $E_x \pm \Delta E_x$	This exp $l(t)=(d,t)$ $l(p)=(d,p)$	This exp $S(J^\pi)$	Nuclear data sheets E_x (keV)	Nuclear data sheets J^π
62	4		4	1815.2 ± 1.6			1816 ± 6	
63	3	3		1822.9 ± 1.6 [1232 keV in ^{173}Yb]				
64	3	3		1833.9 ± 1.6			1830 ± 3	
65	4		4	1842.0 ± 1.2			1844	
66	3	3		1851.8 ± 1.6				
67	4		4	1861.1 ± 1.5			1861 ± 3	
							1864.9	
68	3	3		1870.8 ± 1.2				
69	4		4	1876.5 ± 1.5				
70	3	3		1881.6 ± 1.5				
71	3	3		1902.4 ± 1.2			~1898	
72	3	3		1911.6 ± 1.5				
73	4		4	1918.9 ± 1.4				
74	4		4	1932.5 ± 1.7				
							~1939	
75	4		4	1948.9 ± 1.5				
76	3	3		1960.9 ± 1.2 [1362 keV in ^{173}Yb]				
77	4		4	1966.0 ± 1.2			1968.4	
78	7	3	4	1979.1 ± 1.0			1980.5	
79	3	3		1989.9 ± 1.4				
80	4		4	1997.6 ± 1.3			1999.8	
							2015.2	
81	7	3	4	2023.8 ± 1.0				
82	7	3	4	2040.4 ± 1.1			2040	
83	7	3	4	2053.9 ± 1.1 [(d,t)908 keV in ^{171}Yb]				
84	4		4	2091.9 ± 1.2			2093.6	
85	8	3	5	2108.2 ± 0.9			2107.8	
86	3	3		2119.4 ± 1.5			2114.8	
87	5	3	2	2131.7 ± 1.2				
88	7	3	4	2142.6 ± 1.0			2140	
89	2		2	2162.6 ± 2.0			2161	
90	8	3	5	2181.7 ± 0.9				
							2189.9	
91	7	3	4	2195.8 ± 1.1				
92	3	3		2209.1 ± 1.7				
93	4		4	2215.8 ± 1.4				
94	3	3		2220.5 ± 1.7				
95	8	3	5	2234.2 ± 1.1	$2(p)$	$0.173(\frac{3}{2}^+)$		
						$0.115(\frac{5}{2}^+)$		
96	6	3	3	2251.4 ± 1.0				
97	3	3		2279.5 ± 1.2				
98	4		4	2284.5 ± 1.2	$3(p)$	$0.128(\frac{5}{2}^-)$		
						$0.096(\frac{7}{2}^-)$		
99	7	3	4	2300.7 ± 1.0	$2(t)$	$0.062(\frac{3}{2}^+)$		
						$0.053(\frac{5}{2}^+)$		
100	7	3	4	2317.6 ± 0.9	$2(p)$	$0.208(\frac{5}{2}^+)$		
					$4(p)$	$0.717(\frac{9}{2}^+)$		
101	3	3		2331.2 ± 1.2	$2(t)$	$0.139(\frac{3}{2}^+)$		
						$0.118(\frac{5}{2}^+)$		
102	7	3	4	2349.1 ± 1.2				
103	4		4	2366.5 ± 1.5				
104	5		5	2385.9 ± 1.1				

TABLE I. *(Continued)*.

^{175}Yb via ^{176}Yb$(d,t)^{175}$Yb and ^{174}Yb$(d,p)^{175}$Yb

Level number	Total runs	(d,t) runs	(d,p) runs	$E_x \pm \Delta E_x$	This exp $l(t)=(d,t)$ $l(p)=(d,p)$	This exp $S(J^\pi)$	Nuclear data sheets E_x (keV)	J^π
105	7	3	4	2398.9 ± 1.0	2(t)	0.051($\frac{3}{2}^+$) 0.043($\frac{5}{2}^+$)		
106	7	3	4	2415.9 ± 1.6				
107	4		4	2431.1 ± 1.5				
108	3	3		2438.4 ± 1.2	2(t)	0.076($\frac{3}{2}^+$) 0.064($\frac{5}{2}^+$)		
109	4		4	2450.9 ± 1.6				
110	3	3		2458.4 ± 1.5 [1867 keV in ^{173}Yb]				
111	7	3	4	2471.0 ± 1.0				
112	7	3	4	2491.4 ± 1.4	2(t)	0.240($\frac{3}{2}^+$) 0.203($\frac{5}{2}^+$)		
113	3	3		2506.7 ± 2.3				
114	4		4	2515.0 ± 1.3				
115	2	2		2523.5 ± 1.8 [1933 keV in ^{173}Yb]				
116	5		5	2533.5 ± 1.2				
117	3	3		2541.6 ± 1.1	2(t)	0.047($\frac{3}{2}^+$) 0.039($\frac{5}{2}^+$)		
118	5		5	2552.1 ± 1.3				
119	5		5	2571.6 ± 1.6				
120	4		4	2583.3 ± 1.6				
121	4		4	2599.8 ± 1.4				
122	4		4	2613.5 ± 1.4				
123	5		5	2630.1 ± 1.1	2(p) 3(p)	0.110($\frac{5}{2}^+$) 0.116($\frac{7}{2}^-$)		
124	4		4	2646.4 ± 2.2				
125	4		4	2662.2 ± 1.4				
126	4		4	2677.7 ± 1.5				
127	4		4	2693.2 ± 1.4				
128	4		4	2712.3 ± 1.3				
129	3		3	2737.1 ± 1.4				

^{177}Yb via ^{176}Yb$(d,p)^{177}$Yb

Level number	Runs	$E_x \pm \Delta E_x$	This exp l	This exp $S(J^\pi)$	Nuclear data sheets E_x (keV)	J^π
					0.0	$\frac{9}{2}^+$
					104.5 ± 0.2	$\frac{7}{2}^-$
					124.6 ± 0.8	$\frac{11}{2}^-$
1	4	220.9 ± 1.4			222 ± 3	($\frac{9}{2}^-$)
2	4	264.7 ± 1.2 [1075 keV in ^{173}Yb]			268 ± 3	$\frac{13}{2}^+$
3	3	331.3 ± 1.6			331.5 ± 0.3	$\frac{1}{2}^-$
4	4	375.9 ± 1.1	1	0.354($\frac{3}{2}^-$)	375 ± 2	$\frac{3}{2}^-$
5	4	423.5 ± 1.1	3	0.412($\frac{5}{2}^-$)	423.3 ± 0.4	$\frac{5}{2}^-$
6	4	526.4 ± 1.1	3	0.062($\frac{7}{2}^-$)	530 ± 3	$\frac{7}{2}^-$
7	4	612.9 ± 1.2 [872 keV in ^{175}Yb]			615 ± 5	($\frac{9}{2}^-$)
8	4	706.1 ± 1.4	1	0.114($\frac{3}{2}^-$)	703 ± 2	($\frac{3}{2}^-$)

TABLE I. *(Continued)*.

		^{177}Yb via ^{176}Yb$(d,p)^{177}$Yb			Nuclear data sheets	
Level number	Runs	$E_x \pm \Delta E_x$	This exp l	$S(J^\pi)$	E_x (keV)	J^π
9	4	715.4 ± 1.5				
10	4	770.6 ± 1.1	3	$0.425(\frac{5}{2}^-)$	774 ± 3	$(\frac{5}{2}^-)$
					822 ± 3	
					833 ± 2	$(\frac{1}{2},\frac{3}{2})$
					866 ± 2	$(\frac{1}{2},\frac{3}{2})$
11	2	865.0 ± 1.5	3	$0.127(\frac{7}{2}^-)$	867 ± 3	$(\frac{7}{2}^-)$
12	3	961.3 ± 2.0				
13	4	975.3 ± 1.2			976 ± 5	
					997 ± 2	
14	4	1048.6 ± 1.8			1050 ± 6	
15	4	1108.9 ± 1.6[1367 keV in ^{175}Yb]			1104 ± 6	
16	4	1125.5 ± 1.4			1124 ± 6	
17	4	1169.0 ± 1.9[1424 keV in ^{175}Yb]			1173 ± 6	
					1208.6 ± 1.1	$(\frac{3}{2}^-,\frac{5}{2}^+)$
18	4	1221.3 ± 1.1	3	$0.412(\frac{7}{2}^-)$	1222 ± 6	$(\frac{7}{2}^-)$
					1282 ± 2	$(\frac{1}{2},\frac{3}{2})$
					1318.9 ± 1.0	$(\frac{1}{2}^-,\frac{3}{2}^-)$
19	4	1359.0 ± 1.1	1	$0.756(\frac{3}{2}^-)$	1359.5 ± 1.5	$(\frac{3}{2}^-)$
					1416.0 ± 1.5	
20	4	1443.6 ± 1.2	3	$0.223(\frac{5}{2}^-)$	1447 ± 6	$(\frac{5}{2}^-)$
21	4	1493.6 ± 1.2	2	$0.141(\frac{3}{2}^+)$	1496 ± 6	
				$0.094(\frac{5}{2}^+)$		
22	3	1562.3 ± 1.4			1564 ± 6	$(\frac{7}{2}^-)$
23	2	1589.5 ± 2.8			1591.2 ± 2.0	$(\frac{1}{2},\frac{3}{2},\frac{5}{2}^+)$
24	4	1625.9 ± 1.7				
25	4	1643.1 ± 1.1			1646 ± 3	
26	4	1659.3 ± 1.2			1657.2 ± 1.5	$(\frac{1}{2}^-,\frac{3}{2}^-)$
27	4	1690.4 ± 1.2				
					1700.4 ± 1.5	$(\frac{1}{2},\frac{3}{2})$
28	4	1702.9 ± 1.2			1701 ± 3	
29	4	1725.3 ± 1.2				
					1734 ± 3	
30	3	1750.3 ± 1.4			1756 ± 3	
31	3	1849.9 ± 1.3[2109 keV in ^{175}Yb]				
32	4	1863.3 ± 1.2			1859 ± 3	
					1876 ± 3	
33	4	1899.0 ± 2.1				
34	4	1921.0 ± 1.2	1	$0.349(\frac{1}{2}^-)$	1920 ± 2	
			2	$0.480(\frac{3}{2}^+)$		
					1926 ± 3	
35	4	1936.3 ± 1.2				
36	4	1957.3 ± 1.2				
37	4	1985.9 ± 1.2				
38	4	1999.4 ± 1.2	2	$0.253(\frac{3}{2}^+)$	2000 ± 3	
				$0.167(\frac{5}{2}^+)$		
39	4	2022.5 ± 1.2			2021 ± 2	
					2031 ± 2	
40	4	2060.6 ± 1.4[2318 keV in ^{175}Yb]			2067 ± 2	
41	4	2080.2 ± 1.6			2085 ± 3	
42	4	2115.6 ± 1.2			2120 ± 3	
					2139 ± 2	
43	2	2144.9 ± 1.6			2142 ± 3	

TABLE I. *(Continued)*.

^{177}Yb via ^{176}Yb$(d,p)^{177}$Yb

Level number	Runs	$E_x \pm \Delta E_x$	This exp		Nuclear data sheets	
			l	$S(J^\pi)$	E_x (keV)	J^π
44	2	2161.2 ± 1.6	2	$0.381(\frac{3}{2}^+)$ $0.254(\frac{5}{2}^+)$	2161 ± 2	
					2168 ± 3	
45	3	2174.5 ± 2.7			2178.0 ± 1.8	$(\frac{1}{2}^-,\frac{3}{2}^-)$
46	2	2194.0 ± 1.6				
47	3	2210.9 ± 1.6			2207 ± 3	
48	3	2227.2 ± 1.4			2235 ± 3	
49	3	2242.5 ± 1.5			2242 ± 2	
50	3	2274.6 ± 1.4				
51	4	2291.7 ± 1.4			2287 ± 3	
52	4	2308.1 ± 1.3			2303 ± 3	
53	4	2325.3 ± 1.4				
54	3	2340.6 ± 2.0			2347 ± 3	
55	3	2371.6 ± 3.2 [2630 keV in ^{175}Yb]			2376 ± 2	
56	4	2384.6 ± 1.6				
57	2	2396.3 ± 1.6			2394 ± 2	
					2395 ± 3	
58	3	2423.5 ± 2.7				
59	3	2441.7 ± 3.3			2437 ± 3	
60	2	2460.7 ± 1.7				
61	4	2476.2 ± 1.5			2478 ± 2	
					2487 ± 3	
62	4	2508.7 ± 2.2				
63	4	2525.3 ± 1.5			2521 ± 3	
					2533 ± 3	
64	4	2546.6 ± 2.0			2555 ± 3	
65	4	2560.9 ± 1.9			2568 ± 3	
66	4	2584.8 ± 1.2				
67	3	2601.8 ± 1.6			2598 ± 3	
68	2	2622.6 ± 1.7				
69	2	2635.1 ± 1.7			2636 ± 3	
70	2	2653.1 ± 1.7				
71	3	2667.4 ± 1.9			2664 ± 3	

[a] Possible doublet.

strengths for the contaminant states, but their identifications are not very certain. At higher excitation, energy groups which might be identified with contaminants appear too strong for such an assignment. The greatest possibility is state 110, but we have additional evidence that this is a true state in ^{175}Yb, which we will show later.

We can demonstrate the accuracy of our measurements by comparing our energies with the very accurate γ-ray measurements from Ref. 6. For 23 levels our (d,t) energies compared to the γ-ray numbers show an average difference of −0.08 keV with a standard deviation of 1.5 keV. For 28 levels our (d,p) measurements give a difference of −0.95 keV with a standard deviation of 2.15 keV. These numbers give us confidence in our measurements such that we feel discrepancies with the adopted levels such as level 13 should be resolved in favor of our measurements. Levels 13, 19, 26, 35, 37, 74, and 91 are all cases where the adopted levels appear significantly in error although the uncertainties for many of these levels are not given. Our accuracy is also important in a number of cases where a level is seen in the (d,t) reaction and another in the (d,p) reaction with the energy spacing being outside the overlap of uncertainties but less than three times the overlap. We present all such cases as two separate states, based on the accuracy demonstrated above. In some cases we suspect the two levels to be the same state, such as states 68–69 or 97–98; however, the only experimental evi-

TABLE II. A comparison of some γ-ray data from Ref. 9 with our measured excitation energies.

^{174}Yb$(n,\gamma)^{175}$Yb $Q=5822.6\pm0.5$ keV (Ref. 9)			This experiment	
Number	E_γ	Capture state energy-E_γ	Level number	E_x
30	3589.5 ± 2.0	2233.1 ± 2.1	95	2234.2 ± 1.1
31	3583.9 ± 2.5	2238.7 ± 2.5		
32	3569.9 ± 1.5	2252.7 ± 1.6	96	2251.4 ± 1.0
33	3531.0 ± 1.5	2291.6 ± 1.6		
34	3503.0 ± 2.0	2319.6 ± 2.1	100	2317.6 ± 0.9
35	3492.8 ± 2.0	2329.8 ± 2.1	101	2331.2 ± 1.2
36	3424.8 ± 1.5	2397.8 ± 1.6	105	2398.9 ± 1.0
37	3392.3 ± 2.5	2430.3 ± 2.5	107	2431.1 ± 1.5
38	3385.7 ± 2.0	2436.9 ± 2.1	108	2438.4 ± 1.2
39	3365.0 ± 2.5	2457.6 ± 2.5	110	2458.4 ± 1.5
40	3356.0 ± 1.5	2466.6 ± 1.6	(111	2471.0 ± 1.0)
41	3334.6 ± 2.5	2488.0 ± 2.5	112	2491.4 ± 1.4
42	3329.0 ± 2.0	2493.6 ± 2.1		
43	3306.3 ± 1.5	2516.3 ± 1.6	114	2515.0 ± 1.3
44	3287.3 ± 1.5	2535.3 ± 1.6	116	2533.5 ± 1.2
45	3260.2 ± 2.0	2562.4 ± 2.1		
46	3248.3 ± 2.0	2574.3 ± 2.1	119	2571.6 ± 1.6
47	3221.1 ± 2.0	2601.5 ± 2.1	121	2599.8 ± 1.4
48	3196.0 ± 2.0	2626.6 ± 2.1	(123	2630.1 ± 1.1)
49	3172.7 ± 1.5	2649.9 ± 1.6	124	2646.4 ± 2.2
50	3161.3 ± 1.5	2661.3 ± 1.6	125	2662.2 ± 1.4
51	3142.6 ± 1.5	2680.0 ± 1.6	126	2677.7 ± 1.5
52	3126.2 ± 1.5	2696.4 ± 1.6	(127	2693.2 ± 1.4)
53	3116.0 ± 2.0	2706.6 ± 2.1	(128	2712.3 ± 1.3)
54	3089.0 ± 2.5	2733.6 ± 2.5	129	2737.1 ± 1.4

dence we have supports the separation of such states. This evidence is detailed below for states 107–108. The following analysis also points out another value of these accurate particle measurements. Table II presents 25 unplaced γ rays from the work of Alenius *et al.*[9] These authors had great success in placing most of the higher energy γ rays as transitions from the capturing state in the ^{174}Yb (n,γ) ^{175}Yb, $Q=5822.6\pm0.5$ keV reaction to states in ^{175}Yb. The adopted levels end with the 2189.9-keV state which was the final state for the γ ray labeled #29 at 3632.3 ± 1.5 keV in the work of Ref. 9. Of the next 25 γ rays listed in this reference we have possible placements for 22, the placement of γ-rays 41 and 42 is double due to the limits of our resolution. Only four of the placements fall outside the overlap of uncertainties, and only one of those is more than 50% outside the overlap. The placement of γ's 37 and 38 to our states 107 and 108 supports the measurements of these as separate states. The correspondence of γ-ray 39 with level 110 supports this state as being in ^{175}Yb rather than the possible contaminant 1867-keV state in ^{173}Yb.

We measure 24 new states below 2190 keV although three or four of these states are probably isotopic contaminant states. The adopted level scheme above 1600 keV is somewhat confusing, because although the states from Ref. 8 are generally adopted, some (d,p) and (d,t) levels[10] as well as some $(^3$He$,\alpha)$ levels[11] appear in the adopted scheme with rather poorly defined energies. Below 1600 keV we see all the adopted levels with the exception of the 514.867-keV level, perhaps the 1067.87-keV state where states 24 and 25 bracket this energy, and the 1468.87-keV state where the correspondence of state 41 is unclear. We cannot separate the 1009.1- and 1009.386-keV states. Above 2 MeV we have many new levels although Table II suggests that many of these levels can be related to data already in the literature.

^{177}Yb

We studied ^{177}Yb with the single reaction ^{176}Yb (d,p) ^{177}Yb using plate exposures at 60, 70, 80, and 90°. We chose the higher angles to avoid the masking of lower excitation states by the ^{12}C and

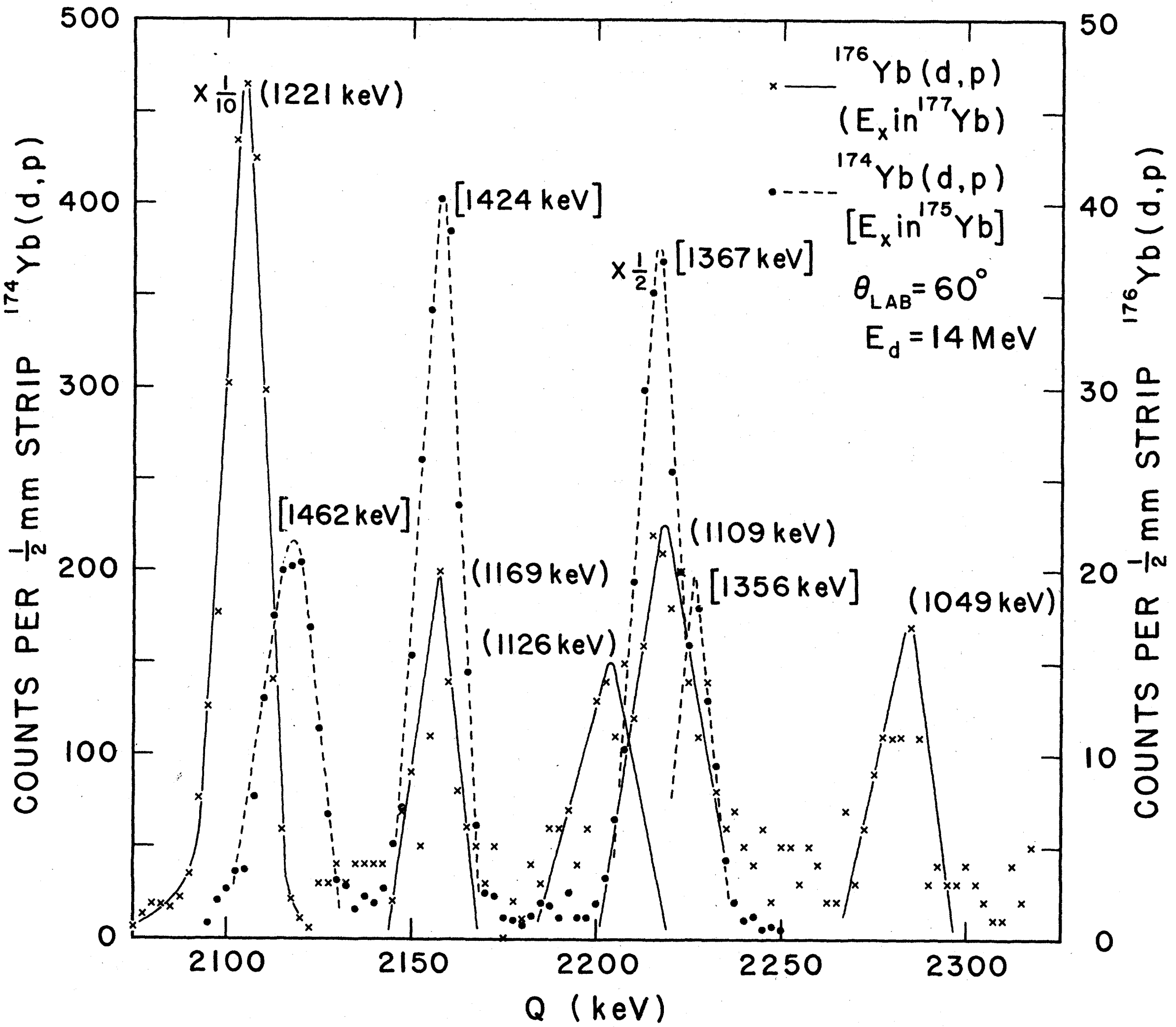

FIG. 4. Portions of spectra of protons observed at 60° from a ^{176}Yb target (x's) and from a ^{174}target (dots) bombarded with 14-MeV deuterons. Excitation energies in ^{177}Yb are shown in parentheses and those in ^{175}Yb are shown in square brackets. These overlapped spectra seem to support the identification of the 1109- and 1169-keV states in ^{177}Yb as contaminant states in ^{175}Yb.

^{16}O (d,p) contaminant reactions. With this single reaction we do not expect to populate all states. Again, analysis required a careful consideration of isotopic contaminant reactions, but in this case some of the adopted levels[7] came under suspicion. Figure 4 shows a portion of the ^{176}Yb (d,p) 60° spectrum with an overlap of a 60° ^{174}Yb (d,p) spectrum. The adopted states at 1104 and 1173 keV in ^{177}Yb seem actually to be the 1367- and 1424-keV states in ^{175}Yb. These adopted levels come directly from the ^{176}Yb (d,p) work in Ref. 10 so such a confusion in identification is not unreasonable. The 264.7- and 612.9-keV states have reasonably strong identifications as true states in ^{177}Yb. The comparison of our energies to all those matched in Ref. 7 yields an average deviation of −0.667 keV for 51 levels with a standard deviation of 3.58 keV. The larger standard deviation in the ^{177}Yb case is understandable in view of the much larger uncertainties in the adopted levels. We see two new low-lying levels, one at 715.4 keV, the higher member of a 9-keV doublet, and the other at 961.3 keV. We extracted the 715.4-keV state on the basis of the width and poor peak shape of the 706.1-keV particle group compared to nearby single states. Other new levels appear at 1625.9, 1690.4, 1725.3, 1899.0, 1936.3, 1957.3, and 1985.9 keV. The new level at 1849.9 keV may be a contaminant state in ^{175}Yb. The adopted 1104- and 1173-keV states which would correspond to our states at 1108.9 and 1168.0 keV should definitely be reduced to uncertain states if not removed from the adopted scheme entirely. There are several other new states above 2 MeV in excitation.

Distributions

We measured angular distributions with position sensitive gas proportional counters mounted at the focal surface of the spectrograph. The distributions covered an angular range of 20°–120° in 10° steps in the ^{176}Yb (d,t) ^{175}Yb reaction. An additional point was taken at 16°. We also obtained distributions for the ^{176}Yb (d,d_0) and ^{174}Yb (d,d_0) reactions to use both for normalizing cross sections and for determining parameters for use in DWBA calculations. We present the parameters used in all our calculations in Table III. We obtained deuteron parameters from the (d,d_0) distributions and triton parameters were obtained by adjusting the parameter set used in Ref. 1 for best fit of the 729.4-keV state. Shape dependence of the curves is very insensitive to the choice of parameters and the differences between the parameters in Table III and those in Ref. 1 are due mainly to the methods of choosing starting deuteron parameters and not indicative of any major difference in the physics of the reactions. We did not include finite range or nonlocal effects in the calculations. Figure 5 contains the results for the ^{176}Yb (d,t) distributions. We adjusted the magnitude of the best fit. Our fits are consistent with the assignments of the 104.1- and 557.0-keV state but we cannot fit the shape of the distribution for the 603.3-keV state with a single l transfer. The fits for several states with tentative assignments demanding $l=3$ transfers such as the 639.2-, 729.4-, 872.3-, and 1174.8-keV states are excellent, so that the 603.3-keV state seems to have an anomalously shaped distribution. The expected $l=6$ curves do not give good fits for the 522.2- and 1346.4-keV states. Although the shapes of the experimental distributions are in some ways similar to those of Song *et al.*[5] for $l=6$ transitions in ^{168}Er (d,t) ^{167}Er which they label as anom-

TABLE III. Optical model parameters.

	V	R_0	A_0	W	R_W	A_W	R_C
d	122.8	1.106	0.833	21.13	1.275	0.613	1.30
t	165.0	1.20	0.72	15.0	1.25	0.75	0.95
p	54.27	1.231	0.661	15	1.5	1.00	1.25

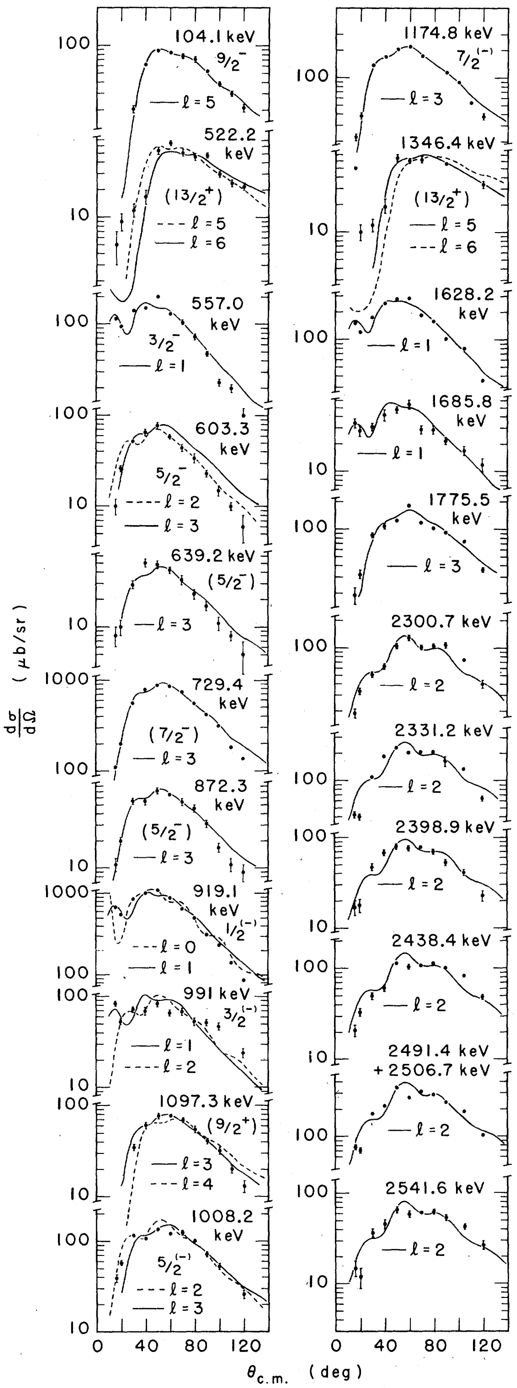

FIG. 5. Angular distributions of triton groups from the ^{176}Yb$(d,t)^{175}$Yb reaction at a deuteron energy of 14 MeV. The excitation energy of the state in ^{175}Yb is shown on each plot. Curves are the results of calculations with the code DWUCK for the l values shown. Adopted or tentative (in parentheses) J^{π} values are shown for some states.

alous, our fits at back angles are not so poor as to warrant a similar label. Only two of the anomalous states in Ref. 5 are members of bands for which we have corresponding levels. These are the $\frac{5}{2}^-$ member of the $\frac{1}{2}^-$ [521] band and the $\frac{9}{2}^-$ member of the $\frac{7}{2}^-$ [514] band. Our fits for the 104.1 keV, $\frac{9}{2}^-$ state in ^{175}Yb and the 492.0-keV, $\frac{5}{2}^-$ state in ^{173}Yb (Ref. 1) are quite good and show no signs of anomalous behavior. The 1008.2-keV state in ^{175}Yb is more confusing. If it corresponds to the 1009.386 keV, $\frac{5}{2}^{(-)}$ state which has been placed as the $\frac{5}{2}^-$ member of the $\frac{1}{2}^-$ [521] band, then the distribution is anomalous in that its shape is very close to an $l=2$ transfer, but if this $l=2$ fit is indicative of the true spin of our 1008.2-keV state then we have not populated the $\frac{5}{2}^-$ band member. This is further confused by the existence of another state at 1009.1 keV with a J^π of $(\frac{7}{2}^+)$, which we do not seem to populate. We therefore find no evidence that this anomalous behavior is connected with the band structures of these nuclei. Our $l=2$ fit for the 919.1-keV state supports the negative parity assignment. For the 991.0-keV state the evidence is not as strong although the 16° datapoint strongly favors the $l=1$ curve and hence the negative parity. For the 1097.3-keV state the $l=3$ fit appears superior to the $l=4$ curve in contradiction to its $(\frac{9}{2}^+)$ assignment. At higher excitations the states have no previous assignments so that definitive fits here will fix the parity of the states and limit the spin assignments to the $l\pm\frac{1}{2}$ values. The 1628.2- and 1685.8-keV states both show $l=1$ character while the 1775.5-keV state is well fit by $l=3$. The remaining states listed are those few strongly populated states amongst the very densely populated region above 2 MeV in excitation. Each of these distributions favor an $l=2$ fit. We present the results of these fits and the calculated spectroscopic factors in Table I where the preferred l fit, the reaction, and the spectroscopic factor for the appropriate J's are given in the 6th and 7th columns. The (d,t) spectroscopic factors are calculated as

$$S(J)=\frac{2J+1}{3.33}\,\frac{\sigma(\theta)_{\text{exp}}}{\sigma(\theta)_{\text{DWBA}}}\,.$$

We show ^{174}Yb (d,p) distributions and fits in Fig. 6 and the parameters in Table III. We used the same proton parameters for the two (d,p) reactions. The proton parameters were taken from Perey and Perey[12] for 19 MeV protons on ^{176}Yb and adjusted for best fit to the 557.0-keV state in ^{175}Yb and the 379.9-keV state in ^{177}Yb. Spin-orbit terms did not affect the shapes or significantly change the magnitudes of the calculated differential cross sections and consequently were omitted. The data cover the angular range from 15°–110° in 5° steps. The fits are consistent with the assigned and tentatively assigned spins for the 557.0-, 603.3-, 698.0-, 729.4-, and 872.3-keV states. The fits for the 811.7- and 957.4-keV states are not very good but do not contradict the assignments. The doublet at 1355.9 and 1367.4 keV is not resolved in the distribution measurements, but the fit suggests the $l=2$ member is dominant, in agreement with the $(\frac{5}{2}^+)$ assignment for the 1367.4-keV state. The $l=4$ fit for the 1424.9-keV state is reasonably good as is the $l=2$ fit to the 2234.2-keV state and the $l=3$ fit to the 2284.5-, 2300.7-keV doublet. Our state at 1461.1 keV appears to be a doublet and an $l=2$ fit is favored. This is consistent with the $(\frac{3}{2}^+)$ assignment for the state at 1468.87 keV although our energy measurements suggest the existence of a separate $l=2$ state at about 1461 keV with the 1468.87-keV state not populated in our reactions. The only anomalies in these distributions are the 2317.6- and 2630.1-keV states which we cannot fit with single-l curves. However, at this high excitation the possibility of more than one state contributing to the strength of a particle group is high. The (d,p) l values and spectroscopic factors are also given in Table I, with the factors calculated by

$$S(J)=\frac{1}{1.53}\,\frac{\sigma(\theta)_{\text{exp}}}{\sigma(\theta)_{\text{DWBA}}}\,.$$

The $S(J)$ tabulated does not contain the $(2J+1)$ weighting factor as calculated for $\sigma(\theta)$DWBA from the code DWUCK, hence these spectroscopic factors will vary for the two J's of a given l by the ratios of the $(2J+1)$ factors. The spectroscopic factors are presented as an indication of the relative strengths of these states. We chose the DWBA parameters to give the best shape fits to the data with little concern for matching absolute cross sections. We did compare the calculated cross sections and the experimental cross sections according to the methods in Ref. 10. These comparisons suggest our calculated (d,t) cross sections to be only 30% low but our calculated (d,p) cross sections fall a factor of 3 lower than the experimental data. Neither of these discrepencies are important to our analyses. The relative values of the spectroscopic factors should be accurate to within 10–20% for a given reaction.

We show the distributions for ^{176}Yb (d,p) in Fig. 7. The data are consistent with the assigned and tentatively assigned J values up through the 1221.3-keV state. The fit for the 1359.0-keV state, however, would favor $l=2$ rather than the $l=1$ necessary to conform to the $(\frac{3}{2}^-)$ assignment.

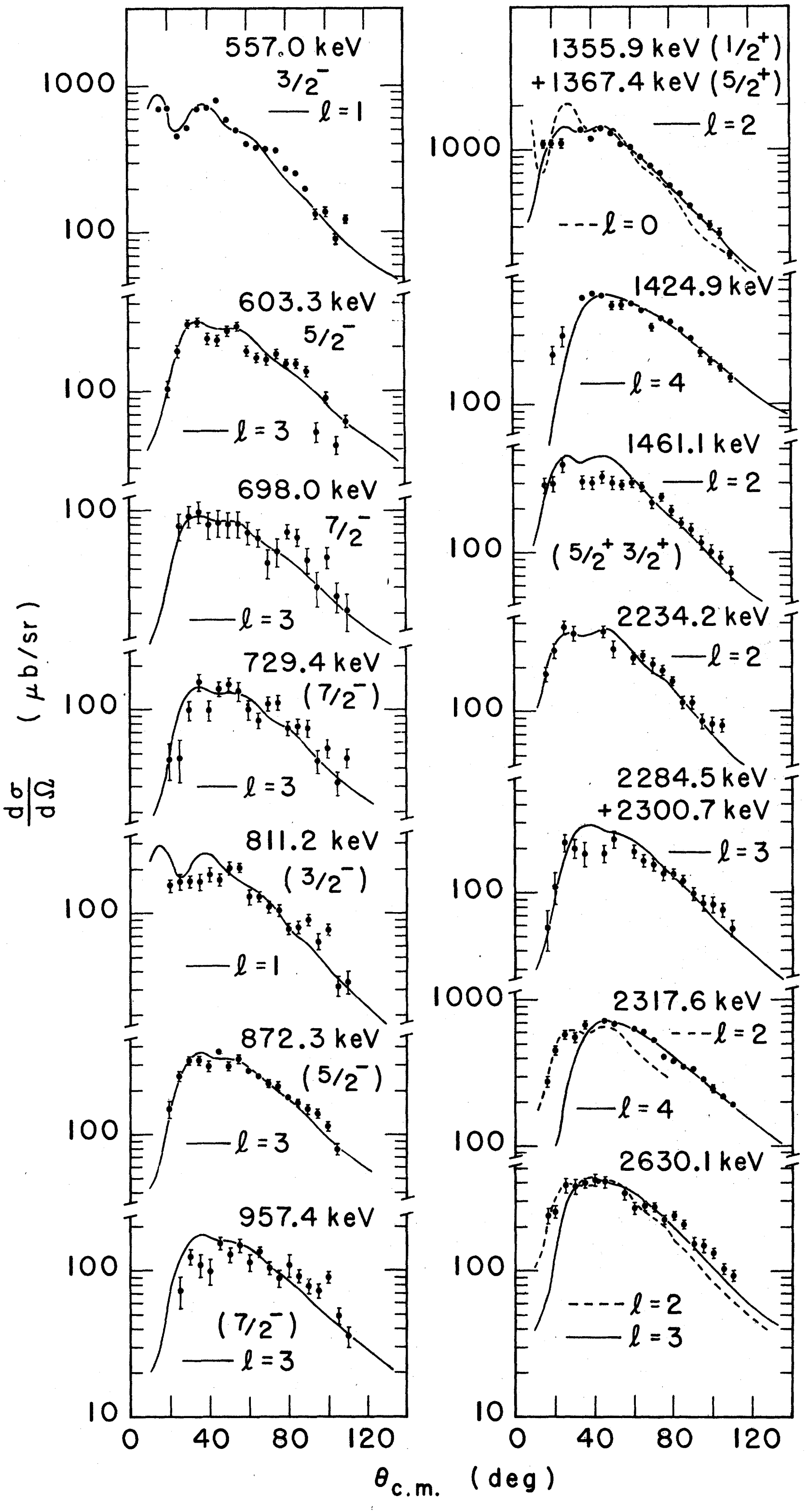

FIG. 6. Angular distributions of proton groups from the ^{174}Yb$(d,p)^{175}$Yb reaction at a deuteron energy of 14 MeV. The excitation energy of the state in ^{175}Yb is shown in each plot. Curves are the results of calculations with the code DWUCK for the l values shown. Probable J^{π} values are shown for some states.

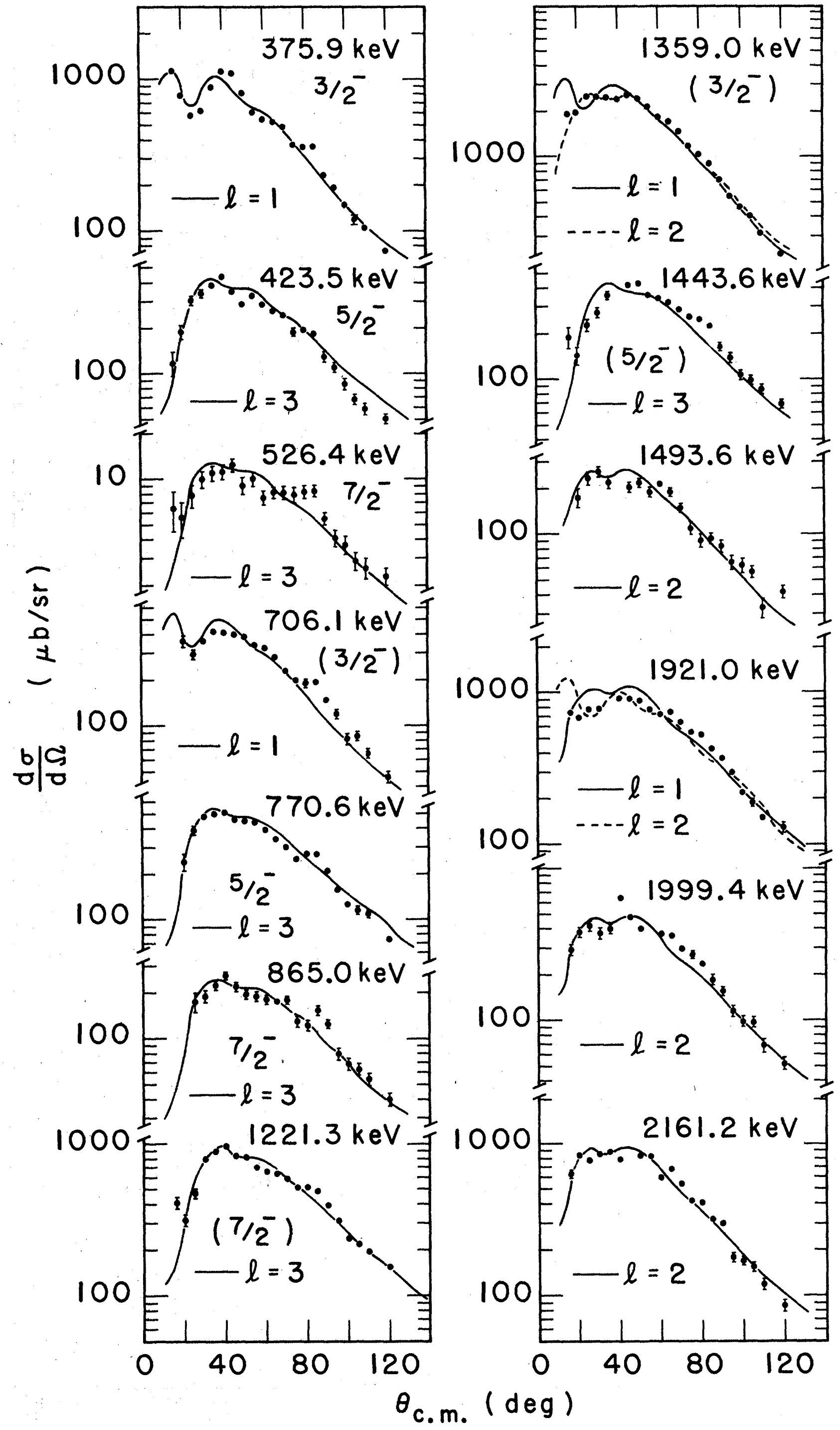

FIG. 7. Angular distributions of proton groups from the ^{176}Yb$(d,p)^{175}$Yb reaction at a deuteron energy of 14 MeV. The excitation energy of the state in ^{177}Yb is shown in each plot. Curves are the results of calculations with the code DWUCK for the l values shown. Probable J^{π} values are shown for some states.

This discrepancy is important in light of the assignment of this state as the bandhead for the $\frac{3}{2}^-$ (501) band; however, one must remember that there is always a possibility of a closely spaced doublet with one or the other member dominating in a given reaction. The previously unassigned states at 1493.6, 1999.4, and 2161.2 keV all favor $l=2$ fits but the strong state at 1921.0 keV cannot be fit with a single l value. Once again at this high an energy the reason for the failure to obtain a fit could easily be due to more than one state contributing to the strength of this proton group.

Band structure

We have deliberately analyzed the data in a manner that minimizes model dependence. In the following band analyses, for example, we use only the empirically determined band formula constants to predict energies and our l values as determined from the simplest possible DWBA analysis. While energy agreement alone is certainly not definitive evidence of band placement especially in high density regions, such agreement coupled with l values from DWBA and with positive identifications of all nearby states provides strong candidates for band assignments. This analysis is summarized in Fig. 8. We populate all the previously assigned members of the $\frac{7}{2}^-$ [514], $\frac{5}{2}^-$ [512], and the $\frac{1}{2}^-$ [510] bands with the exception of the $\frac{1}{2}^-$ member of the latter. The predicted yield for this state is very small. The l values we measure for states in these bands confirm the previous assignments; consequently we have omitted these three bands from Fig. 8. Levels are placed in this figure on the basis of energy only, the l values measured in this experiment then are criteria for further restrictions on placements. The first possible placement is that of our 676.1-keV state as the $\frac{15}{2}^+$ member of the $\frac{9}{2}^+$[624] band; however, it is unlikely that we could populate such a high spin state at these energies and our 676.1-keV state [seen only in the (d,t) reaction] is suspected of being a contaminant state in ^{173}Yb. We do have two reasonable placements in the $\frac{3}{2}^-$ [512] band with our 1073.3- and 1210.3-keV states matching well with the expected energies of the $\frac{9}{2}^-$ and $\frac{11}{2}^-$ members of this band. Such a placement would add further credence to our 1073.3-keV state which seems to be the higher member of a doublet seen in the (d,t) reaction. Both of these states are possible isotopic contaminant states but the yields of both appear too high for this. The favored fit for our state at 1008.2 keV has $l=2$ with $l=3$ giving a good fit behind 35°. An $l=3$ assignment would confirm the correspondence with the adopted 1009.386-keV state with $\frac{5}{2}^{(-)}$ spin. The $l=2$ assignment would suggest a $\frac{5}{2}^+$ assignment but would also remove this state from its $\frac{1}{2}^-$ [521] band placement. Together with the adopted 1009.1 $(\frac{7}{2}^+)$ and 1009.386 $\frac{5}{2}^{(-)}$ states there would then be three states at this energy, making this an incredibly complicated region of excitation. Our state at 1461.1 keV has a number of possible placements; as the $\frac{11}{2}^-$ member of the $\frac{1}{2}^-$ [521] band, the $\frac{7}{2}^+$ member of the $\frac{1}{2}^+$ [651] band, or it could be the $\frac{3}{2}^+$ member of that band measured to be 1468.87 keV in γ-ray work. Our distribution work suggests an $l=2$ assignment and hence the last placement; but because this state shows evidence of being a doublet two levels may be populated. The energy of our state appears too low to be the 1468.87-keV state and the width is such that the lower energy member of the doublet is most likely the 1456.3-keV state. This then suggests a third state at about 1461 keV with an $l=2$ character but not fitting into any of the adopted bands. The $\frac{7}{2}^+$ member of the $\frac{1}{2}^+$ [651] band has not been seen. The 1195.2-keV state fits both in the $\frac{7}{2}^+$ [633] band as the $\frac{11}{2}^+$ member and in the $\frac{3}{2}^+$ [?] band as the $\frac{7}{2}^+$ member with the latter placement prefered. This latter band provides possible placements for our 1290.0- and 1424.8-keV states as the $\frac{9}{2}^+$ and $\frac{11}{2}^+$ members, respectively, although we get an $l=4$ fit for the 1424.8-keV distribution. The $\frac{1}{2}^+$ [651] band also provides possible placements of our 1628.2-, 1861.1-, and 1604.2-keV states although our measured l for the 1628.2-keV state would eliminate its placement as the $\frac{7}{2}^+$ member of this band. Figure 8 points out just how complicated and confusing the structures of these nuclei are. The energy placements of states that are contradicted by direct l-value measurements suggest an even denser level population with some states either hidden in very close spaced doublets, or not populated at all in the (d,p) and (d,t) reactions. These same placements then suggest that more bands exist in this energy range.

The band analysis of ^{177}Yb is not very fruitful, due largely to the limitations of using a single selective reaction. The possible placements include the $\frac{11}{2}^-$ members of the $\frac{1}{2}^-$ [510] and $\frac{3}{2}^-$ [512] bands. The 770.6-keV state is already placed as the $\frac{5}{2}^-$ member in the $\frac{3}{2}^-$ [512] band, its distribution following an $l=3$ shape, and the 1108.9-keV state has a strong identification as a contaminant state from ^{175}Yb. There are three very weak placements in the $\frac{3}{2}^-$ [501] band. The likelihood of populating the $\frac{13}{2}^-$ state is very small. The energy disagreement with the $\frac{9}{2}^-$ and $\frac{11}{2}^-$ band members may be linked to the assignment of the 1359.0-keV state as the $\frac{3}{2}^-$ band head in light of

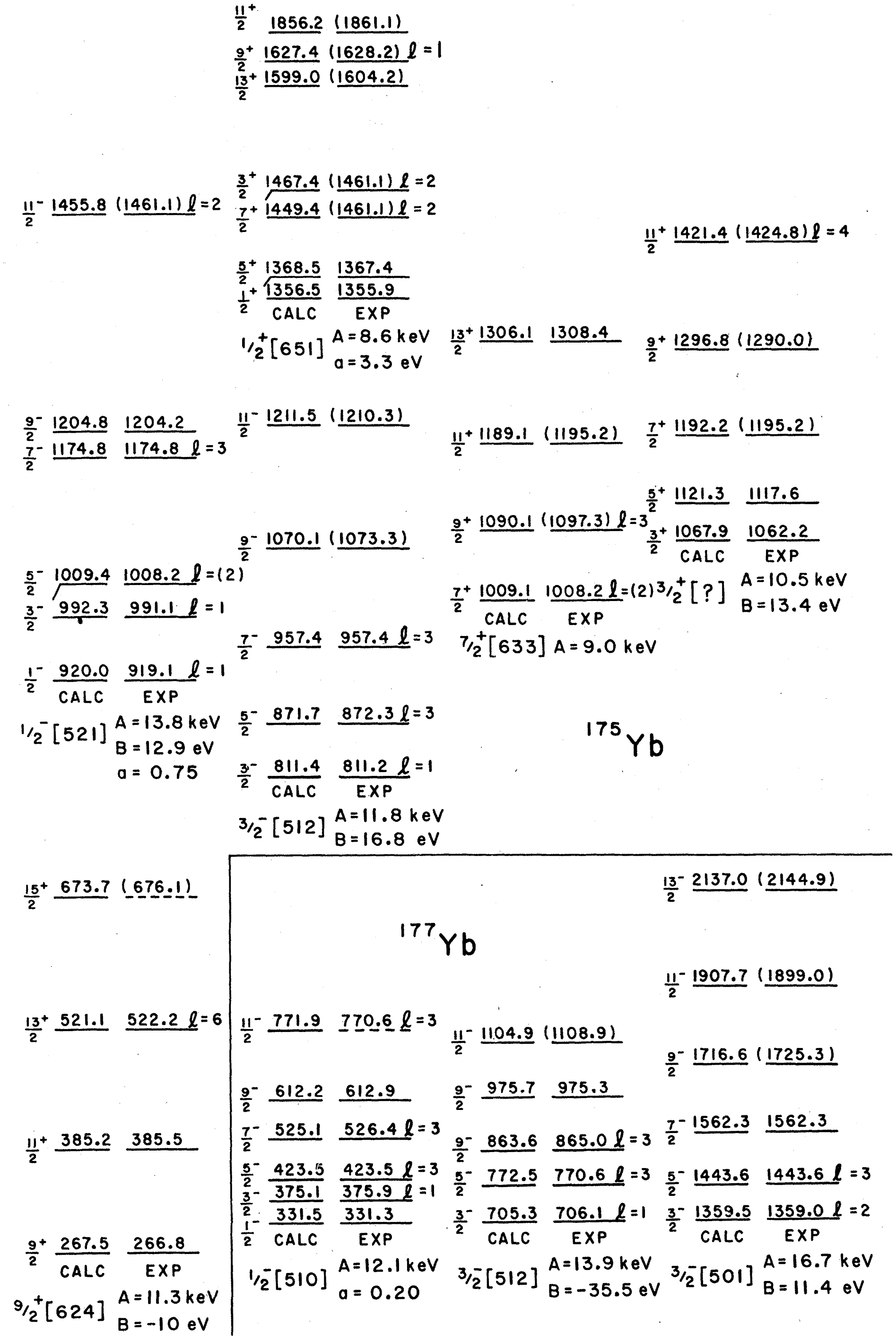

FIG. 8. Possible band structures for ^{175}Yb and ^{177}Yb. Energies are calculated from the band parameters shown according to the formula:

$$E_j = E_0 + A\,[J(J+1) + \delta_{K,1/2}(-1)^{J+1/2}a\,(J+1/2)] + BJ^2(J+1)^2.$$

Our experimentally determined levels are then matched by energy only. l values determined in this experiment are shown next to some experimental levels.

what appears to be a strong $l = 2$ fit for the distribution of this state. Several other low lying band members are not excited in the (d,p) reaction.

SUMMARY

We have measured excitation energies of 129 states in ^{175}Yb and 71 states in ^{177}Yb. Sixty-three of the states in ^{175}Yb and 19 of those in ^{177}Yb are previously unreported. A few of these new states may be attributable to isotopic contamination and are so identified. We analyzed the angular distributions of the three reactions we used with DWBA theory which proved adequate to extract l values for most of the states strong enough to yield statistically meaningful data. We find one definite case of an anomalously shaped distribution for a state of known spin and a few cases where our extracted l-value disagrees with previous but tentative assignments. Extension of the proposed band structures provides the possible placements of a few new levels and consequently suggests spin and parity assignments for these states. The revised level schemes can then be of value in interpreting other data already in the literature.

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