A STUDY OF THE DECAY LEVELS OF $^{169}Tm_{69}$

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The purpose of this investigation was to study the radiations of the ^{169}Tm nucleus as it de-excites after the electron capture decay of the ^{169}Yb. Numerous unreported gammas were present in the sample. The origins of these gamma rays were found.

An efficiency curve was determined for the Ge(Li) detector. This curve is to be used in later work on this subject. Seven contaminants were found. Two additions were made to the present decay scheme and one addition was strongly suggested pending work involving a higher resolution detector. The additions are gamma rays of energies 105.7 KeV, 228.9 KeV and 51 KeV.

It was suggested that exact intensity measurements of these new radiations be made. Also a purer sample should be obtained, possibly through ion exchange techniques.

A STUDY OF THE DECAY LEVELS OF $^{169}Tm_{69}$

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CHAPTER I

INTRODUCTION

$^{169}Yb_{70}$ decays to $^{169}Tm_{69}$ by electron capture. Electron capture is a process in which the nucleus captures an extranuclear electron. Normally the capture is made from the K or the L electronic shell. Capture from other shells is possible but much less probable due to their greater distance from the nucleus. The captured electron combines with a proton, forming a neutron. Thus the atomic number of the nucleus is diminished by one. The equation for this decay can be written as

$$^{169}Yb_{70} + {}^{0}e_{-1} \rightarrow {}^{169}Tm_{69} + \gamma$$

Since the electronic configuration of the atom is left in an unstable state, x-rays are given off by the electrons as they cascade down to fill the vacancy left by the captured electron. Thulium has K_{α} radiations of 50.7 and 49.8 KeV and K_{β} radiations of 57.6 and 59.0 KeV.[1] The disintegration energy of the capture reaction is given by the equation

$$Q = [M(Z) - M(Z-1)]c^2$$

where M(Z) is the parent nucleus and M(Z-1) is the daughter nucleus. The Q value for this reaction is estimated to be 1.2 MeV.[2]

The $^{169}Tm_{70}$ nucleus is left in one of four excited states. Twelve percent of the decays go to the .47283 MeV energy level.[3] Less than .14 percent of the decays are to the .4334 MeV level, while the .37922 MeV and the .31610 MeV energy levels receive 84[5] and 4[6] percent of the decays respectively. This decay scheme is shown in Figure 1.

Diamond, Elback, and Stephens[7] have studied coulomb excitation of $^{169}Tm_{69}$. They used O^{16} ions rather than protons or alpha particles for their excitation. Their reasoning behind this procedure was that since the excitation probability is increased when using the heavier ions, observation of higher energy levels, levels connected with the ground state by small transition moments, and multiple excitations would be made possible. Information was obtained on the ground and 570 KeV bands. The 570 band was assigned an even parity and a spin of 3/2. They also concluded that transitions from this band were magnetic dipole in nature.

In 1962, Alexander and Boehm[8] reported transitions of 117.25 KeV, 156.66 KeV, and 336.5 KeV in the gamma ray energy spectrum of $^{169}Tm_{69}$. They assigned the ground state band a spin of 1/2. Three excited states were found. Bands based on a K = 7/2- state at 379.31 KeV and on a K = 7/2+ state at 316.19 KeV were also found. The three new transitions had intensities of .108, .024, and .017 relative to the intensity of the 197.97 KeV line.

Mihelich, Ward, and Jacob[9] have obtained much data on the conversion electron spectrum. Data on fifty conversion lines were taken supporting the decay scheme of Figure 1. The existence of two meta-stable levels of 4.5×10^{-8} second and 4×10^{-7} second half-lives was shown. The same multipole assignments as before were made.

Hatch, Boehm, Marmier and DuMond[10] arrived at the same results using a semi-circular beta-ray spectrometer. Their reported energy values differed slightly, but they assigned the same spins and multipolarities.

Alexander and Boehm suggested that further study of the gamma-ray transitions of $^{169}Tm_{69}$ should be undertaken. This study is the object of this investigation. Upon observing the thulium spectrum a number of new gamma lines were found. A search of the literature revealed that no gamma rays above 307 KeV had been reported. The half-lives of these newly found emissions were measured to see if they belonged to the 32 day half-life state or possibly belonged to an isomeric state. The gamma rays were inspected to determine possible contaminants in the sample. The resulting gammas were compared with the transition energies between the existing states of $^{169}Tm_{69}$. This comparison led to an investigation of the low energy end of the spectrum. Other additions to the decay scheme are proposed as a result of this study. Finally, recommendations on further work concerning this decay scheme are made.

CHAPTER II

EXPERIMENTAL TECHNIQUE AND ANALYSIS

A $^{169}Yb_{70}$ source was obtained from New England Nuclear. The source is in liquid form with Yb_2Cl_3 in a HCl solution. The sample was produced by activating $^{168}Yb_{70}$ in a reactor via neutron capture. When $^{168}Yb_{70}$ is bombarded by thermal neutrons, i.e. neutrons with velocity corresponding to an energy of 0.026 eV,[11] the Ytterbium nucleus absorbs the neutron and emits gamma radiation. The source is dated 11-17-69, which means approximately ten months passed after activation before these measurements were taken.

Immediately after production the samples activity was found to be 2 mc. A curie is defined to be 3.7×10^{10} disintegrations per second.[12] The rate of decay of a radioactive element is given by

$$-\frac{dN}{dt} = \lambda N_o e^{-\lambda t} .$$

N_o is the original number of active atoms; λ is the decay constant, and is related to the half-life of the element by the equation

$$t_{1/2} = \frac{.693}{\lambda} .$$

Thus λN_o gives the rate of decay at time t = 0. This value we know to be 2 mc. If we assume the time lapse between the activation and the measurement to be ten half-lives or 320 days, we can estimate the present rate of decay to be given by

$$-\frac{dN}{dt} = (2 \times 10^{-3} \text{curies})\ e^{-6.93}$$

or

$$-\frac{dN}{dt} = (2 \times 10^{-3} \text{curies})(1000)^{-1} = 2 \times 10^{-6} \text{ curies.}$$

New England Nuclear obtained the $^{168}Yb_{70}$ from Oak Ridge National Laboratory. Table 1 gives a spectroscopic analysis of the impurities and their percentages. These impurities were verified by a New England Nuclear representative.[13]

The detection apparatus consisted of a Canberra lithium drifted germanium detector, a Canberra Model 1408C spectroscopic preamplifier, a Tennelec TC-200 linear amplifier, an Ortec 408 modular biased amplifier, a Nuclear Data 1024 channel analyzer, and a Nuclear Data model ND2200 4096 channel analyzer. The detector is a right circular cylinder with a diameter of 32.5 mm. It is drifted coaxially with a conic p-core which has end diameters of 5 and 2 mm. The detector is mounted so that the smaller end of the core is facing the window. There is a 5 mm gap between the detector and the window of the cryostat. Canberra Industries determined the resolution of the detector at 122 KeV, 662 KeV, 1332 KeV,

2614 KeV to be 1.6 KeV, 2.0 KeV, 2.4 KeV, and 3.1 KeV respectively. The resolution is given in terms of full width at half maximum, using ^{57}CO, ^{137}CS, ^{60}Co, and ^{228}Th to supply the above gamma lines.[14]

Before any work was begun, an efficiency curve was determined. Fourteen well known gammas ranging from 53.2 KeV to 383.9 KeV were used in this calibration (Table 2). The major lines from Barium-133 and Ytterium-168 were used in the efficiency curve of Figure 2. The detector's relative efficiency at a particular energy was found by dividing the measured intensity of the peak by the reference intensity. The work of Donnelly, Reidy and Wiedenbeck was used as the barium reference.[15] The results of Alexander and Boehm were used for the Ytterbium lines. This efficiency curve is a relative curve. It is necessary to obtain a standard reference source to obtain the true efficiency. This has not been done at present since an absolute efficiency was not required for this work.

The next step in the experiment was to obtain a good energy calibration. ^{133}Ba, ^{125}Sb, and ^{110}Ag sources were used in the energy calibration. The energies of the prominent gammas in the above sources are well known and were extracted for most part from the Berkeley Table of Isotopes. Certain exceptions will be mentioned later.

The normal procedure followed was to take a calibration spectrum, background spectrum, and then the ytterbium spectrum. The order of the last two spectra was sometimes reversed.

After collecting the data in the analyzer, it was either punched out on IBM cards, as in the case of the Nuclear Data 1024 channel analyzer; or it was printed out on paper tape as in the case of the 4096 channel analyzer. Processing the data was much more convenient when using the 1024 analyzer because the data was analyzed by computer instead of by hand.

Spectra analysis was done using a program called Sampo. Sampo was written by J. T. Routti and S. G. Prussin.[16] The program is on disk at the North Texas State University Computing Center for use on the IBM 360/50 system. Ronald L. White has written a user's manual entitled IBM 360 SAMPO Manual, explaining how the program is used. The user must supply clean photopeaks from which the program can deduce a functional form of the peak shapes. Calibration data must also be supplied. If desired, efficiency data may be fed in and the program will fit the data to an efficiency curve of the form

$$Eff = C_1 E^{C_2} + C_3 e^{C_4 E}$$

where C_1, C_2, C_3 and C_4 are parameters determined in the program. The functions of the program used in analyzing data for this project were datagraph, peakfind, fitdo and fittest.

These terms are fairly self-explanatory. The function datagraph plots the number of counts versus the channel numbers. Peakfind searches the data for peaks which meet the specified shape parameters. Fitdo takes each peak and fits it with a gaussian distribution and exponential tails. Finally, fittest determines and prints the peaks and their fitting intervals.

Figure 3 is an example of the gamma ray energy spectrum which led to this investigation. It shows numerous peaks above the 300 KeV range. In order to determine whether or not these peaks belonged to $^{169}Yb_{70}$, half-life measurements were made. Due to the great number of peaks, some expedient method of determining the half-life was needed. Since the source has a half-life of 32 days, it would take a great amount of time to measure the peaks separately or it would incapacitate the large amount of equipment needed to study each peak for at least the 32 day half-life. The most expedient method seemed to be to use the 1024 channel analyzer and to let the Sampo program analyze the data. The source was placed in the bottom half of the styrofoam shipping container, which in turn was mounted to the front face of the cryostat. This assembly was left undisturbed throughout the course of the measurement so as not to affect the detector-sample geometry.

Each day for 16 days the sample was counted for a period of 80 minutes. The spectra were taken at 9:40 AM each day.

After the 80-minute collection period, the data was punched out on computer cards and fed into Sampo. Table 3 gives a listing of the pertinent data obtained from one such run. The peaks range in energy from 318.9 KeV to 1089 KeV. The last peak and possibly the last two are not accurate and were ignored due to the pulse pile-up in the analyzer. After each run and Sampo analysis the peaks were compared with the corresponding peaks from the previous run. Their shapes, fits and continuums were checked to see that they did not vary drastically with those of the earlier runs. A drift in the electronics caused the peaks to be shifted upward in energy by approximately 4 KeV in the Sampo output over the period of the measurements. The intensity of each peak was recorded and plotted against time. Figure 4 is the half-life plot for the 723 KeV gamma ray. This plot is typical of all of the high energy gammas. The data shows an extremely long half-life. This result eliminates the possibility of having an addition to the high energy band of the decay scheme for the thirty-two-day half-life state.

The problem that now arises is what is the source of the high energy gammas. There are two possible suggestions. First, the gammas might be from an extremely long-lived isomeric state of ytterbium. Isomers are nuclei which have the same mass number and the same atomic number but differ in energy content.[18] Secondly, the gammas could be due to the

impurities in the sample. The first suggestion can be ignored on the grounds that the gamma rays under consideration do not fit the proposed level structure to any extent. If an isomeric state existed there would be some correlation between known transition energies and observed gamma energies.

In order to determine whether or not the gammas originated in the contaminates, a very careful energy calibration was made of the spectrum. The 4096-channel Nuclear Data Analyzer was used. Barium-133, Antimony-125, and Silver-110 were used to calibrate the analyzer giving thirty-two calibration points over a 1000 KeV energy range. Figure 5 is the channel-versus-energy calibration plot. Linearity of the amplifier is shown by this plot. It was assumed that the resulting line could be extrapolated for a few hundred KeV. In addition to the calibration plot a mathematical equation for the channel-versus-energy curve was calculated. A subroutine involving least squares curve fitting was obtained from the North Texas State Computing Center. This program, utilizing the calibration data, arrived at the equation

$$y = .262586x + 18.0711$$

where y is the energy corresponding to the x^{th} channel. This value was accepted because the coefficient of the x^2 term in the expansion was $-.250287 \times 10^{-6}$. The assumption that the system is linear is quite justified.

The ytterbium spectrum possessed forty-two peaks. The peaks ranged from 84.7 KeV to 1087.4 KeV. These peaks are listed in Table 4. A background count revealed no substantial peaks in the range of interest. The next problem involved was sorting out the contaminants. According to Figure 1, the 8.4 KeV, 20.7 KeV, 63.1 KeV, 94.1 KeV, 110.1 KeV, 118.6 KeV, 130.8 KeV, 117.4 KeV, 198.2 KeV, 261.0 KeV and the 308.0 KeV are the well known gamma lines from $^{169}Yb_{70}$. In order for an element to be a contaminant it had to meet several requirements. The first requirement was that the element decay yielding the proper energy gamma lines. The Nuclear Data Tables give lists of gamma energies and possible elements which produce these gammas. Also tabulated are the half-lives of the elements. A second requirement is that the contaminant be long-lived. This was determined by the half-life measurements. Thirdly, a number of possible contaminants were discarded because their formation must have been due to thermal neutron bombardment. Also the elements cross-section must be sufficiently large to yield a detectable quantity of active atoms. As a final requirement, the gammas from a suspected contaminant must be present in the approximate intensity ratios per its decay scheme. For example, consider the 98.03 KeV gamma line. The Nuclear Data Tables list a 98 KeV gamma present in $^{231}Th_{90}$.[19] Thorium fails to meet two requirements of the contaminants. It has a lifetime

of 25.6 hours, which is too small to consider, and it can not be produced by an (n, γ) reaction. A 123.0 KeV gamma line is present in $^{154}Eu_{63}$.[20] Europium passes the test for contaminants since it has a sixteen year lifetime, can be produced from Europium-153, and along with other gammas approximates the appropriate intensity ratios. A cross-reference of the Nuclear Data Tables and the Table of Isotopes yielded the following results. Europium-154, whose decay scheme is given in Figure 6, decays to $^{154}Gd_{64}$ by β^- emission producing an intense 123.3 KeV gamma line.[21] Europium also contributes gammas of energies 248.1 KeV, 444.7 KeV, 592.2 KeV, 692.9 KeV, 724.1 KeV, 757.8 KeV, 874.5 KeV, 904.4 KeV, 997.8 KeV and 1006.4 KeV.[22] The Nuclear Data Tables show a 216 KeV gamma attributed to terbium-160, which has a 72.3-day half-life.[23] Figure 7 is the accepted decay scheme for terbium. The cross-reference in the Berkley tables shows that $^{160}Tb_{65}$ is also responsible for the 298.9 KeV, 880 KeV, and the 967 KeV peaks.[24] Cesium-134, which has a half-life of 2 years, shows a 569.0 KeV gamma ray.[25] From Figure 8 one can see that the $^{134}Cs_{55}$ also provides gammas of 605 KeV, 662 KeV, and 796 KeV.[26] The 84.0 KeV peak could be attributed to either thulium-170 or terbium-160.[27] Figure 9 is the decay scheme for thulium. There are two peaks which lie extremely close to 511 KeV. They are 510.99 KeV and 512.2 KeV. These peaks are discarded as being annihilation radiation. A strong 229-KeV line is produced by tantalum-182, as shown in

Figure 10.[28] $^{182}Ta_{73}$ also produces a 780-KeV gamma line.[29] Figure 11 shows the decay of $^{152}Eu_{63}$, which provides the 344-KeV and the 1087-KeV line entries.[30] Finally, Figure 12 shows a strong 98-KeV line present in gadolinium.[31] The 378-KeV and the 516 entries in the gamma listing of Table 4 are small and essentially undefinable due to their broad peak shapes.

The procedure detailed above eliminated all except two of the forty-two gamma rays in that energy region. The two remaining gammas have energies of 105.7 KeV and 228.9 KeV. A comparison of these energies with the energy differences of the levels of $^{169}Tm_{69}$ shows that the 105.7 KeV is a transition between 472.8 KeV and the 368 KeV levels and that the 228.9 KeV gamma is a transition between the 368 KeV level and the 138.9 KeV level. Neither of these transitions has previously been reported. In addition, there has been no mention of a transition into or out of the 368 KeV energy level.

Observation of the two new transitions prompted a study of the low energy end of the ytterbium spectrum. An attempt was made to locate other transitions about the 368 KeV level. Figure 13 shows the low energy spectrum. There is a significant peak at 51 KeV, which possibly represents a transition between the 368 KeV and the 316.1 KeV levels. Thulium is listed as having an x-ray at 50.4 KeV.[32] These peaks are unresolvable and merit further study.

The 105.7 KeV gamma represents a transition from a 9/2- state to a 11/2+ state, which may be catagorized as electric dipole in nature. The 228.9 KeV radiation is a transition from a 11/2+ to a 7/2+ state, which would be E2 radiation. The 51 KeV gamma represents a transition from a 11/2+ to a 7/2+ state. This is an M2 radiation. Relative intensity calculations gave an intensity of 39.8 for the 105 KeV gamma and 2.5 for the intensity of the 228 KeV gamma relative to the 197 KeV gamma line. The measurements are relative to the data obtained by Alexander and Boehm. Other intensity measurements are impossible due to the lack of detector resolution. The preceding measurements have a 25% accuracy. No electron conversion lines have been reported at these energies.

There are numerous other peaks in Figure 13 which need to be explained. The 84 KeV peak is resolved into two peaks. One has an energy of 84 KeV and the other has an energy of 86.2 KeV. The 84 KeV line is attributed to thulium-170, while the 86.2 KeV is from the decay of terbium-160. The double peak of approximately 57.3 KeV and 59 KeV is formed due to x-rays of thulium. X-rays from samarium, europium, and thulium make up the double peak at 50.5 KeV. Europium"s K_{α} x-ray is responsible for the peak at approximately 42 KeV. Lastly, the K_{α} x-ray of samarium yields the 40 KeV peak.

Figure 14 shows the decay scheme of $^{169}Yb_{70}$ modified to include the newly found and proposed gamma rays.

CHAPTER III

CONCLUSION

This study has shown the existence of two gamma rays which have not been previously reported. A 105.7 KeV gamma represents a transition between the 427.8 KeV and the 368 KeV energy levels. A 228.9 KeV gamma ray represents a transition between the 368 KeV and the 138.9 KeV energy levels. In addition, evidence has been found supporting the possible existence of a 51 KeV gamma ray which would correspond to a transition from the 368 KeV energy level to the 316.1 KeV level.

Investigation of other ways for the 368 KeV level to de-excite should be made. One should look for a 36 KeV transition either with a gamma ray spectrometer or possibly as weak lines in a conversion electron spectrum.

Exact intensity measurements need to be made to verify these findings. To do this it is necessary to obtain a standard reference source and determine the absolute efficiency of the detector.

A purer sample should be obtained and studied. Activation of Yb-168 by thermal neutron bombardment is possible by using the 2.5 MV Van de Graaff accelerator located in the Regional Nuclear Physics Laboratory at North Texas State

University. The sample used in this experiment could be refined using ion exchange techniques. Information on this subject may be obtained in a book entitled Ion Exchange, which is distributed by the Dow Chemical Corporation.

Lastly, it is suggested that a study of the low-energy end of the spectrum be made with a detector which has a higher resolution. Resolving the multiple peaks might lead to further findings. It is possible that in the future a silicon detector with a resolution of 200 eV will be available for use.

APPENDIX A

TABLE I

ANALYSIS OF TARGET MATERIAL

Isotopic Analysis		
Isotope	Percent	Precision
168	22.50	±0.2
170	6.20	±0.1
171	17.20	±0.1
172	19.50	±0.1
173	11.20	±0.1
174	18.10	±0.1
176	5.30	±0.1

Rare Earth Analysis			
Y	< .005%	GD	< .02%
LA	< .02%	TB	< .05%
CE	< .2%	DY	< .1%
PR	< .05%	HO	< .02%
ND	< .05%	ER	< .3%
SM	< .05%	TM	< .05%
EU	< .005%	LU	< .007%

TABLE I--Continued

Spectrographic Analysis	
AG < .01%	MG < .01%
AL < .05%	MN < .02%
B < .01%	MO < .02%
BA < .01%	NA < .01%
BE < .001%	NI < .05%
BI < .02%	PB < .02%
CB < .05%	PT < .05%
CD < .05%	RB < .02%
CO < .05%	SB < .05%
CR < .05%	SI < .01%
CS < .05%	SN < .02%
CU < .01%	SR < .01%
FE < .02%	TI < .01%
GE < .05%	V < .02%
HG < .05%	W < .05%
K < .01%	ZN < .2%
LI < .005%	ZR < .05%

TABLE II

Efficiency Calibration Data

Energy (KeV)	Intensity (measured)	Intensity (relative)	Efficiency (relative)
Yb-169			
61.267	104.7	121.	86.529
92.501	9.007	7.2	125.083
108.995	60.405	50.	120.810
130.096	41.190	31.	132.870
177.534	69.068	62.	111.400
198.532	100.	100.	100.
308.791	20.577	28.	73.489
Ba-133			
53.2	3.523	3.16	111.487
81.0	84.14	52.0	161.808
223.2	1.150	.72	159.583
276.4	13.770	11.62	118.502
302.9	33.627	29.4	114.377
356.0	100.	100.	100.
383.9	13.75	14.3	96.154

TABLE III

Sampo Analysis

Channel	Energy (KeV)	Energy Error	Intensity
55.135	332.935	0.146	2.5451D 03
65.387	331.312	0.057	5.3957D 03
86.041	348.189	0.002	4.7780D 04
95.448	355.876	0.152	2.1247D 03
114.800	371.567	0.140	1.9814D 03
128.056	382.652	0.031	7.3862D 03
144.991	396.071	0.056	2.2372D 03
156.192	404.814	0.066	1.5702D 03
169.888	415.506	0.387	2.9845D 03
177.664	421.576	0.130	3.0293D 03
209.911	448.173	0.021	7.5142D 03
252.618	481.436	0.116	1.0995D 03
294.794	514.967	0.312	1.1019D 03
353.180	561.396	0.085	1.3782D 03
360.279	567.030	0.032	3.3622D 03
367.775	572.990	0.015	5.0936D 03
383.958	585.856	0.005	5.2045D 03
396.177	595.570	0.007	2.5072D 04
412.450	608.424	0.002	3.0565D 04
438.311	629.339	0.013	1.9480D 03
484.347	666.005	0.004	5.9743D 03
523.033	696.421	0.009	6.0530D 03
562.034	727.425	0.003	8.0666D 04
604.176	760.871	0.392	1.6437D 04
614.917	769.449	0.015	8.9403D 02
632.019	783.146	0.003	8.0475D 03
653.322	800.208	0.134	1.9343D 04
660.794	806.193	0.007	1.3725D 03
677.985	819.946	0.040	1.7767D 03

TABLE III--Continued

Channel	Energy (KeV)	Energy Error	Intensity
715.738	849.937	0.054	1.8850D 03
743.262	871.802	0.093	1.7962D 03
750.457	877.519	0.008	3.8697D 04
758.255	883.713	0.018	1.2987D 04
774.890	897.013	0.141	1.3369D 03
789.173	908.436	0.044	2.8094D 03
904.489	1000.667	0.020	2.9808D 04
915.036	1009.103	0.016	5.1602D 04
974.592	1056.736	0.096	9.3942D 02
987.245	1066.856	0.094	8.9249D 03
995.326	1073.319	0.039	1.5261D 04
1008.141	1083.569	0.087	1.2771D 05
1013.188	1087.606	0.226	3.1804D 04

TABLE IV

Gamma Ray Location and Energy

Channel	Energy (KeV)
253.4	84.68
289.2	94.09
304.2	98.03
333.3	105.68
350.	110.07
382.4	118.59
400.4	123.32
429.	130.84
606.	177.36
685.2	198.18
724.5	208.51
749.	214.95
802.	228.88
875.	248.07
924.2	261.01
1068.4	298.91
1102.8	307.95
1241.4	344.39
1370.2	378.24
1623.1	444.72
1635.	447.72
1875.2	510.99
1880.	512.25
1896.	516.45
2099.	569.81
2148.	582.69

TABLE IV--Continued

Channel	Energy (KeV)
2184.	592.16
2234.2	605.35
2449.2	661.87
2452.2	662.66
2567.4	692.94
2686.	724.11
2814.	757.76
2897.5	779.71
2962.	796.66
3258.	874.47
3282.	880.78
3372.	904.44
3611.	967.26
3727.	997.75
3760.	1006.42
4068.	1087.39

APPENDIX B

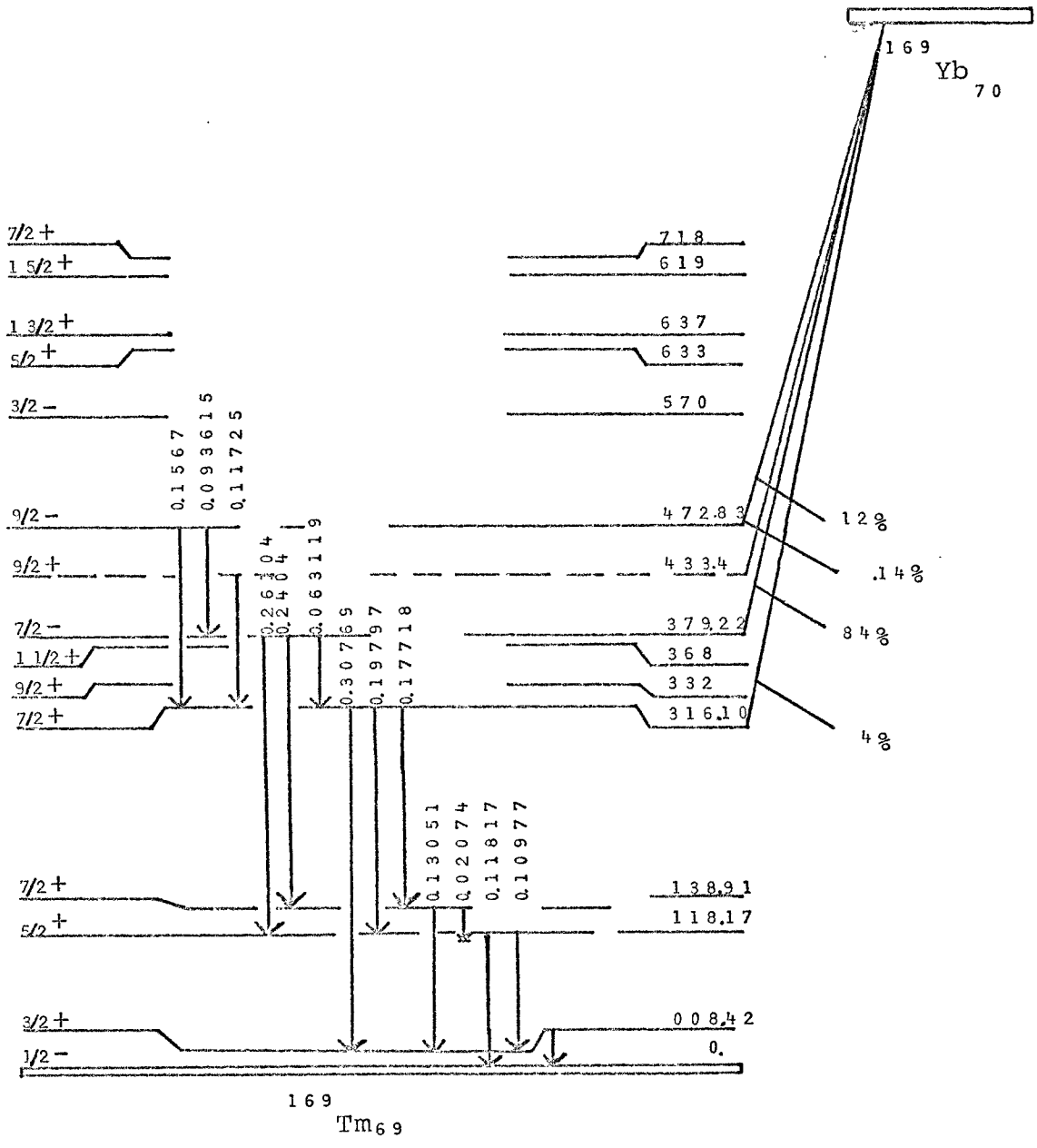

Fig. 1--Decay Scheme for ^{169}Yb

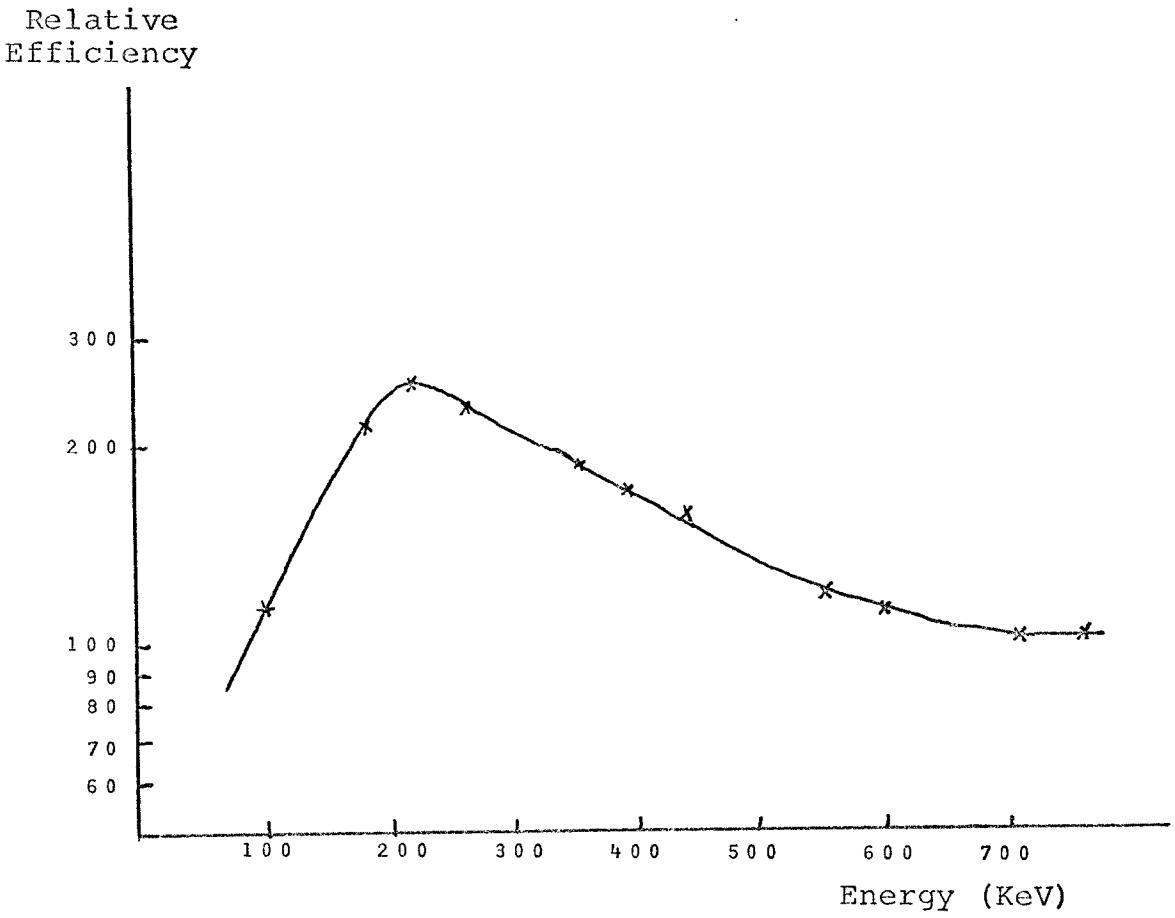

Fig. 2--Relative Efficiency Curve

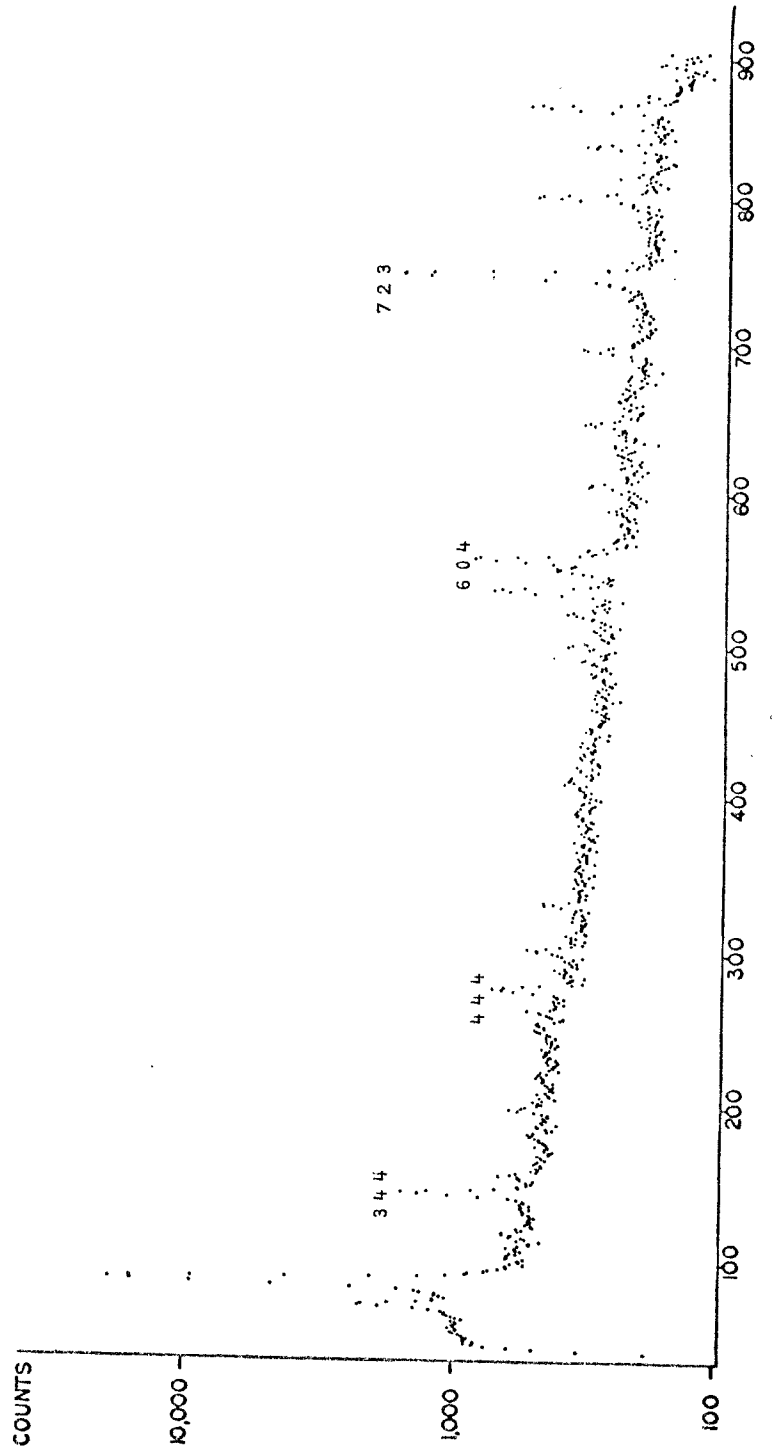

Fig. 3--High Energy Spectrum of ^{169}Yb

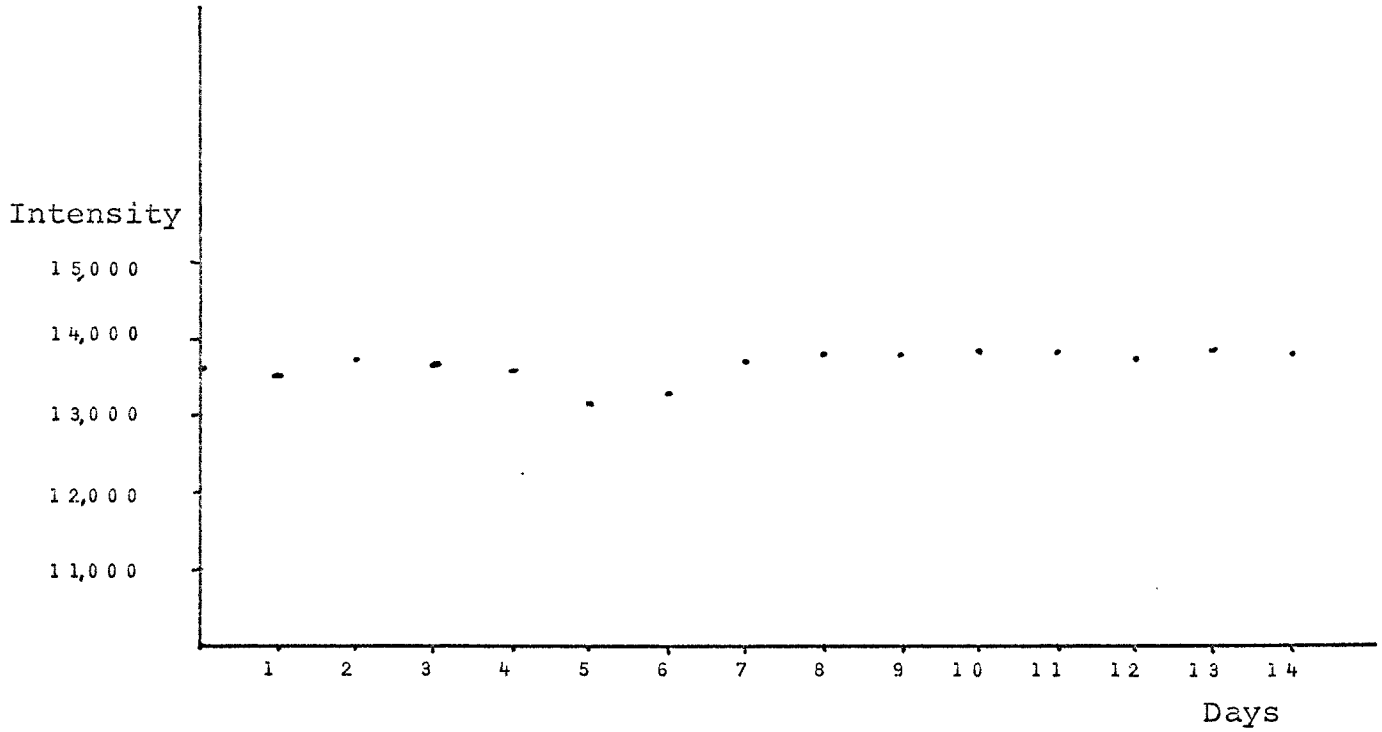

Fig. 4--Half-life Plot of High Energy Gammas

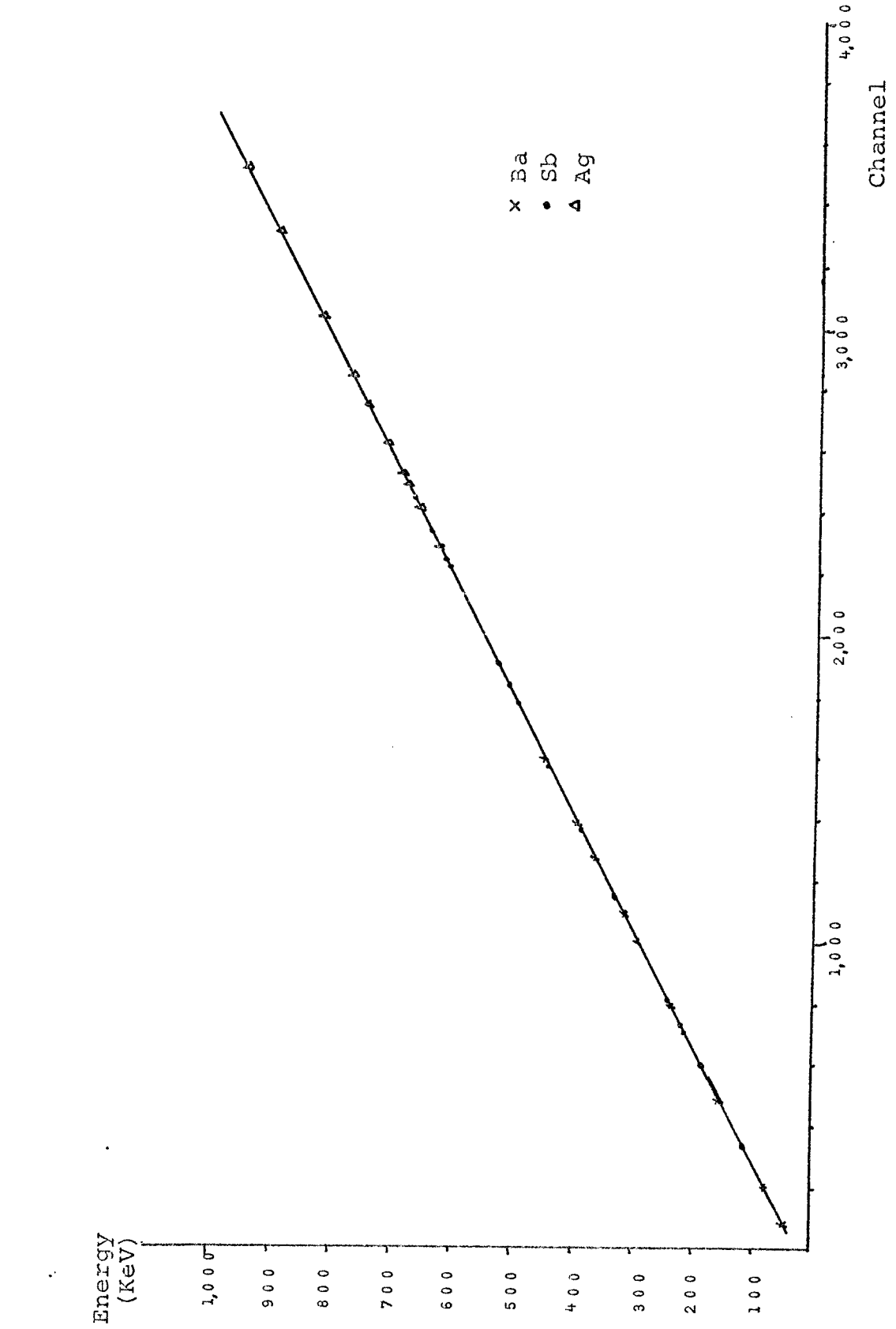

Fig. 5--Energy Calibration Plot

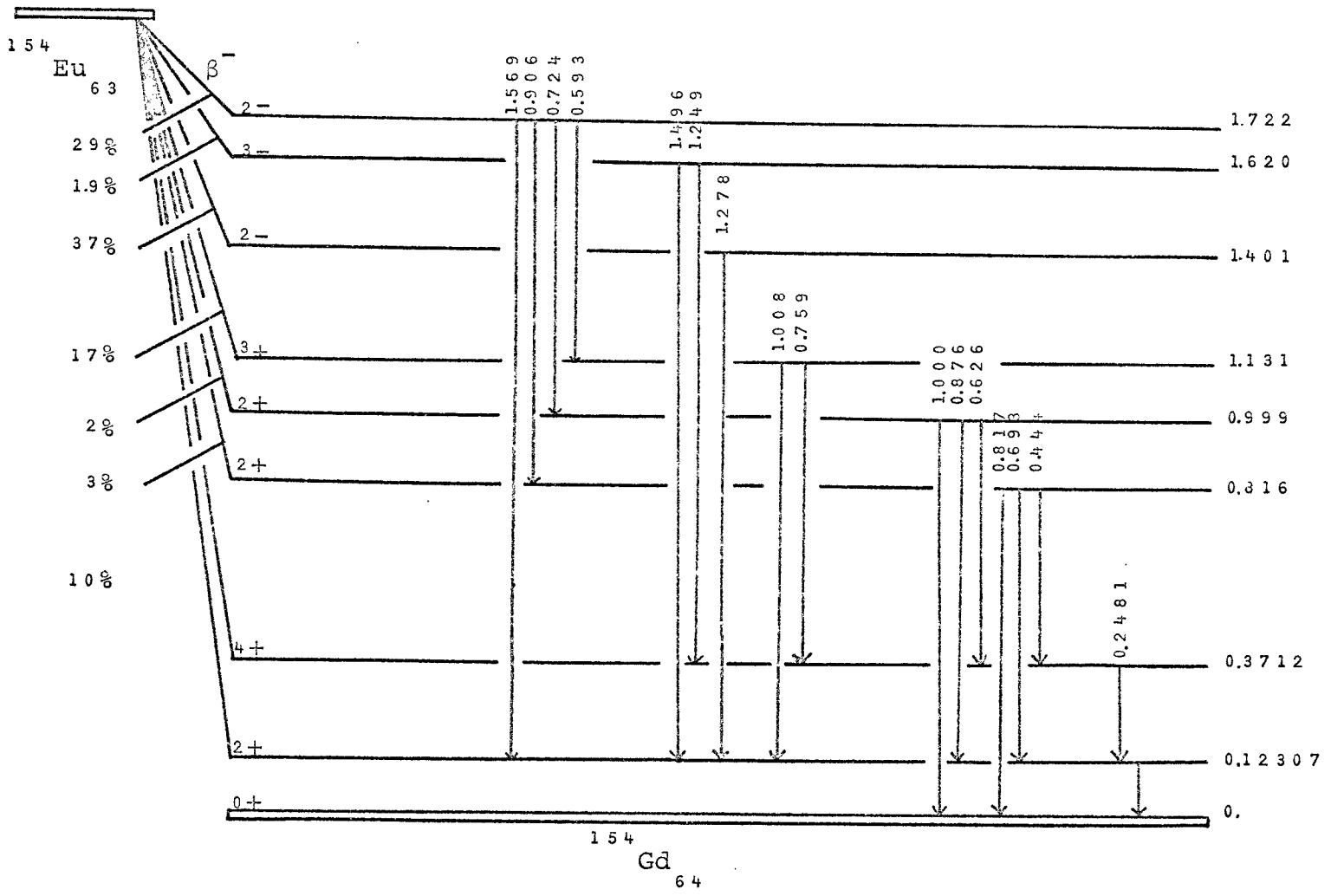

Fig. 6--Decay Scheme for ^{154}Eu

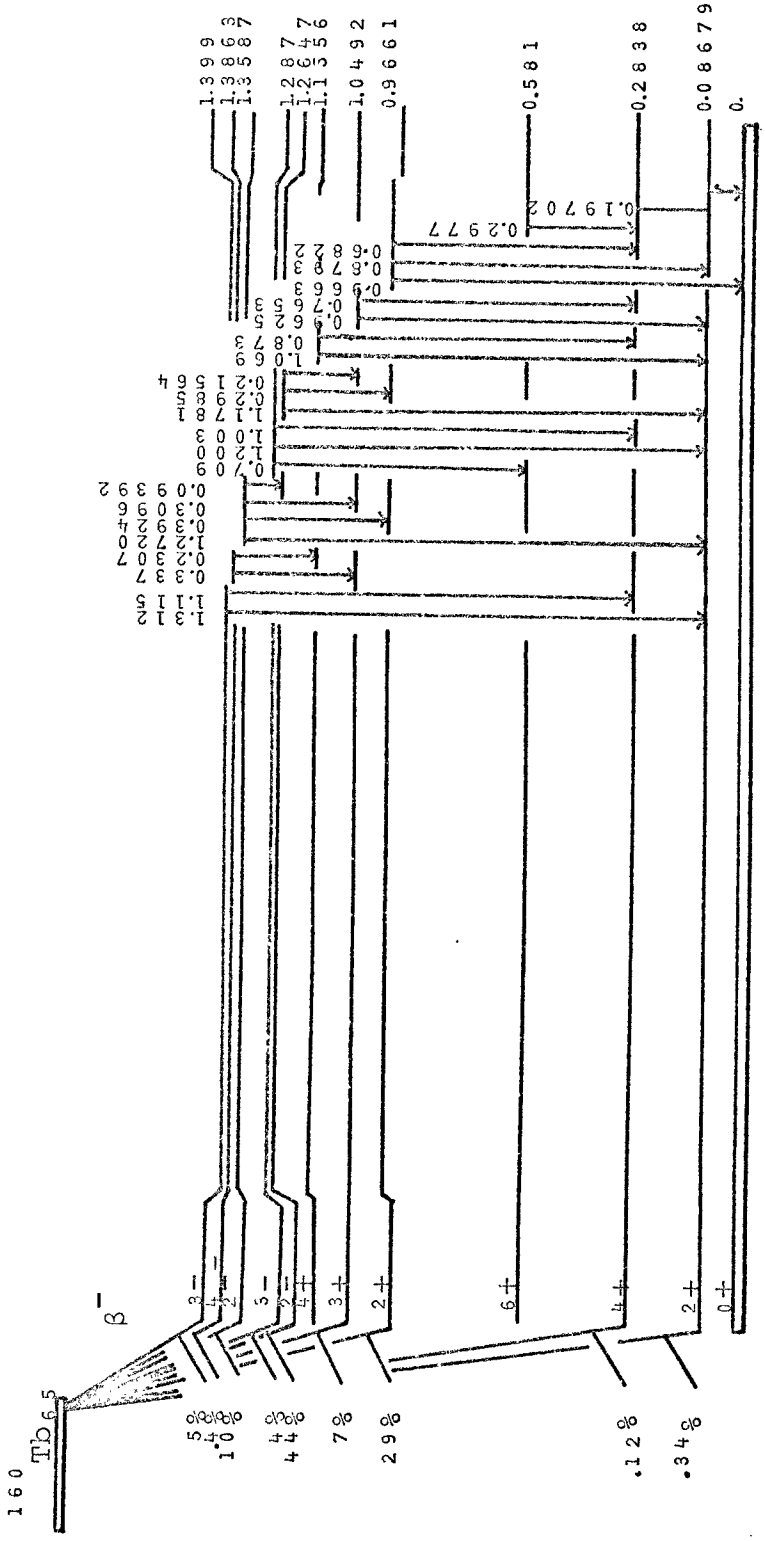

Fig. 7--Decay Scheme for ^{160}Tb

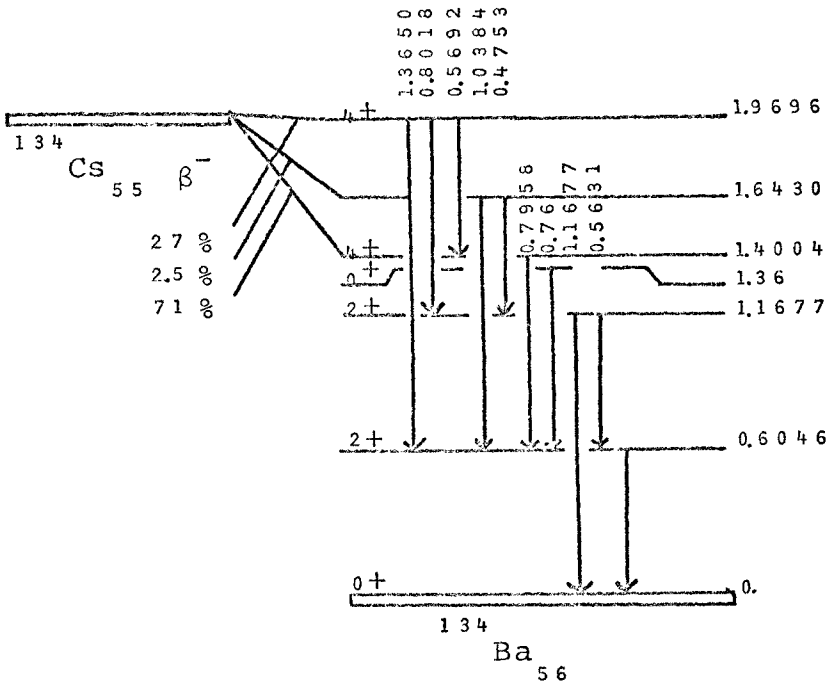

Fig. 8--Decay Scheme for ^{134}Cs

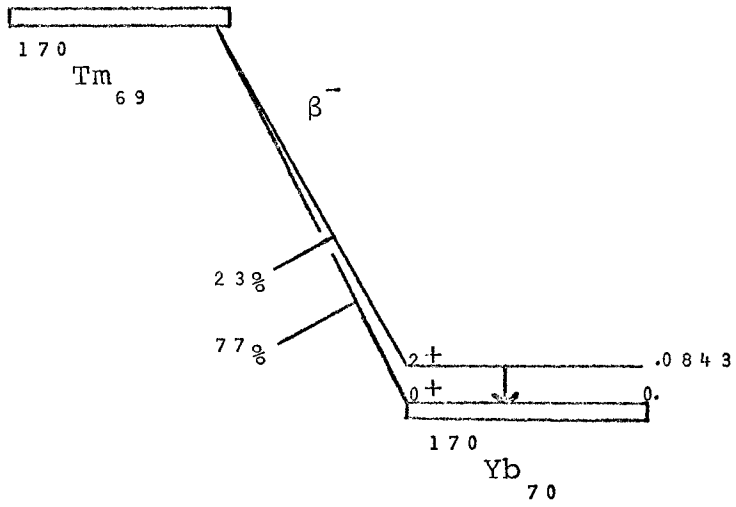

Fig. 9--Decay Scheme for ^{170}Tm

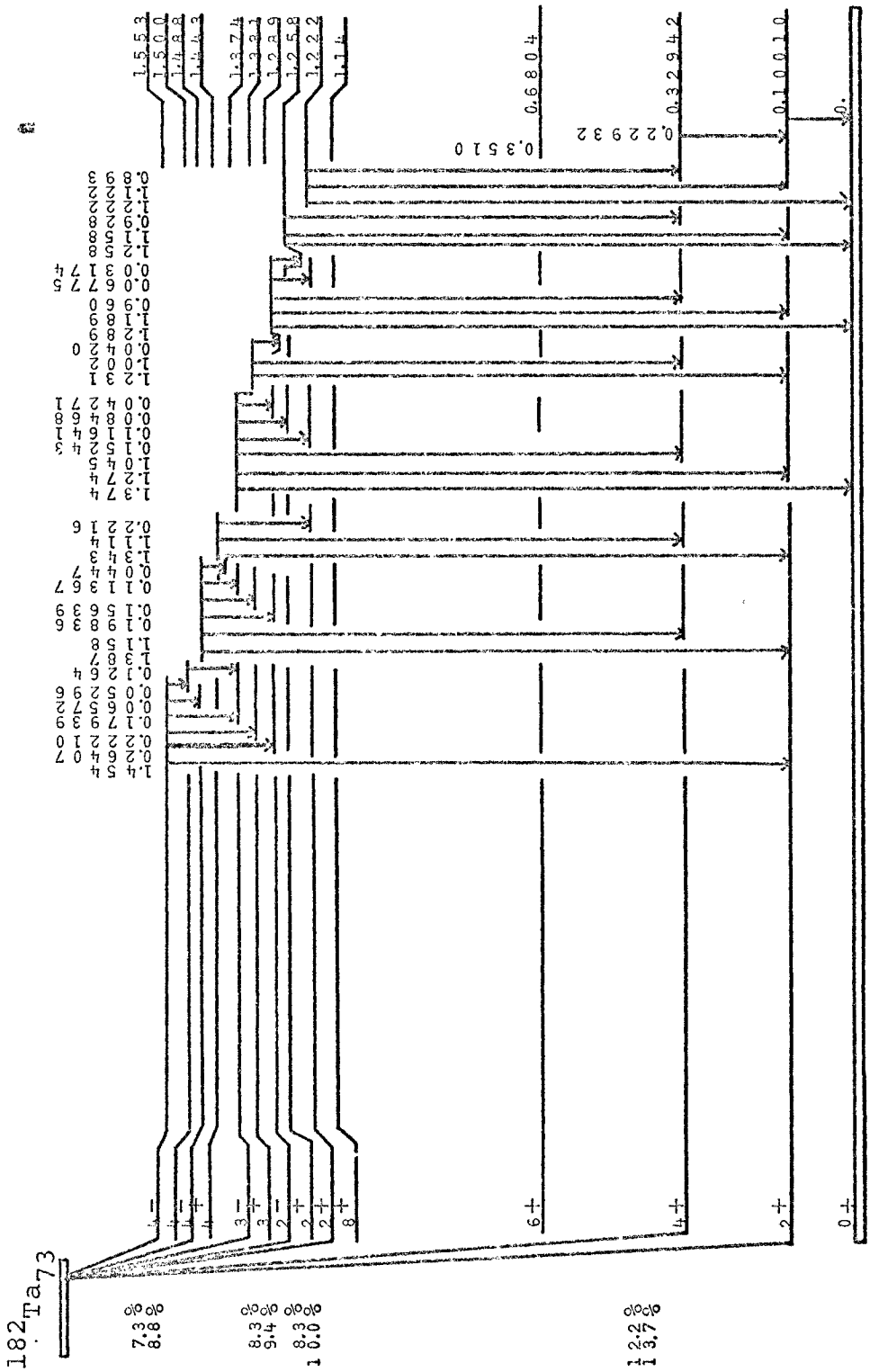

Fig. 10--Decay Scheme for ^{182}Ta

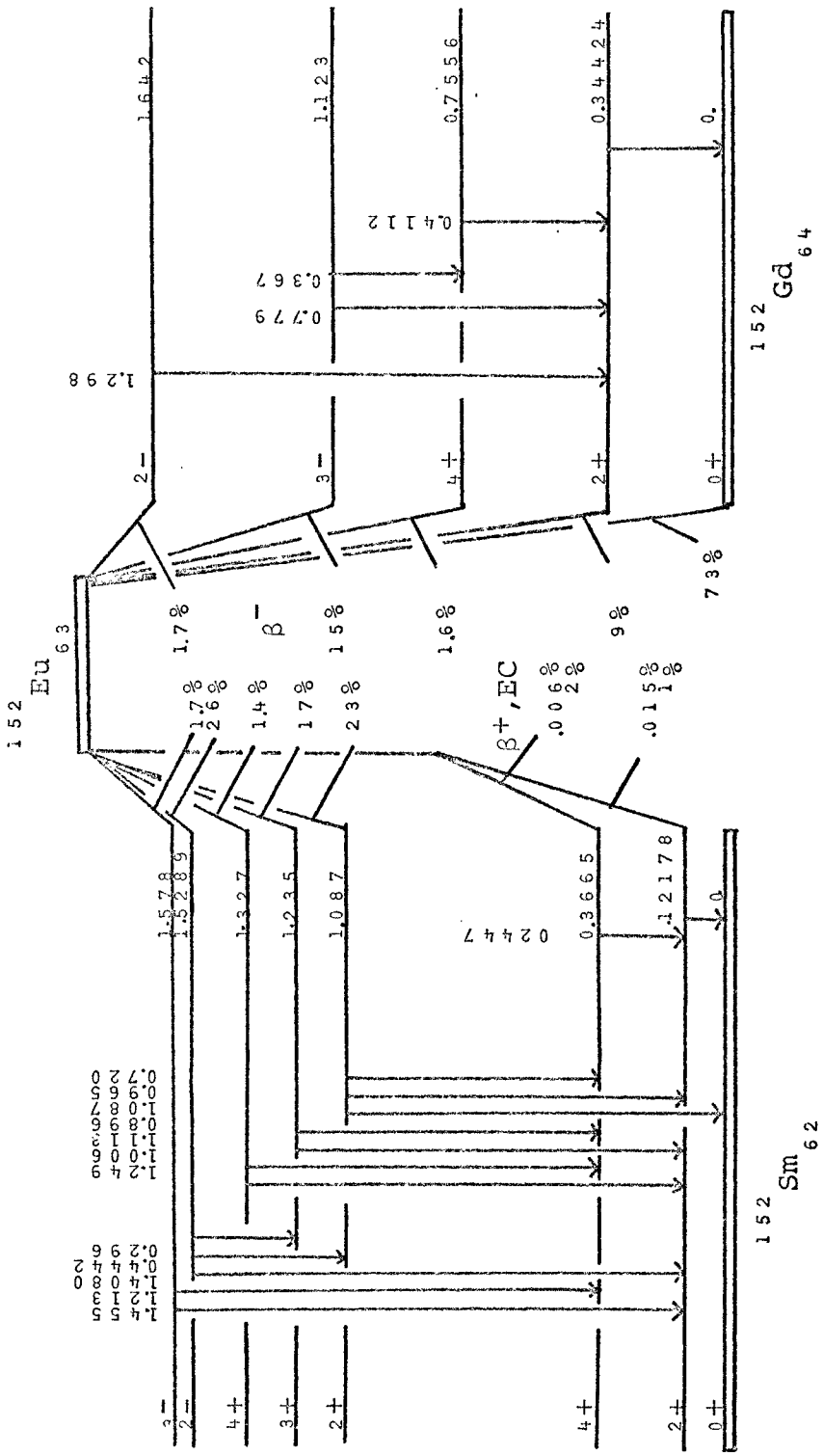

Fig. 11--Decay Scheme for ^{152}Eu

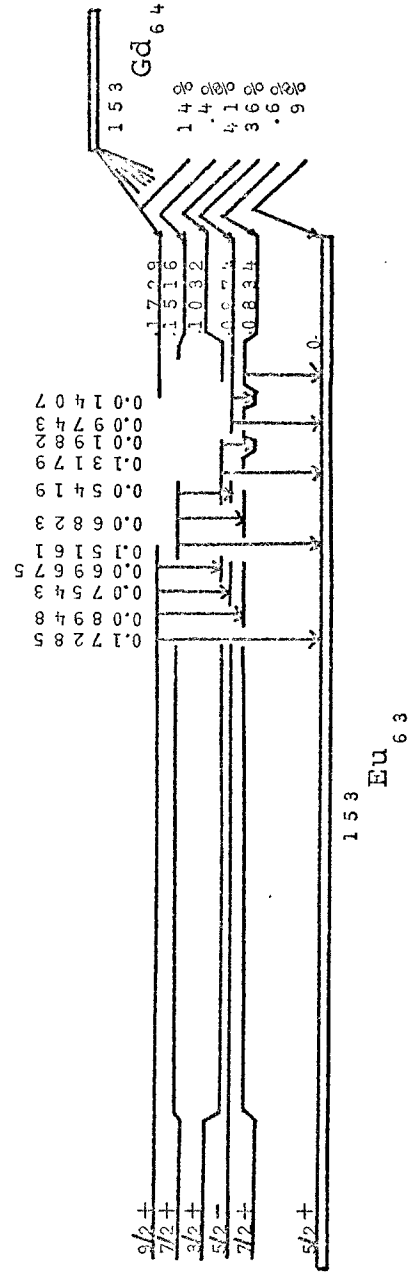

Fig. 12--Decay Scheme for ^{153}Gd

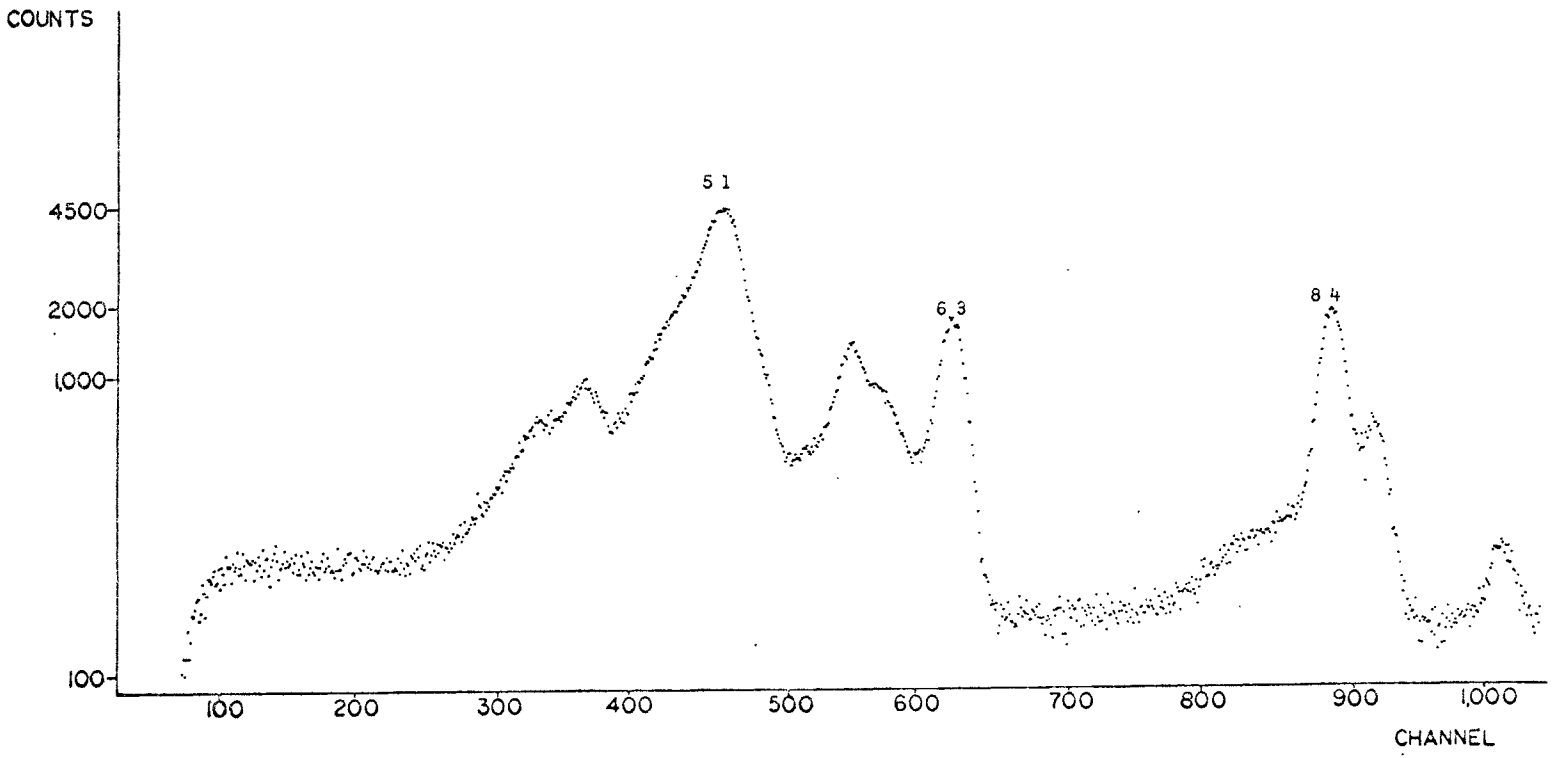

Fig. 13--Low Energy Spectrum of ^{169}Yb

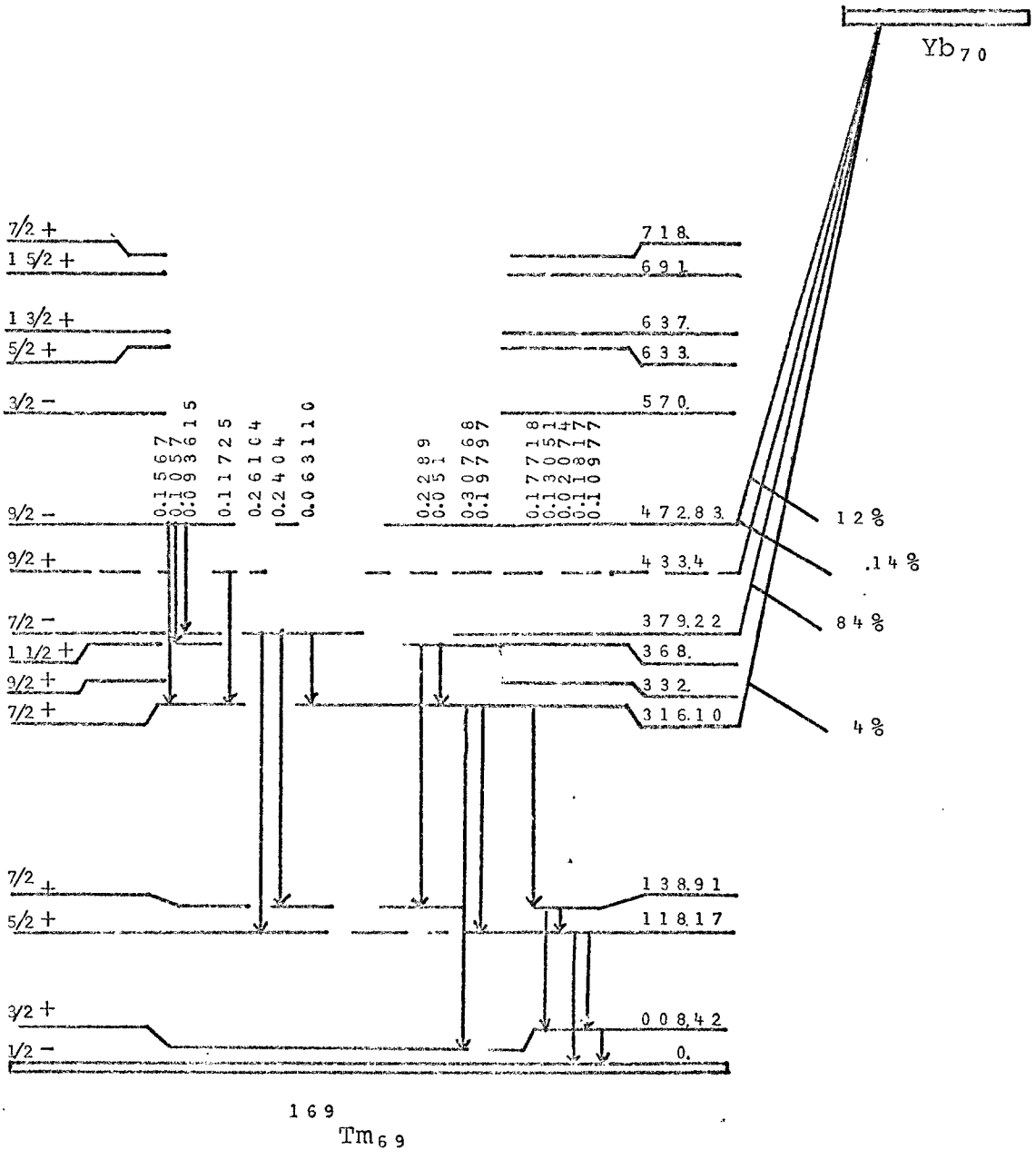

Fig. 14--Proposed Decay Scheme for ^{169}Yb

FOOTNOTES

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