Levels of Sr^{85} Populated in the Decay of Y^{85} and Y^{85m}†

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Evidence is presented for the existence of two isomers in Y^{85} with half-lives of 2.9±0.2-h and 4.7±0.2-h. Positron, photon, and x-ray measurements, both singles and coincidence, were performed. No evidence was obtained for the existence of an isomeric transition between the two isomers.

PHOTONS associated with the 2.9-h decay had energies of 0.150 (in Rb^{85}), 0.231, 0.511 (annihilation radiation and 0.503-MeV photon) and 0.915 MeV. The positron singles spectra indicated the presence of branches with endpoint energies of ~2.0 (which was masked by positrons associated with the 4.7-h decay) and 1.58±0.07 MeV. Another group with endpoint energy of 1.15±0.05 MeV was found in coincidence with 0.915-MeV photons. No photon-photon coincidences were observed which did not involve annihilation quanta. A tentative decay scheme for 2.9-h Y^{85} is presented which includes levels in Sr^{85} at 0.237 (Sr^{85m}, $\frac{1}{2}^-$), 0.740 ($\frac{1}{2}^-$, $\frac{3}{2}^-$) and 1.152 ($\frac{1}{2}^-$, $\frac{3}{2}^-$) MeV.

Thirty photons ranging in energy from 0.231 to 3.009 MeV were observed in the 4.7-h singles spectrum. Photon-photon coincidence measurements indicated that some of these were doublets. The positron singles spectrum contained groups with endpoint energies of 1.45±0.15 and 2.25±0.05 MeV. A group with endpoint energy of 2.0±0.1 MeV was observed in coincidence with the 0.231-MeV photon. A decay scheme for 4.7-h Y^{85} is proposed with levels at 0.231 ($\frac{7}{2}+$), 0.769, (0.802), 1.263, 1.353, 1.556, 1.630, 2.118, 2.169, (2.329), 2.351, and 2.779 MeV.

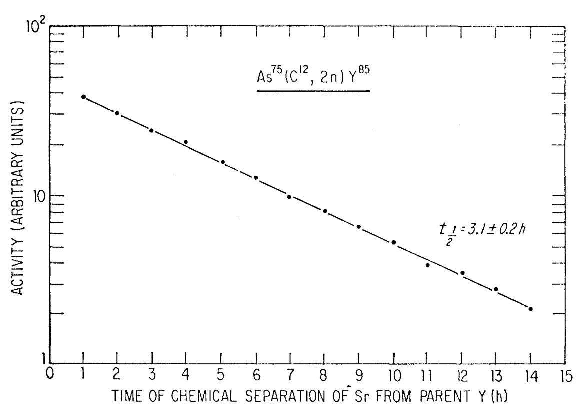

FIG. 1. Yield of Sr^{85m} as a function of time of chemical separation of strontium from yttrium parent. The yttrium was produced by bombarding arsenic with carbon ions.

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Consideration of the data suggests that 2.9-h Y^{85} has spin and parity $\frac{1}{2}^-$, and lies approximately 0.040 MeV above 4.7-h Y^{85} which has spin and parity $\frac{9}{2}^+$. The log *ft* values suggest that most of the levels populated in the 4.7-h decay have spins and parities $\frac{7}{2}^+$, $\frac{9}{2}^+$ or $\frac{11}{2}^+$, the latter being less preferred because of the photon branching ratios. Although additional experimental data are required to make possible a detailed comparison with the even parity-level structure of Sr^{85} as predicted by Talmi and Unna, the apparent preponderance of levels with spins between $\frac{7}{2}$ and $\frac{11}{2}$ indicates one might expect poor agreement.

I. INTRODUCTION

Caretto and Wiig have previously reported the half-life of Y^{85} as 5±1 h.[1] While investigating an isomeric level in Y^{86}, Kim, Horen, and Hollander observed that the strontium fraction separated from the parent yttrium, which was produced by the bombardment of Rb^{85} with 48-MeV alpha particles, contained Sr^{85m}. From timed chemical separations it appeared as though the half-life of the yttrium parent was about 3 h.[2] The present work was undertaken in an effort to determine whether Y^{85} was isomeric, as well as to obtain information pertaining to the level structure of Sr^{85} for which calculations had been made by Talmi and Unna.[3]

During the course of the present work, papers were published by Patro and Basu[4] and by Dostrovsky *et al.*[5] pertaining to the isomers of Y^{85}. A preliminary report of the present work has been given elsewhere.[6]

II. IDENTIFICATION OF Y^{85} AND Y^{85m}

A. Methods of Production and Chemical Procedure

Sources of the yttrium-85 isomers were produced by utilizing the Berkeley HILAC to bombard high-purity

[1] A. A. Caretto and E. O. Wiig, J. Am. Chem. Soc. **74**, 5235 (1952).
[2] Y. E. Kim, D. J. Horen, and J. M. Hollander (private communication, 1961).
[3] I. Talmi and I. Unna, Nucl. Phys. **19**, 225 (1960).
[4] A. P. Patro and B. Basu, Nucl. Phys. **37**, 272 (1962).
[5] I. Dostrovsky, S. Katcoff, and R. W. Stoenner, Phys. Rev. **132**, 2600 (1963).
[6] D. J. Horen and W. H. Kelly, Bull. Am. Phys. Soc. **7**, 341, 419 (1962).

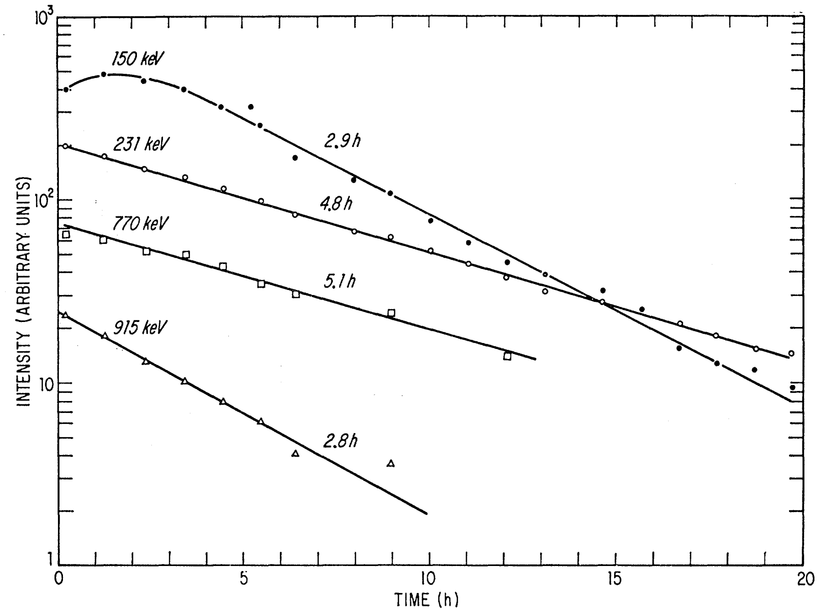

FIG. 2. K-x-ray coincidences as a function of time after chemical purification of yttrium produced by the bombardment of strontium (enriched in Sr^{84}) with 5-MeV deuterons.

arsenic metal[7] with about 120-MeV C^{12} ions and RbCl (enriched in Rb^{85})[8] with about 30-MeV He^3 ions, and the 60-in. Crocker Laboratory cyclotron to bombard RbCl (enriched in Rb^{85}) with 45-MeV alpha particles and $Sr(NO_3)_2$ (enriched in Sr^{84})[8] with about 5-MeV deuterons. However, since the He^3 and He^4 bombardments resulted in excessive amounts of Y^{86}, the major portion of this work was performed with sources produced by the C^{12} and deuteron-induced reactions.

The chemical procedure was essentially that discussed by Peppard *et al.*[9] Briefly, the target materials were dissolved in 0.5*N* HCl and contacted with 1.5*M* di 2 ethyl-hexyl phosphoric acid (HDEHP) in toluene, and the yttrium activities extracted. The extractions were washed several times with 0.5*N* HCl, and the yttrium was then back extracted with 10*N* HCl. Sources of carrier-free yttrium so obtained were liquid deposited onto thin microscope slides for counting experiments. For some experiments, the purified yttrium was left in the inorganic phase, i.e., HDEHP.

B. Half-Life Measurements

That the yttrium activities, produced by the methods described in the previous section, contained Y^{85} was shown by the growth of 70-min Sr^{85m} in freshly separated yttrium fractions. Timed chemical separations of Sr^{85m} from the yttrium parent, made by washing the organic phase (HDEHP) with 0.5*N* HCl at 10 to 60-min intervals, yielded a half-life of 3.0 ± 0.2 h for Y^{85}. In Fig. 1 is shown a typical curve of the yield of Sr^{85m} versus the time of chemical separation of strontium from the parent yttrium. These results are in substantial agreement with those obtained by Kim *et al.* who utilized other chemical techniques.[2]

The photon spectra of yttrium sources produced by the $As^{75}(C^{12},xn)Y^{87-x}$ reaction taken a few hours after production showed peaks that decayed with 39-min, 4.7-h, 14-h, and 80-h half-lives. The 39-min activity has been assigned to Y^{84}, while the 14-h activity is known to arise mainly from Y^{86}, and the 80-h activity from the decay of Y^{87}. From a knowledge of the impurities in the arsenic, we have tentatively concluded that the Y^{87} is formed by the capture process. The origin of the 4.7-h activity was suspected to be an isomer of Y^{85}. No 3-h activity was observed in the direct decay of the yttrium fractions produced by the C^{12} ion induced reactions. (Although as noted above, its presence was detected by chemical separations of Sr^{85m}.)

Photon spectra of the 5-MeV deuteron-induced reactions exhibited peaks which decayed with 3-, 4.7-, 14-, and 80-h half-lives. The 14- and 80-h activities were due to Y^{87} and Y^{87m}. There was no indication of the presence of Y^{84}, and little indication of Y^{86} in these sources. Coincidences between K x rays and photons were measured as a function of time, and the results are shown in Fig. 2. The intensity of the 0.150-MeV photon (Sr^{85m}) initially increased, and then decayed with a half-life of 2.9 h, as would be expected from the decay scheme to be presented later (i.e., Fig. 11).

There was no indication of a 3-h component in the 0.231-MeV photon intensity. However, the 5-h decay of this photon is additional evidence of the correctness of the assignment of the 5-h yttrium decay to Y^{85}. It is clear from Fig. 2 that there is a 0.915-MeV photon associated with the short-lived decay and a 0.780-MeV

[7] Obtained from Johnson Matthey and Co., Ltd., London, England.

[8] Obtained from Stable Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

[9] D. F. Peppard, G. W. Mason, and S. W. Moline, J. Inorg. Nucl. Chem. 5, 141 (1957).

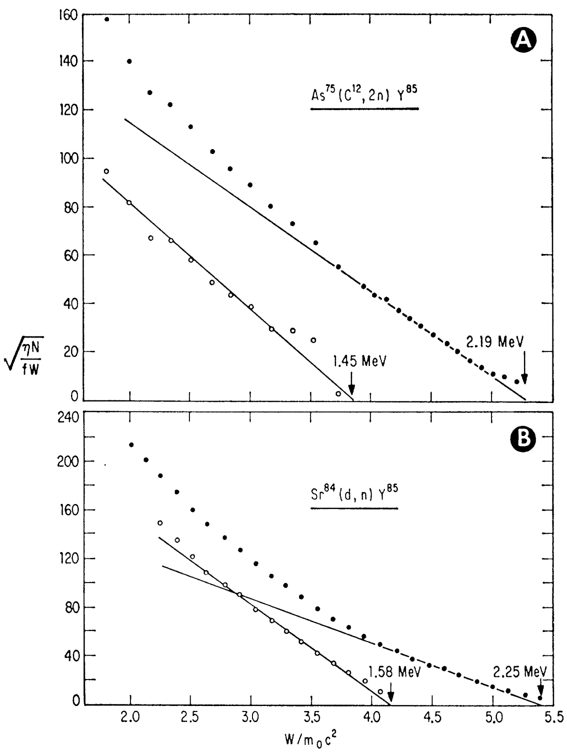

FIG. 3. Fermi-Kurie plots of positron spectra of $Y^{85,85m}$. (a) Spectrum of source produced by the $As^{75}(C^{12},2n)Y^{85}$ reaction. (b) Spectrum of source produced by $Sr^{84}(d,n)Y^{85}$ reaction.

photon with the long-lived decay. Also in coincidence with K x rays was found a peak at an energy of about 0.511 MeV. The decay of this peak was composite and consisted mainly of two components with half-lives of 2.9 and 80 h (plus, as will be obvious from the following, a small contribution from the 5-h activity). The long-lived component was due to the presence of Y^{87}, and was responsible for the peak shift to lower energies with decay. Coincidences were also recorded with the gate set just above the K x ray. The spectrum in coincidence with these pulses consisted mainly of a peak at 0.511 MeV which, over the period of data collection, decayed with components of 2.9 and 5 h. These events were most likely caused by the detection of 0.511-MeV annihilation photons in the photon counter in coincidence with Compton pulses from their partners detected in the x-ray counter. (The geometry was 180°.) After corrections were made for the long-lived component as well as the greater than K x-ray coincidences, a significant portion of the 0.511-MeV peak remained in the K x-ray coincidence spectrum which indicated the presence of a photon with energy of about 0.511 MeV in the 2.9-h decay.

Decay of the positron spectra were followed with plastic scintillators, as well as with flowing-methane, proportional counters. From a consideration of all the data, our best values for the half-lives of the Y^{85} isomeric states are 2.9±0.2 h and 4.7±0.2 h.

III. SINGLES SPECTRA

A. Positron Spectrum

Positron spectra were measured with a plastic scintillator. The spectrum obtained from a Y^{85} source produced by the carbon ion reaction showed essentially a pure 5-h decay over a 25-h period. For this reason, as well as the fact that no transitions known to occur in the 3-h decay were observed in the gamma-ray spectrum, the positron spectrum so obtained was assumed to be solely that due to the decay of 5-h Y^{85}. The detector was calibrated by using the conversion lines of Cs^{137} and Bi^{207} and Compton edges due to gamma rays from an Y^{88} source. The calibration was checked by determining the endpoint energies of the highest energy positron branch from a Ge^{68}–Ga^{68} source, and negatron branch from a Rh^{106} source. A Fermi-Kurie analysis of the "5-h" Y^{85} positron spectrum [see Fig. 3(a)] showed two branches with endpoint energies of 2.19±0.10 and 1.45±0.15 MeV. Analysis of a spectrum taken with the same source 15 h later yielded identical results.

Sources produced by the (d,n) reaction contained more nearly equal quantities of the two isomers of Y^{85}, and the decay of the positron spectrum was composite up to energies of about 2 MeV. The positron spectrum of a Y^{85} source, produced by the (d,n) reaction, was

TABLE I. Relative intensities of photons from singles spectrum associated with the decay of 4.9-h Y^{85}.

Photon energy (MeV)	Relative intensity NaI(Tl)	Ge(Li)	Assumed values	Comments
0.231	100		100	
0.511	400		400	Annihilation radiation
0.540}	16.6	10.3	11.6	
0.550}		2.9	3.3	
0.571}	10.7	4.6	4.9	
0.614}		5.2	5.6	Broad in Ge(Li)
0.699}	7.2	3.4	3.4	
0.724}		0.98	0.98	
0.769}		16.3	14.1	
0.789}	18.6	4.6	4.1	
0.816}		3.4	3.2	
0.862	4.4	3.9	4.1	
1.031	5.9	6.5	6.2	
1.123	5.5	5.1	5.3	
1.223}	7.3	5.2	5.2	
1.264}		2.0	2.0	
1.323}	3.7	2.9	2.9	
1.354}		0.8	0.8	
1.400	11.1	11.1	11.1	Spectra normalized here
1.556}	5.0	0.54	0.55	
1.583}		3.7	3.8	
1.888	3.5	2.4	3.5}	Sitting on large Compton background in Ge(Li) spectrum
1.940	2.2		2.2}	
2.120	12.0	19.4	12.0}	Discrepancy between NaI and Ge(Li) data not understood
2.169	5.8	8.1	5.8}	
2.351	1.5	1.6	1.5	
2.550	0.6	0.54	0.57	
2.745}		0.36	0.36	Possible impurity
2.779}	1.5	1.1	1.1	
2.812}		0.36	0.36	Possible impurity
3.009	0.3		0.3	Possible impurity

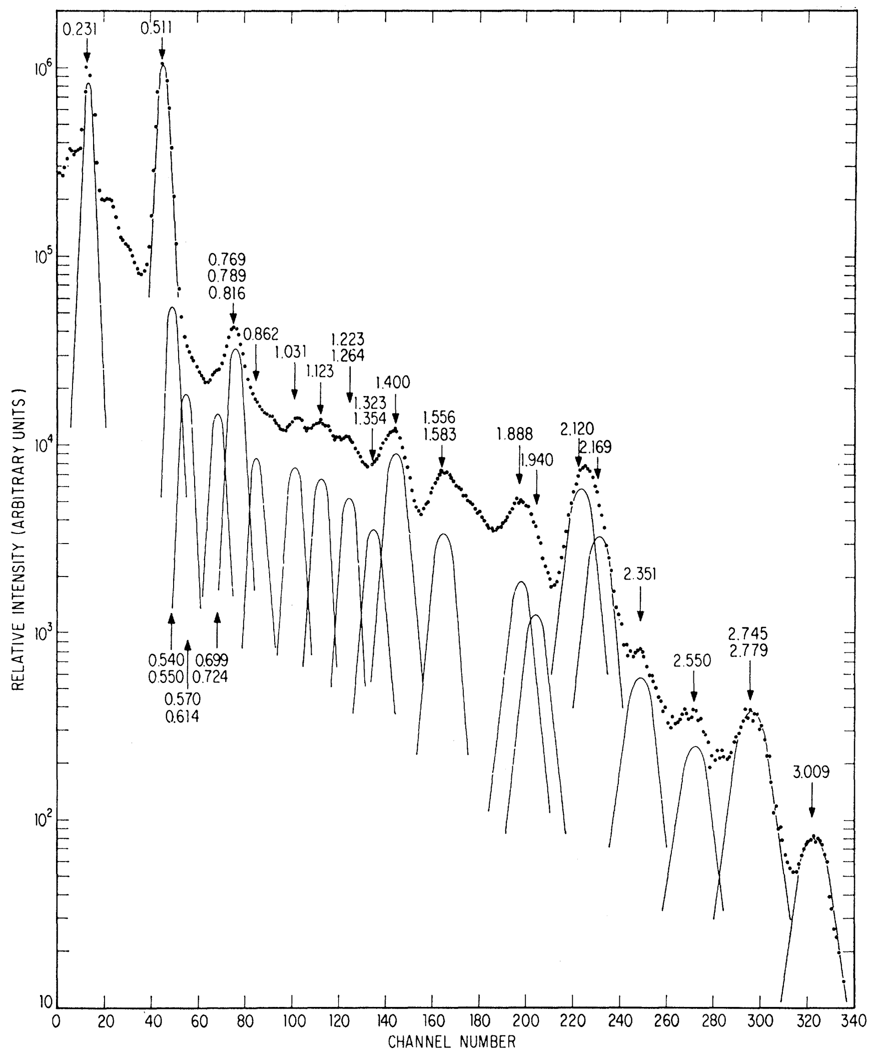

FIG. 4. Photon spectrum of $Y^{85,85m}$ produced by the carbon ion reaction taken with a 3-in. ×3-in. NaI(Tl) crystal. The spectrum has been corrected for Y^{86} impurity, and essentially represents pure 4.7-h Y^{85}.

measured about 2 h after production, and the data analyzed by means of a Fermi-Kurie plot as shown in Fig. 3(b). The data showed positron groups with endpoint energies of 2.25±0.05 and 1.58±0.07 MeV. There was some indication of additional groups at lower energies. The same source was measured again approximately 25 h later, and a Fermi-Kurie analysis was performed on the positron spectrum so obtained. From a comparison of the latter analysis with that shown in Fig. 3(b), it could be concluded that the decay of the 2.25-MeV branch was composite, with the major portion arising from the 5-h activity; and the 1.58-MeV branch was associated mainly with the 3-h decay.

B. Photon Spectra

Measurements with NaI(Tl)

The photon spectra of sources of Y^{85} produced by the carbon-ion and (d,n) reactions were measured with a 3-in.-diam×3-in.-long NaI(Tl) crystal. A variety of source-to-crystal distances and absorber geometries were used.

Figure 4 shows a typical spectrum obtained with a source produced by the carbon-ion reaction. As previously mentioned, photons known to be associated with the 3-h decay were not detectable in such sources. The data for Fig. 4 were obtained with a source-to-crystal distance of 6.7 in., and a 0.5-in. thick carbon absorber placed midway to reduce the detection of annihilation-in-flight photons. The measurements were started after allowing sufficient time (approximately 12 h after production) for the Y^{84} activity to decay, and were extended over a period of five days. From the decay of the photon spectrum, it was determined that the source contained 5-h Y^{85}, 14.6-h Y^{86}, 80-h Y^{87}, and possibly some 14-h Y^{87}. The spectrum shown in Fig. 4 has been corrected for room background, Y^{86} and 80-h Y^{87}. It was analyzed by using standard techniques (ignoring possible contributions due to annihilation-in-flight photons), and the results are given in Table I.

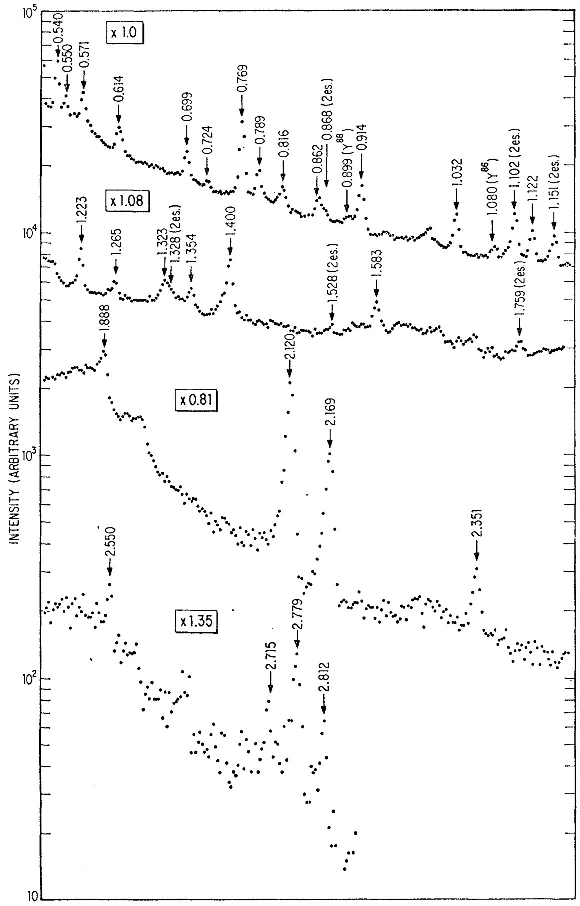

FIG. 5. Photon spectrum of $Y^{85,85m}$ produced by the d,n reaction taken with a Ge(Li) crystal.

The procedure used to determine the photon spectrum associated with the 3-h decay was as follows. A source of Y^{85} produced by the (d,n) reaction was mounted in a geometry (source-to-crystal distance of 10 in.) similar to that previously used for a HILAC produced source and the amplifier gain adjusted accordingly. The decay of the photon spectrum was followed over a period of 5 days. It was found that part of the spectrum extending above about 1.2 MeV decayed with only a 5-h half-life, and, in this region, was identical to that obtained from a HILAC source. A photon with energy of 0.915 MeV decayed with a 2.9-h half-life. The decay of the peak at 0.511 MeV was composite, and contained components with half-lives of 3-, 5-, and 80-h (Y^{87}). The peak at 0.231 MeV initially showed growth, and then decayed with 3- and 5-h components. A 5-h Y^{85} spectrum was normalized above 1.2 MeV, to the spectra obtained from a source produced by the (d,n) reaction and, by subtraction, it was then possible to remove the 5-h component from the decay curve of the 0.231-MeV peak. The resulting decay curve was similar to what one would expect from the decay of a 70-min daughter populated by a 3-h parent. The decay of the 0.150-MeV peak was similar to the latter results.

TABLE II. Relative intensities of photons associated with the decay of 2.9-h Y^{85}.

Photon energy (MeV)	Relative intensity: Singles NaI(Tl)	Singles Ge(Li)	X-ray coincidences
0.150[a]	6.0±1.0	7.1±1.4	9.6±1.4
0.231	32.4±6.5		
0.51[b]			14.6±7.3
0.915	2.4	2.4	2.4

[a] Photon from transition in Rb^{85} populated in the decay of Sr^{85m}.
[b] Observed in x-ray–photon coincidences.

Comparisons of the 5-h spectrum with those obtained with the (d,n) spectra indicated, that within the experimental statistics, only peaks with energies of 0.150, 0.231, 0.511, and 0.915 MeV are associated with the 3-h decay. The 0.511-MeV peak arises mainly from annihilation quanta but, as mentioned in Sec. IIB, it also contains a contribution from a photon with an energy of about 0.51 MeV. Dostrovsky *et al.* have observed conversion electrons from this transition and have determined its energy as 0.503 MeV.[5] Henceforth, we assume this value. Relative intensities of the photons associated with the 3-h decay are given in Table II.

Measurements with Ge(Li) Detectors

Measurements of the photon spectrum of (d,n) produced Y^{85} sources were also made with Ge(Li) detectors of 2 $cm^2 \times 5$ mm deep and 4.3 $cm^2 \times 8$ mm deep.[10] These detectors had resolutions of about 7 keV full width at half-maximum. A typical spectrum in the energy region above 0.51 MeV is shown in Fig. 5. The photons, together with their relative intensities, associated with the 5-h decay are given in Table I.

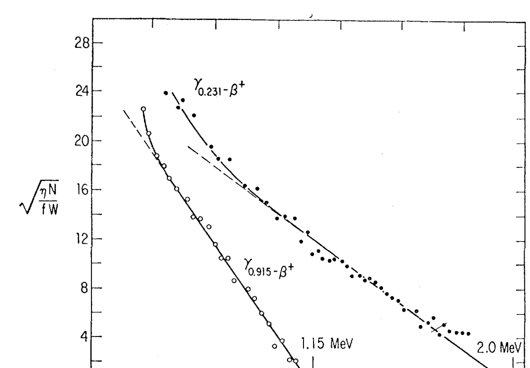

FIG. 6. Fermi-Kurie plots of the positron spectra in coincidence with photons of energies 0.231 (4.7-h Y^{85}) and 0.915 (2.9-h Y^{85}) MeV.

[10] The authors are indebted to J. P. Hurley and J. M. Mathiesen of NRDL for the loan of these counters.

Experimentally determined two escape peak to full energy peak intensity ratios indicated that the entire intensity of the escape peaks noted in Fig. 5 could be accommodated in this way. However, from the errors involved in these determinations the presence in the spectrum of photons with energies corresponding to the two escape peak energies so noted cannot be completely ruled out. Normalization between the Ge(Li) data and the NaI data was made utilizing the photon with energy 1.4 MeV. The higher resolution of the Ge(Li) detectors confirmed the existence of all of the photons observed in the NaI work (in singles and coincidence), and exhibited a few additional lines. On the average, the relative intensities determined with the two types of detectors agree fairly well, but considerable discrepancies occur at a few energies. We have been unable to determine the source of these disparities. Hence, in column 4 of Table I we give the relative intensities assumed in this work on the basis of these data.

The only photons associated with the 3-h decay that were observed with the Ge(Li) detectors occurred at energies of 0.150, 0.231, 0.511 (composite, but unresolved), and 0.915 MeV. From these measurements, relative intensities for the 0.150- and 0.915-MeV photons were determined; and these are given in Table II.

TABLE III. Results of photon coincidence measurements associated with decay of 4.9-h Y^{85}.

Photon energy (MeV)	Singles	K x-ray[a]	Gate energy (MeV) 0.231[b]	0.77	1.40[c]	1.58[c]
0.231	100	35.8		x	100	100
0.511	400		x[d]	x	?	
0.540	11.6 } [e]	12.5 } [e]	8 } [e]	x	75	75
0.550	3.3					
0.571	4.9 } [e]	12.0 } [e]	1.1 } [e]	x		
0.614	5.6					
0.699	3.4 } [e]	5.7 } [e]	0.7 } [e]	? } [e]	31	?
0.724	0.98					
0.769	14.1 } [e]	16.1 }	3.2 }	x } [e]	75	100
0.789	4.1					
0.816	3.2					
0.862	4.1	5.0	2.6	x		
1.031	6.2	5.9	4.4	?		
1.123	5.3	5.5	4.5	x		
1.223	5.2 } [e]	5.0 } [e]	0.8 } [e]	x		
1.264	2.0					
1.323	2.9 } [e]	4.0 } [e]	1.8 } [e]	x		
1.354	0.8					
1.400	11.11	11.1	4.6	x		
1.556	0.55 } [e]	4.0 } [e]	1.1 } [e]	x		
1.583	3.8					
1.888	3.5	4.6 } [e]	5.7			
1.940	2.2	2.7				
2.120	12.0	12.4	2.0			
2.169	5.8	5.3				
2.351	1.5					
2.550	0.57					
2.745	0.36					
2.779	1.1					
2.812	0.36					
3.009	0.3					

[a] The K-x-ray coincidence data were normalized to the singles data at 1.400-MeV photon.
[b] The 0.231-MeV photon coincidence data were normalized to the singles data assuming that the full intensities of the 1.888- and 1.940-MeV photons directly populate the 0.231-MeV level.
[c] Intensities in coincidence not normalized to singles data.
[d] x indicates coincidence observed but relative intensity not determined.
[e] The indicated groups of photons were not resolved in the coincidence work.

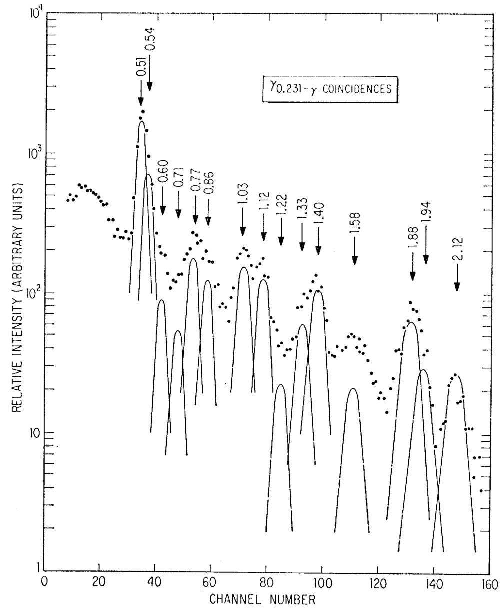

FIG. 7. Photon spectrum in coincidence with 0.231-MeV photons. The spectrum has been corrected for contributions due to events other than those involving a coincidence with a 0.231-MeV photon. The source was produced by heavy ion bombardment of arsenic.

IV. COINCIDENCE SPECTRA

A. Positron-Photon Coincidences

In general, the sources produced by the carbon-ion reaction were too weak and contained too much Y^{86} activity to utilize for positron-photon coincidence measurements. Hence, the only useful data of this type were obtained with (d,n) produced sources. Of the many measurements attempted, only those involving coincidences with the 0.231- and 0.915-MeV photons proved fruitful. All measurements were taken as a function of time to assure proper identification. Generally the detectors consisted of a plastic scintillator 2 in. in diameter by 1.5 in. long and a 3-in. diameter by 3-in. long NaI(Tl) crystal.

In Fig. 6 are shown Fermi-Kurie plots of the positron spectra in coincidence with the 0.231- and 0.915-MeV photons. The raw data were corrected for contributions to the coincidence spectra due to Compton events in the gate crystal arising from higher energy photons. An endpoint energy of 2.0 ± 0.1 MeV was found for the positron branch in coincidence with the 0.231-MeV photon associated with 4.7-h Y^{85}. The 0.915-MeV photons associated with 2.9-h Y^{85} were coincident with a positron branch with endpoint energy of 1.15 ± 0.05 MeV.

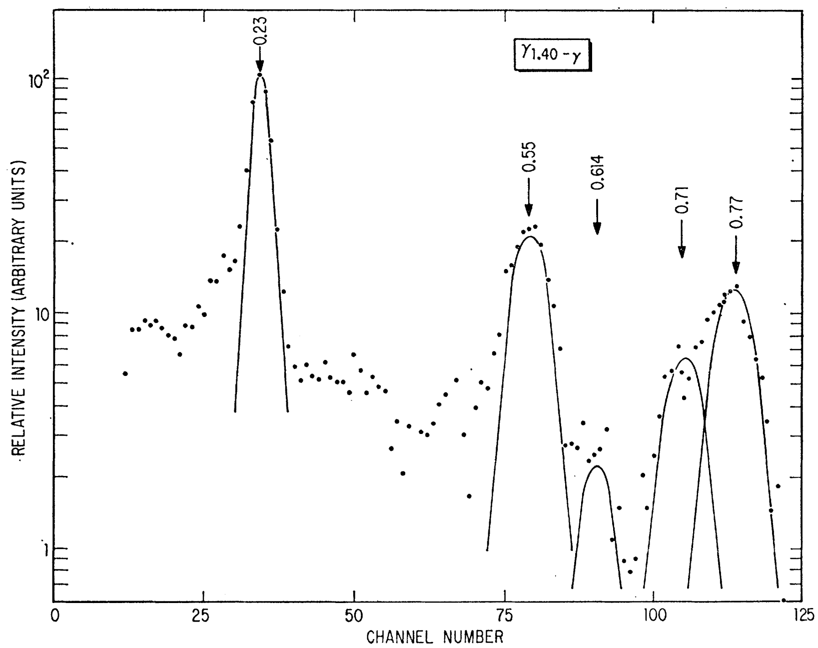

FIG. 8. Spectrum in coincidence with 1.40-MeV photons. The spectrum has been corrected for contributions due to events other than those involving a coincidence with a 1.40-MeV photon.

B. X-Ray–Photon Coincidences

Utilizing a carbon-ion produced source, x-ray–photon coincidences were measured over a period of about twenty hours. Within statistics, the spectrum decayed with approximately a 5-h half-life. For these measurements, the x-ray and photon counters were in 90° geometry with an antiscattering shield between them. Single channel analyzers were set on and just above the x-ray peak, and the outputs of these were used to gate the display of the photon counter into one or the other half of a 400-channel pulse-height analyzer. The spectrum obtained with the gate set above the x-ray peak exhibited peaks only at 0.231 and 0.511 MeV, and was subtracted out in order to obtain a "pure" x-ray–photon coincidence spectrum. The latter was analyzed and normalized to a singles spectrum at the high energy end, and the photon energies and relative intensities are given in column 3 of Table III.

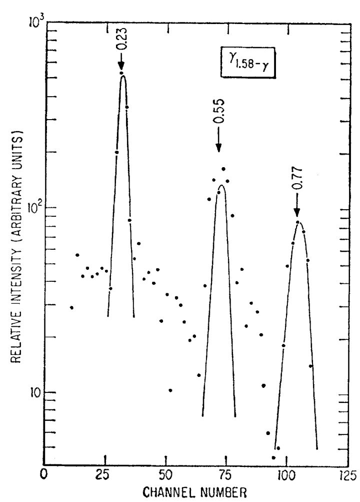

FIG. 9. Spectrum in coincidence with 1.58-MeV photons. The spectrum has been corrected for contributions due to events other than those involving a coincidence with a 1.58-MeV photon.

As previously mentioned in Sec. IIB, x-ray coincidence measurements were also made (as a function of time) using a source produced by the (d,n) reaction. The intensity of the 0.150-MeV photon relative to that of the 0.915-MeV photon was determined from the coincidence spectra that were taken after equilibrium was reached between the 3-h Y^{85} and 70-min Sr^{85m} activities. The relative intensity of the 0.503-MeV photon was determined from a coincidence spectrum taken right after chemical separation when the effect of the contribution due to 80-h Y^{87} was a minimum. In calculating the relative intensities, the data were first corrected by subtracting the "greater than" x-ray coincidence spectrum from the x-ray coincidence spectrum, and then applying the usual corrections for detector efficiency, etc. These results are given in Table II.

C. Photon-Photon Coincidences

Photon-photon coincidences were measured using two 3-in. diameter by 3-in. long NaI(Tl) crystals and standard electronic circuitry. In most cases the crystals were set at 90° with respect to each other with a graded antiscattering shield between them. Most of the sources used in these measurements were produced by either the (d,n) or heavy ion reactions. All the coincidence data were taken as a function of time.

Within the experimental errors, the only observed photon-photon coincidences associated with the 2.9-h decay involved annihilation quanta. In particular, no coincidences were observed which involved the 0.231-MeV photon.

Coincidence spectra associated with the 5-h decay were taken with the gate selector set to pass pulses corresponding to energies of 0.23, 0.78, 1.40, 1.58, 1.89+1.94, and 2.12+2.17 MeV. Except for the latter two cases, additional coincidences were measured simultaneously with the gates set above and below these energies in an effort to determine the contributions to the spectra from Compton events, etc. The background corrected spectra in coincidence with the peaks at 0.23, 1.40, and 1.58 MeV are shown in Figs. 7, 8, and 9, respectively. The data obtained with the gate set to pass pulses corresponding to energies between 0.70 and 0.86 MeV proved useful only in a semiquantitative way, mainly because of the lack of energy resolution in the gate crystal and the uncertainty as to the corrections to be applied to the spectrum due to Compton events, etc. In Fig. 10 is shown a spectrum taken with the gate set to pass such pulses, as well as one with the gate set to pass pulses between 0.57 and 0.70 MeV. Only the 0.231-MeV photon was observed in coincidence with the (1.89+1.94)- and (2.12+2.17)-MeV groups. The data were analyzed using standard methods, and the results are given in Table III.

V. DECAY SCHEME

It was assumed that the Y^{85} isomer decays directly to Sr^{85}, since no evidence was found for an isomeric transition (i.e., such a transition was not directly observed, nor was there evidence in the decay curves for such a transition). Hence, for clarity, in the following the two decays shall be dealt with separately.

A. 2.9-h Y^{85}

Since the data show the decay of 2.9-h Y^{85} populates the isomeric level at 0.237 MeV in Sr^{85} (spin and parity $\frac{1}{2}-$), it was assumed that the yttrium parent also has spin and parity $\frac{1}{2}-$ (as would be expected from the systematics of other odd-A yttrium isotopes). The fact that the 0.915-MeV photon is not in coincidence with the 0.231-MeV photon indicates that it decays either to the isomeric level or ground state of Sr^{85}. The latter is highly unlikely due to the large spin change between the 2.9-h Y^{85} ($\frac{1}{2}-$) level and the Sr^{85} ground state ($\frac{9}{2}+$). Hence, the 0.915-MeV photon is assumed to decay to Sr^{85m}, and this places a level in Sr^{85} at 1.152 MeV. From the positron-photon coincidence data, the endpoint energy of the positron branch in coincidence with the 0.915-MeV transition was found to be 1.15 MeV. This indicates that the 2.9-h Y^{85} lies at an energy of 3.32 MeV above the ground state of Sr^{85}. The 1.58-MeV positron group observed in singles would then suggest a level in Sr^{85} at 0.76 MeV. The difference between the energy of this level and the isomeric level at 0.237 MeV is about 0.52 MeV, which is in reasonable agreement

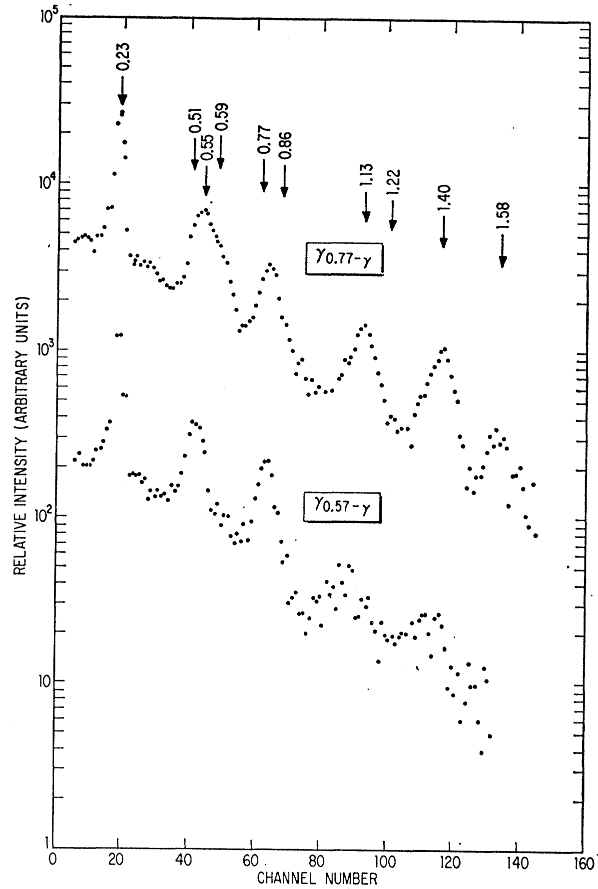

FIG. 10. Spectra in coincidence with gate pulses corresponding to energies in the region of 0.77 and 0.57 MeV.

with the ~0.503-MeV photon observed in the x-ray–photon coincidence measurements. These results suggest the decay scheme for 2.9-h Y^{85} as shown in Fig. 11.

The absolute branching ratios for the scheme shown in Fig. 11 were calculated as follows. Using the known[11] decay scheme of Sr^{85m} and the x-ray coincidence data from Table II, the K-capture intensities leading to the levels at 0.74 and 1.152 MeV were calculated from the expression,

$$\frac{N_{x-\gamma}}{N_{x-0.150}}=\frac{\epsilon_K\omega_K(\mathrm{Sr})}{0.14(\epsilon_K/\epsilon)_{0.150}[\omega_K(\mathrm{Rb})/(1+\alpha_{0.150})]}.$$

The ratio on the left side of the equation represents the intensity of either the 0.915- or 0.51-MeV photons relative to the 0.150-MeV photon in the x-ray coincidence data. The values for the fluorescent yields ω_K were taken from Wapstra *et al.*, as were the K to total capture ratios, ϵ_K/ϵ.[12] From these calculations it was

[11] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.), NRC 60-3-35.

[12] A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

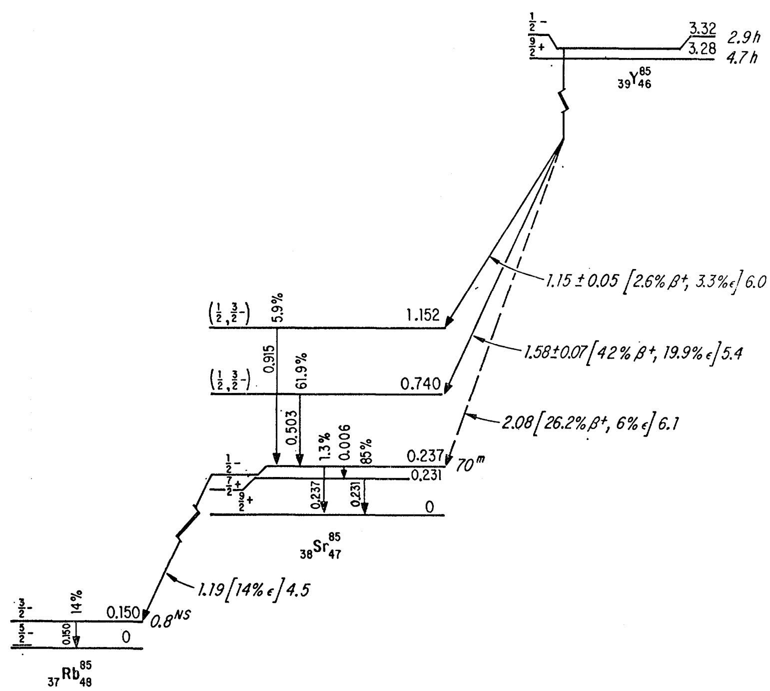

FIG. 11. Tentative decay scheme for 2.9-h Y^{85}. The decay of Sr^{85m} has been taken from Ref. 11. Level and transition energies are given in mega-electron volts, and the log *ft* values are given to the right of the percent branches. The dashed branch indicates that the positron group has not been measured directly.

found that 2.9 and 17.6% of the decays proceed by *K* capture to the levels at 1.152 and 0.74 MeV, respectively. Use was then made of the theoretical K/β^+ ratios as given by Zweifel[13] to calculate the remaining branching ratios as shown in Fig. 11. The correctness of the scheme was checked by comparing the predicted ratios for the relative intensities of the 0.231- and 0.915-MeV photons with the experimental values. These agreed to within 10%.

The decay schemes for 2.9-h Y^{85} as proposed by Patro and Basu[4] and by Dostrovsky *et al.*[5] are essentially in agreement with that shown in Fig. 11. However, Patro and Basu observed some additional transitions not seen in this work.

B. 4.7-h Y^{85}

The endpoint energy of the positron spectrum associated with the 4.7-h decay determines the total decay energy as 3.27 ± 0.06 MeV. Coincidences with the 0.231-MeV photon have shown that the level at this energy is populated by positrons with an endpoint energy of 2.0 MeV. The 1.45-MeV positron group observed in the singles spectrum indicates a level at about 0.80 MeV. From the singles and coincidence photon data we place this level at 0.769 MeV. Coincidence attempts to observe direct positron decay to this level were unsuccessful, mainly because of the weakness of the positron branch and the impurities present in the sources. The remainder of the levels have been placed on the basis of energy sums and the photon data. The proposed decay scheme is shown in Fig. 12.

[13] P. F. Zweifel, Phys. Rev. **107**, 329 (1957).

The 1.40- and 2.12-MeV photons were assumed to be doublets because their relative intensities in the coincidence data were not sufficient to accommodate their total intensities in singles, plus the fact that the decay scheme allowed for two such transitions. In some of the Ge(Li) spectra the 0.614-MeV peak appeared broad. In addition, intensity balances and the coincidence data suggested this transition might be a doublet, and the level scheme could accommodate two such transitions. Its intensity was split on the basis of the feeding of the 1.556-MeV level. The level scheme also allowed two positions for a 1.35-MeV transition. This transition has tentatively been placed between a level at this energy and the ground state. The fact that the sum of the 0.550- and 0.571-MeV photons is within a few kilovolts of the 1.123-MeV transition might suggest that these two photons form a cascade from the 1.353-MeV level to the 0.231-MeV level. For this reason, we have tentatively placed a level at 0.802, MeV. The 2.745-, 2.812-, and 3.009-MeV transitions have not been assigned.

As can be seen from Fig. 12, the evidence for a level at 2.329 MeV is rather meager and hence, its existence must be considered tentative. It is rather surprising that no transitions were observed between this level and the ground or first few excited states.

Absolute branchings have been calculated by making use of the proposed level scheme, the photon intensities, the theoretical K/β^+ ratios as given by Zweifel,[13] and ϵ_K/ϵ values from Wapstra *et al.*[12] The percent branching and log *ft* values are given in Fig. 12. The states at 0.231, 0.769, 1.630, and 2.169 MeV are in agreement

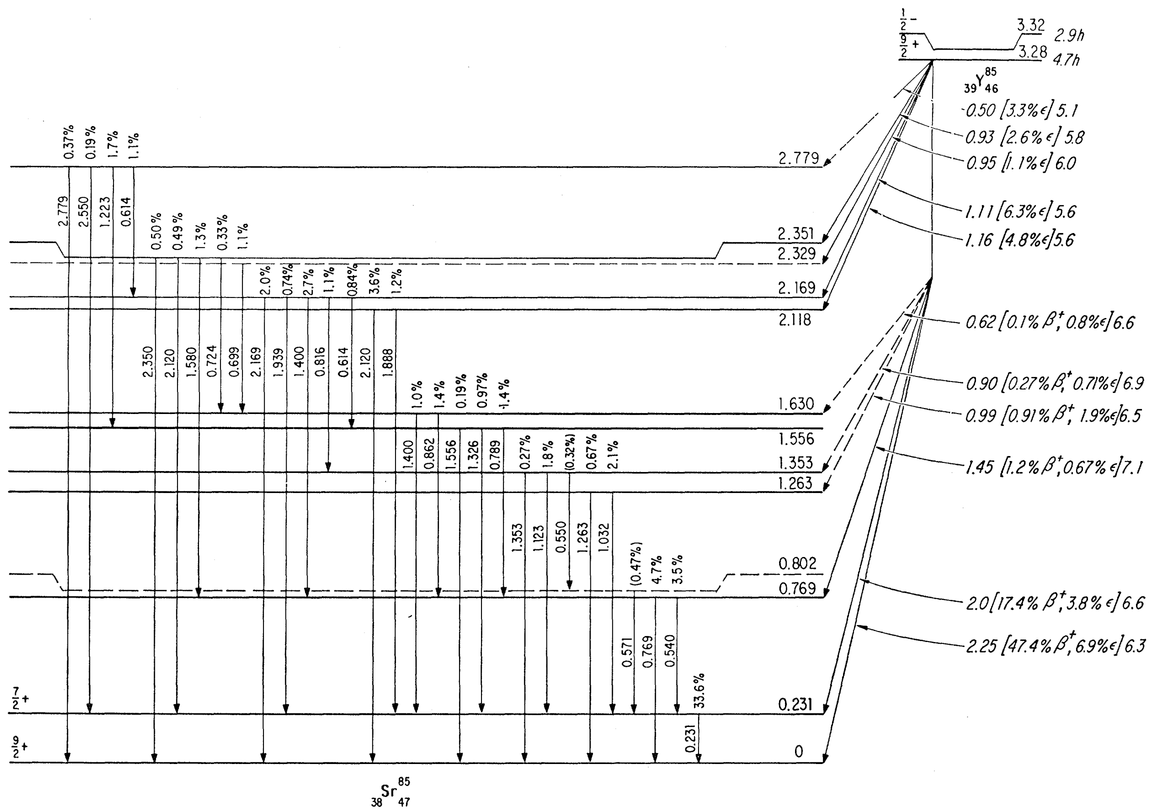

FIG. 12. Tentative decay scheme for 4.7-h Y^{85}. Level and transition energies are given in mega-electron volts, and the log *ft* values are given to the right of the percent branches. The dashed positron branches indicate that the positron groups have not been measured directly.

with those reported by Dostrovsky *et al.*[5] at 0.231, 0.772, 1.620, and 2.160 MeV. However, contrary to their results, our data indicate the 1.888- and 1.939-MeV photons are in coincidence with the 0.231-MeV photon, and most probably arise from levels at 2.118 and 2.169 MeV, respectively.

VI. DISCUSSION

The experimental results show that the two isomers of Y^{85} are nearly degenerate, and indicate that the 4.7-h level is probably the ground state. The allowed nature of the log *ft* values for the transitions from the 4.7-h state to the ground ($\frac{9}{2}+$) and first excited ($\frac{7}{2}+$) states of Sr^{85} implies a spin and parity $\frac{7}{2}+$ or $\frac{9}{2}+$ for this level in Y^{85}. Likewise, the allowed log *ft* value for the transition to Sr^{85m} ($\frac{1}{2}-$) indicates a spin and parity $\frac{1}{2}-$ or $\frac{3}{2}-$ for 2.9-h Y^{85}. In Y^{87}, Y^{89}, and Y^{91}, the ground states are known to have spin and parity $\frac{1}{2}-$ and the first excited state $\frac{9}{2}+$, which corresponds to the single-particle levels $2p_{1/2}$ and $1g_{9/2}$, respectively. It is natural to assume that these will also be the lowest lying levels in Y^{85}, except in this case it appears as though the relative positions of the $2p_{1/2}$ and $1g_{9/2}$ orbitals have been reversed.

Assuming then that the 2.9-h level has spin and parity $\frac{1}{2}-$, the allowed log *ft* values for the transitions to the 0.740 and 1.152-MeV levels in Sr^{85} indicate that these levels have spin and parity $\frac{1}{2}-$ or $\frac{3}{2}-$. There is at present no experimental information available with which to choose between these possibilities. On the basis of the simple shell model one might expect to observe a $\frac{3}{2}-$ level formed by the promotion of a $2p_{3/2}$ particle to the $2p_{1/2}$ orbital. The presence of two levels with spin and parity $\frac{1}{2}-$, or two levels with spin and parity $\frac{3}{2}-$ would be difficult to explain within the framework of the simple shell theory.

With the assumption that 4.9-h Y^{85} has spin and parity $\frac{9}{2}+$, the allowed log *ft* values for the branches to the levels in Sr^{85} directly populated in this decay implies that they have spins and parities $\frac{7}{2}+$, $\frac{9}{2}+$, or $\frac{11}{2}+$. The possibility that the transitions with the higher log *ft* values (i.e., ~ 7) could be first-forbidden can probably be ruled out, as negative parity levels with spin greater than $\frac{7}{2}$ are considered unlikely to be present here. Without additional information, such as angular correlation or electron conversion data, it is difficult to further choose between the possible spin assignments for the levels in Sr^{85} populated in the 4.9-h decay. However, the relative photon branchings from most of them to the ground ($\frac{9}{2}+$) and first excited ($\frac{7}{2}+$) states would seem to favor spins of either $\frac{7}{2}$ or $\frac{9}{2}$. The apparent lack of direct

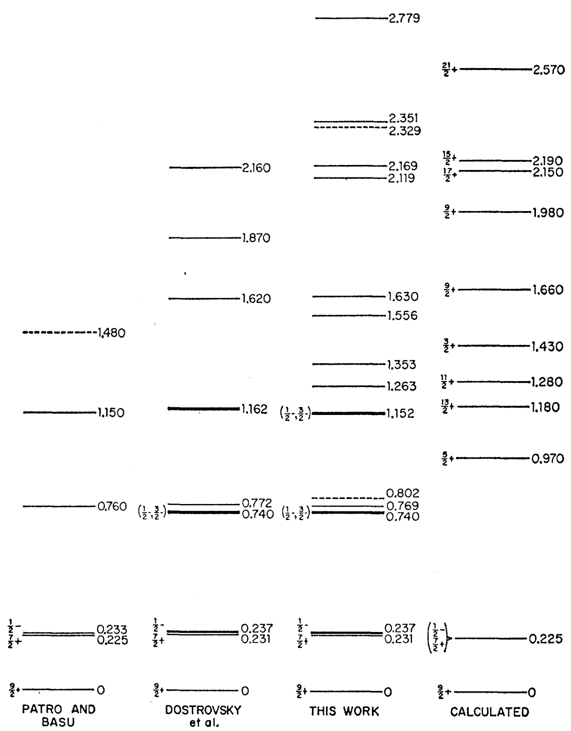

FIG. 13. Comparison of the energy levels or Sr^{85} reported in this work with those given in Refs. 4 and 5. The states populated in the 2.9-h decay are shown with heavy lines. The calculated levels are from Ref. 3. Level energies are given in mega-electron volts.

decay to the level at 1.556 MeV, and possibly the one at 1.630 MeV, plus the preference for decay from these levels to the first excited state rather than the ground state, might suggest spin $\frac{5}{2}$ for these two levels.

Talmi and Unna have reported calculations for the even parity levels in Sr^{85} which can be formed by $(g_{9/2})^{-3}$ and $(p_{1/2})^{-2}$ $(g_{9/2})^{-1}$ neutron configurations.[3] The results of their calculations are shown in Fig. 13. In the same figure are also shown the energy levels of Sr^{85} as reported by Patro and Basu,[4] Dostrovsky *et al.*,[5] and the present authors. It does not appear fruitful at this time to attempt a more detailed comparison of the level scheme proposed in this work with the theoretical predictions. However, it might be noted that the present work suggests the presence of considerably more $\frac{7}{2}+$ and $\frac{9}{2}+$ levels in Sr^{85} than would be predicted on the basis of the neutron configurations that were utilized in the calculations of Talmi and Unna.

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Errata

Mean Lives of the 2.15- and 1.74-MeV Levels in ^{10}B, J. A. LONERGAN AND D. J. DONAHUE [Phys. Rev. **139**, B1140 (1965)]. To obtain the mean lives quoted in this paper, the approximation was used that the time at which recoil ions reached the mean final velocity was their mean life. This proves to be not true for mean lives greater than about 10^{-13} sec. A more precise analysis of our data yields a value for the mean life of the 2.15-MeV state in ^{10}B of $(5\pm2)\times10^{-12}$ sec.