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Decays of $^{117}Xe \rightarrow {}^{117}I \rightarrow {}^{117}Te$

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Mass separated $^{117}Xe \rightarrow {}^{117}I \rightarrow {}^{117}Te$ decays were studied on-line by bombarding ^{104}Pd with 86 MeV ^{16}O ions and off-line by bombarding $^{107,109}Ag$ with 50–70 MeV ^{12}C. From gamma ray and x ray singles, half-life, excitation function, and coincidence measurements, 26 gamma rays are assigned to the decay of ^{117}Xe and 31 gamma rays are assigned to the ^{117}I decay. The half-lives were measured to be 61 ± 2 sec, 2.22 ± 0.04 min, 62 ± 2 min, and 2.8 ± 0.2 h for ^{117}Xe, ^{117}I, ^{117}Te, and ^{117}Sb, respectively. Eight new levels are deduced in ^{117}I and seven new levels in ^{117}Te. From the Kurie plot of the positron spectrum, the Q_{EC} ($^{117}Xe \rightarrow {}^{117}I$) was determined to be $\geq 6.27\pm0.30$ MeV.

INTRODUCTION

In one of the first experiments at UNISOR,[1] after its initial tests, a ^{104}Pd target was bombarded with 86 MeV ^{16}O from the Oak Ridge Isochronous Cyclotron to produce $^{115,116,117}Xe$ and to study their decays. Simultaneously, one of the first experiments of the group formed to study nuclei far from stability with the Lanchow cyclotron after it was modified to accelerate heavier ions like carbon, was to study the decays of $^{115,117,118}I$ found in the bombardment of natural silver with ^{12}C ions. The results of these complementary studies are reported here.

While the half-lives of ^{117}Xe and ^{117}I have been reported,[2] no levels in ^{117}I from the ^{117}Xe decay have been established previously. Levels in ^{117}I have been investigated via $^{109}Ag(^{12}C,4n)^{117}I$ (Ref. 3) and $^{114}Sn(^{6}Li,3n)^{117}I$ (Refs. 4 and 5) reactions. The latter established a $\frac{7}{2}^+$, 58 keV excited state with a sequence of high spin ($\frac{9}{2}^+$, $\frac{11}{2}^+$, $\frac{13}{2}^+$, . . .) states on top of that level.

In the present work we have established seven new low spin states up to 660.7 keV and one additional state at 1878.6 keV in ^{117}I. These are compared with the systematics of the levels in odd A iodine nuclei. In addition, seven new levels have been established in ^{117}Te from the decay of ^{117}I.

EXPERIMENTAL PROCEDURES AND RESULTS

For the UNISOR experiments an integrated-target ion source[1] was used. The recoils from the target were stopped by a tungsten catcher foil which was held at a high temperature so that the recoil products rapidly evaporated into the plasma region of the ion source. The nuclei were then electrostatically extracted and accelerated through focusing lenses into the separator magnet. In the off-line experiments, the mass 117 activity was deposited on aluminum foil tape located at the focal plane of the separator. Within approximately 2 min, the foils were extracted via a vacuum lock and carried to a nearby counting area. In the on-line experiments, a moving tape system was used to transport the activities rapidly to a position in front of the detectors. After separation, mass 117 activities passed along a 3 m drift tube and were deposited on an aluminized Mylar tape. A computer controlled tape drive moved the activities typically in less than 2 sec to a position between two detectors located 2 cm apart. Continuous collection and counting of new sources were carried out with this system.

At Lanchow the production of neutron deficient isotopes ^{118}I, ^{117}I, and ^{115}I was studied by means of the helium-jet technique by bombarding natural silver with ^{12}C ions with energies ranging from 50 to 70 MeV from the Lanchow cyclotron. The reaction products were transported through a 10-m long capillary and collected on a movable tape. Again continuous collection and counting of new sources were carried out with the movable tape system. The singles spectrum, time sequential spectra, and excitation functions for the γ-ray yields were measured with an 80 cm^3 Ge(Li) detector. In order to increase the transport efficiency of the iodine reaction products through a long capillary, $AgCl_2$ was added to the helium gas.

Multiscaled singles spectra and half-life determinations

The first UNISOR runs were off-line studies where series of spectra were recorded sequentially for each source. One such spectrum is shown in Fig. 1 as measured with a Ge(Li) detector with 18% efficiency relative to a 7.6 cm×7.6 cm NaI detector. Energy calibration was carried out with γ rays from ^{137}Cs, ^{60}Co, ^{241}Am, and the well-known γ rays in the ^{117}Te and ^{117}Sb decays. The detector efficiencies were measured with National Bureau of Standards (NBS) standard sources and known lines in the ^{117}Te and ^{117}Sb decays. Both the γ ray energies and intensities were calculated by fitting each peak to a Gaussian shape and determining the parameters of the peak.

Typically, off-line spectra were acquired in the multiscale mode for time periods of 30 sec duration for the first 20 spectra then in time periods of 200 sec duration until the total elapsed time approached 1 h. Then the source being counted was replaced by a new source which was produced in the separator during the recording period of the previous source. The short data collection periods at the beginning allowed the determination of the half-life of ^{117}I and the γ rays associated with this decay. The longer data collection periods at the end of the recording period facilitated the half-life and γ-ray measurements for ^{117}Te and ^{117}Sb.

In the on-line experiments, sources were collected and counted for time periods of 2 min to maximize the amount of ^{117}Xe present without allowing large buildups of ^{117}I. The sources were counted in the multiscale mode with the 18% efficient Ge(Li) detector. A Si(Li) detector was also used to record the x-ray spectrum from each source to provide additional information for the accurate determination of the half-lives involved and to allow clear determination of which half-life was associated with each nuclide. An on-line singles spectrum from summed multiscaled data is shown in Fig. 2.

In the multiscale mode, each 2 min counting period was divided into eight 15 sec time segments. The spectra recorded during each of the segments were used for the half-life determination of the gamma rays. The corresponding spectra from each of the sources were summed to provide better statistics for the gamma ray singles intensities. The total collection time for a typical on-line run was approximately 8 h.

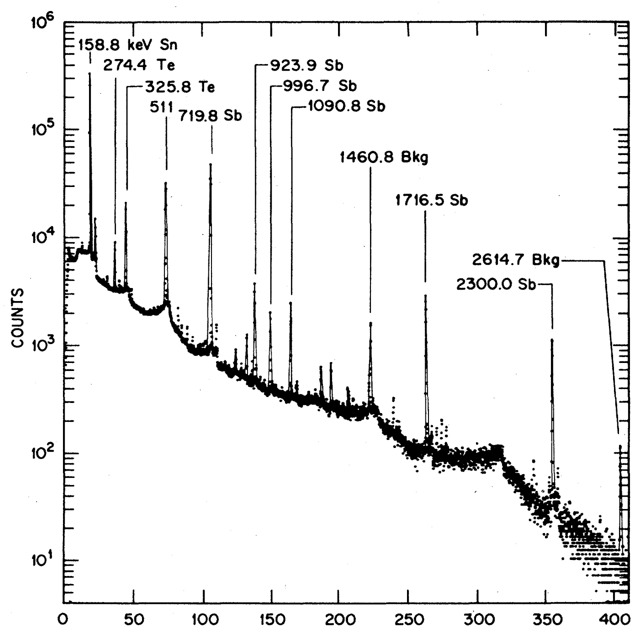

FIG. 1. A singles spectrum taken at UNISOR to emphasize the decay $^{117}I \rightarrow ^{117}Te$. The isotopes in which some of the prominent γ rays belong are given (e.g., if the γ ray is between levels in Te, it is so indicated by Te).

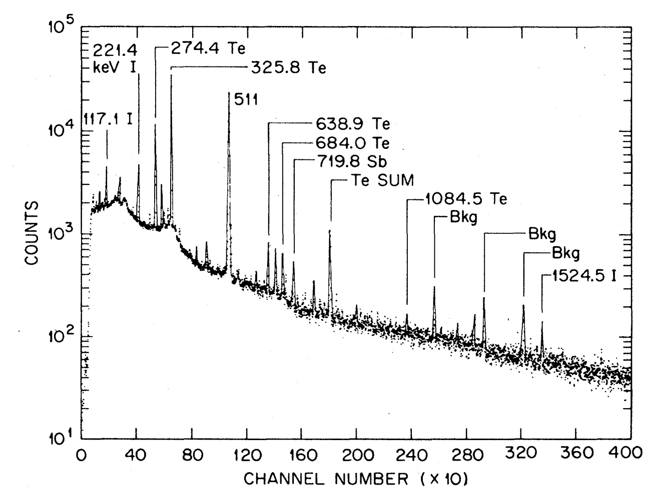

FIG. 2. A singles spectrum taken at UNISOR to emphasize the decay $^{117}Xe \rightarrow ^{117}I$. This is the sum of several spectra taken in multiscaling modes. Prominent transitions are identified by the isotope in which they occur.

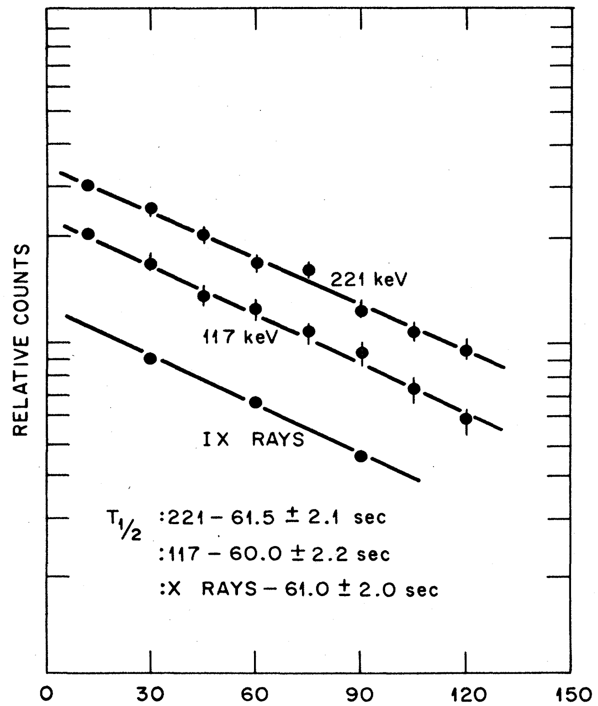

FIG. 3. Half-lives of the K x rays and most intense gamma rays in the ^{117}Xe decay.

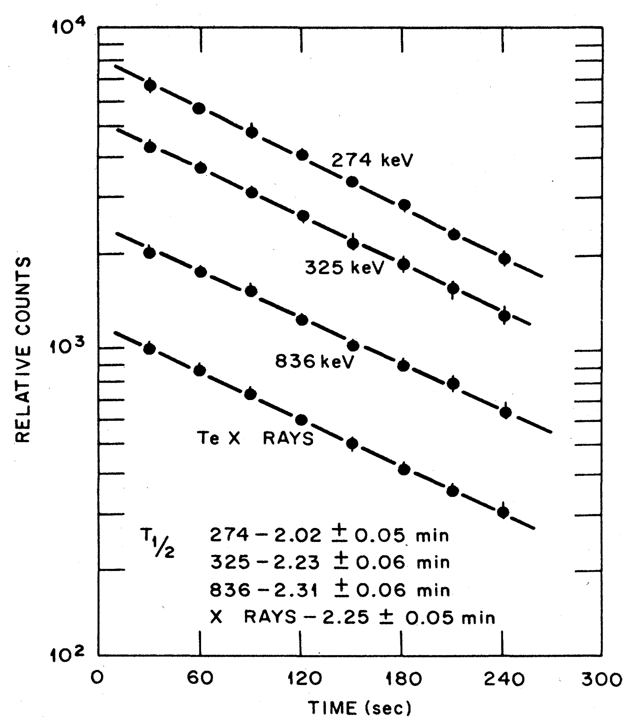

FIG. 4. Half-lives of the K x rays and gamma rays in the ^{117}I UNISOR work. The 836 keV peak is a sum of the 511 and the 325 keV γ rays.

Figures 3 and 4 show the results which were used to measure half-lives of ^{117}Xe and ^{117}I, respectively. The UNISOR data yielded values of 61 ± 2 sec and 2.20 ± 0.05 min, respectively, for the half-lives of the ^{117}Xe and ^{117}I decays, in reasonable agreement with previous results,[2] 65 ± 6 sec and 2.4 ± 0.1 min. No evidence was found for a longer 7 min ^{117}I half-life which was reported earlier.[6] The possibility of the existence of a long-lived isomeric state that was not populated by the production methods used in the UNISOR experiments cannot, of course, be ruled out but seems unlikely.

The decay curves for the 275.6, 326.9, and 604.2 keV transitions observed in the He jet work and obtained from eight time sequential spectra yielded half-lives of 1.8 ± 0.2 min for the 275.6 keV, 2.28 ± 0.09 min for the 326.9 keV, and 13.4 ± 0.14 min for the 604.2 keV transition. These energies were measured in Lanchow and have an accuracy of 0.5 keV. The half-life errors indicated are statistical ones only. The 275.6 keV line may be complex at the higher bombarding energies where the half-life was measured as discussed later. Our averaged half-life for ^{117}I is 2.22 ± 0.04 min.

The half-life of ^{117}Te was measured to be 62 ± 2 min, in agreement with the reported values[7–10] of 68.4 ± 5, 61 ± 2, 66 ± 6, and 65 ± 5 min. The half-life for ^{117}Sb was determined to be 2.8 ± 0.2 h, in agreement with the previously reported values of 2.76 ± 0.06 (Ref. 8), 2.8 ± 0.1 (Ref. 11), and 2.80 ± 0.1 (Ref. 12) h.

Gamma rays with intensities $\gtrsim 10$–20 percent of the most intense ones were assigned to particular decays from their measured half-lives. Assignments of the weaker lines were made on the basis of coincidence measurements. Tables I and II show the energies and intensities of the gamma rays assigned to the ^{117}Xe and ^{117}I decays.

Yield measurements

In the $^{107,109}Ag + ^{12}C$ reactions the yields of different gamma rays were measured from 50 to 70 MeV. The yield curve for the 604.2 keV transition agrees with that expected for a transition in ^{118}I where a transition of that energy is known. The surprise is that the 326.9 and 275.6 keV transitions seen in Lanchow have different yield curves. These data and relative intensities compared with the UNISOR data indicate that at low bombarding energy there may be present a second transition of about 326 keV at the Lanchow work. Also, since the 275.6 keV transition seen in Lanchow has a shorter half-life (however, there is agreement within two standard deviations), it is possible that the Lanchow 275.6 keV transition is also a doublet with a second component in the 1.3 min ^{115}I decay.

Coincidence measurements

A number of γ-γ coincidence experiments were performed with two Ge(Li) detectors of 18% efficiency each positioned 2 cm apart in a 180 deg geometry at UNISOR. A nuclear data 3300 dual parameter analyzer system was used for the first on-line coincidence experiments. The Xe-I coincidence data were recorded in five separate ex-

TABLE I. Transitions in ^{117}I from the decay of ^{117}Xe. x indicates transition placed in the decay scheme.

	This work		Other works		
	Energy (keV)	Relative intensity (%)	Energy (keV)		Relative intensity (%)
	45.6±0.4	3.1±0.6			
x	59.7±0.2	25.7±1.4			
x	94.9±0.2	14.9±0.7	Conlon (Ref. 3)[a]		
x	104.3±0.3	6.2±0.6	^{107,109}Ag(^{12}C,xn)$^{114-117}$I		
x	117.1±0.2	41.0±2.0			
x	155.4±0.2	11.0±0.6	46.9±1.0		95±25
x	160.7±0.2	33.8±1.7	90.9±0.6		93±10
x	203.3±0.5	4.5±0.7	275.3±0.6		330±20[b]
x	221.4±0.2	100	322.5±0.5		970±5[b]
x	256.9±0.3	16.6±0.9			
x	294.8±0.5	74.4±3.7			
x	316.1±0.2	25.6±1.3			
	323.6±0.5	weak	Gai *et al.* (Ref. 5)		
x	344.2±0.2	5.9±0.3			
x	353.5±0.2	14.2±0.9	^{114}Sn(^{6}Li,3n)^{117}I		
	410.6±0.5	weak			
x	438.8±0.2	19.9±1.0			
	450.4±0.2	6.9±0.4	58.4±0.3		
x	519.1±0.2	55.4±2.8	294.8±0.3	100	
x	543.8±0.2	8.5±0.8	300.6±0.3	60	
x	660.9±0.4	23.2±2.0	317.6±0.3	35	
	714.7±0.3	9.8±0.5	337.5±0.3	66	
	733.1±0.3	10.1±0.5	346.3±0.3	17	
	757.2±0.2	15.8±1.0	353.4±0.3	8	
	1433.6±0.2	7.2±0.8	368 ±1		
x	1524.5±0.2	23.7±1.2	470.8±0.3	38	
			605 ±1	32	
			619.7±0.3	36	
			663.1±0.3	42	
			714 ±1		

[a]These transitions could also be in the decay of ^{115}I.
[b]Possibly in the ^{117}I to ^{117}Te decay.

TABLE II. Transitions in ^{117}Te from the decay of ^{117}I. x indicates the transition is placed in the decay scheme.

	This work		Other works	
	Energy (keV)	Relative intensity (%)	Energy (keV)	Relative intensity (%)
x	21.6±0.5	0.3±0.1		
x	30.1±0.5	0.1±0.1		
	45.6±0.5	0.3±0.1		
x	52.2±0.5	0.5±0.1	Brinckmann *et al.* (Ref. 17)	
	112.3±0.5	0.4±0.1		
	122.2±0.5	0.3±0.1	21.6±0.2	
x	274.4±0.2	27.2±1.4	274.4±0.2	
x	296.0±0.5	0.6±0.3		
x	303.4±0.5	1.5±0.1		
x	325.8±0.2	100		
x	340.9±0.5	0.6±0.1		
	353.0±0.5	0.6±0.1	Ladenbauer-Bellis *et al.* (Ref. 18)	
x	407.0±0.5	1.1±0.1		
	475.9±0.5	0.6±0.1	274 ±1	21%
	583.3±0.5	0.7±0.1	325 ±1	100%
x	609.8±0.5	0.6±0.3	599 ±1	16%

TABLE II. (*Continued*).

This work			Other works	
	Energy (keV)	Relative intensity (%)	Energy (keV)	Relative intensity (%)
x	638.9±0.5	3.3±0.2		
	655.4±0.5	0.5±0.1		
x	661.5±0.5	6.8±2.0		
x	684.0±0.5	4.3±0.3		
x	689.7±0.5	0.8±0.1		
	695.8±0.5	1.7±0.1		
	858.8±0.5	1.3±0.1		
x	935.5±0.5	0.6±0.1		
x	948.6±0.5	0.4±0.1		
x	964.4±0.5	0.9±0.1		
x	969.9±0.5	0.7±0.1		
	989.7±0.5	0.6±0.1		
	1084.5±0.5	0.8±0.1		
	1232.4±0.5	0.4±0.1		
x	1302.9±0.5	1.7±0.1		

periments of several hours each; one had a 60 sec observation with a new source being prepared during this time, with the next period added to it. Three runs had 2 min observations while a new source was collected and one run had 4 min observation-collection times. More than one million events from the decays of ^{117}Xe and ^{117}I were recorded. The same equipment was used for the off-line studies where first 1 h and then 2 h counting-collection periods were used for the ^{117}Te and ^{117}Sb decays, in which approximately two million coincidence events were recorded.

Additional coincidence runs were performed with the same detectors but with a TP-5000 multiparameter system. In these later experiments, several million coincidence events were recorded during several different experimental runs. Figures 5 and 6 are representative of gated coincidence spectra observed in the initial and later runs. Tables III and IV summarize the coincidence results for the ^{117}Xe and ^{117}I decays.

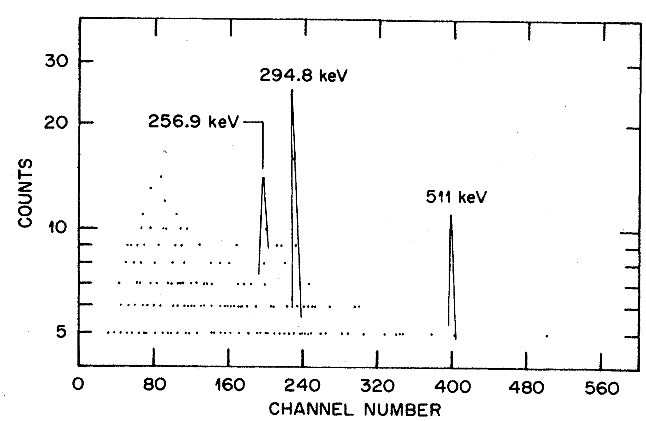

FIG. 5. Coincidence spectrum gated by the 59.7 keV γ ray in the decay of ^{117}Xe.

^{117}Xe-^{117}I mass difference

In a related experiment in which ^{117}Xe was produced as described above, the positrons from the decays of ^{117}Xe and ^{117}I were detected with a 7.5×7.5 cm diam cylindrical plastic scintillator. Spectra were acquired during 1-min intervals for a total of ten intervals. In the analysis, the energy spectra were divided into 12 sections and the yields of each section plotted versus the ten time intervals. It was found that the highest energy positrons (4.38—5.30 MeV) decayed with the 60-sec half-life of ^{117}Xe. The lower energy positrons decayed with a half-life of approximately 2.5 min, and evidently were due to the decay of ^{117}I.

From a Kurie plot of yield of positrons the end point energy of the highest-energy group was determined to be 5.25 ± 0.30 MeV. The energy calibration for the positron

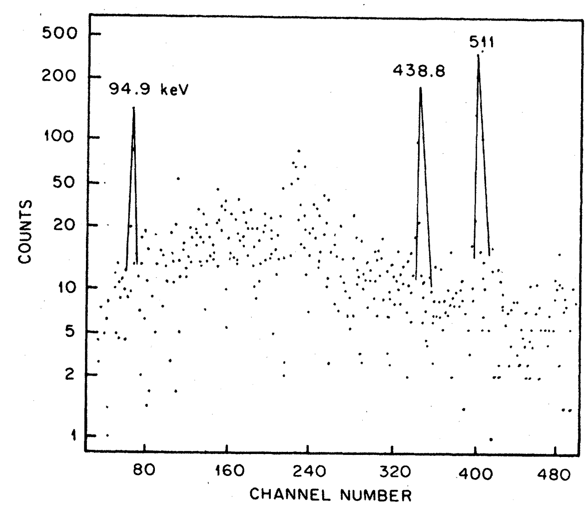

FIG. 6. Coincidence spectrum gated by the 221.4 keV γ ray in the decay of ^{117}Xe.

TABLE III. Coincidence data for transitions in ^{117}I following the decay of ^{117}Xe. [(w) indicates the transition is seen weakly in the gate; (*) indicates that only 511 keV annihilation radiation is seen above background. The 203.3 keV γ ray was too weak to be seen.]

Gate energy (keV)	Coincident transition energy (keV)
59.7	256.9(w), 294.8
94.9	104.3(w), 221.4
117.1	104.3, 543.8(w)
155.4	160.7
160.7	155.4,
203.3	94.9, 155.4(w), 221.4(w) , 256.9(w), 316.1(w)
221.4	94.9, 438.8
256.9	(*)
294.8	1524.5
316.1	(*)
1524.5	294.8

spectrum was obtained by calibrating the spectrometer with Compton edges and beta-ray end points from standard radioactive sources. Linearity was verified up to 5 MeV by use of short-lived beta sources prepared at the University of Kentucky 6-MV accelerator. If one assumes that the ground-state to ground-state transition was observed, the Q_{EC} for the decay of ^{117}Xe is 6.27 ± 0.30 MeV. In any case, this number is a lower limit for the Q_{EC}. For comparison, there is the report of Beck[13] who gives $Q_{EC}\geq 6020\pm160$ keV. Model predictions[14] range from 2.43 to 6.88 MeV, with the Seeger and Howard[14] value of 6.30 MeV giving the best agreement with the experimental result.

Energy levels in ^{117}I

In 1973, Conlon[3] reported an isomeric state in ^{115}I or ^{117}I following the production of iodine via the ^{107,109}Ag(^{12}C,xn)$^{114-117}$I reactions. A conclusive identification of the isotope was not possible at that time, but a lifetime of 144 μsec was reported for an isomeric state that was assigned an energy of 413 keV.[3] Additional levels were proposed at 323 and 47 keV. In the present work transitions with similar energies 45.6, 323.6, and 410.6 keV are observed. However, the intensities of these gamma rays are small and their locations adjacent to much more intense peaks make their assignment to the decay of ^{117}Xe difficult. For a ground state spin of ^{117}Xe of $\frac{3}{2}^+$, direct feeding of the suggested 413 keV $\frac{11}{12}^-$ level would be unlikely in our work. At best, our data can only suggest that the results presented by Conlon[3] are possible. However, his results[3] are not supported by other in-beam data on high spin excited states in ^{117}I via the ^{114}Sn(^{6}Li,3nγ)^{117}I reaction,[4,5] where no gamma transitions which correspond to those of Conlon[3] were reported. This would suggest that the proposed 413 keV isomeric state is not in ^{117}I.

In their most recent publication, Gai *et al.*[5] report levels at 58 keV, $\frac{7}{2}^+$; 353 keV, $\frac{9}{2}^+$; 620 keV, $\frac{9}{2}^+$; 654 keV, $\frac{11}{2}^+$; 663 keV, $\frac{11}{2}^-$; 972 keV, $\frac{13}{2}^+$; 1000 keV, $\frac{15}{2}^-$; 1318 keV, $\frac{15}{2}^+$; 1472 keV, $\frac{19}{2}^-$; and 1686 keV, $\frac{17}{2}^+$. Three of their levels have energies similar to ones deduced from our coincidence data. These correspondences will be discussed below.

Many of the most intense γ rays in the ^{117}Xe decay are not in coincidence (see Tables I and III). Thus, most of the strong γ rays feed the ground state. The excited states in ^{117}I populated by ^{117}Xe, as determined from our singles and coincidence data, are shown in Fig. 7 and are discussed below. The branching ratios and absolute intensities of the beta delayed protons from ^{115,117}Xe decays suggest a ground state spin of $\frac{5}{2}^+$ for ^{115}Xe and $\frac{3}{2}^+$ for ^{117}Xe (Ref. 15). If the ground state spin of ^{117}Xe is $\frac{3}{2}^+$, then all the levels, in Fig. 7, have possible spins of $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, or $\frac{7}{2}$ under the assumption that their direct beta feeding is allowed or at most first forbidden.

The 59.2+0.4 keV level

A level at 58 KeV with $I^{\pi}=\frac{7}{2}^+$ was reported from the ^{114}Sn(^{6}Li,3nγ)^{117}I reaction.[5] Our data established a level

TABLE IV. Coincidence data for transitions in ^{117}Te following the decay of ^{117}I. [(w) indicates the transition was seen weakly.]

Gate energy (keV)	Coincident transition energy (keV)
274.4	303.4, 407.0, 475.9, 661.5, 684.0, 689.7, 969.9(w), 1302.9
303.4	274.4
325.8	638.9
407.0	274.4
684.0	274.4, 340.9
1302.9	274.4

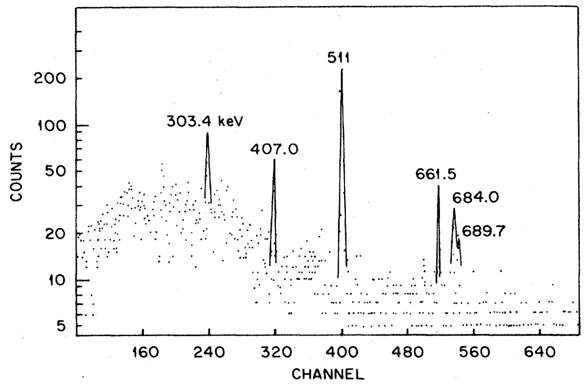

FIG. 7. Level scheme of ^{117}I based on gamma-gamma coincidence data and energy sums. Spins and parities are assigned on the basis of the odd-mass iodine systematics. A dot on a transition indicates a coincidence relation with a transition feeding or depopulating the level. The star on the ($\frac{7}{2}^+$) indicates an alternate interpretation as discussed in the text. The 353.6 keV level may be a low and high spin doublet, and much less likely so could be the 660.6 keV level, see the text.

with an energy of 59.2 keV (from averaging the 59.7 keV transition with the energy differences of the transitions from the 316.2 and 353.6 keV levels). Our evidence for this level is a 59.7 keV transition in the singles spectrum and the presence of the 294.8 and 256.9 keV lines (from the 316.2 and 353.6 keV levels) in the 59.7 keV coincidence gate (see Fig. 5). It is not definite that the level we observe is the same one seen in the reaction work.[4,5] As discussed in the level systematics, we believe that the level we observe is a $\frac{1}{2}^+$ state and not the $\frac{7}{2}^+$ one seen in reaction studies.[5]

The 117.1±0.2 keV level

The 117.1 keV level is the lowest energy state deduced solely from the UNISOR data. The absence of the other very intense lines in the 117 keV gate supports this assignment. Coincidence with the 104.3 keV transition which sums to the energy of the 221.4 keV level established below confirms this level.

The 160.7±0.2 keV level

The present data show that the 160.7 keV transition and the 155.4 keV transition are in coincidence. Neither of these transitions are coincident with any of the other strong transitions. These facts support a level at either 160.7 or 155.4 keV. However, the intensity of the 160.7 keV transition is larger than that of the 155.4 keV transition. Thus, a level is placed at 160.7 keV. A spin parity of $\frac{3}{2}^+$ is suggested by the systematics discussed below.

The 221.4±0.2 keV level

The 221.4 keV line is the strongest one in the singles data, and the obvious absence of this line in any of the coincidence gates of the strong lines establishes a level at 221.4 keV. Additional support is provided by the presence of the 104.3 keV line in the 117.1 keV gate. A tentative assignment of $\frac{3}{2}^+$ for this level is made on the basis of the iodine systematics discussed later.

The 316.2±0.2 keV level

The assignment of this level is based on the coincidence data of the 160.7 and 155.4 keV gates. The fact that these two gamma rays are in coincidence and that their energies sum to 316.1 keV, plus the existence of a gamma ray with energy 316.1 keV in the singles data, establishes a level at this energy. Care was taken to ensure that the 316.1 keV line in the singles was actually a real transition and not just the summing of the 155.4 and 160.7 keV gamma rays. The level is confirmed by the presence of the 94.9 keV transition in the 221.4 keV gate (see Fig. 6).

The 353.6±0.7 keV level

Gai *et al.*[5] report a $\frac{9}{2}^+$ level at 353.4±0.3 keV. Our data also provide evidence for a level at 353.6 keV. The singles data show a gamma ray with energy 353.5 keV. Our coincidence data show that the 294.8 keV transition and the 59.7 keV transition are coincident. These two energies sum to 354.5±0.7 keV. (The error on the 59.7 keV transition energy may be underestimated.) It is possible that there are two levels at nearly the same energy. Since the 353 keV level seen in the reaction data has a spin of $\frac{9}{2}^+$, it is probably not the same level as seen in the ^{117}Xe decay which should not have a strong beta branch to a $\frac{9}{2}^+$ level. However, if the $\frac{3}{2}^+$ is incorrect, and $\frac{7}{2}^+$ is correct for the ^{117}Xe ground state, then these would likely be the same levels.

The 519.2±0.2 keV level

This level is assigned on the basis of the existence of a 519.1 keV transition which is not in coincidence with any of the other strong lines. Additional evidence is provided in the 203.3 keV gate by the presence of the 316.1 keV line.

The 660.6±0.2 keV level

This level is assigned on the basis of three facts. First, the 660.9 keV gamma ray is not in coincidence with any of the other intense gamma rays in the ^{117}Xe decay. Second, the 438.8 keV line is strong in the 221.4 keV gate (see Fig. 6). Third, the 543.8 keV line is indicated in the 117.1 keV coincidence gate. Additional evidence is provided by the energy sum of the 344.2 and 316.1 keV transitions. The $\frac{11}{2}^-$, 663 keV level reported from the reaction studies[4] is very unlikely to be the same level as seen in the present work unless there is an unknown high spin isomer in ^{117}Xe with a half-life similar to that of the ground state or the ^{117}Xe spin is higher and not $\frac{3}{2}^+$. Also the multiple decay modes of our 660.6 keV level, including a strong decay to the $\frac{5}{2}^+$ ground state, argue strongly against $\frac{11}{2}^-$ for the level we observe.

The 1878.1±0.8 keV level

This level is based on the coincidence of the 1524.5 keV and the 294.8 gamma rays. No transitions from the 1878.1 keV level to other lower energy states are established by our data.

Iodine level systematics

The systematics of the odd mass iodine isotopes are shown in Fig. 8. In ^{117}I one finds that the $\frac{7}{2}^+$ level continues to drop, as seen in ^{119}I after its maximum energy in $^{121-123}$I compared to the $\frac{5}{2}^+$ level. From a comparison of Figs. 7 and 8, one is tempted to identify the $\frac{3}{2}^+$ level at nearly constant energy of 180 keV in $^{119-125}$I, with the 160.7 keV level in ^{117}I and the 221.4 keV ^{117}I level with the second $\frac{3}{2}^+$ level seen in the heavier isotopes at a similar energy. The 316.2 keV level could similarly be connected with the $\frac{5}{2}^+$ level at 321 and 310 keV in ^{119,121}I, respectively. A puzzling question from the systematics is that of the $\frac{1}{2}^+$ level which drops continuously with decreasing N. A $\frac{1}{2}^+$ state should be populated under the assumption that the ^{117}Xe ground state is $\frac{3}{2}^+$. If the 117 keV ^{117}I level would have $\frac{1}{2}^+$, then there is a sharp break in the energy trend. It is possible that the $\frac{1}{2}^+$ level lies well below 60 keV, and its decay was masked by other lines in the low energy spectrum. The third possibility is that the 59.7 keV level we see is in fact the $\frac{1}{2}^+$ level and not the $\frac{7}{2}^+$ level seen in reaction studies.[4] The γ-ray intensities and theoretical conversion coefficients indicate strong beta population to the 59.7 keV level. A $\frac{1}{2}^+$ assignment for the level we observe is more reasonable than $\frac{7}{2}^+$ because a $\frac{7}{2}^+$ assignment would involve a second forbidden unique beta decay or higher for a $\frac{3}{2}^+$ assignment for the ground state of ^{117}Xe. If the spin assignment from the delayed proton measurement is incorrect, the ^{117}Xe spin could be $\frac{7}{2}^+$ as proposed for ^{119}Xe. Then one would see beta decay to the 58 keV $\frac{7}{2}^+$ and 353 keV $\frac{9}{2}^+$ levels as reported from in-beam studies. In this case, our other collective spin assignments in Fig. 7 also would change. At present we suggest that there are two levels at 58 and

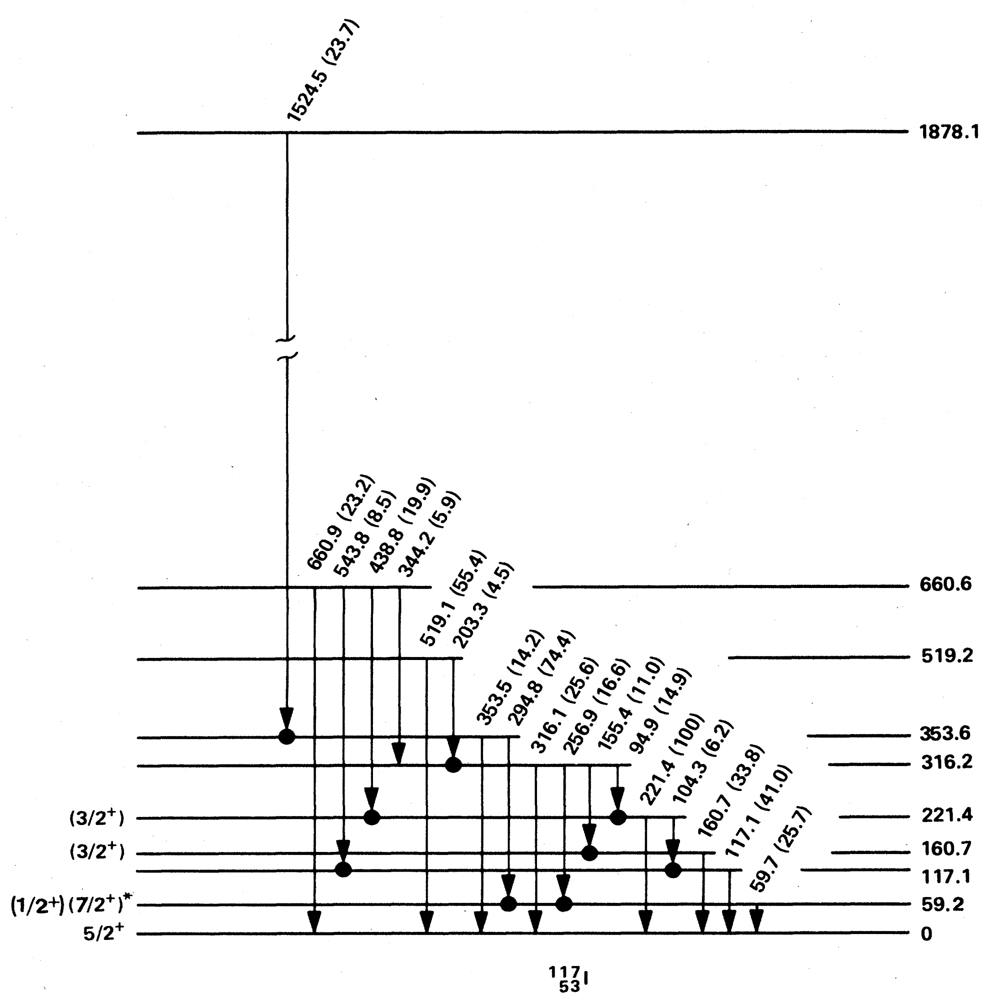

FIG. 8. The systematics for the odd mass iodine isotopes. Data are taken from the Nuclear Data Tables, and from the 354 and 661 keV levels in ^{117}Xe may be low and high spin doublet, for the isotopes with $A \geq 119$. The 59 and 58 keV levels are shown in parentheses because it is possible that there is only one level at this energy as discussed in the text.

59 keV in ^{117}I with $I^{\pi} = \frac{7}{2}^{+}$ and $\frac{1}{2}^{+}$, respectively, as shown in Fig. 8.

Levels in ^{117}Te

The levels in ^{117}Te populated by the decay of ^{117}I are discussed below. Several of these levels have been previously reported, and these will be discussed first. Following these discussions, levels assigned on the basis of the present data will be reported and discussed. Figure 9 shows the excited states in ^{117}Te as discussed below.

The 274.4±0.2 keV ($\frac{5}{2}^{+}$) level

This level is reported as the first excited state in ^{117}Te by other research groups.[16,17] A tentative assignment of $\frac{5}{2}^{+}$ for the spin and parity has been given to this level.[17] The coincidence data of the present work support a level at this energy. The 684.0 keV gated coincidence spectrum indicates that this level has a half-life comparable to the known resolving time of the coincidence circuit, which was ~50 nsec. From the loss of 274.4 keV γ-ray intensity in the 684.0 keV gated spectrum, we estimate this half-life to be in the range of 40–120 nsec.

The 296.0±0.4 keV level

This level was initially reported by Brinckmann *et al.*[17] on the basis of an observed 21.6 keV transition in coincidence with the 274.4 keV γ ray. The 21.6 keV transition was deduced[17] to be $M1$, and the 296.0 keV level proposed to have $I = \frac{7}{2}^{+}$. However, $\frac{3}{2}^{+}$ or $\frac{5}{2}^{+}$ are equally allowed. A 296.0 keV transition to the ground state, placed on the basis of an energy fit and weak coincidence data, would suggest $\frac{3}{2}^{+}$ or $\frac{5}{2}^{+}$ for this level. An $\frac{11}{2}^{-}$ isomeric state[16] in ^{117}Te was assumed[17] to lie slightly higher in energy than 296.0 keV. We find no evidence for this isomer in our work, but a $\frac{11}{2}^{-}$ state should not be populated by low spin ^{117}I.

The 325.9±0.3 keV ($\frac{3}{2}^{+}$) level

This level was reported as the first excited state for ^{117}Te by Ladenbauer-Bellis *et al.*[18] Our data support this energy level which is the third excited state seen in our work.

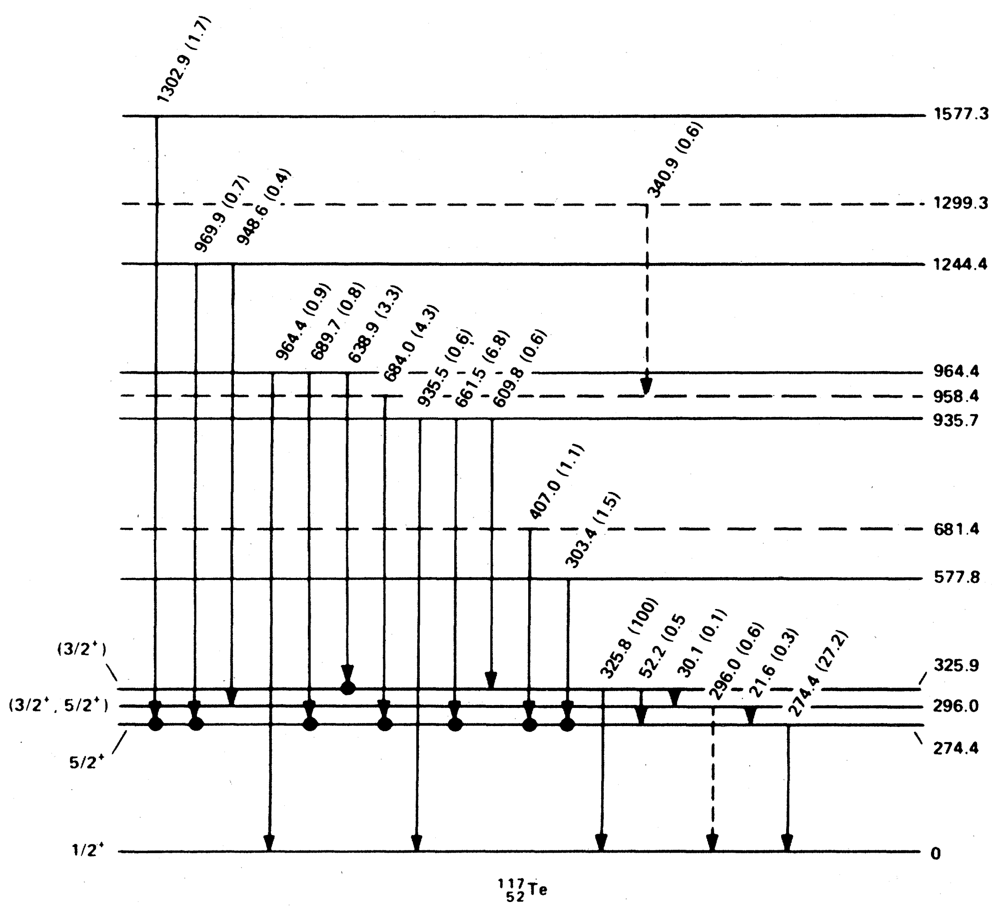

FIG. 9. Level scheme for ^{117}Te. Dots indicate coincidence relations with transitions depopulating a level. The 681.4 and 958.4 keV levels could be 21.6 keV higher as discussed in the text and so are shown as dashed lines.

The 599 keV level

Ladenbauer-Bellis *et al.*[18] also reported a level at 599 keV. Their justification for this level was an observed coincidence between the 325.8 keV gamma ray and the 274.4 keV gamma ray and the existence of a 599 keV gamma line in the singles data of their work.

In our coincidence data, there is no evidence of a coincidence between the 325.8 and 274.4 keV gamma rays in either the 274.4 or 325.8 keV gates. Since these are the two most intense lines in the singles data of the decay of ^{117}I, such a coincidence should be very evident if present. On this basis, we conclude that the 599 keV level does not exist, and that the 599 keV gamma ray is the result of chance summing of the 325.8 and 274.4 keV gamma rays.

The following new levels are deduced on the basis of the coincidence data and energy summing. No assignment of spins or parities is attempted here. The levels are presented in the order of increasing energy which is not necessarily the order of highest confidence.

The 577.8±0.6 and 681.4±0.6 (or 703.0) keV levels

The 303.4 and 407.0 keV transitions are seen in the 274.4 keV gate and only the 274.4 keV transition in the 303.4 and 407.0 keV gates. For $\alpha \lesssim 10$ for the 21.6 keV transition, one can exclude the possibility that the 303.4 keV transition feeds the 296.0 keV level by the absence of the 296 keV transition in the 303 keV gate. Thus the 303.4 keV transition feeds the 274.4 keV level to establish the 577.8 keV level. The exclusion of the 296 keV transition is not possible in the 407.0 keV gate. So there the level energy can be either 681.4 or 703.0 keV. No other transitions are seen in or out of these levels, but weak transitions could have been missed.

The 935.7±0.4 keV level

The presence of a transition with an energy of 661.5 keV in the 274.4 keV gate indicates the existence of this level. Additional support is given by the existence of a 935.5 keV line in the singles data. (This is not a sum peak since no sum peak is seen for the 684.0 keV transition.) Also the weak 609.8 keV line can be fitted as connecting this level to the 325.9 keV level.

The 958.4±0.6 (or 980.0) keV level

The 684.0 keV transition is seen in the 274.4 keV gate with the right singles intensity. In the 684.0 keV gate one sees the 274.4 and 340.9 keV transitions, but cannot exclude a 296.0 keV transition with branching via the 21.6 keV transition. Thus, this band could feed the 296.0 keV level and so have the alternate energy shown of 980.0 keV. The 340.9 keV transition is tentatively placed as feeding this level.

The 964.4±0.4 keV level

Evidence for this level comes from two coincidence gates. In the 274.4 keV gate, a 689.7 keV line is seen and in the 325.8 keV gate the 638.9 keV line is seen. There is also a 964.4 keV line seen in the singles data.

The 1244.4±0.5 keV level

The level is based on the presence of the 969.9 keV line in the 274.4 keV gate. The 948.6 keV line fits energetically from this level to the 296.0 keV level. No peak with an energy of 1244.4 keV is seen in the singles data.

The 1299.3±0.8 keV level

This level is based on the presence of the 340.9 keV transition in the 684.0 keV gate. Since only this coincidence relation was observed, this level is considered tentative and so is dashed in Fig. 9.

The 1577.3±0.6 keV level

The presence of this level is deduced from the strong presence of the 1302.9 keV gamma ray in the 274.4 keV gate. Both of these lines have sufficiently large intensities to be clearly linked to the 2.2 min half-life of ^{117}I. In the 1302.9 keV gate the presence of a 296 keV transition is excluded under the assumption as given for the 577.8 keV level. So this level feeds the 274.4 keV level directly.

The UNISOR experiments were designed to yield maximum information about the ^{117}Xe and ^{117}I decays. For this reason, information obtained from the ^{117}Te and ^{117}Sb decays is small. Only the stronger transitions in the latter decays were seen.

The excited states in ^{117}Sb populated by the decay of ^{117}Te have been studied by Berzins *et al.*[7] Berzins *et al.* tentatively report a level with a tentative 2213 keV transition to the ground state. In our work the 2213 keV transition is seen, and in addition, in the 923.9 keV gate a transition with energy 1289.1 keV is clearly seen. The presence of the 2213 keV line and the 924—1289 keV coincidence establish a level at 2213 keV.

Our data gives no new information for the decay of ^{117}Sb to excited states of ^{117}Sn. What information there is agrees with the works of Beery *et al.*[19] and Heath.[20]

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[1]R. L. Mlekodaj, E. H. Spejewski, H. K. Carter, and A. S. Schmidt, Nucl. Instrum. Methods **139**, 299 (1976).

[2]P. G. Hansen, P. Hornshøj, H. L. Nielsen, K. Wilsky, H. Kugler, G. Astner, E. Hagebø, J. Hudis, A. Kjelberg, F. Munnich, P. Patzelt, M. Alpsten, G. Andersson, Aa. Appleqvist, B. Bengtsson, R. A. Naumann, O. B. Neilsen, E. Bech, R. Foucher, J. P. Husson, J. Jastrzebski, A. Johnson, J. Alstad, T. Jahnson, A. C. Pappas, T. Tunaal, R. Henck, P. Siffert, and G. Rudstam, Phys. Lett. **28B**, 415 (1969).

[3]T. W. Conlon, Nucl. Phys. **A213**, 445 (1973).

[4(a)]D. B. Fossan, M. Gai, A. K. Gaigalas, D. M. Gordon, R. E. Shroy, K. Heyde, M. Waroquier, H. Vincx, and P. Van Isacker, Phys. Rev. C **15**, 1732 (1977). [(b)] D. M. Gordon, M. Gai, A. K. Gaigalas, R. E. Shroy, and D. B. Fossan, Phys. Lett. **67B**, 161 (1977).

[5]M. Gai, D. M. Gordon, R. E. Shroy, D. B. Fossan, and A. K. Gaigalas, Phys. Rev. C **26**, 1101 (1982).

[6]G. Andersson, G. Rudstam, and G. Sorensen, Ark. Fys. **28**, 37 (1965).

[7]G. Berzins, W. H. Kelley, G. Graeffe, and W. B. Walters, Nucl. Phys. **A104**, 241 (1967).

[8]R. W. Fink, G. Andersson, and J. Kantele, Ark. Fys. **19**, 323 (1961).

[9]N. A. Vartanov *et al.,* Zh. Eksp. Teor. Fiz. **41**, 303 (1961) [Sov. Phys.—JETP **14**, 215 (1962)].

[10]D. E. Khulelidze *et al.,* Izv. Akad. Nauk. SSSR, Ser. Fiz. **26**, 1026 (1962).

[11]K. A. Baskova, S. S. Vasilev, M. A. Khamo-Leila, and L. Ya. Shavtvalov, Zh. Eksp. Teor. Fiz. **47**, 1162 (1964) [Sov. Phys.—JETP **20**, 781 (1965)].

[12]C. Ekstrom, W. Hagervorst, S. Ingleman, and G. Wannaberg, Nucl. Phys. **A226**, 219 (1974).

[13]E. Beck, International Conference on the Properties of Nuclei Far from the Region of Beta-Stability, Leysin, Switzerland, 1970, CERN Report 70-30, 1970, p. 353.

[14]A. H. Wapstra and K. Bos, At. Data Nucl. Data Tables **17**, 474 (1976).

[15]P. Hornshoj, K. Wilsky, P. G. Hansen, B. Jonson, and O. B. Nielsen, Nucl. Phys. **A187**, 609 (1972).

[16]H. F. Brinckmann, C. Heiser, and U. Hagemann, Nucl. Phys. **A123**, 689 (1969).

[17]H. F. Brinckmann, W. D. Fromm, C. Heiser, H. Rotter, D. D. Clark, N. J. S. Hansen, and J. Pedersen, Nucl. Phys. **A193**, 236 (1972).

[18]I. M. Ladenbauer-Bellis, H. Bakhru, and A. Luzzati, Phys. Rev. **187**, 1739 (1969).

[19]D. B. Beery, G. Berzins, W. B. Chaffee, W. H. Kelly, and Wm. C. McHarris, Nucl. Phys. **A123**, 649 (1969).

[20]R. L. Heath, Aerojet Nuclear Company Report ANCR-1000-2, 1974.