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Levels of ^{138}Cs Fed in the β-Decay of ^{138}Xe

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The energy levels of ^{138}Cs populated in the decay of 14.2-min ^{138}Xe have been investigated using on-line techniques. The γ-ray energies and intensities in the range 0.1–2.5 MeV were determined with Ge(Li) detectors. Using a Si(Li) x-ray detector, a 10.7-keV γ ray was found and its L-shell conversion coefficient determined to be 150 ± 70. Conversion-electron lines have been measured with a Si(Li) detector and the following K conversion coefficients have been calculated (transition energies in keV, within brackets): $(290 \pm 30)\times 10^{-3}$ [154.0], $(62 \pm 14)\times 10^{-3}$ [242.8], $(56 \pm 5)\times 10^{-3}$ [258.5], $(16 \pm 3)\times 10^{-3}$ [396.7], $(37 \pm 8)\times 10^{-3}$ [401.5], and $(15 \pm 2)\times 10^{-3}$ [434.6]. Ge(Li)-Ge(Li) and Si(Li)-Ge(Li) γ-γ coincidences have been measured. From these experiments the following level sequence is proposed (energies in keV, J^π within brackets): 0 [$3^{(-)}$]; 10.79 ± 0.11 [$2^{(-)}$]; 15.71 ± 0.12 [$1^{(-)}, 0^{(-)}, 2^{(-)}$]; 258.49 ± 0.11 [$2^{(-)}, 1^{(-)}$]; 412.45 ± 0.16 [$1^{(-)}$]; 450.33 ± 0.16 [$0^{(-)}, 1^{(-)}$]; 541.05 ± 0.13; 815.7 ± 0.4; 876.21 ± 0.22; 912.62 ± 0.14 [$1^{(-)}, 2^{(-)}$]; 951.6 ± 0.4; 1109.67 ± 0.17; 1127.0 ± 0.3 [$0^\pm, 1^\pm, 2^-$]; 1367.5 ± 0.3; 1395.8 ± 0.4; 1489.0 ± 0.4; 2026.67 ± 0.17 [1^+]; 2263.01 ± 0.23 [1^+]; 2337.62 ± 0.19 [1^+]; 2468.5 ± 0.5 [0,1]; and 2509.00 ± 0.24 [1^+].

I. INTRODUCTION

Nagahara *et al.*[1] studied ^{138}Xe activities extracted chemically from ^{235}U fission products, and, based on singles and coincidence measurements, proposed a level scheme with excited levels at 15.4, 258.2, 411.4, 434.6 (or 450.0), 2028.2, and 2413.4 keV. They concluded that the existence of the 15.4-keV level would seem reasonable, even though no low-energy transition was observed which could depopulate this level.

We investigated the low-energy γ-ray region using a Si(Li) x-ray detector in search of the transitions responsible for the depopulation of the proposed 15.4-keV level and a γ ray of 10.7 keV was found. Further studies at this low-energy region, as well as at energies up to 4.0 MeV, showed that previous level schemes[1,2] could be substantially improved.

Medium- and high-energy γ rays were investigated with Ge(Li) detectors. These, and a Si(Li) x-ray detector, were used to perform γ-γ coincidence experiments. Conversion coefficients were determined for several transitions by measuring the electron lines with a solid-state detector.

In this work 55 transitions are assigned to the ^{138}Xe decay and a well-supported level scheme consisting of 20 levels is proposed, with spin and parity assignments for 12 of them.

II. EXPERIMENTAL PROCEDURE

A target of uranyl stearate containing 14 g of ^{235}U was enclosed in a stainless-steel container and exposed to a thermal-neutron flux of about 10^8 $n\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$ at the Buenos Aires isotope separator on-line facility (IALE project[3]). Stable Xe was used as sweeping gas to convey the rare-gases fission products into the ion source of the mass separator and the ion beam corresponding to the mass of interest was extracted beyond the focal surface of the separator.

Three different types of collectors, an aluminized Mylar moving tape, several 0.5-mm-thick detachable beryllium plates, and a special arrangement to determine conversion coefficients,[4] were used to collect the activity.

For singles γ-ray measurements we used a 25-mm^2 × 3-mm Si(Li) x-ray detector [290-eV resolution full width at half maximum (FWHM) at 5.9 keV] and a 35-cm^3 Ge(Li) detector (2.0-keV resolution FWHM at 1.33 MeV). Another 45-cm^3 Ge(Li) detector (3.0-keV resolution at 1.33 MeV) was employed for Ge(Li)-Ge(Li) γ-γ coincidence measurements. A Si(Li) electron detector (1-cm^2 area × 3-mm depletion depth, 8.0-keV resolution FWHM at 482 and 976 keV) was used for conversion-electron detection.

The data were recorded in an analyzer system provided with two 4096-channel analog-to-digital converters (ADC) and several readout peripherals under control of a small computer having a 16 000 memory. For coincidence measurements we used the coincidence circuit ($2\tau \sim 500$ nsec) included in the ADC units.

The relative photopeak-detection efficiency for the 35-cm^3 Ge(Li) detector was determined as a function of E_γ according to the methods described by Kane and Mariscotti[5] and using ^{51}Cr(n, γ), ^{60}Co, ^{226}Ra, and ^{228}Th sources whose relative γ intensities were taken from Lederer, Hollander, and Perlman[6] and Campbell and Mowat.[7] The energies of the most important γ rays of the mass-138 activity were measured against standard transitions from ^{241}Am, ^{57}Co, ^{207}Bi, ^{54}Mn, ^{226}Ra, ^{60}Co, and ^{228}Th decays.[6,7] Those energies, in turn, were used for internal-calibration purposes.

The low-energy region of the γ-ray spectrum was measured with the Si(Li) x-ray detector whose efficiency curve was obtained using ^{137}Cs, ^{57}Co, ^{75}Se, ^{241}Am, and ^{203}Hg standard sources.[6-8] The linearity of the energy calibration below 20 keV was checked using ^{57}Co and ^{241}Am sources. The K x-ray lines of Cs, Ba, and Ag were used for energy calibration (the K x-ray line of silver was produced by fluorescent excitation inside the detection device).

III. EXPERIMENTAL RESULTS

A. Singles γ-Ray Spectrum

The only member of the mass-138 chain significantly extracted from the uranium target was ^{138}Xe. In order to assign transitions properly to either the 14.2-min Xe or the 32.2-min Cs decays,[9] an identification by means of the half-lives was made.

In Fig. 1 an intermediate energy spectrum is shown. The 412.8-keV crossover transition was assigned to ^{138}Xe after reducing the contribution of the 413.6-keV peak (double-escape ^{138}Cs). Different detection geometries were used to evaluate summing effects of the 154.0- and 258.5-keV γ rays.

Figure 2 shows a spectrum up to 2.5 MeV which was recorded in order to search for high-energy transitions. It was taken with an 8-mm-thick Pb absorber interposed to reduce the counting rate at low and intermediate energy. We have not observed γ peaks above 2.5 MeV; if they exist, they must have a relative intensity lower than 3.

The spectrum in the low-energy range (Fig. 3) was measured off line with the Si(Li) x-ray detector. A 10.7-keV γ ray was identified as belonging to the ^{138}Xe decay by measuring its half-life (14.5 ± 1.0 min), and because no γ rays were observed below the K x ray of Cs when the ^{137}Xe or ^{139}Xe isotopes were selected with the mass separator.

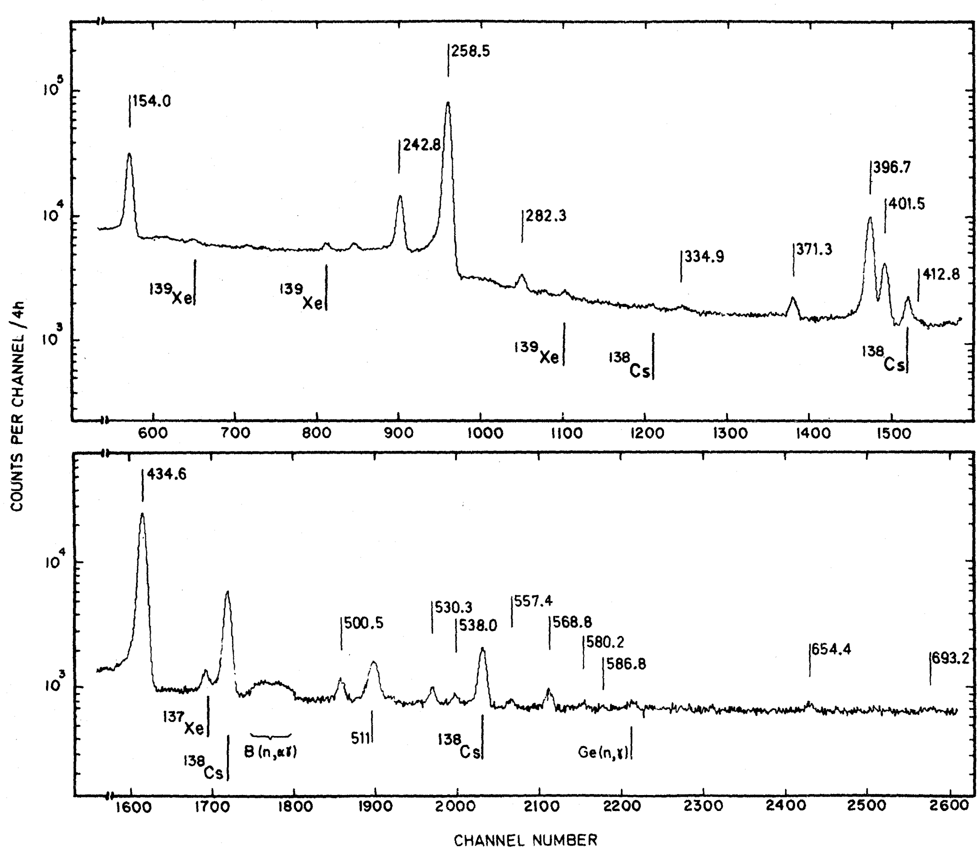

FIG. 1. One of several similar γ-ray spectra in the intermediate-energy region. ^{138}Xe lines, as well as ^{137}Xe and ^{139}Xe short-lived contaminations, are strongly enhanced. The energies are given in keV above each peak.

TABLE I. Measured γ-ray energies and relative intensities in the decay of ^{138}Xe.

Energy (keV)	Relative intensity [a]	Energy (keV)	Relative intensity [a]	Energy (keV)	Relative intensity [a]	Energy (keV)	Relative intensity [a]
10.69 ± 0.15	9 ± 2	941.6 ± 0.7	9 ± 1	557.4 ± 0.3	4 ± 1	1768.17 ± 0.18	600 ± 60
153.96 ± 0.11	174 ± 11	1040.9 ± 1.1 [b]	3 ± 2	568.75 ± 0.17	11 ± 1	1812.6 ± 0.6	6 ± 2
242.77 ± 0.11	105 ± 5	1076.0 ± 0.6	2.0 ± 0.4	580.2 ± 0.6	1.0 ± 0.5	1850.7 ± 0.3	47 ± 2
258.49 ± 0.11	1000 ± 30	1093.6 ± 0.4	16 ± 2	586.8 ± 0.8	0.6 ± 0.3	1925.1 ± 0.3	17 ± 2
282.53 ± 0.15	14 ± 1	1101.3 ± 0.7	7 ± 2	654.4 ± 0.5	3 ± 1	2004.4 ± 0.3	182 ± 15
334.9 ± 0.3	7 ± 1	1113.9 ± 0.3	46 ± 2	693.2 ± 0.5	1.0 ± 0.5	2015.7 ± 0.3	460 ± 25
371.34 ± 0.15	15 ± 1	1141.7 ± 0.3	19 ± 2	775.0 ± 1.0	1.0 ± 0.8	2079.16 ± 0.20	64 ± 4
396.67 ± 0.10	190 ± 8	1160.0 ± 1.5 [b]	3 ± 1	815.0 ± 0.6	2.0 ± 0.4	2252.24 ± 0.22	74 ± 3
401.48 ± 0.15	61 ± 7	1310.3 ± 0.8	2 ± 1	865.60 ± 0.25	10 ± 1	2322.4 ± 0.5	26 ± 2
412.8 ± 0.7	2 ± 1	1358.0 ± 1.5	2 ± 2	868.4 ± 0.3	17 ± 2	2457.5 ± 1.0	2 ± 2
434.61 ± 0.11	590 ± 25	1384.5 ± 0.8	5.0 ± 0.6	896.3 ± 0.3	6 ± 1	2475.9 ± 0.3 [b]	14 ± 1
500.48 ± 0.15	11 ± 1	1398.0 ± 1.0 [b]	2 ± 2	912.9 ± 0.3	12 ± 4	2493.8 ± 0.7	8 ± 2
530.30 ± 0.15	6 ± 2	1572.1 ± 0.7 [b]	9 ± 2	917.1 ± 0.3	29 ± 4	2498.0 ± 0.3	16 ± 3
538.0 ± 0.3	4 ± 1	1614.3 ± 0.5	13 ± 2	935.0 ± 1.0	8 ± 1		

[a] The error stated for the intensity normalized to 1000 has not been included in the error of the other intensities.

[b] Not placed in the level scheme.

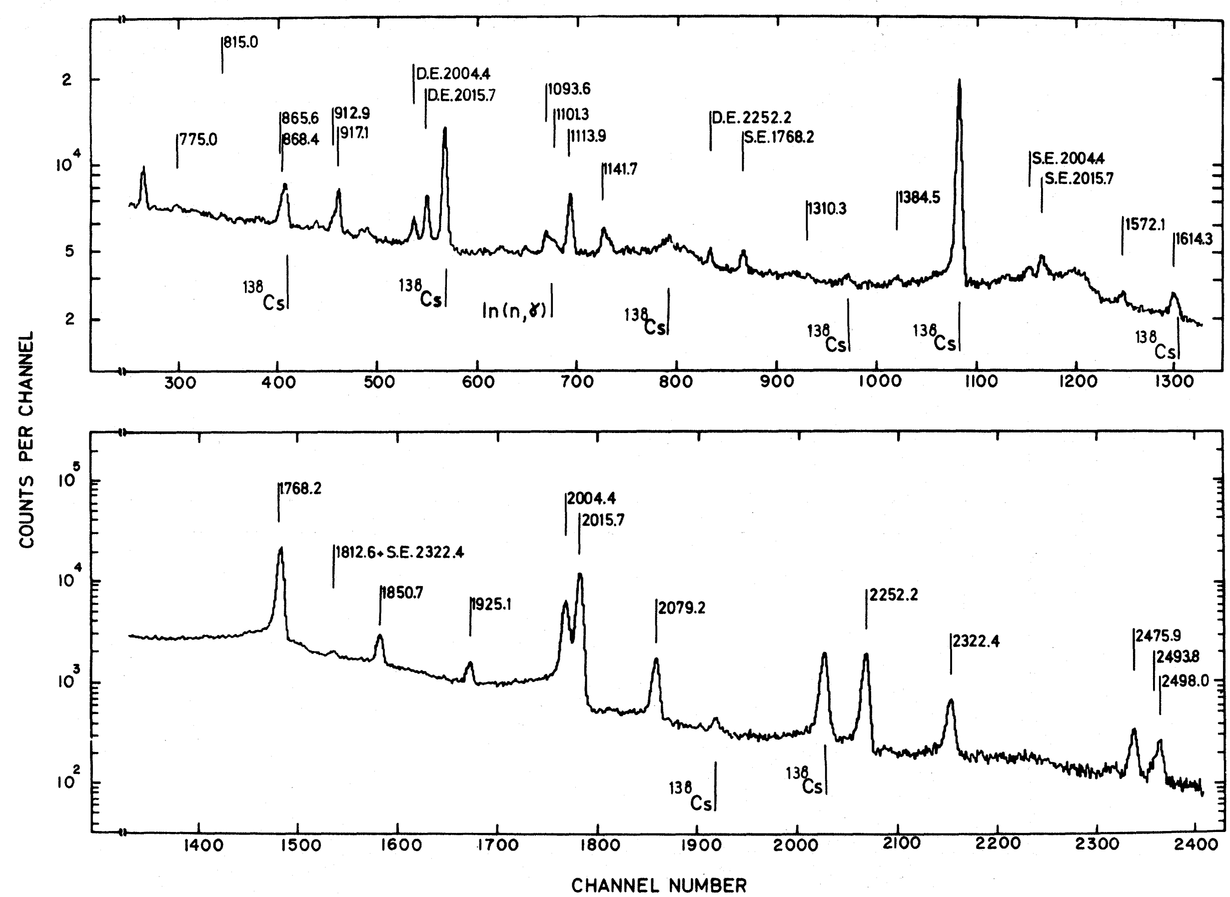

FIG. 2. γ-ray spectrum, high-energy region. Sum of 20 spectra, each accumulated during the first 15 min of the activity growth. An 8-mm-thick lead absorber was used to reduce the counting rate due to low- and medium-energy γ rays. The energies in keV are given above each peak. SE and DE denote single escape and double escape, respectively.

TABLE II. Internal-conversion coefficients and multipolarities.

Transition energy (keV)	α_K	Assigned multipolarity [a]
4.9		$M1$, $E2$ [b]
10.7	150 ± 70 [c]	$M1 + (<0.8\% E2)$
154.0	$290 \pm 30 \times 10^{-3}$	$M1 + (<31\% E2)$
242.8	$62 \pm 14 \times 10^{-3}$	$E2$, $M1$
258.5	$56 \pm 5 \times 10^{-3}$	$E2$, $M1$
396.7	$16 \pm 3 \times 10^{-3}$	$E2$, $M1$
401.5	$37 \pm 8 \times 10^{-3}$	$M1$
434.6	$15 \pm 2 \times 10^{-3}$	$M1 + (<45\% E2)$

[a] The order of the possible multipolarities indicates preference.

[b] Obtained from coincidence results.

[c] Corresponds to the L-shell conversion coefficient.

TABLE III. γ-ray coincidence results.

Coincident γ-ray (keV)	Gate energy (keV) 10.7	154.0	258.5	434.6	1768.2
154.0	YES	NO	YES	NO	NO
242.8	YES	YES	NO	NO	YES
258.5	NO [a]	YES	NO	NO	YES
282.5	...	...	(YES)	...	...
396.7	YES	NO	NO	NO	NO
401.5	(YES)	(NO)	(NO)	(NO)	(NO)
434.6	YES	NO	NO	NO	NO
1768.2	YES	NO	YES	NO	NO
1850.7	...	YES	YES	...	...
1925.1	...	YES	(YES)	...	...
2004.4	...	NO	YES	NO	NO
2015.7	YES	NO	NO	...	NO
2079.2	...	...	YES	NO	...
2252.2	...	NO	NO	NO	...

[a] By comparing the intensities of the 154.0-, 242.8-, and 258.5-keV γ peaks in single and in coincidence measurements, one is led to the conclusion that the 10.7-keV transition depopulates a level not higher than 258.5 keV. Thus, the 10.7-258.5, NO results is assured and can be used for random coincidences normalization (Fig. 5).

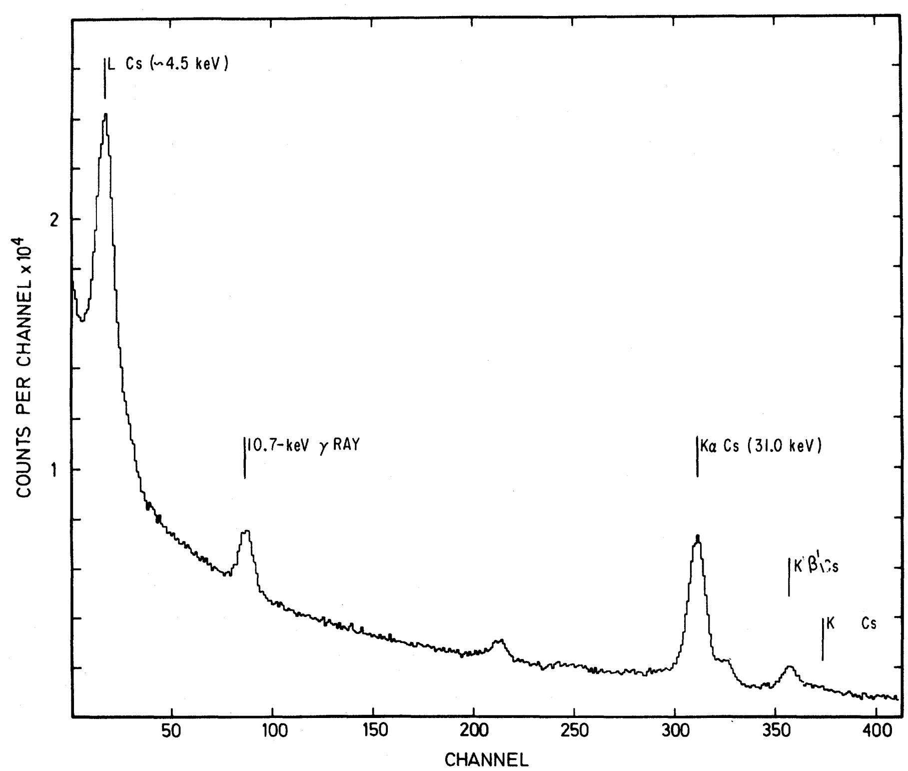

FIG. 3. Low-energy spectra taken off line with the Si(Li) x-ray detector. Sum of 20 spectra, each accumulated during the 15 min following the end of irradiation. Arrows below the spectrum indicate the contributions due to Cs decay (mainly ^{138}Cs to ^{138}Ba) and to the silver fluorescent excitation inside the detector.

The relative intensity was obtained by comparison with the 154.0- and 258.5-keV γ rays. Table I shows the γ-ray energies and intensities we determined.

B. Conversion-Coefficient Measurements

The method and the experimental setup used to measure the internal-conversion coefficients above 100 keV are fully described in Ref. 4. A typical electron spectrum is shown in Fig. 4. The values of the internal-conversion coefficients given in Table II were obtained normalizing the experimental results to the α_K of the 1435.7-keV ($E2$) transition in ^{138}Ba.

The K-shell conversion of the 10.7-keV transition is energy forbidden. Consequently the x-ray detector was used to study the L-shell conversion. The formula $\alpha_L = L_{x_L}/(\omega_L \times I_\gamma)$ gives the conversion coefficient, provided I_{x_L} corresponds to the L x-ray intensity and ω_L to the fluorescence yield.[10] To obtain I_{x_L} one must subtract from the intensity of the peak at about 4.5 keV: (a) the intensity of γ rays included in the 4.5-keV peak, which is less than 2% of the peak area (see Sec. IV A); (b) the L-conversion intensity of all transitions of energy larger than 31 keV, which is 3% and was calculated using the average K/L ratio and ω_L; (c) the intensity due to K-conversion holes transferred to the L shell, which is 12% of the peak area and was calculated taking into account I_{x_K} (intensity of the K x-ray peak), N_{KL} (Ref. 10), and ω_L; (d) the L-conversion intensity of the possible 15.7-keV transition for which it was possible to set an upper limit of 25% of the ~4.5-keV peak area based on

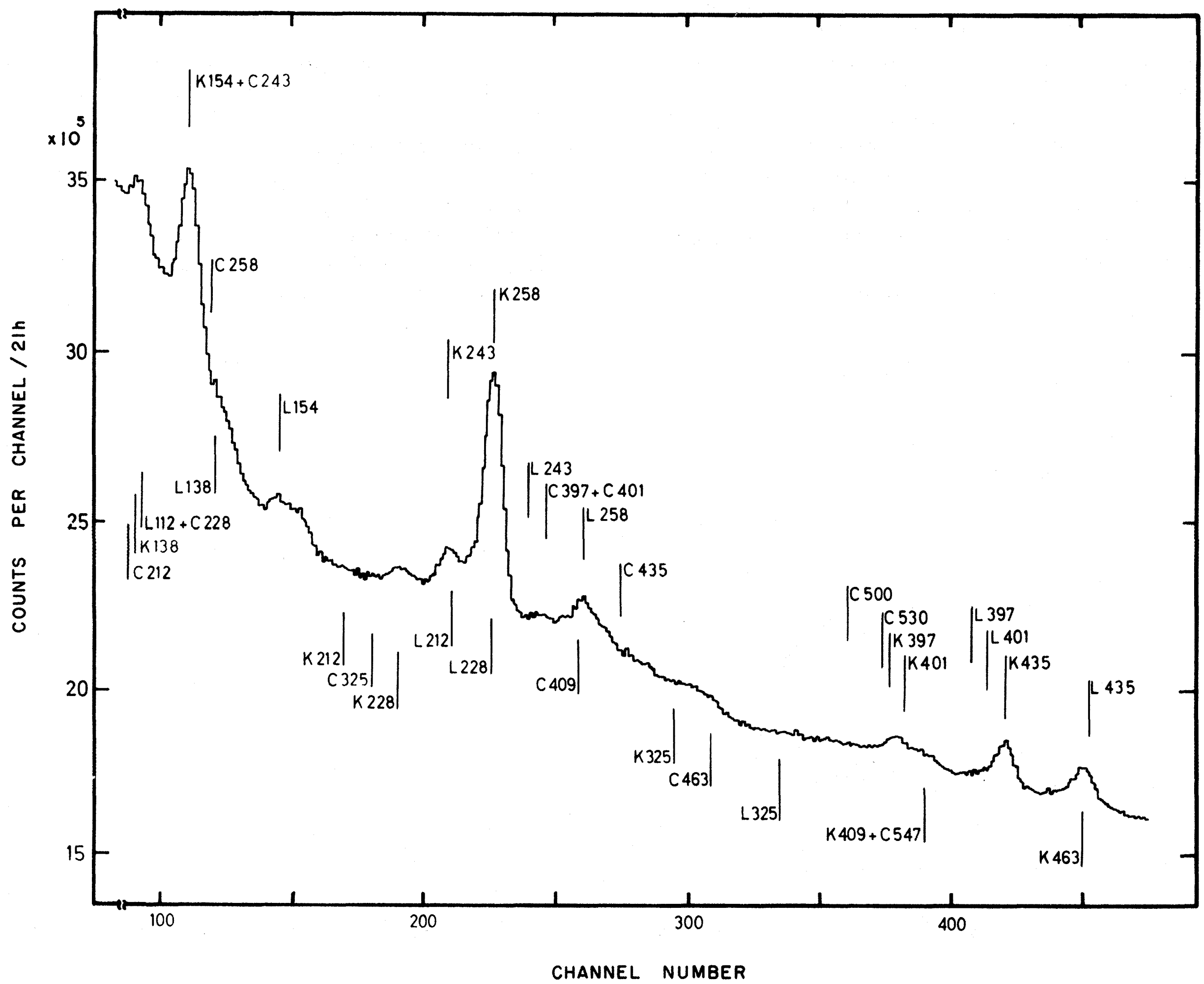

FIG. 4. Conversion-electron spectrum measured with the Si(Li) detector. Peaks identified from above belong to ^{138}Xe decay; from below, to ^{138}Cs decay. K, L, and C mean, respectively, K-shell conversion, L-shell conversion, and Compton edge.

the balance of intensities (see Sec. IV A). The value $\alpha_L = 150 \pm 70$ obtained for the conversion coefficient was compared with the theoretical ones[11] and, without considering the possibility of an $E1+M2$ mixture, an $M1+(\leq 0.8\% E2)$ multipole character was deduced.

C. Measurements of γ-γ Coincidences

Ge(Li)-Ge(Li) and Si(Li)-Ge(Li) coincidence measurements were performed. The Si(Li) x-ray detector was used to accept the 10.7-keV γ ray as the gating transition.

Each run of Ge(Li)-Ge(Li) coincidences lasted about eight hours. Five runs of six hours each were taken with the 10.7-keV gate using the Si(Li) detector. Table III shows the results obtained and the degree of confidence achieved. Our 154.0-2004.4, NO and 258.5-2004.4, YES results rule out the 2413-keV level proposed by Nagahara *et al.* on the basis of an interpretation of their coincidence spectra leading to 153-2002, YES and (242+258)-2002, YES.

The 434.6-keV γ ray was not observed to be in coincidence with medium- or high-energy transitions although it is in coincidence with the 10.7-keV γ ray; however, its multipolarity excludes the possibility that it comes directly from long-lived levels.

Coincidence experiments gated by the 10.7-keV transition were made with the beryllium collector which had to be replaced frequently to maintain the background under this peak to less than twice the peak height. This experiment (Fig. 5) showed that the half-lives of the 10.8- and 15.7-keV levels were smaller than 500 nsec. The use of the Weisskopf estimate with this limit for the half-life combined with the criteria established by the Nuclear Data Group[12] allowed us to establish the multipolarity of the 4.9-keV transition as $M1$, $E2$, $E1$. Moreover, comparing the sum of the intensities of the 396.7- and 1768.2-keV γ rays with the intensity of the 2015.7-keV γ ray in singles and coincidence spectra, we could say that at least $\frac{2}{3}$ of the intensity arriving at the 15.7-keV level goes through the 4.9-keV transition.

IV. LEVEL SCHEME

A. Level-Scheme Construction

Coincidence results with the 154.0-, 258.5-, and 1768.2-keV γ rays in gate and the fact that the 258.5-keV transition, owing to its intensity, must be considered as feeding the ground state, strongly suggest the existence of energy levels at 258.5, 412.5, 2026.7, 2263.0, and 2337.6 keV. This allows placement of the γ rays of 154.0, 258.5, 412.8, 1614.3, 1850.7, 1925.1, 2004.4, and 2079.2 keV, carrying 53% of the total γ-ray intensity.

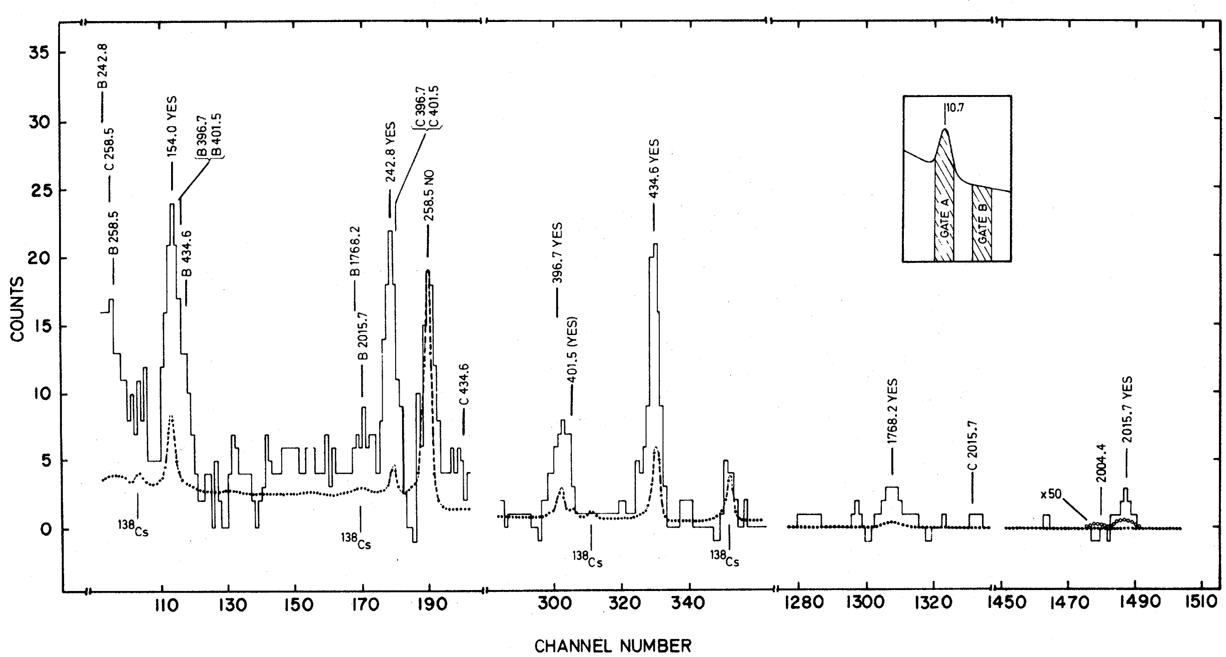

FIG. 5. γ-γ coincidence spectrum with the 10.7-keV γ ray in gate. The solid line corresponds to smoothed coincidence results after subtracting coincidences with gate B (see insert). The dotted line is a singles spectrum representing the random coincidences. B and C mean, respectively, backscattering peak and Compton edge.

The 242.8-keV transition depopulates either the 258.5-keV level or a lower one as follows from the fact that this transition is in coincidence with the 154.0- and 1768.2-keV γ rays but not with the 258.5-keV one. Hence, the 258.5-keV level is depopulated not only by the ground-state transition but also through a cascade which includes the 242.8-keV transition. As the 10.7-keV γ ray is in coincidence with the 242.8-keV γ ray, but not with the 258.5-keV γ ray, one is led to the conclusion that the energy difference $258.5 - 242.8 = 15.7$ keV is only partially due to the 10.7-keV transition. Therefore the existence of at least one additional low-energy transition is inferred.

The peak at about 4.5 keV was identified as including all the L x rays of the selected mass chain. As the γ ray of 4.9 keV is completely contained within this peak we could not measure its intensity. However, the intensity balance (see Sec. III B and below) at the 15.7- and 10.8-keV levels, allows one to infer a relative γ-ray intensity of 5^{+2}_{-5} if we take into account that the transition has $E1$, $M1$, $E2$ multipolarity (Sec. III C) and assume that it is completely converted in the M and higher shells. We have not observed either the γ ray corresponding to the possible ground-state transition from the 15.7-keV level but, from the measured spectrum, an upper limit of 0.2 can be established for its relative intensity.

From the possibilities left by the preceding discussion regarding levels below 258.5 keV, the 434.6-242.8, NO; 434.6-258.5, NO; and 434.6-10.7, YES coincidence results, the 10.7-keV transition must be placed below the 242.8-keV one. Therefore, only three possibilities remain for the two first excited levels: 10.8-15.7, 4.9-15.7, and 10.8-253.5 keV. The first arrangement was preferred as it allows the placing, by energy-sum relations, of the 242.8-, 396.7-, 401.5-, 2015.7-, 2252.2-, and 2322.4-keV γ rays carrying 50% of the remaining intensity, without introducing new levels. Coincidences with the 10.7-keV γ ray in gate give additional support to the basic level structure so far established. From this level scheme and the coincidence results we propose a 4.92 ± 0.16-keV transition. The level scheme was completed with energy levels obtained by sum relations.

The level scheme in Fig. 6 was obtained as described above; the energy levels are placed at 10.79 ± 0.11, 15.71 ± 0.12, 258.49 ± 0.11, 412.45 ± 0.16, 450.33 ± 0.16, 541.05 ± 0.13, 815.7 ± 0.4, 876.21 ± 0.22, 912.62 ± 0.14, 951.6 ± 0.4, 1109.67 ± 0.17, 1127.0 ± 0.3, 1367.5 ± 0.3, 1395.8 ± 0.4, 1489.0 ± 0.4, 2026.67 ± 0.17, 2263.01 ± 0.23, 2337.62 ± 0.19, 2468.5 ± 0.5, and 2509.00 ± 0.24 keV. It includes 99.2% of the observed γ intensity and only five γ rays are not placed.

The β feedings to both the 10.8- and 15.7-keV levels were obtained combining our experimental results for internal L-shell conversion, and the transition intensities feeding the levels themselves. In this way a maximum β feeding of 2.5% to both levels combined was obtained. For the 15.7-keV

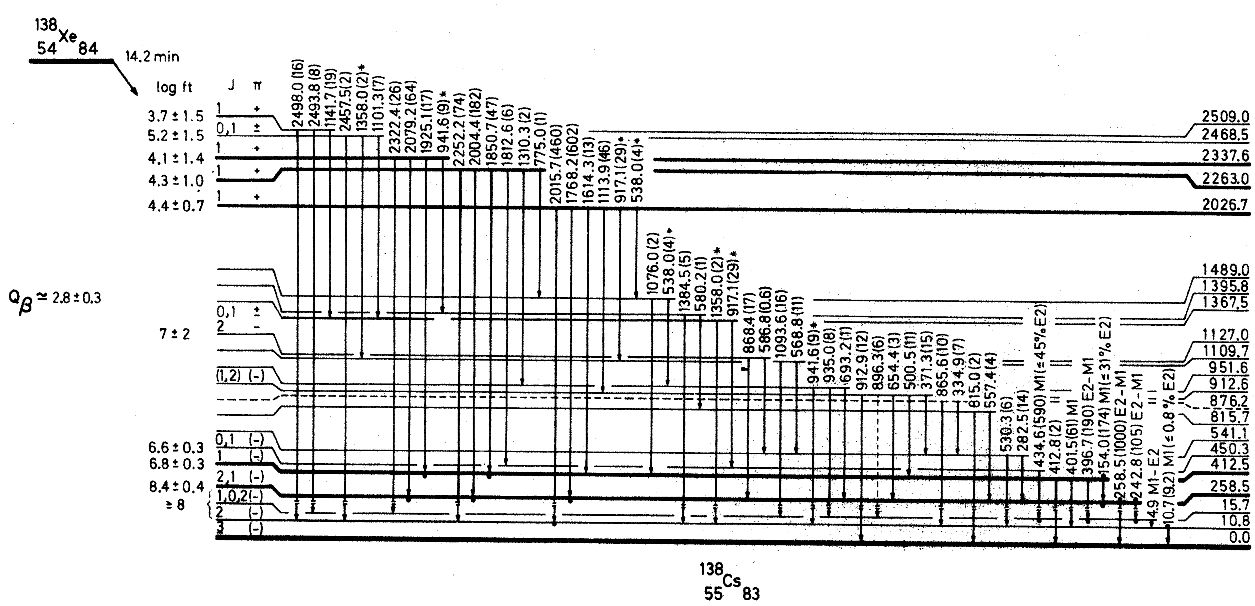

FIG. 6. The disintegration scheme of 14.2-min ^{138}Xe. Observed coincidences and intensities of γ rays are indicated. An asterisk indicates transitions placed twice in the level scheme.

level additional information was obtained using coincidence results (Sec. III C). Thus, the total relative intensities of the 4.9- and 15.7-keV transitions (258.5-keV transition intensity stated as 1000) were calculated to be 740 ± 240 and ≤ 320, respectively. The possible β feedings to the 10.8- and 15.7-keV levels were taken into account to arrive at the former value. An additional result from this last calculation is the total conversion coefficient for the 10.7-keV transition, yielding 165 ± 20, in good agreement with the experimental result.

B. Spin and Parity Assignments

The 0^+ ground-state decay of even-even ^{138}Xe populates levels of ^{138}Cs by β^- emission with branching ratios which have been deduced from transition-intensity balances.

For the Q_β we assumed the value 2.8 ± 0.4 MeV obtained by Nassif and Seelman-Eggebert,[13] which is in agreement with the theoretical value reported,[14] when one takes into account the fact that the lowest level with a significant β feeding is about 0.4 MeV above the ground state. The $\log ft$ values shown in Fig. 6 were computed assuming that the $J=3$ ground state[15] of ^{138}Cs is not fed in ^{138}Xe decay. With these values and based on the criteria established by the Nuclear Data Group[12] the following spins and parities for excited levels can be deduced (energies in keV, J^π values within brackets): 258.5 [$0^\pm$, $1^\pm$, $2^\pm$]; 412.5 [0, 1]; 450.3 [0, 1]; 1127.0 [$0^\pm$, $1^\pm$, 2^-]; 2026.7 [1^+]; 2263.0 [1^+]; 2337.6 [1^+]; 2468.5 [0, 1]; and 2509.0 [1^+]. It should be noticed that the large uncertainty in the value of the Q_β value does not affect the J^π assignments because the corresponding $\log ft$ values define the characteristics of the β decay to well within the Nuclear Data Group limits.

The ^{138}Cs ground state most probably has negative parity in view of the systematic trends of several $N=83$ neighbors in the isotope table and also based on very general features of the shell model. Thus, the linking of the low-energy levels by the no-parity-change transitions (Table II) of 10.7, 154.0, 242.8, 258.5, 396.7 and 434.6 keV establishes negative parity for the levels at 10.8, 15.7, 258.5, 412.5, and 450.3 keV, but the parenthesis around the π values (Fig. 6) must be kept in view of the uncertainty in the ^{138}Cs ground-state parity. Consequently, the possibility of an $E1$ character for the 4.9-keV transition, as well as the $E3$ character for the 401.5-keV transition (see Table II), are ruled out.

A comparison of the experimental intensities of the 154.0-, 396.7-, and 412.8-keV γ rays with Weisskopf estimates excludes for the latter transition the possibility of an $M3$ multipole character. Therefore, the 412.5-keV level has a value of $J^\pi = 1^{(-)}$. The possible spins of the 10.8-, 15.7-, and 258.5-keV levels are 2; 0, 1, 2; and 1, 2, respectively. In each case, this result is obtained from a combination of the possibilities given by transitions of known multipolarity connecting the level itself with other levels of better known spins, namely: 10.7 ($M1$) and 401.5 ($M1$) for the 10.8-keV level, 434.6 ($M1$) for the 15.7-keV level, and 154.0 ($M1$) and 258.5 ($E2$-$M1$) for the 258.5-keV level. Taking into account the feeding from the 912.6-keV level to the lower ones we propose (1^-, 2^-) for it. Whenever spins are not given in the natural sequence (Fig. 6), preference for the first one is implied.

C. Level Structure of ^{138}Cs

The level scheme proposed here for ^{138}Cs has 20 excited levels. Spin and parity assignments have been made for 12 levels, five of them unambiguously, based on $\log ft$ values and transition multipolarities. The most prominent feature of the level scheme built on the $3^{(-)}$ ground state is a group of low-lying negative-parity levels and a higher-lying positive-parity group.

The 55th proton belongs either to the $1g_{7/2}$ or to the $2d_{5/2}$ single-particle states. For the 83rd neutron the possibilities are $2f_{7/2}$ or $1h_{9/2}$. Hence, four quasiparticle multiplets arise straightforwardly from these considerations: $[g_{7/2}f_{7/2}]$, $[g_{7/2}h_{9/2}]$, $[d_{5/2}f_{7/2}]$, and $[d_{5/2}h_{9/2}]$, which give rise to a number of negative-parity states. The first of these configurations is likely to give the largest contribution to the ground state in view of the ground-state spins of ^{133}Cs, ^{135}Cs, ^{137}Cs, and ^{137}Xe, ^{139}Ba, ^{141}Ce, ^{143}Nd. In addition, the coupling of quadrupole vibrations to the previously mentioned multiplets gives a number of other possible negative-parity states. Most of the 1^+ states that we established between 2.0 and 2.5 MeV probably are due to the coupling of the collective octupole vibrational state with the quasiparticle states.

This character of the level structure could be present in other odd-odd nuclei with $N=83$ such as ^{140}La and ^{142}Pr (Ref. 16), but in these cases, up to now, only the negative-parity group has been established. Since ^{138}Cs is the only odd-odd cesium isotope with $N>82$ for which spin and parity assignments have been made, no reasonable comparison can be attempted. The nucleus ^{88}Rb$_{51}$, which also has one neutron outside a closed shell, shows a level structure very similar to that of ^{138}Cs and was interpreted[17] in terms of two-quasiparticle states and of vibrations coupled to them.

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Detailed Study of Alpha Emission in ^{252}Cf Fission

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Long-range α-accompanied fission of ^{252}Cf is investigated in a five-parameter correlation experiment and the behavior of each component of total energy, including the prompt neutrons from the individual fragments, as well as from the fragment pairs and the prompt-γ emission, is studied and compared with the binary fission. The problem of determining the nucleon contribution by binary fragments to the α-particle formation is discussed. The average energy of the α particle is observed to increase towards the symmetric fission region, which is understood in terms of a possible shift of the scission point towards the heavy fragment. The dependence of the average number of total neutrons on the α-particle energy and the dependence of the α-particle energy on the fragment total kinetic energy is not linear, which is interpreted to yield some qualitative information on the initial energy of the α particle. Several differential correlations are also discussed.

I. INTRODUCTION

The α-particle accompanied fission [long-range-α (LRA) fission] in ^{252}Cf has been extensively studied in the past few years[1-4] and has recently been reviewed by Halpern.[5] Since the characteristics of the binary and LRA mode of fission, which are determined by the initial conditions at the moment of scission, are so similar, it is recognized that the study of the emission of the α particle could possibly yield some concrete information on the dynamical conditions at scission. A considerable effort in this direction has been made by comparing the LRA-fission experimental results with the asymptotic solutions of the trajectory calculations.[6-15]

Two main qualitative features of the dynamical conditions at the LRA scission point seem to emerge from these studies. First, the fissioning nucleus is on the average a little more elongated in the LRA mode of fission, and second, the fission fragments are already moving with an appreciable part of their final kinetic energy at the moment of scission. However, a quantitative agreement on these points is far from satisfactory, and moreover, the trajectory calculations made by some authors[13-15] yield appreciably different initial dynamical conditions.

The problem of arriving at a consistent set of initial dynamical variables is extremely complicated because of the multitude of free parameters and the lack of understanding of the mechanism