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New Isomers and Their Decay in Odd-Odd Neutron-Deficient Cesium Isotopes

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By a systematic on-line cesium mass separation from $A=122$ to $A=132$ and subsequent gamma and electron decay spectroscopy at very low energy, new isomers have been precisely identified: ^{122m}Cs ($T_{1/2}=0.36\pm0.02$ s), ^{124m}Cs ($T_{1/2}=6.3\pm0.2$ s) and ^{130m}Cs ($T_{1/2}=3.46\pm0.06$ min). Detailed level schemes are given for both ^{124m}Cs and ^{130m}Cs. Comparison of excited levels known in the odd-odd nuclei of the same region shows that more experimental informations are needed to propose a clear and realistic picture of the nuclear states structure.

Radioactivity: $^{122m, 124m, 130m}$Cs [from La or Ce, ^{3}He xn]-measured $T_{1/2}$, E_γ, I_γ, E_{CE}, I_{CE}, $\gamma-\gamma-t$, $\gamma-ce$ coinc.; deduced ICC, $^{124, 130}$Cs deduced levels, J, π. On-line mass separated sources, Ge(Li), intrinsic Ge, Si(Li), magnetic electron selector.

1. Introduction

The large availability of rich high-spin spectra excited in odd-mass nuclei has revealed collective properties in the $50<Z$, $N<82$ transitional region. Extensive systematic studies of long chains of isotones and isotopes have established clearly the evolution of nuclear level structure from spherical to deformed nuclei.

Comparatively, experimental information on odd-odd nuclei of the same transitional region is poor. For example, in the case of neutron-deficient cesium isotopes, odd-mass nuclei have been systematically well studied from $A=119$ to $A=133$ [1] while only few states have been precisely identified in doubly-odd nuclei [2]. Nevertheless, for several cases, spins of both ground-state and long-lived isomeric state have been measured [3] by the on-line Atomic-Beam Magnetic Resonance technique [4]. In addition, from recent measurements, experimental dipole and quadrupole moments of the spin $I=1$ doubly-odd cesium isotopes, $^{120-130}$Cs, are available [5, 6]. From these measurements three different aspects of nuclear structure can be distinguished for these spin $I=1$ cesium isotopes. In the frame of particle-rotor calculations within the Nilsson model [7] applied to neighbouring odd-A nuclei, experimental dipole and quadrupole moments can be well accounted for by the different following configurations:

i) a combination of the configurations

$1^+ \{\pi[422\ 3/2]\ \nu[402\ 5/2]\}$

and

$1^+ \{\pi[420\ 1/2]\ \nu[411\ 1/2]\}$

in about equal amplitudes for ^{122}Cs, *ii)* a predominantly configuration

$1^+\{\pi[420\,1/2]\,\nu[411\,1/2]\}$

for ^{124,126,128}Cs and
iii) a main ground state configuration

$1^+(\pi d5/2\,\nu d3/2)$

for the weakly deformed ^{130}Cs nucleus [8]. Due to the fact that the relative energy positions of neutron and proton intrinsic states are already well known in odd-mass Xe, Cs and Ba nuclei, more experimental informations in the odd-odd cesium nuclei, as low-energy intrinsic states and collective bands based upon it, could be able to give a new insight on the neutron-proton coupling in transitional nuclei. In addition, as few states are known in several doubly-odd $_{53}$I [2], [9] and $_{57}$La [2], [10] neutron-deficient isotopes, the new results could be used to extract some systematics in the region.
As a first step of such a study, using the in-beam ISOCELE 2 facility at the Orsay Synchro-cyclotron [11], we have searched carefully the presence of isomeric states in doubly-odd cesium isotopes from $A=122$ to $A=132$. Then, for the new ones or for the already known, we have observed their decay. In this paper, results of investigations on high activity sources of cesium isotopes produced and isotopically separated at ISOCELE 2 are presented only for ^{122m}Cs, ^{124m}Cs and ^{130m}Cs, because no long-lived isomeric states have been observed for ^{126,128}Cs and ^{132}Cs.

2. Experimental Techniques

Mass-separated cesium samples have been investigated at the ISOCELE 2 separator [11] on line with the ORSAY synchrocyclotron. The activities were produced by bombardment of thick molten cerium or lanthanum metallic targets with a 280 MeV ^{3}He beam or a 200 MeV proton beam. Details of the target holder and ion source of the mass-separator were described previously [12]. The beam delivered by the synchrocyclotron had intensities in the range of 1 to 2 μA. The measurements on cesium samples were performed during 24 h or more without ion source change on the isotopic separator.
The mass separated cesium nuclei were carried out on a modular tape transport system able to permit easy installation of several different detection stations. The tape was moved by a step-motor controlled by an electronic circuit. The tape was running at a maximum speed of 2 m/s and was positioned with 1 or 2 mm resolution [13]. Special cubic boxes had been mecanically arranged that allowed Ge(Li), intrinsic Ge or X-ray detectors to be placed within a few milimeters of the tape. For low-energy photon measurements, thin beryllium windows had been sealed on faces of the boxes. With such devices, singles spectra and gamma-gamma or gamma-X-ray coincidence measurements have been performed with high geometrical efficiency.
For collection of electron spectra the tape progressed inside a magnetic selector previously described [14]. Inside the spectrometer, the cooled electron silicon detector was shielded from X-rays, γ-rays and β^+ issued from the source spot, with a 35 mm gold block. In addition, it was possible to place at 4 cm of the radioactive tape, behind a thin Be window, an external γ-ray or X-ray Ge detector, in order to allow not only collection of singles electron and γ-ray or X-ray spectra but also of electron-gamma or electron-X-ray coincidence data. Obviously, the efficiency of the system was experimentally measured with standard radioactive samples placed at identical geometry, for a given magnetic field. As it will be mentioned later in this paper, the measurements realized with this magnetic electron selector were decisive for the establishment of the decay schemes presented.
For each mass-separated cesium sample collected, conventional γ-ray and conversion electron multiscaling analysis (generally eight time groups per spectrum) had been performed to deduce half-lives.
The coincidence data were recorded event by event on a magnetic tape together with the time delay between the two energy pulses and the tapes were subsequently scanned for selected energy and time gates.

3. Isomeric States in Odd-Odd Cesium

In agreement with the cesium production rates at ISOCELE 2 [12], the first experiments were devoted to a systematic search of eventual new isomers in doubly-odd cesium nuclei from $A=122$ to $A=132$.

3.1. The Previous Results

From prior investigations, isomeric states have been already observed in both 122 and 130 odd-odd cesium isotopes.
Two different half-lives have been established at CERN [15] in ^{122}Cs. The ^{122m}Cs ($T_{1/2}=4.2$ min) and the ^{122g}Cs ($T_{1/2}=21$ s) reported appear respectively in agreement with the $I=8$ and the $I=1$ nuclear spins measured by Ekström and collaborators [16]. Using several heavy-ion induced reactions,

Droste et al. [17] had previously identified both 21 s ^{122m_1}Cs and 4.2 min ^{122m_2}Cs activities. In addition, a third half-life has been observed at DUBNA in ^{122}Cs by Alexander, Neubert and coworkers. Two values have been successively determined, (0.50 $\pm$0.05) s in 1967 and (0.35$\pm$0.07) s in 1969, by this group [18].

The ^{124}Cs isotope has been identified in several experiments. A precise (26.5$\pm$1.5) s activity has been already reported in 1969 by Chaumont et al. [19] using an on-line mass spectrometer operating with Ta, Th or U targets bombarded by 24 GeV protons at the PS at CERN. Then at the DUBNA U-300 heavy-ion cyclotron, Droste and coworkers have observed a (34$\pm$6) s half-life produced in the ^{115}In(^{12}C, 3n)^{124}Cs reaction at 60 MeV [17].

In a more recent measurement also performed at CERN on pure isotopically separated samples of ^{124}Cs produced in lanthanum targets bombarded with 600 MeV protons, only one half-life of 31 s has been found [20]. The authors have underlined that no other ^{124}Cs activity with half-life greater than 5 s has been observed.

The situation is similar for both ^{126}Cs and ^{128}Cs. For the first one, half-life of (98.6$\pm$1.0) s has also been obtained at CERN by Chaumont et al. [19]. A comparable result $T_{1/2}=(100\pm2)$ s, has been measured by Pathak et al. in 1976 [21]. The ^{115}In(^{16}O, 5n), ^{121}Sb(^{11}B, 6n) reactions at the YALE accelerator laboratory or the ^{133}Cs (p, 8n) reaction induced with 100 MeV protons at the McGill synchrocyclotron have been used as production modes in these experiments.

For the second one, ^{128}Cs, a precise half-life measurement of (3.62$\pm$0.02) min has been made by Droste et al. [22] on the Swierk linear accelerator with the ^{128}Xe(p, n)^{128}Cs reaction at 10 MeV. This determination is in agreement with the value reported by Ekström et al. [16] and observed on isotopically separated samples at ISOLDE.

The ^{130}Cs isotope has been specially well studied. Extensive γ-ray measurements have been performed by Watson and Silvester [23] on the ^{127}I(α, n)^{130}Cs reaction and a period of (29.11$\pm$0.12) min has been established. One year later, in 1968, a slightly different value of (29.9$\pm$0.1) min was reported [24]. During a systematic determination of nuclear spins by the atomic beam magnetic resonance method, Ekström et al. [5] have observed at CERN, a 3.7 min ^{130m}Cs component. Very recently, in order to estimate the P_K/P_β ratio for the $^{130}\mathrm{Cs}\xrightarrow{\beta+(EC)}{}^{130}$Xe decay, Hagberg and coworkers have established a more precise half-life of (29.21$\pm$0.04) min for ^{130}Cs [25]. However, the existence of the 3.7 min isomer previously reported was not observed in this experiment, although a special effort was developped to identify eventual activities present in the isotopically separated samples used.

3.2. The Present Measurements

As mentioned above, a systematic search for short isomeric states in odd-odd cesium isotopes has been undertaken at ISOCELE 2. During a first run, using γ-ray singles spectra and a rapid multispectrum analysis, the long-lived species have been identified from ^{122}Cs to ^{130}Cs and found in agreement with the previous reported half-lives. Then, as the collection times of the separated samples were progressively lowered, a careful multispectrum analysis was made on both γ-ray and conversion electron singles spectra.

As more or less suspected, three different half-lives are present in the ^{122}Cs isotope. Besides the 4.2 min and the 21 s activities, the decay curves, reported in Fig. 1, unambiguously establish the presence of a (0.36$\pm$0.02) s isomeric state. It corresponds likely to the previous one given twice by the DUBNA group with somewhat different half-lives [18]. The present result is mainly based upon low-energy conversion electron lines, well observed at ISOCELE 2 with the magnetic selector on pure samples collected during 2 s each. A typical multiscaling singles electron spectrum is reproduced in Fig. 2. The 81.20 keV transition is observed by its L and M conversion lines and the 45.85 keV one by its L group. Moreover, the wide line, at approximately 45.2 keV, corresponds to a mixture of $K_{81.2}$ with $M_{45.8}$ and presents the same decay curve than the separated electron groups, as illustrated in Fig. 1. In conclusion the 0.36 s isomeric level in ^{122}Cs is well confirmed in the present study

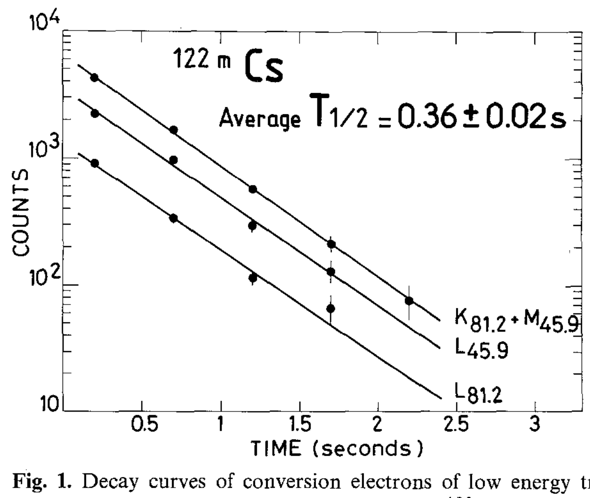

Fig. 1. Decay curves of conversion electrons of low energy transitions associated to a 0.36 s isomeric level in ^{122}Cs

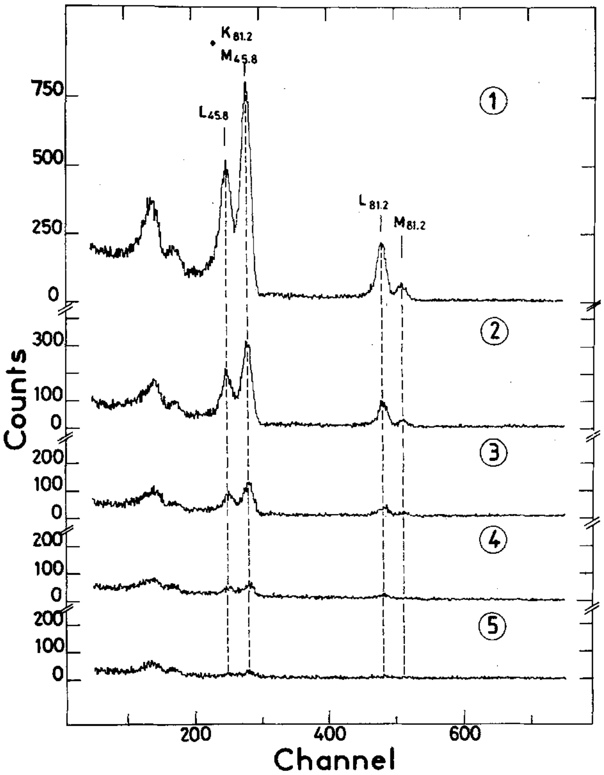

Fig. 2. Part of a multispectrum analysis on the conversion electrons of the 0.36 s isomeric level in ^{122}Cs. The collection time was 2 s. Each spectrum was recorded during 0.5 s. Lower energy parts of the spectra correspond to Auger electrons

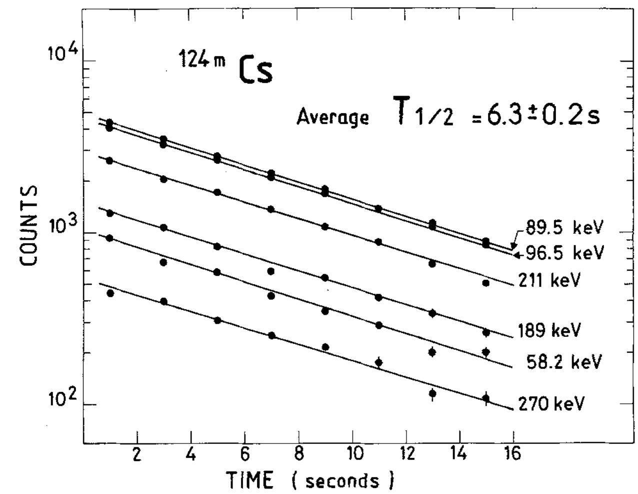

Fig. 3. Decay curves of low-energy gamma transitions observed in ^{124m}Cs

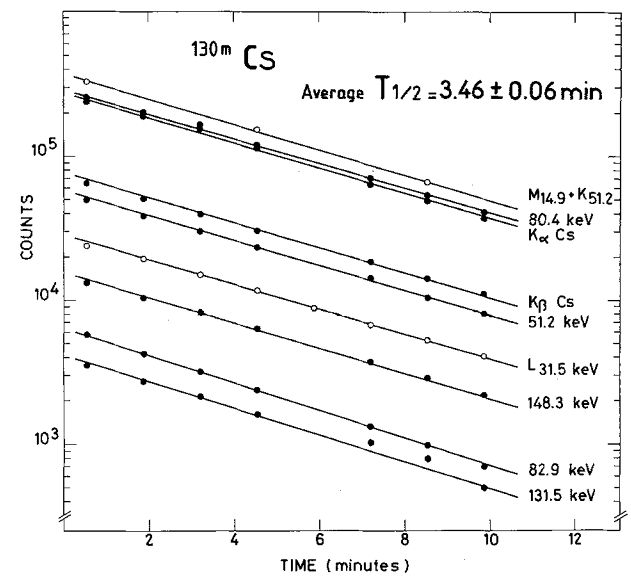

Fig. 4. Decay curves of low-energy transitions observed in ^{130m}Cs. The full circles show measurements taken with a Ge(Li) detector while the open circles show measurements with the electron selector

by the decay of two new transitions at 45.8 and 81.2 keV respectively.

As the ^{124}Cs production rate is very high at ISOCELE 2, it was easy to get both low-energy γ-ray and electron singles spectra with small collection times of the samples. In our first investigation, in addition to the 31 s activity, five new low-energy transitions have been rapidly identified and assigned to an isomeric state in ^{124}Cs. A (6.3 ± 0.3) s half-life had been deduced and already reported [26]. As several experiments have been undertaken to establish energy measurements and multipolarities of the transitions, the half-life estimation has been refined. With samples collected during one or two seconds, the decay curves obtained for the stronger γ-lines at 58.2, 89.5, 96.5, 189.0, 211.6 and 270.3 keV are reported in Fig. 3. The mean value deduced for the half-life of this new longlived isomer is (6.3 ± 0.2) s.

As the ^{130}Cs case was ambiguous in spite of the numerous and recent studies developped for it, a special effort has been made to detect an eventual short half-life isomeric state. Different samples collected during 20 to 200 s have been measured with low-energy γ-ray detectors or with the electron selector operating at various magnetic fields. All these low-energy singles spectra exhibit new transitions assigned to the $A = 130$ mass isotope. Using a multispectrum analysis, the decay curves displayed in the Fig. 4 have been obtained for the K_α and K_β X-ray characteristic of a cesium isotope, for the γ-rays at 51.2, 80.4, 82.9, 131.5 and 148.3 keV and for conversion electron lines as $L_{31.5}$ and $M_{14.9} + K_{51.2}$, respectively. Obviously, the existence of an isomeric state in ^{130}Cs is well established by several low-energy transitions and a relatively precise half-life of (3.46 ± 0.06) min has been measured.

4. Results and Decay Schemes

4.1. Decay of the (0.36±0.02) *seconds Isomeric State in* ^{122}*Cs*

After identification of this short half-life isomer, singles γ and conversion-electron spectra have been used to investigate energies, intensities and multipolarities of the low energy transitions involved in its decay. The results are summarized in Table 1. Only two strongly converted transitions (Fig. 2) have been completely identified and as no low energy transition in the daughter ^{122}Xe was available, it was difficult to normalize the experimental values and to extract multipolarities. In practice, we have extensively used the comparison of the K/L experimental ratio with the theoretical ones. The $K/L = 2.20 \pm 0.18$ estimated for the 81.2 keV transition can be reproduced with an admixture of $E2 + (9 \pm 4)\%\ M1$. For a pure $E2$ multipole at 81.2 keV, $\alpha_K = 2.26$ while it reaches 2.19 by inclusion of 9% $M1$. In such a situation, a normalization of the results with α_K 81.2 $= [2.19]$ seems correct (see Table 1). The α_L value deduced for the 45.8 keV transition gives a predominant $M1$ character with $(9 \pm 5)\%$ of $E2$.
From the present experiment, the placement of the well defined 45.85 and 81.20 keV transitions in the ^{122}Cs level scheme is not established. Indeed, from low-energy $\gamma-\gamma$ coincidence data, recorded successively with 1 s and 2 s collection times of the samples, these two transitions are not in cascade and there is no evidence of any complementary very low-energy transition. Nevertheless, an attempt has been done to examine if it exists connexions of the short isomeric state with the previous observations on the $^{122m+g}$Cs decays. From studies undertaken at CERN [15], the relative position of ^{122m}Cs ($I = 8$ $T_{1/2} = 4.2$ min) and ^{122g}Cs ($I = 1^+$ $T_{1/2} = 21$ s) remains unknown but γ-rays observed in their decay have different relative intensities.

In the ^{122m}Cs case ($T_{1/2} = 4.2$ min)

$$\frac{I_{497}(4^+ \to 2^+ \text{ in } ^{122}\text{Xe})}{I_{331}(2^+ \to 0^+ \text{ in } ^{122}\text{Xe})} = 0.85,$$

$$\frac{I_{371}(3^+ \to 2'^+ \text{ in } ^{122}\text{Xe})}{I_{331}(2^+ \to 0^+ \text{ in } ^{122}\text{Xe})} = 0.037$$

and transitions at 278.1, 208.4 and 307.6 keV are well detected.
In the ^{122g}Cs decay ($T_{1/2} = 21$ s) $I_{497}/I_{331} = 0.021$, $I_{371}/I_{331} = 0.006$ and the lower energy lines are not found.
In the singles γ-ray spectrum of the 0.36 s ^{122}Cs isomeric state the transitions at 331, 371 and 497 keV were observed with the following ratios $I_{371}/I_{331} \approx 0.007$, $I_{497}/I_{331} \approx 0.05$; these values are in quite good agreement with the ones reported for the 21 s activity. Clearly, the 0.36 s isomeric state confirmed in ^{122}Cs by the present work feeds the 1^+ ^{122g}Cs. From these data, there is no way to establish its decay scheme; the 81.2 keV ($E2$) and 45.8 keV ($M1$) transitions are certainely placed just above the 1^+ ground-state of ^{122}Cs but they cannot explain the half-life observed nor give energies of the first excited levels in this isotope.

4.2. Decay of the (6.3±0.2) *seconds Isomeric State in* ^{124}*Cs*

This half-life has been easily identified on samples collected during one or two seconds at the ISOCELE 2 separator. As several low-energy transitions have been observed, a more detailed study has been undertaken. Low-energy γ-rays and X-rays singles spectra have been carried out with a 50 μm thick entrance Be window, intrinsic Ge detector of 1 cm^3 (528 eV FWHM at 122 keV). Medium-energy γ-rays have been observed with a coaxial, intrinsic Ge detector of 70 cm^3 (1.78 keV FWHM at 1.33 MeV).

Table 1. Energies, relative intensities, internal conversion electrons data and multipolarities of γ-rays observed in the decay of the 0.36 s isomeric level in ^{122}Cs

$E_\gamma(\Delta E_\gamma)$ keV	$I_\gamma(\Delta I_\gamma)$	Electron line	$I_{e^-}(\Delta I_{e^-})$	Exp. $\alpha_{norm}/\alpha_{K(81)}$; K/L	Theory $E1$	$E2$	$E3$	$M1$	$M2$	$M3$	Multipolarity
81.20 (10)	1.20 (25)	K	573 (18)	α_K = [2.19]	0.335	2.26	12.1	1.41	15.6	114	$E2 + (9 \pm 4)\%\ M1$
		L	260 (13)	K/L = 2.20 (18)	7.32	1.70	0.29	7.5	4.4	1.7	
		M	61 (11)	α_M = 0.28	0.0092	0.286	9.47	0.038	0.76	15.5	
45.85 (15)	0.60 (15)	L	330 (15)	$\alpha_L = 2.5\left\{\begin{matrix}3.5\\1.9\end{matrix}\right.$	0.235	19.5	1,100	1.0	39	1,150	$M1 + (9 \pm 4)\%\ E2$
		M	72 (5)								

Precise energy and efficiency calibrations have been performed with different radioactive samples, as ^{133}Ba, ^{152}Eu, displayed in the same geometrical conditions as the collected isotopes. The γ-rays observed in the decay of ^{124}Cs samples isotopically separated at ISOCELE (collecting time $=10$ s - counting time $=10$ s) are reported in Table 2 and compared with the previous measurements performed at CERN on the same $A=124$ isotope [20]. It appears that the low-energy domain is completely new; moreover, with a normalization on the 354 keV ($2^+ \to 0^+$) transition fed in ^{124}Xe by the 31 s ^{124}Cs activity, the present comparison reveals a perfect agreement in both experiments for energies and intensities, above 300 keV. This situation indicates that the new identified 6.3 s isomeric level decays essentially to the ^{124}Cs ground-state.

As the transitions associated with the ^{124m}Cs isomer have low energies, a special effort has been developped to measure conversion electron. The singles spectra have been carried out at different set-up of the magnetic field in the electron selector by applying various courant intensities ($I=3$; 2 or 1.5 amperes). An example is displayed in Fig. 5. The efficiency calibration curve of the magnetic selector has been carefully controlled at low energy with stantard radioactive samples [^{241}Am, ^{212}Pb(Th B)].

Complete results concerning ^{124m}Cs decay transitions are reported in Table 3. From both gamma-rays and conversion electron intensity measurements, multipolarities of the transitions have been deduced. The presence of the pure $E2$ ($2^+ \to 0^+$) 354 keV transition in ^{124}Xe suggested an obvious normalization of the conversion coefficients. Unfortunately, to favour the 6.3 s isomer, few seconds collecting times have been used in several experiments, giving weak 354 keV transition intensity. In practice, we have done a two-steps analysis; first, with spectra taken with 10 s collection time, a preliminary α_K coefficient estimation has been made; secondly, as the 89.5 keV transition had typical characteristics of an electric dipole, it has been used as reference to estimate all the other experimental conversion coefficients, as reported in column 5 of the table. For several transitions, total intensities are very weak; nevertheless their multipolarities have been given in the table because they have been confirmed with a better precision in the ^{124}Ba$\to$^{124}Cs decay [27; work in progress]. When large uncertainties are present on conversion coefficients, the ratio K/L is specially usefull to establish the assignment.

The $\gamma-\gamma$ coincidence measurements have been undertaken with two different sets of detectors: set 1 consisted of two 70 cm^3 intrinsic Ge detectors for

Table 2. Energies and relative intensities of gamma transitions observed in the decay of isotopically separated ^{124}Cs samples. The results (collection time $=10$ s - counting time $=10$ s) are in good agreement with the previous ones found at CERN [20], for energies greater than 350 keV

Present work		CERN results [20]	
E_γ (keV)	I_γ	E_γ (keV)	I_γ
29.62	K_{α_1} Xe		
30.80	K_{α_1} Cs		
33.56	K_{β_1} Xe		
34.74	{K_{β_2} Xe, K_{β_1} Cs		
35.81	K_{β_2} Cs		
53.85±0.05	0.42±0.04		
58.20±0.05	1.23±0.06		
64.90±0.05	0.15±0.03		
(74.8 ±0.1)	<0.15		
89.50±0.05	3.10±0.10		
96.55±0.05	3.05±0.10		
111.8 ±0.15	~0.05		
169.5 ±0.1	0.34±0.05		
188.98±0.05	1.6 ±0.1		
211.64±0.05	3.3 ±0.1		
270.30±0.10	0.62±0.05		
353.99±0.07	[100]	353.9±0.2	[100]
355.6 ±0.4	–		
		359.9±0.5	0.6 ±0.3
		368.5±1.0	0.2 ±0.1
381.0 ±0.2	0.10±0.05	380.7±0.5	0.10±0.05
		388.1±1.0	1.80±1.0
401.2 ±0.3	0.30±0.03	401.1±0.3	0.22±0.04
422.5 ±0.1	1.07±0.05	422.2±0.3	0.92±0.15
492.55±0.05	9.10±0.4	492.5±0.2	9.1 ±1.5
524.8 ±0.1	0.88±0.05	524.8±0.3	1.0 ±0.3
749.5 ±0.2	0.47±0.04	749.6±0.3	0.50±0.08
781.9 ±0.15	0.49±0.04	781.9±0.3	0.50±0.09
846.5 ±0.1	3.00±0.06	846.6±0.2	3.0 ±0.3
863.7 ±0.4	0.80±0.12	864.8±0.4	1.0 ±0.3
865.3 ±0.3	1.60±0.08		
866.7 ±0.4	0.40±0.09	866.4±0.8	0.57±0.3
		879.8±0.5	0.17±0.10
893.6 ±0.3	0.42±0.04	893.6±0.3	0.40±0.06
914.8 ±0.15	10.0 ±0.3	914.8±0.2	10.0 ±1.0
(1,003 ±1.5)	~0.1	1,002.9±0.7	0.08±0.02
(1,020 ±1.5)	0.2 ±0.1	1,020.0±1.0	0.10±0.06
		1,073.6±0.9	0.07±0.02
1,100 ±1	0.20±0.06	1,099.7±0.5	0.24±0.04
1,132 ±1	0.33±0.05	1,132.0±0.6	0.36±0.06
(1,143 ±2)	~0.10		
(1,217 ±2)	~0.10		
1,268.9 ±0.6	0.30±0.06	1,268.4±0.6	0.23±0.06
1,274.4 ±0.3	1.16±0.08	1,274.0±0.3	1.10±0.15
		1,291.5±1.0	0.08±0.04
1,335.9 ±0.2	1.25±0.10	1,335.7±0.4	1.2 ±0.2
1,358.8 ±0.4	0.42±0.07	1,358.9±0.5	0.40±0.10
(1,425 ±1)	0.2 ±0.1	1,425.3±1.0	0.06±0.02
		1,528.0±1.0	0.08±0.02
		1,544.5±1.0	0.09±0.03
1,628.5 ±0.3	2.3 ±0.3	1,628.5±0.3	2.4 ±0.3
(1,639 ±1)	–		
(1,655 ±1)	~0.1		
1,665.6 ±0.5	0.4 ±0.1		
(1,673 ±1)	0.2 ±0.1	1,673.4±0.5	0.08±0.02
1,689.4 ±0.4	1.4 ±0.2	1,689.6±0.8	1.4 ±0.2
		1,759.3±1.0	0.08±0.02
1,851.2 ±0.5	0.7 ±0.2	1,851.6±1.0	0.70±0.15
(1,979 ±1)	0.2 ±0.1	1,979.5±1.0	0.25±0.06
2,020.1 ±0.4	1.6 ±0.3	2,020.5±1.0	1.60±0.25
		2,126.0±1.0	2.0 ±0.5
2,165.9 ±0.4	2.3 ±0.5		
		2,382.0±1.0	0.4 ±0.2

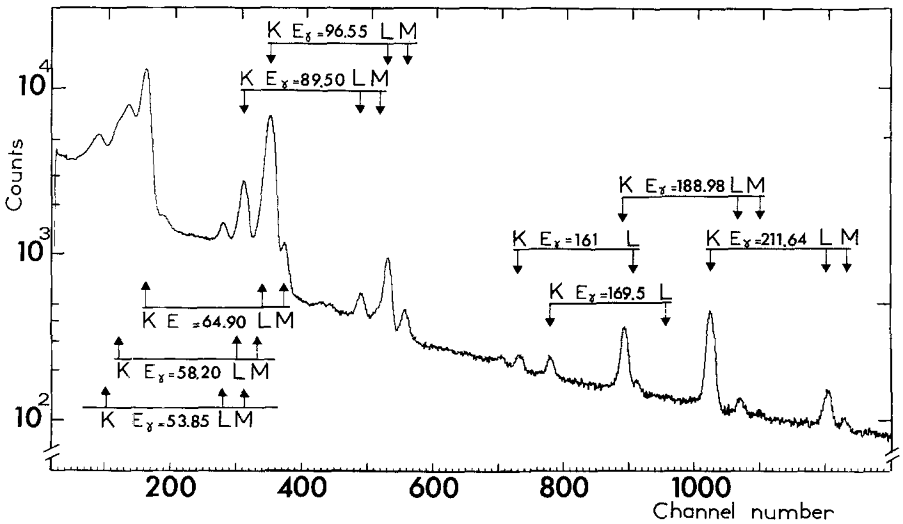

Fig. 5. Conversion electron spectrum recorded with the magnetic selector for ^{124m}Cs samples collected during 10 s

Table 3. Internal conversion electron data and deduced multipolarities of the gamma transitions observed in the decay of ^{124m}Cs

E_γ (KeV)	$I_\gamma(\Delta I_\gamma)$ (rel.)	Electron line	$I_{e^-}(\Delta I_{e^-})$ (relative)	Exp. $\alpha_{K\,\mathrm{norm}}/\alpha_{K(89.5)}$ K/L, etc...	Theory $E1$	$E2$	$E3$	$M1$	$M2$	$M3$	Multipolarity
53.85	0.42 (4)	K	1,450 (300)	α_K = 3.2 (10)	1.05	6.50	28.3	4.70	74.5	530	$M1$ ($E2$)
		L	243 (9)	K/L = 6.0 [9.3, 3.8]	6.85	0.70	0.06	7.49	3.64	0.79	
58.20	1.23 (6)	K	1,530 (220)	α_K = 1.15 (22)	0.835	5.45	25.5	3.65	53.0	394	$E1$
		L	168 (15)	K/L = 9.1 [12.8, 6.5]	7.00	0.84	0.09	7.47	3.79	0.97	
64.90	0.15 (3)	K	4,350 (150)	α_K = 26.7 [34, 21]	0.620	4.23	21.3	2.70	36.0	268	$M2$
		L	1,030 (52)	K/L = 4.2 (4)	7.10	1.12	0.135	7.46	4.01	1.19	
		M	266 (27)								
89.50	3.10 (10)	K	874 (75)	[α_K = 0.260]	0.260	1.72	9.13	1.08	11.1	78.3	[$E1$]
		L	126 (13)	K/L = 6.9 (14)	7.40	1.98	0.37	7.53	4.60	1.92	
		M	56 (14)								
96.55	3.05 (10)	K	3,320 (150)	α_K = 1.03 (8)	0.21	1.36	7.17	0.87	8.35	57.5	$M1$ ($E2$)[a]
		L	454 (14)	K/L = 7.68 (50)	7.48	2.22	0.46	7.53	4.74	2.11	
		M	140 (6)								
161.0		K	44 (4)								
		L	44 (6)	K/L = 1.0 (3)	7.70	3.78	1.35	7.35	5.55	3.45	$E3$
169.5	0.34 (5)	K	53 (4)	α_K = 0.144 (35)	0.044	0.225	0.984	0.179	1.11	5.76	$M1$ ($E2$)[a]
188.98	1.6 (1)	K	245 (11)	α_K = 0.141 (15)	0.033	0.158	0.660	0.132	0.764	3.71	$M1+(45\pm15)\%$ $E2$
		L	40 (1)	K/L = 6.1 (5)	7.78	4.38	1.71	7.58	5.84	3.84	
		M	36 (5)								
211.64	3.3 (1)	K	429 (12)	α_K = 0.120 (7)	0.024	0.109	0.432	0.097	0.519	2.35	$E2$
		L	91 (5)	K/L = 4.7 (4)	7.81	4.73	2.03	7.60	6.02	4.13	
		M	23 (5)								
270.30	0.62 (5)	K	15 (3)	α_K ≃ 0.025	0.012	0.049	0.18	0.049	0.23	0.95	($M1+E2$)

[a] The mixing ratio can be deduced in the ^{124}Ba → ^{124}Cs decay [27]

classical gamma-gamma coincidences while set 2 consisted of one $1\,cm^3$ and one $70\,cm^3$ Ge detectors for X-rays - gamma coincidences. The last arrangement was very useful to extract coincidence events between low-energy transitions but also to assign correctly the γ-lines to the cesium isotope from X_K Cs-γ coincidence events. The resolution times were of the order of 30 ns. The three parameters $(E_{\gamma 1}-E_{\gamma 2}-t_{\gamma 1 \gamma 2})$ coincidence events were recorded on a magnetic tape and sorted afterwards. The main results are summarized in Table 4.

The conversion electron - low-energy gamma coincidences have been carried out with the magnetic electron selector operating at $I=2.5$ A and a $3\,cm^3$ (830 eV FWHM at 122 keV) planar Ge(Li) detector. The information derived from these $e^- - \gamma$ coincidence data is reported in Table 5.

Table 4. Prompt and delayed gamma-gamma coincidences observed in the decay of ^{124m}Cs

Gate energy (keV)	Coincident γ-rays energies (keV)
A) Prompt events	
53.8	58.2, 96.5, 188
58.2	53.8, 96.5, 188
89.5	96.5, 211
96.5	53.8, 58.2, 64.9, 89.5, 189, 211
188.9	53.8, 58.2, 64.9, 96.5
211.6	89.5, 96.5
B) Delayed events	
58.2	96.5, (189)
89.5	96.5, 211
96.5	58.2, 96.5
211.6	89.5, 96.5
270.3	96.5

Brackets denote weak coincidences

Table 5. Gamma-electron coincidences observed in the decay of ^{124m}Cs

Gate energy (keV)	Conversion electron lines in coincidence
53.8	$(K_{64.9})-K_{96.5}-L_{96.5}-K_{189}$
58.2	$K_{53.8}-K_{64.9}-L_{53.8}-K_{96.5}+L_{64.9}-L_{96.5}-K_{189}$
89.5	$K_{64.9}-K_{96.5}-L_{96.5}-K_{211}-L_{211}-M_{211}$
96.5	$K_{64.9}-L_{53.8}-K_{89.5}-K_{96.5}+L_{64.9}-M_{64.9}-L_{89.5}-(K_{189})-K_{211}$
169.5	$K_{96.5}$
188.9	$K_{53.8}-K_{59.2}-K_{64.9}-L_{53.8}-L_{58.2}-K_{96.5}-L_{96.5}$
211.6	$K_{64.9}-K_{89.5}-K_{96.5}-L_{89.5}-L_{96.5}$
270.3	$(L_{\sim 31})^a-(K_{64.9})-K_{96.5}$

Brackets denote weak coincidences

[a] The 31 keV transition is only tentative (Sect. 4.2)

The $E1$ multipolarity assignments for both the 58.20 and 89.50 keV transitions and the delayed events observed in the $\gamma-\gamma$ coincidence data have suggested a precise time measurement experiment. This very short half-life search has been undertaken with two planar Ge(Li) gamma detectors and a special adjustment of electronics. Indeed, even with small detectors, timing properties are not perfect so a pulse shape selection method has been used. In this technique, the signal detector feeds two different CFPHT units (Constant Fraction of Pulse Height Trigger). On one path, the signal is attenuated by a fraction f_1, inverted and delayed; on the other path, the signal is attenuated by a fraction f_2. The new pulses are added again to deliver an adjustable timing output pulse. As checked in details on large Ge(Li) detectors by Engel and coworkers [28], this method improves considerably the time resolution. In the present experiment, a carefull preliminary adjustment has been done with ^{133}Ba sample providing a 6.3 ns isomeric level at 81.0 keV.

The measurement has been performed on ^{124}Cs isotopic separated samples collected during three seconds. The $\gamma-\gamma-t$ coincidence counting rate was very low; the experiment was running during five hours to get significant time spectra. An example is reproduced in Fig. 6, indicating clearly the presence of a short half-life isomeric level $[T_{1/2}=(69\pm 3)\,ns]$ in the decay scheme of the 6.3 s ^{124m}Cs.

The level scheme of ^{124m}Cs was mainly built from coincidence data. Examples of typical coincidence spectra are reproduced in Figs. 7 and 8. Taking into account sum energies, multipolarities, intensity bal-

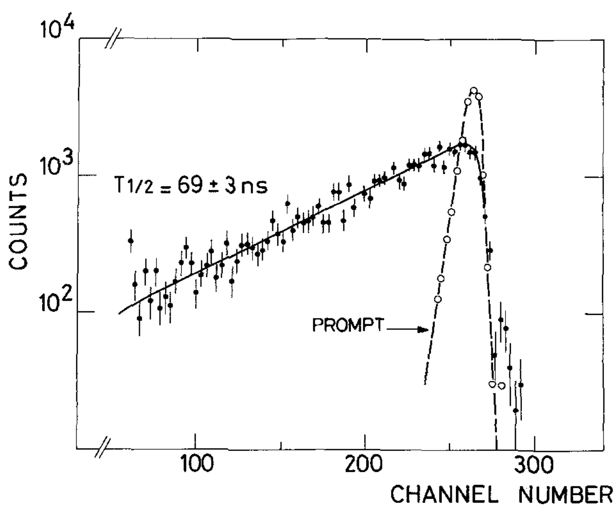

Fig. 6. Example of timing distribution observed in ^{124m}Cs and associated to the 301 keV short half-live isomeric state. The comparison is made between the delayed coincidence curve of the 89.5 keV γ-ray and the prompt line measured between the 89.5 and the 211.6 keV γ-rays

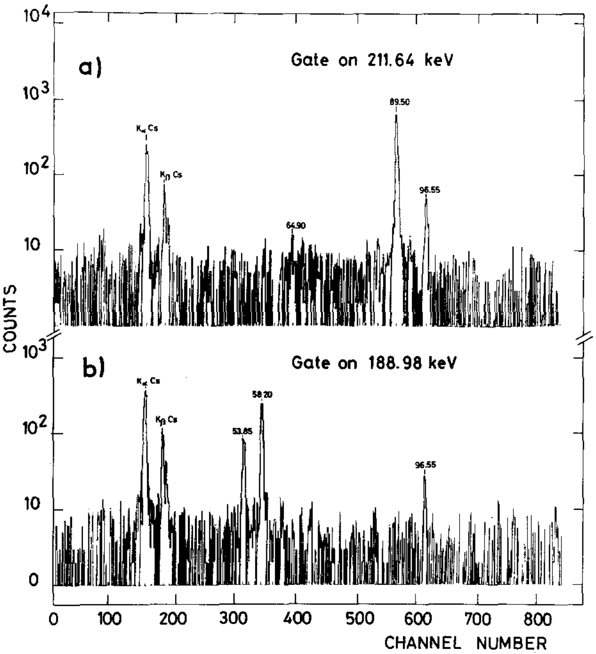

Fig. 7. Examples of gamma-gamma coincidence spectra which show two different parallel cascades of transitions in the ^{124m}Cs decay

ances and including the presence of the 69 ns short half-life, the level scheme proposed in Fig. 9 has been retained for the decay of the 6.3 s isomeric level in the ^{124}Cs. Obviously, spin and parity assignments are based upon the 1^+ ^{124}Cs ground-state [5] and the multipolarities involved in the cascades. The 69 ns isomeric level included at 301 keV is well established by both the two parallel decaying paths, the 89.50 keV ($E1$)–211.64 keV ($E2$) transitions on one side and the 58.20 keV ($E1$)–53.85 keV ($M1$)–188.98 keV ($M1+E2$) transitions on the other side. The relative position of the 58.2 and 53.8 keV lines has been mainly based upon the $E1$ character of the first one and the strong prompt $\gamma-\gamma$ coincidence observed between them. The existence of the 161 keV transition has been found in electron singles spectra and its $E3$ multipolarity is clearly established from its K/L ratio.

This 161 keV transition appears very likely as crossover of the 64.90 keV ($M2$) and the 96.55 keV ($M1$) transitions. On the 301 keV state, the intensity balance is quite correct; its feeding is of 6.8 ± 0.3 in the arbitrary units of the Table 3 and the sum of its two deexciting paths reaches $(4.1+2.8)=6.9 \pm 0.4$ in the same scale.

The 169.5 and the 270.3 keV γ-rays have not been placed in the level scheme displayed in Fig. 9 though they roughly represent 4% and 2% of the total gamma intensity, respectively. Nevertheless these lines have been observed in our coincidence data. The 270.3 keV has been detected in delayed coincidence gated on the 96.5 keV line suggesting that its place in the level scheme is probably below the short half-life isomeric level located at 301 keV. In the gamma-electron coincidence measurement, the 270 keV γ-ray has been found in coincidence whith a line at

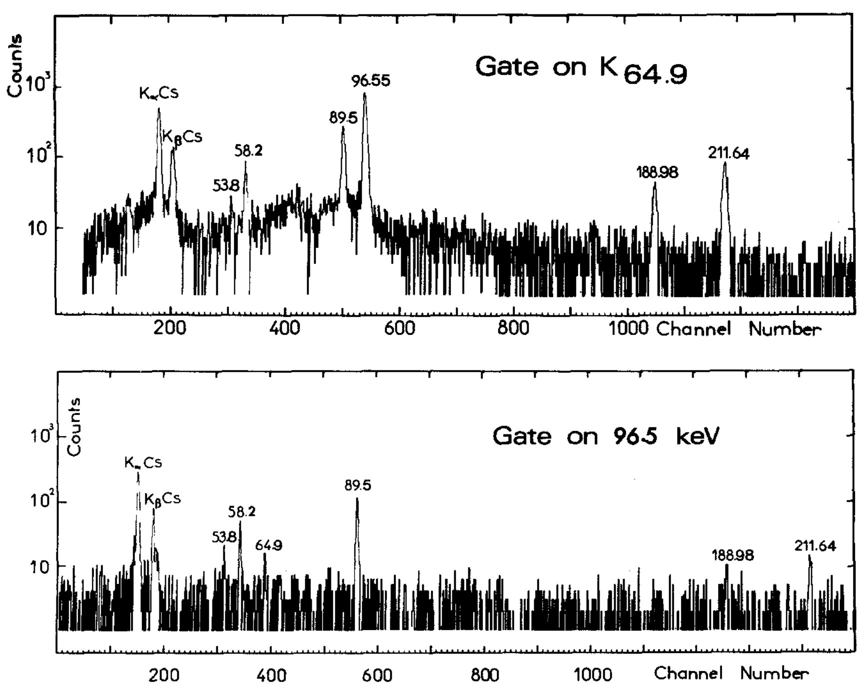

Fig. 8. Electron-gamma and gamma-gamma coincidence spectra gated respectively on the $K_{64.9}$ line and on the 96.5 keV γ-ray, transitions which are both above the 301 keV ($T_{1/2}=69$ ns) isomeric level

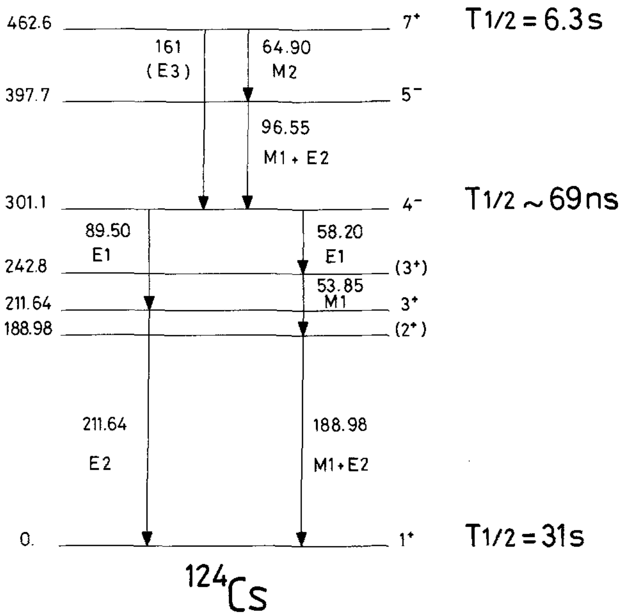

Fig. 9. Partial level scheme of ^{124}Cs fed by the ^{124m}Cs decay ($T_{1/2}$ = 6.3 s)

approximately 26 keV and with both the $K_{64.9}$ and the $K_{96.5}$ electron lines. All these results suggest the existence of a 270.3 keV excited level, fed from the 301 keV state by a transition of approximately 31 keV (the electron group observed at 26 keV in the $\gamma - e^-$ coincidence measurement could be the L conversion lines of this transition). This proposition is only a tentative. It is in desagreement with the first partial level scheme given by Droste et al. [17] in the ^{124}Ba$\rightarrow ^{124}$Cs decay where a 271 − 169 cascade was placed above the 1^+ ^{124}Cs ground-state. In the 6.3 s ^{124m}Cs decay, the 169 keV is very weak and any $\gamma-\gamma$ coincidence has been observed with it. Nevertheless, in $e^- - \gamma$ coincidence data, the K_{96} electron conversion line presents a weak coincidence with the 169 KeV γ line. In conclusion, from the present study of the ^{124m}Cs decay, both the 169 and 270 keV transitions appear in connection with the 69 ns 301 keV state by very weak converted transitions and could feed directly the 1^+ ground-state from two different excited levels at 169 and 270 keV respectively; this proposition is in agreement with our measurements in progress on the ^{124}Ba$\rightarrow ^{124}$Cs decay [27].

Moreover, we have searched for a direct deexcitation of excited states in ^{124}Cs to ^{124}Xe levels. Such a situation have been observed at CERN [15] for the ^{122}Cs isotope, the 4 min activity decaying to high-spin high-energy levels in ^{122}Xe while the 21 s activity populates mainly low-spin lower-energy levels in the same nucleus. In the ^{124}Cs, the 1^+ ground-state feeds alone low-spin levels in ^{124}Xe.

With the partial decay scheme presently established, the new 6.3 s isomeric level in ^{124}Cs supports a 7^+, I^π assignment. In atomic beam measurements of nuclear spins performed at Uppsala or at CERN on cesium isotopes, such characteristics have not been observed [5]. As the main configurations involved in the lower excited levels of ^{124}Cs are not completely defined, it is difficult to assign a correct structure to the 7^+ isomeric state from its decay. Due to the relative position of the different configurations available in this region for both odd-neutron and odd-proton a $\pi g_{7/2}\, \nu g_{7/2}$ coupling could explain such I^π characteristics. Nevertheless, $9/2^+$ proton-hole states have been observed at very low energy in odd-A Cs isotopes [1] and odd-A I isotopes [29] so a 7^+ state in odd-odd Cs could present a mixing of different proton-neutron configurations involving $d_{5/2}$, $g_{7/2}$ and $g_{9/2}$ shells and up to now, the exact situation cannot be extracted from the present study alone.

4.3. Decay of the (3.46±0.06) *min Isomeric State in* ^{130}*Cs*

As already mentioned, the ^{130}Cs isotope has been intensively studied. Its 1^+ ground state and a $J=5$ isomer are known [5] but their relative positions and their connexion are undetermined. Hardy and coworkers [30] have measured the mass of ^{130}Cs with a good precision and deduced that an isomeric level could be 121±15 keV above the ground-state; nevertheless, from angular distribution data for the ^{129}Xe(^{3}He, d)^{130}Cs reaction used, a $L=2$ character has been obtained for this 121 keV excited state, leading to a spin assignment $I<3$ with positive parity, result which cannot explain the $I=5$ isomer.

As the production rate of the $T_{1/2}=3.46$ min ^{130m}Cs was very large at the ISOCELE 2 separator, a tentative to establish its decay scheme has been undertaken and the results are reported in the present paper.

Singles gamma-ray and conversion electron spectra (Figs. 10 and 11) have been recorded with collection times of 200 s and 150 s respectively. Combining these data, energies, intensities and multipolarities of the transitions involved were deduced (Table 6). As the transitions are mainly concentrated at very low energy, in some cases, difficulties occured to separate completely the K, L, M conversion lines in the electron spectra.

For example, for both the 131.5 and the 80.45 keV transitions which have pure lines only for K conversion electrons, it was necessary to use the fact

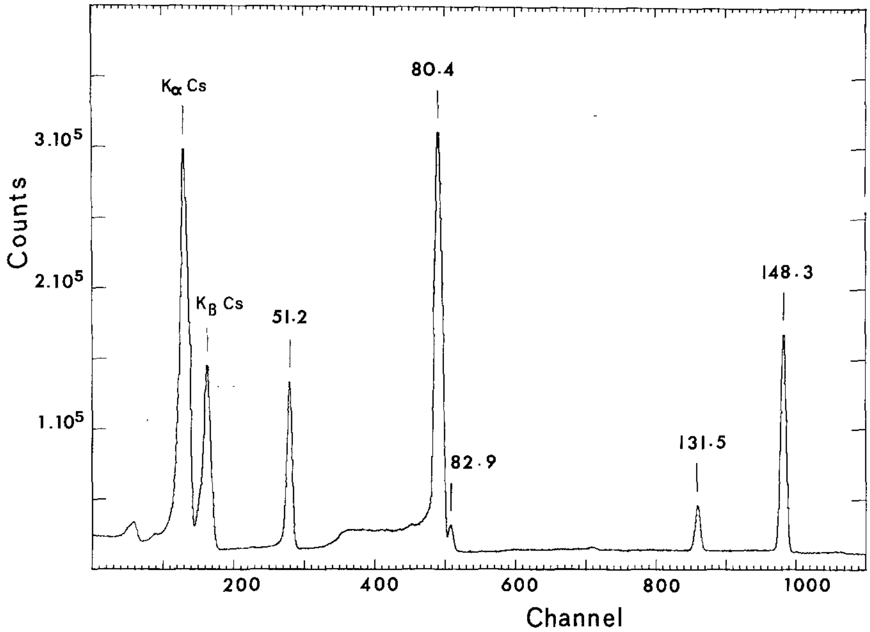

Fig. 10. Singles gamma-rays spectrum measured with ^{130}Cs samples collected during 200 s

that the L/M ratios are quite stable, independently of the transition multipolarities, to roughly estimate the L and M components.

For the 51.2 keV transition, the extraction of its K conversion line has been difficult due to the presence of the $M_{14.9}$ group at the same energy (Fig. 11) and to the absence of a correct experimental line shape

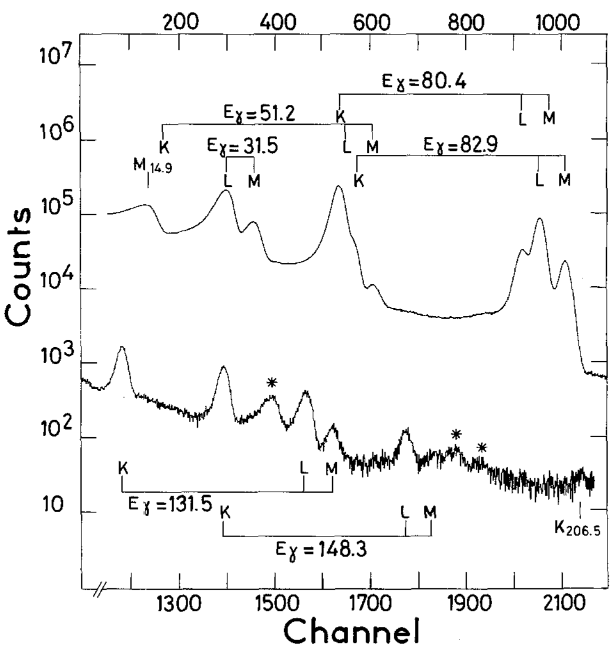

Fig. 11. Single conversion electron spectrum recorded with the magnetic selector for ^{130}Cs samples collected during 150 s. The broad lines marked by a star have been identified as summing events

in this energy range; indeed, the K_{131} line used all over the electron spectrum as a standard to analyse the data, was too narrow and unable to give a reasonable $K_{51.2}$ electron intensity. Nevertheless, from the singles spectra an high multipolarity character was rejected. The intensity estimation has been mainly deduced from electron intensities in the electron-gamma coincidence spectra (Fig. 12 – gate on the 80.45 keV transition). Moreover, to remove the ambiguity between an $E1$ or $M1$ character for the 51.2 keV transition the argument of the intensity balance at the 80.45 keV level (Fig. 14) has also been used, taking into account that this state is clearly established from the coincidence data. Indeed, this first excited level observed is completely deexcited by the 80.45 keV $M1$ ($E2<5\%$) transition, the intensity of which reaches $1{,}840\pm100$ in the relative scale reported in Table 6. From the experimental data, the same level is fed by two transitions of 51.18 and 82.9 keV. For the last one, its total intensity equals 795 ± 15, giving a rest of $1{,}045\pm105$. From the intensity balance, the total electron conversion coefficient of the 51.18 keV transition deduced is $\alpha_T=6.6\pm0.3$. By comparison with the theoretical values $\alpha_T(E1)\approx1.37$ and $\alpha_T(M1)\approx6.5$ an $M1$ multipolarity is retained for this transition. The $K_{51.18}$ electron intensity reported in Table 6 has been estimated with these previous assumptions.

The 31.5 keV transition corresponds to a special case because its γ-line is mixed with the Cs X_K-rays in both singles and coincidence spectra. Nevertheless electron intensities estimations for the 31.5 keV transition have been made in both singles and

Table 6. Energies, relative intensities, internal conversion electrons data and multipolarities of gamma transitions observed in the decay of the $T_{1/2}=3.46$ min isomeric level in ^{130}Cs

$E_\gamma(\Delta E_\gamma)$ (KeV)	$I_\gamma(\Delta I_\gamma)$ (relative)	Electron line	$I_{e^-}(\Delta I_{e^-})$ (relative)	Exp. $\alpha_{K\,\mathrm{norm}}/\alpha_{K(148)}$ K/L, etc...	Theory E1	E2	E3	M1	M2	M3	Multipolarity
14.9 (3)[a]	–	M	<150								
31.5 (3)[a]	–	L	≈1,030								
		M	≈340								
51.18 (5)	138 (6)	K	≈570•								(M1)*
		L	95 (24)								
		M	31 (2)	α_M = 0.165 (18)	0.035	2.55	142	0.148	5.70	210	
80.45 (10)	680 (30)	K	1,274 (34)	α_K = 1.38 (10)	0.342	2.32	12.1	1.45	16.0	119	M1(E2≦5%)
		L	<250								
		M	38 (9)								
82.9 (1)	13.0 (7)	K	208 (12)	α_K = 11.8 (11)	0.309	2.12	8.1	1.33	14.2	106	E3
		L	722 (13)	K/L = 0.288 (22)	7.38	1.75	0.3	7.50	4.47	1.75	
		M	190 (5)								
131.50 (7)	25.4 (20)	K	13.0 (1)	α_K = 0.377 (30)	0.088	0.50	2.50	0.355	2.63	16.2	M1(E2)
		L	<4.0								
		M	<1.1								
148.35 (7)	100 (3)	K	8.70 (14)	α_K = 0.064	0.064	0.340	1.66	0.251	1.75	10.2	E1
		L	1.04 (13)	K/L = 8.36 (12)	7.72	4.17	1.13	7.55	5.15	3.18	
		M	0.40 (6)								
206.5 (2)	0.58 (16)	K	0.14 (4)	α_K = 0.18 (10)	0.0242	0.113	0.47	0.098	0.517	2.47	[Δ]M1+E2[b]
470.8 (3)	3.0 (3)										[Δ]E1[b]
536.2 (3)	34.7 (7)										[Δ]E2[b]

Comments: Conversion electron intensities in column 4 have been estimated from singles electron spectra, except for the very low energy transitions.

• This $K_{51.2}$ line has been deduced from electron-gamma coincidence spectra (see Sect. 4.3) and confirmed by intensity balance arguments on the 80.45 keV level in ^{130}Cs

[a] Transitions observed by conversion electron lines only; corresponding mean energies have been estimated from electron-gamma coincidence spectra

[Δ] Transitions belonging to ^{130}Xe, as the conversion coefficients mentioned in the table

[b] Multipolarities established from in-beam measurements performed by Goettig et al. [31] on the ^{130}Te(^{3}He, $3n\gamma$) reaction

* Multipolarity discussed in the text (Sect. 4.3)

coincidence spectra gated on the 51 and 131 keV γ-rays. Moreover, two different attempts have been realized, using successively the standard K_{131} electron line as reference and then a larger and more realistic electron line shape at very low energies. In such a way, one gets $680 < I_{e^-}\ (L_{31}+M_{31}) < 1{,}440$, in the arbitraty units of Table 6. From the coincidence data (Table 7) the 31.5 keV transition feeds the 131 keV level which is deexcited by the 131.5 and the 51.18 keV transitions. The total intensity of these two transitions reaches approximatively $1{,}090 \pm 100$, value in good agreement with the electron intensity of the 31.5 keV transition reported above.

The level scheme proposed in the Fig. 14 is mainly based upon coincidence data, multipolarities and energy relationships. In the first experiments, the placement of a 14.9 keV transition was a puzzling problem. Obviously, it is impossible to identify such a low-energy transition and to estimate correctly its intensity in the singles spectra; nevertheless, its existence was revealed from an electron spectrum gated on the 148 keV γ-ray in electron-gamma coincidence measurements. With the magnetic selector operating at very low energy ($I=1.5$ amperes) and an electron - low-energy gamma ray coincidences set-up specially adjusted, a new experiment has been performed, on-line, during five hours. The clean results obtained are displayed in Fig. 13; they show the L and M conversion electrons of the 14.9 keV transition in strong coincidence with the 148.3 keV γ-ray and indicate its place in the level scheme. From all the measurements and taking into account the energy sums $80.45+82.9=163.35\pm0.20$, $80.45+51.18+31.5=163.1\pm0.4$ and $148.35+14.9=163.2\pm0.4$, a level has been proposed at 163.2 keV. Spin and parity assignments, 5^-, for this 3.46 min ^{130m}Cs isomeric

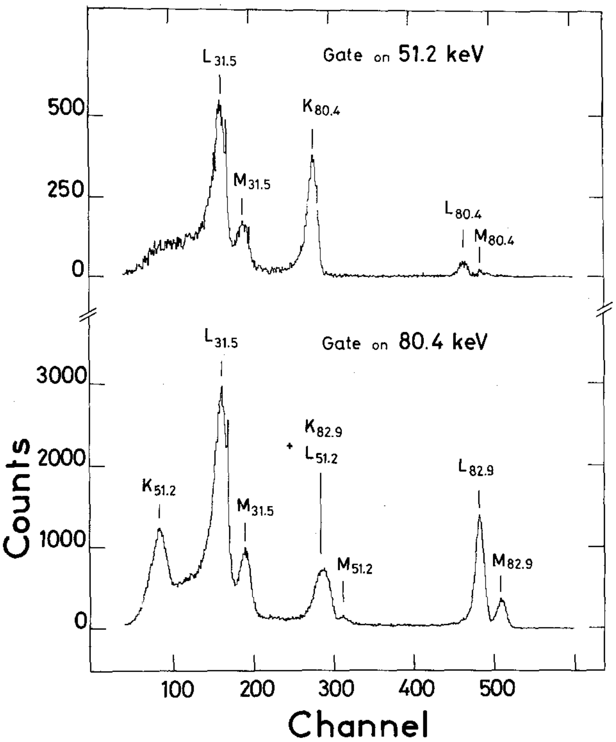

Fig. 12. Examples of electron coincidence spectra gated on γ-rays in the decay of the $T_{1/2}=3.46$ min ^{130m}Cs

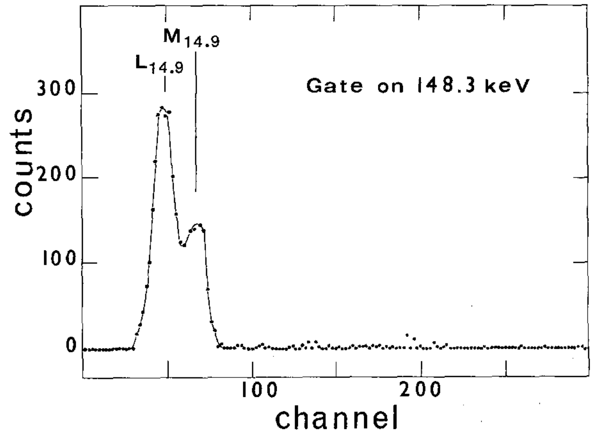

Fig. 13. Electron coincidence spectrum gated on the 148 keV γ-ray in the decay of ^{130m}Cs ($T_{1/2}=3.46$ min). The magnetic selector was operating at very low energy ($I=1.5$ amp.). The spectrum in coincidence with the background has been substracted

Table 7. Electron-gamma and gamma-gamma coincidences observed in the decay of ^{130m}Cs ($T_{1/2}=3.46$ min)

A) Electron $-\gamma$-Rays

Gate (E_γ KeV)	Conversion electron lines in coincidence
51.2	$L_{31.5}-M_{31.5}-K_{80.5}-L_{80.5}-M_{80.5}$
80.5	$K_{51.2}-L_{31.5}-M_{31.5}-L_{51.2}-K_{82.9}$ $-M_{51.2}-L_{82.9}-M_{82.9}$
82.9	$K_{80.5}-L_{80.5}-M_{80.5}$
131.5	$L_{31.5}-M_{31.5}$
148.4	$M_{14.9}$

B) Low-Energy γ-Rays$-\gamma$-Rays

Gate (E_γ keV)	Low-energy γ-ray lines in coincidence (KeV)
51.2	K_αCs$-K_\beta$Cs-80.5
80.5	K_αCs$-K_\beta$Cs$-51.2-82.9$
82.9	K_αCs$-K_\beta$Cs-80.5

state are mainly based upon the $E3$ character of the 82.9 keV transition. The existence of the weak branching ratio ($\sim 10^{-4}$) observed from this level to the 5^- state at 2,310.2 keV in the ^{130}Xe is well established in our gamma - X rays coincidence data since the 206.5 and the 470.9 keV gamma lines found are in coincidence with the xenon X-rays. These two transitions have been already observed by Goettig et al. in ^{130}Xe [31] with in-beam measurements performed on the ^{128}Te (α, $2n$) and the ^{130}Te (^{3}He, $3n$) reactions. This observation constitues a supplementary argument for the spin and parity, 5^-, assigned to ^{130m}Cs.

This result appears in agreement with the $I=5$, 3.7 min ^{130m}Cs observed by Ekström and coworkers [5] while it seems, very likely, that the (2^+), 131.5 keV level observed in the present experiment could be compared to the $I<3$, 121 ± 15 keV level found by Hardy et al. [30] in the ^{129}Xe(^{3}He, d)^{130}Cs reaction.

The present data cannot confirm the $\pi[420\,1/2]$, $\nu[514\,9/2]$ configuration suggested before [5] for the 5^- isomeric level in ^{130m}Cs. Indeed, in the partial level scheme proposed in Fig. 14, it decays by three different paths as follow: approximately 77% to the (2^+) level at 131.5 keV, 16% to the 2^+ level at 80.45 keV and 7% to a (2^-) level at 148.3 keV. If the multipolarities of the highly converted low-energy transitions placed at the top of the scheme are relatively well defined, the mixed nature of the excited levels fed is unknown. In such a situation it appears unrealistic to discuss in details the different transitions probabilities. Additional experiments, as for example in-beam measurements, would be helpful to clarify the nature of the low energy excited levels in ^{130}Cs.

In conclusion, if at the first glance, from systematics and recent spins and magnetic moment performed at CERN [8], the situation of doubly-odd cesium isotopes appeared very simple, the detailed description

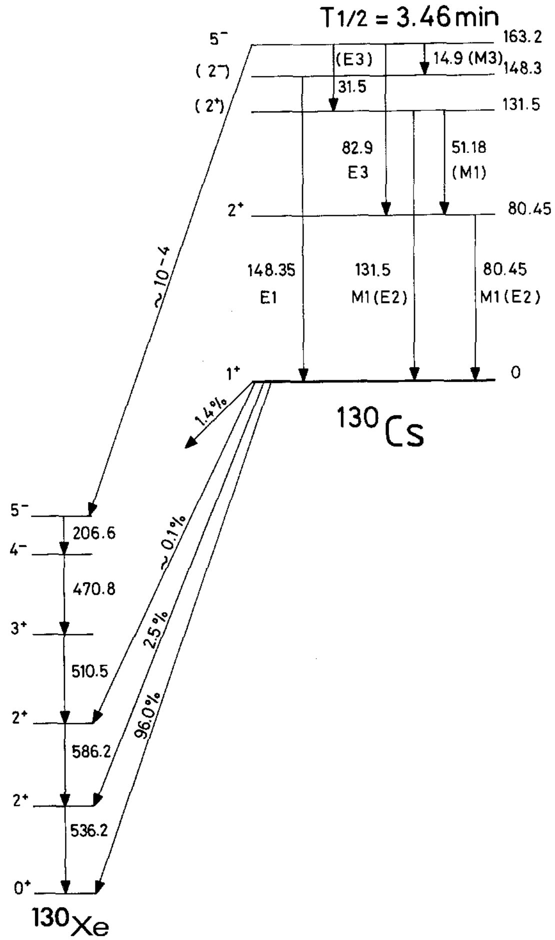

Fig. 14. Partial level scheme of ^{130}Cs fed by the $T_{1/2}=3.46$ min isomeric level. A weak branching to the 5^- level at 2,310 keV in ^{130}Xe has been also observed. The percentage feedings from 1^+, ^{130}Cs to states in ^{130}Xe are those recalculated by E. Hagberg et al. [Ref. 25]. The detailed feeding of states between 1,794 and 2,630 keV in ^{130}Xe is known but has been labelled "1.4%" on the smaller arrow of the figure for clarity

of these nuclei is, in general, a difficult problem. For example, the same spin and parity assignments, 1^+, describe the ground state of these odd-odd cesium from $A=122$ to $A=130$ and experimental dipole and quadrupole moments exhibit similar structures for ^{124,126,128}Cs but from the present investigation on isomeric states and their decays the situation appears quite complex. New half-lives have been well identified and partial level schemes established in ^{130}Cs, ^{124}Cs and even in ^{122}Cs but, up to now, it is impossible to extract systematics among energies or characteristics of low-energy excited states in these cesium isotopes. In fact it is not so surprising because it exists a large number of coupling between the quasiparticle configurations identified at low-energy in the odd-A neighbouring Cs and Xe isotopes, related to the protons and neutrons orbitals $s_{1/2}$, $d_{3/2}$, $d_{5/2}$, $g_{7/2}$, $h_{11/2}$ and $g_{9/2}$ and giving rise to a large number of different $[\pi, \nu]$ two quasiparticle configurations.

The present experiments alone constitue a first step in the knowledge of doubly-odd cesium and several further experimental investigations are needed to get more details. In the ^{124}Cs case we have undertaken at ISOCELE 2 a study on the $^{124}\mathrm{Ba}\rightarrow{}^{124}\mathrm{Cs}$ decay. The corresponding analysis is now in progress and several low-spin levels strongly populated by this mode in ^{124}Cs have been easily identified. A more constructive comparison will be possible with similar states already observed in ^{120,122,124}I [9, 32] and ^{120,122}Sb [33–36]. Heavy ion in beam spectroscopy measurements would be useful to excite selectively collective band structures involving high-spin components and to help in the comparison with theoretical calculations.

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References

1. Garg, U., Sjoreen, T.P., Fossan, D.B.: Phys. Rev. C **19**, 207, 217 (1979)
2. Table of Isotopes. Lederer, C.M., Shirley, V.S. (eds.), 7th Edn. New York: John Wiley 1978
3. Ekström, C., Robertsson, L., Wannberg, G., Heinemeier, J.: Phys. Scr. **19**, 516 (1979)
4. Ekström, C., Ingelman, S., Wannberg, G.: Nucl. Instrum. Methods **148**, 17 (1978)
5. Ekström, C., Ingelman, S., Wannberg, G., Skarestad, M.: Nucl. Phys. A **292**, 144 (1977)
6. Thibault, C., Touchard, F., Büttgenbach, S., Klapisch, R., Saint Simon, M. de, Duong, H.T., Jacquinot, P., Juncar, P., Liberman, S., Pillet, P., Pinard, J., Vialle, J.L., Pesnelle, A., Huber, G.: Nucl. Phys. A **367**, 1 (1981)
7. Larsson, S.E., Leander, G., Ragnarsson, I.: Nucl. Phys. A **307**, 189 (1978)
8. Ekström, C.: Proceedings of the 4th Int. Conf. on Nuclei far from stability, Helsingør, CERN 81-09, p. 12
9. Burde, J., Richter, V., Tsaliah, J., Labaton, I.: Nucl. Phys. A **385**, 29 (1982); A **351**, 238 (1981)
10. Hiddleston, H.R., Browne, C.P.: Nucl. Data Sheets **17**, 225 (1976)
11. Paris, P., Liang, C.F., Lecouturier, D., Arianer, M., Obert, J., Caruette, A., Ferro, A., Fournet, J., Putaux, J.C., Sarrouy, J.L.: Nucl. Instrum. Methods **186**, 91 (1981)
12. Putaux, J.C., Obert, J., Kotfila, L., Roussiere, B., Sauvage-Letessier, J., Liang, C.F., Peghaire, A., Paris, P., Giroux, J., ISOCELE Collaboration: Nucl. Instrum. Methods **186**, 321 (1981)
13. Paris, P., et al.: (to be published)
14. Paris, P., Treherne, J.: Rev. Phys. Appl. **4**, 291 (1969)
15. Genevey, J., Charvet, A., Marguier, G., Richard-Serre, C., D'Auria, J., Huck, A., Klotz, G., Knipper, A., Walter, G.: Nucl. Phys. A **283**, 45 (1977)
16. Ekström, C., Ingelman, S., Wannberg, G., Skarestad, M.: Proc.

of the third Int. Conf. on Nuclei far from Stability, Cargèse, 1976, CERN report 76-13, p. 193
17. Droste, Ch., Neubert, W., Chojnacki, S., Morek, T., Alexander, K.F., Wilhelmi, Z.: Nucl. Phys. A **192**, 595 (1972)
18. Alexander, K., Neubert, N., Rotter, M.: JINR Dubna, P7 - 3185 (1967);
Neubert, W., Droste, Ch., Morek, T., Chojnacki, S., Alexander, K., Wilhelmi, Z.: JINR Dubna, P6 - 4591 (1969)
19. Chaumont, J., Roeckl, E., Nir-el, Y., Thibault, C., Klapisch, R., Bernas, R.: Phys. Lett. **29** B, 652 (1969)
20. Charvet, A., Genevey, J., Carraz, L.C., Richard-Serre, C., Knipper, A., Walter, G.: J. Phys. (Paris) **38**, L-241 (1977)
21. Pathak, B.P., Lessard, L., Nikkinen, L., Preiss, I.L.: Phys. Rev. C **14**, 1573 (1976)
22. Droste, Ch., Blinowska, K.J., Goettig, L., Morek, T., Srebrny, J., Turowiecki, A., Cznosnyka, T.: Z. Phys. A - Atoms and Nuclei **277**, 167 (1976)
23. Watson, I.A., Silvester, D.J.: Radiochim. Acta **7**, 103 (1967)
24. Fessler, T.E., Julian, G.M., Jha, S.: Phys. Rev. **174**, 1472 (1968)
25. Hagberg, E., Hardy, J.C., Jonson, B., Tidemand-Pettersson, P., ISOLDE Collaboration: Nucl. Phys. A **357**, 365 (1981)
26. Liang, C.F., Peghaire, A., Paris, P., Weiss, B., Gizon, A.: Z. Phys. A - Atoms and Nuclei **299**, 185 (1981)
27. Weiss, B., et al.: Private communication on $^{124}Ba \rightarrow {}^{124}Cs$ decay
28. Engel, H., Schneider, H., Spitz, R.: Nucl. Instrum. Methods **142**, 525 (1977)
29. Hagemann, U., Keller, H.J., Brinckmann, H.F.: Nucl. Phys. A **289**, 292 (1977)
30. Hardy, J.C., Ball, G.C., Davies, W.G., Forster, J.S., Schmeing, H., Clifford, E.T.H.: Nucl. Phys. A **357**, 356 (1981)
31. Goettig, L., Droste, Ch., Dygo, A., Morek, T., Srebrny, J., Broda, R., Styczen, J., Hattula, J., Helppi, H., Jääskeläinen, M.: Nucl. Phys. A **357**, 109 (1981)
32. Münnich, F., Lode, D., Schrader, H., Höglund, A., Pessara, W.: Nucl. Phys. A **224**, 437 (1974)
33. Adacht, M., Matsuzaki, T., Taketani, H.: Nucl. Phys. A **314**, 80 (1979)
34. Emigh, R.A., Fields, C.A., Gartner, M.L., Samuelson, L.E., Smith, P.A.: Z. Phys. A - Atoms and Nuclei **308**, 173 (1982)
35. Alexeev, V.L., Emelianov, B.A., Egorov, A.I., Kabina, L.P., Kaminker, D.M., Khazov, Yu.L., Kondurov, I.A., Leushkin, E.K., Loginov, Yu.E., Martynov, V.V., Rumiantsev, V.L., Sakharov, S.L., Sushkov, P.A., Börner, H.G., Davidson, W.F., Pinston, J.A., Schreckenbach, K.: Nucl. Phys. A **297**, 373 (1978)
36. Gunsteren, W.F. van, Rabenstein, D.: Z. Phys. A - Atoms and Nuclei **282**, 55 (1977)

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