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New decay modes of the high-spin isomer of ^{124}Cs

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Abstract. A new β^+/EC branch of $0.11 \pm 0.02\%$ from the $(7)^+$ isomer of ^{124}Cs was identified in a measurement of the decay of ^{124}Cs using the 8π spectrometer at TRIUMF. Combinations of γ-γ, γ-e^-, and e^--e^- coincidence data were used to further investigate the isomeric decay. Six new transitions were observed and their branching ratios were measured.

1 Introduction

Motivated by the lack of low-spin spectroscopic data for isotopes in the region of $Z > 50$ and $N < 82$, a program to study the neutron-deficient Xe isotopes with high-statistics β^+/EC decay has been undertaken at the Isotope Separator and Accelerator (ISAC) facility at TRIUMF. This program complements the recent investigations of the stable even-mass Xe isotopes with Coulomb excitation of Xe beams on ^{12}C targets that resulted in the determination of a large number of matrix elements [1–4]. While these studies provided a wealth of information on $E2$ transition matrix elements, a number of key low-energy branches remained unobserved. β-decay studies, performed with highly sensitive germanium detector arrays equipped with Compton suppression shields, are an excellent tool to probe the existence of weak, low-energy γ-ray branches from states at high excitation energy. The first nucleus studied in this program was ^{124}Xe from ^{124}Cs β^+/EC decay, and the initial results on the observation of the $2^+_3 \to 0^+_2$ and $2^+_4 \to 0^+_3$ in-band transitions were published [5].

During the analysis of the γ-ray and internal conversion electron data, new decays were observed from levels fed from the high-spin isomeric state of ^{124}Cs, as well as decays from known 6^+ states in the daughter nucleus indicating the presence of a previously unknown β-decaying branch from the ^{124m}Cs state. These new decay branches associated with the ^{124}Cs isomeric state are presented here.

2 Experimental details

The measurements were performed at the ISAC facility at TRIUMF. The TRIUMF main cyclotron provided a 25 μA

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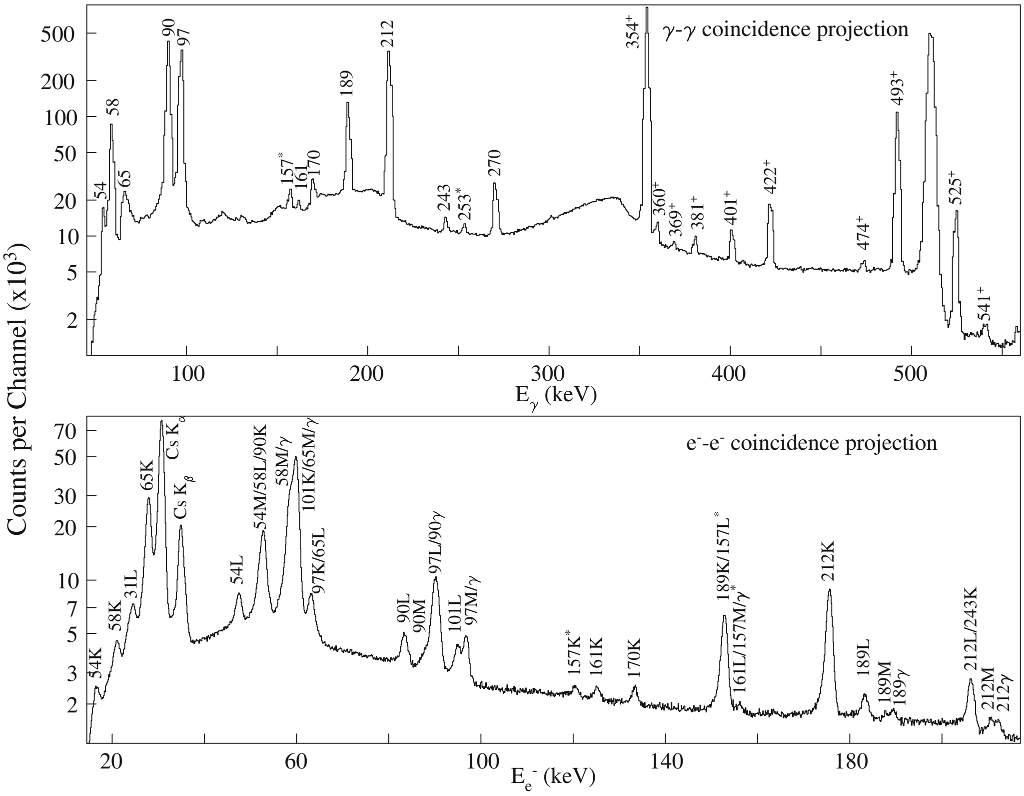

Fig. 1. (Top) Portions of the γ-γ (Ge-Ge) and (bottom) electron-electron (Si-Si) coincidence projections showing γ rays, internal conversion electrons and X-rays from the $^{124}\mathrm{Cs}^m \to {}^{124}\mathrm{Cs}$, $^{124}\mathrm{Ba} \to {}^{124}\mathrm{Cs}(^*)$ and $^{124}\mathrm{Cs} \to {}^{124}\mathrm{Xe}(^+)$ decays. Energies are given in keV.

beam of 500 MeV protons that bombarded a thick tantalum production target. The reaction products diffused through the target, were surface ionized, and then directed through the mass separator. A beam containing 9.8×10^7 ions/s ^{124}Cs ($J^\pi = 1^+$, $T_{1/2} = 30.9(4)$ s) and 2.6×10^6 ions/s ^{124m}Cs ($J^\pi = (7)^+$, $T_{1/2} = 6.3(2)$ s) was produced. The ions were implanted on an iron oxide-coated mylar tape at the center of the 8π γ-ray spectrometer —an array of 20 high-purity germanium detectors each with a bismuth germanate (BGO) Compton-suppression shield [6–8]. Ancillary detector systems were also utilized, including the pentagonal array of conversion electron spectrometers (PACES), an array of five liquid nitrogen cooled Si(Li) conversion electron detectors. Additional details of the spectrometer and its auxiliary detector systems are given in refs. [6–8]. Calibration measurements were performed with sources of ^{152}Eu, ^{56}Co, ^{60}Co and ^{133}Ba.

As described in detail in ref. [5], γ-ray singles, γ-γ, γ-electron and electron-electron coincidence data were collected during the implantation and decay period of the beam cycle. Two implantation and decay cycle times were implemented. The longer cycles with a 300 s implantation and 45 s decay period were performed to investigate excited states in the stable daughter nucleus ^{124}Xe fed by the decay of the ^{124}Cs ground state. The shorter cycles with a 1 s implantation and 12 s decay period were performed to enhance the events associated with the decay of the $T_{1/2} = 6.3$ s high-spin isomer of ^{124}Cs. Figure 1 shows the projections of the γ-γ and e^--e^- (*i.e.*, Si-Si) coincidence matrices collected during the short implantation cycles. In addition to the decays associated with the ^{124m}Cs isomeric state, γ rays and electrons from transitions in ^{124}Xe from the decay of the ^{124}Cs ground state are observed, as well as those in ^{124}Cs from the decay of the very small amount of ^{124}Ba present in the delivered beam.

3 New β^+/EC-decay branch

The $(7)^+$, 6.3 s isomeric state was previously believed to decay 100% internally [9]; however, in our measurements, previously known states of spin-parity 5^+ and 6^+ were observed to be populated in ^{124}Xe. The ground state of ^{124}Cs has a spin-parity of 1^+, thus, making it highly unlikely that the high-spin states would be observed in the daughter.

To explore the possibility of a non-zero β^+/EC-decay branch from the high-spin isomer, γ-ray decay time profiles were compared. Figure 2 shows the time profile for three γ rays. First, in blue, is the histogram of the time profile of the 354 keV $2^+_1 \to 0^+_1$ γ ray in ^{124}Xe with a half-life consistent with the ^{124}Cs ground state, 30.8 s. Displayed in black is the histogram of the time profile of

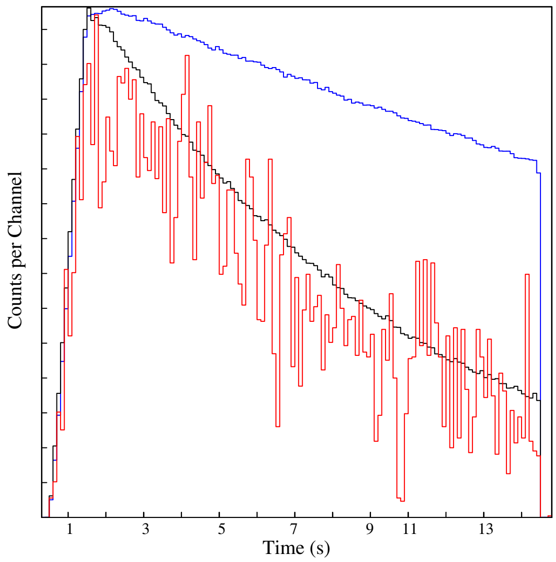

Fig. 2. (Color online) Histograms of the γ-ray decay time profiles for the 354 keV $2_1^+ \to 0_1^+$ γ ray in ^{124}Xe (blue), the 212 keV $(3)_1^+ \to (1)_1^+$ γ ray in ^{124}Cs (black), and the 670 keV $6_1^+ \to 4_1^+$ γ ray in ^{124}Xe (red). The strong similarity of the time profiles of the 212 and 670 keV γ rays confirms that ^{124m}Cs has a β-decay branch populating states in ^{124}Xe.

the 212 keV $(3)_1^+ \to (1)_1^+$ γ ray emitted in the isomeric decay with a half-life of 6.3 s, the same as the isomeric state. Lastly, in red is the histogram of the time profile of the 670 keV $6_1^+ \to 4_1^+$ γ ray in ^{124}Xe. As can be seen, its time profile matches that of the 212 keV γ ray in the isomeric decay path, confirming that, indeed, the $(7)^+$ isomeric state in ^{124}Cs undergoes β^+/EC-decay to populate the high-spin states in the ^{124}Xe daughter nucleus. Exact fits of these lifetimes were not possible due to the experimental set up.

Shown in fig. 3 are the levels of ^{124}Xe populated in the β^+/EC-decay of the $(7)^+$ ^{124}Cs isomer. Several previously known [10] high-spin levels in ^{124}Xe were identified in the present data, and the newly observed levels, labeled in red in fig. 3, were given tentative spin-parity assignments of (6^+), (7^+) or (8^+) according to the assumption of allowed Gamow-Teller transitions and taking into account the spins and parities of levels being fed in their γ-ray decays. Figure 4 shows gated spectra containing the newly observed high-spin transitions. The most intense high-spin transition observed was the 670 keV $6_1^+ \to 4_1^+$ γ ray which acts somewhat as a collector of the decay intensity.

The β^+/EC-decay branch of the isomer was measured by summing the intensities of all of the high-spin transitions occurring in parallel pathways in ^{124}Xe and dividing by the total intensity decaying from the isomer, *i.e.*, the sum of the intensity observed from the high-spin states in ^{124}Xe and the intensity of the isomeric decays to the ^{124}Cs ground state. Table 1 lists the γ-ray singles intensities of the high-spin (^{124}Xe) and internal decay transitions. Since the 670 keV $6_1^+ \to 4_1^+$ γ ray is the only high-spin transition observed in the γ-ray singles spectrum, the intensity of the remaining transitions listed in table 1 were determined from fitting the corresponding peaks in selected coincidence gates, and scaling to the intensity of the 670 keV γ ray. The transitions used to determine the total internal intensity of the isomeric decay are the 161 keV transition from the isomeric state and the 97 keV $(5)^- \to (4)^-$ transition that is directly fed by the highly converted 65 keV transition from the isomeric state. A 0.11(2)% branch was determined. The uncertainty is dominated by a conservative estimate of 20% on the systematic uncertainties.

Table 2 lists the γ-ray singles intensities for the transitions from high-spin levels in ^{124}Xe. Also listed are the δI values, representing the difference in intensities feeding and draining the level as a percent of the total intensity decaying from the high-spin isomer. As the ground state Q-value is very large, $Q = 5.930(8)$ MeV [11], one can expect a significant amount of feeding to much higher levels that decay to the lower-lying states observed here with γ-ray intensities below the current observational limit. Thus, the δI values can be considered as upper limits of the direct β-feeding to the levels, I_β.

4 New ^{124m}Cs decay branches

As ^{124m}Cs was delivered to the 8π spectrometer at a high rate, the short cycles with an implantation time of 1 s were analyzed to seek new transitions within the internal isomer decay to the ^{124}Cs ground state. A combination of γ-γ, γ-e^-, and e^--e^- data were used to validate coincidence relationships.

Two new transitions have been identified, in addition to four transitions previously determined in either the β-decay of ^{124}Ba to ^{124}Cs [12] or in the fusion-evaporation reaction ^{115}In(^{12}C, 3nγ) [13]. The decay scheme for the $(7)^+$ isomeric state in ^{124}Cs is shown in fig. 5, where the red arrows represent transitions newly identified in the present work, and those in blue are observed for the first time.

As an example of the quality of the data, fig. 6 displays the spectrum gated on the K-conversion electrons of the 65 keV transition —the most intense branch from the isomeric state— in which numerous coincident conversion electron lines can be seen. The most intense coincidence electron peak is that of the 97K line, confirming its previous placement [12] immediately below the 65 keV transition. Also observable in this spectrum is evidence of a peak due to the L conversion of a 31 keV transition, which appears in the level scheme as the $(4^-) \to (3^+)$ and $(3^+) \to (3^+)$ transitions. Evidence presented below establishes that the 31 keV line is indeed a doublet, observed for the first time in the isomer decay.

The following spectra were created by gating either on the γ ray or conversion electron above or below the level of interest. Total branching ratios were extracted for the levels shown in fig. 5 and are listed in table 3. Branching ratios and intensities were determined using exclusively γ-ray singles and γ-γ coincidence intensities obtained using eq. (1), when gating from above, or eq. (2), when gating from below.

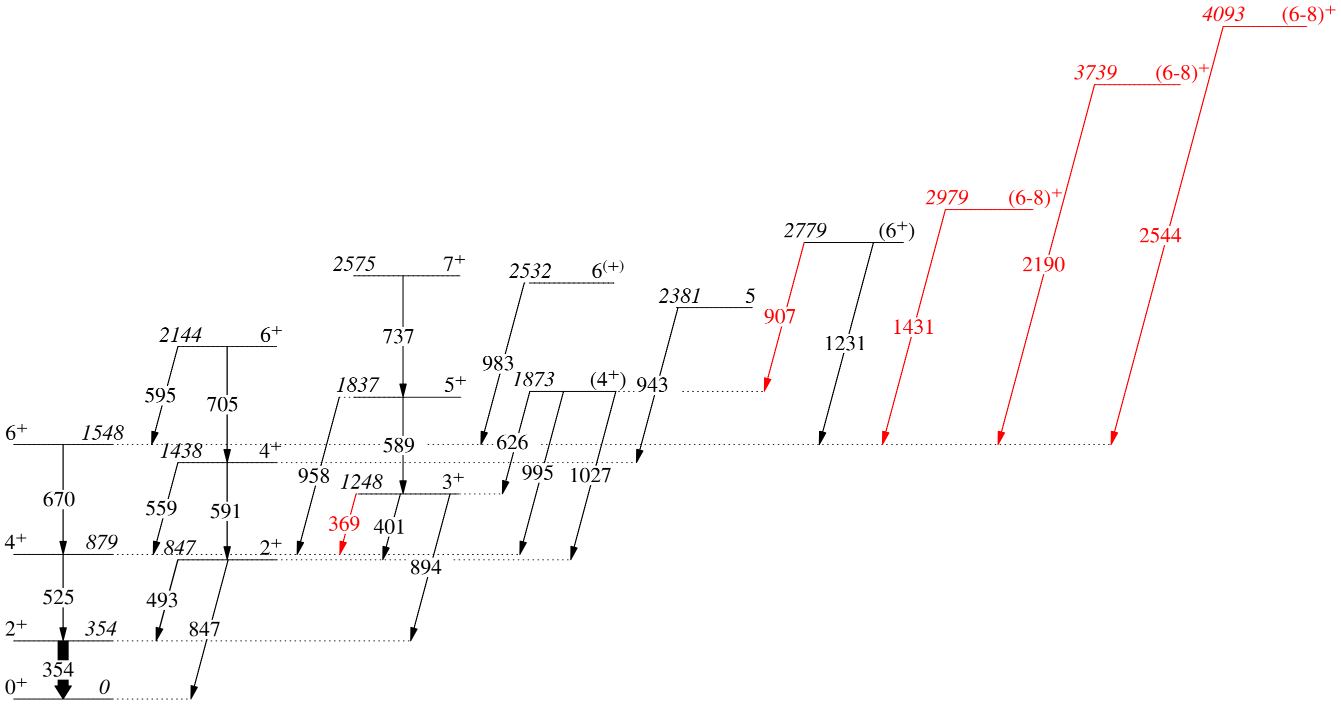

Fig. 3. (Color online) Levels in ^{124}Xe populated in the β^+/EC-decay of the $(7)^+$ isomeric state of ^{124}Cs observed in the present work. Levels are labeled with their energies in keV and their J^π values, with those in red newly established. The transitions are labeled with their energies in keV, with arrow widths proportional to the observed intensities, with those in red newly observed.

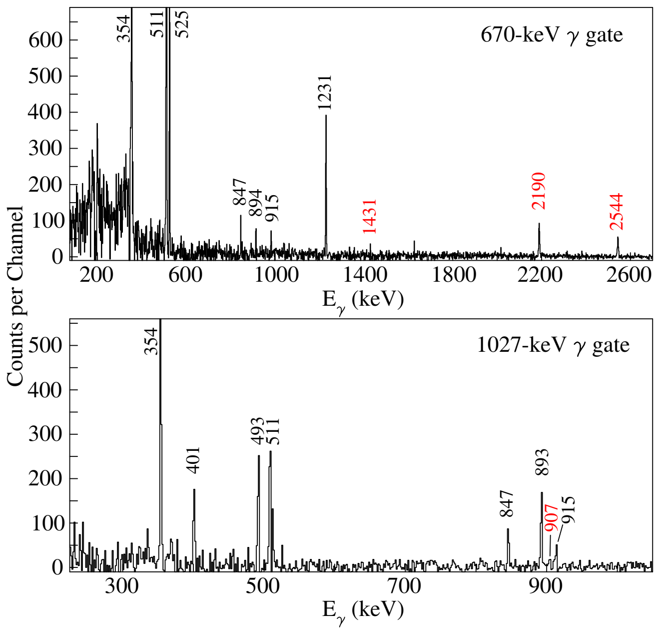

Fig. 4. (Color online) γ-ray spectra gated on the 670 and 1027 keV γ rays showing the new high-spin transitions, labeled in red.

Table 1. Transition energies and intensities from levels in ^{124}Cs and ^{124}Xe populated in the β^+/EC decay of the ^{124}Cs high-spin isomer. The level and transition energies, spins and parities for ^{124}Xe and ^{124}Cs are taken from ref. [10] and ref. [14]. All energies are given in keV. Uncertainties are listed in parentheses and are statistical only. The total intensities listed have been corrected for internal conversion.

E_i (keV)	E_γ (keV)	$I_i^\pi \to I_f^\pi$	I (singles)
1548.46(9)	669.70(2)	$6_1^+ \to 4_1^+$	869(38)
1836.92(9)	588.9(1)	$5_1^+ \to 3_1^+$	92(14)
	958.1(2)	$5_1^+ \to 4_1^+$	34(8)
2143.74(13)	705.1(2)	$(6^+) \to 4^+$	33(8)
2380.9(4)	942.9(2)	$(6^+) \to 4^+$	26(8)
	^{124}Xe total		1054(58)
397.65(8)	96.55(5)	$(5)^- \to (4)^-$	$94(18) \times 10^4$
462.54(9)	161.0	$(7)^+ \to (4)^-$	$27(2) \times 10^3$
	^{124}Cs total		$97(18) \times 10^4$

Table 2. γ-ray singles intensities (in arbitrary units) and δI as a percent of the total isomer decay intensity. Uncertainties are listed in parentheses and are statistical only.

E_i (keV)	E_γ (keV)	I (singles)	δI (%)
1548	670	869(38)	0.0113(52)
1837	589	92(14)	0.0068(28)
	958	33.8(84)	
2144	595	10.8(26)	0.0031(16)
	705	32.8(79)	
2381	943	26.2(76)	0.0019(6)
2532	983	45.3(84)	0.0032(8)
2575	737	30.1(79)	0.0021(7)
2779	907	26.7(77)	0.039(20)
	1231	530(52)	
2979	1431	38.8(81)	0.0027(8)
3739	2190	52(11)	0.0037(10)
4093	2544	32.3(98)	0.0023(8)

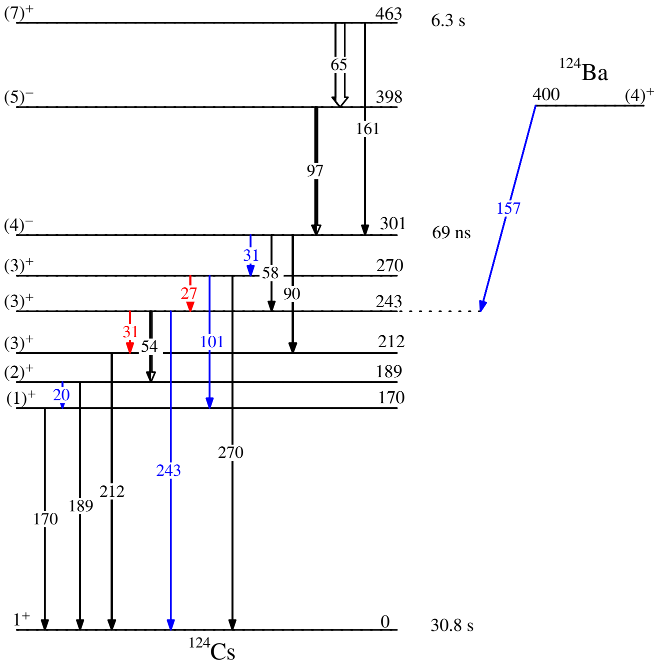

Fig. 5. (Color online) Level scheme observed in the decay of ^{124m}Cs. Levels are labeled with their energies in keV and their J^π values from ref. [10]. The transitions are labeled with their energies in keV, with arrow widths proportional to the observed intensities and white-filled portions of the arrows showing the degree of internal conversion. Black-colored arrows represent transitions that have been previously identified in the isomeric decay, blue arrows are transitions observed in other studies, and red arrows are transitions previously unobserved.

In these equations, N_c is the coincidence peak area, N is an overall normalization constant characteristic to this particular data set, I_γ^f is the intensity of the feeding γ ray, B_γ^d is the branching ratio of the draining γ ray, ε_γ^d and ε_γ^f are the singles photopeak efficiencies of the draining and feeding γ rays, ε_{fd} is the coincidence efficiency and $\eta(\theta_{fd})$ is the angular correlation attenuation factor. The total branching ratios were obtained by converting I_γ to total intensity, I_{Total} using eq. (3), where internal conversion coefficients (ICC) are from ref. [10],

$$B_\gamma = \frac{I_\gamma}{\Sigma_i I_{\gamma_i}}, \quad (1)$$

$$N_c = N I_\gamma^f \varepsilon_\gamma^f B_\gamma^d \varepsilon_\gamma^d \varepsilon_{fd} \eta(\theta_{fd}), \quad (2)$$

$$I_{Total} = I_\gamma(1 + ICC). \quad (3)$$

The appropriate combination of gating was used to isolate as well as possible the peaks of interest. The gating methods are outlined in refs. [15,16]. For new transitions, branching ratios were obtained using the total intensities of the remaining previously known transitions from the same energy level.

In the following subsections, we will discuss the data used to determine the branching ratios for each level. All γ-ray singles and γ-γ coincidence intensities were corrected for internal conversion using mixing ratios obtained from ref. [10]. A 10% systematic uncertainty was applied to measured intensities of transitions with energies less than 120 keV, below which the Ge efficiency rapidly changes, and a 5% systematic uncertainty for all remaining transitions.

4.1 The 212 keV level

A portion of the γ-ray spectrum gated on the 90 keV γ ray is shown in fig. 7. A 22.5 keV transition connecting

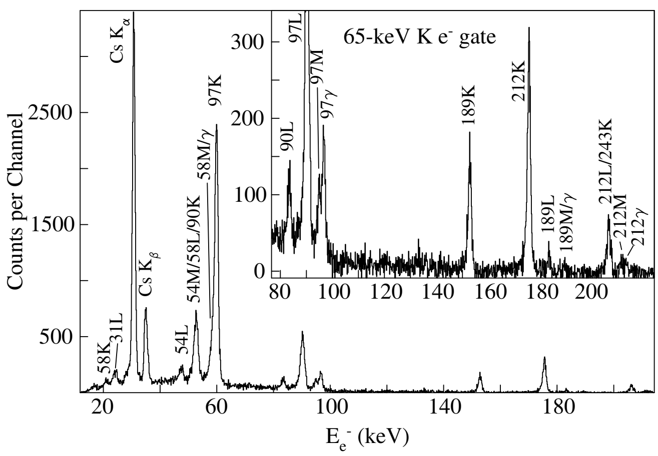

Fig. 6. Example of e^--e^- coincidence spectra obtained in the decay of ^{124m}Cs with the PACES Si(Li) detectors. The spectrum displayed is the low-energy portion of the electron-energy spectrum gated on the 65 keV K conversion electron. The inset shows an expanded portion of the spectrum.

Table 3. Experimental data for transitions in decay of the 6.3 s ^{124}Cs isomer. Energies are given in keV and energy and branching uncertainties are given in parentheses. Spins and parities in parentheses are tentative values from ref. [10].

E_i	E_γ	$I_i^\pi \rightarrow I_f^\pi$	BR (%)
169.5(1)	169.5(1)	$(1)^+ \rightarrow 1^+$	100
189.00(5)	19.5^b	$(2)^+ \rightarrow (1)^+$	7.7(6)
	188.98(5)	$(2)^+ \rightarrow 1^+$	92.3(6)
211.62(5)	211.64(5)	$(3)^+ \rightarrow 1^+$	100
242.87(6)	31.3^a	$(3)^+ \rightarrow (3)^+$	4.3(4)
	53.85(5)	$(3)^+ \rightarrow (2)^+$	90.9(7)
	243.3(3)^b	$(3)^+ \rightarrow 1^+$	4.8(5)
270.3(1)	27.4^a	$(3)^+ \rightarrow (3)^+$	58(6)
	100.7(1)^b	$(3)^+ \rightarrow (1)^+$	4.6(8)
	270.3(1)	$(3)^+ \rightarrow 1^+$	38(5)
301.10(6)	30.8^b	$(4)^- \rightarrow (3)^+$	24(5)
	58.20(5)	$(4)^- \rightarrow (3)^+$	23(3)
	89.50(5)	$(4)^- \rightarrow (3)^+$	54(4)
397.65(8)	96.55(5)	$(5)^- \rightarrow (4)^-$	100
462.54(9)	64.90(5)	$(7)^+ \rightarrow (5)^-$	98.8(2)
	161.0	$(7)^+ \rightarrow (4)^-$	1.2(2)

^{a} New transition.
^{b} New in isomeric decay.

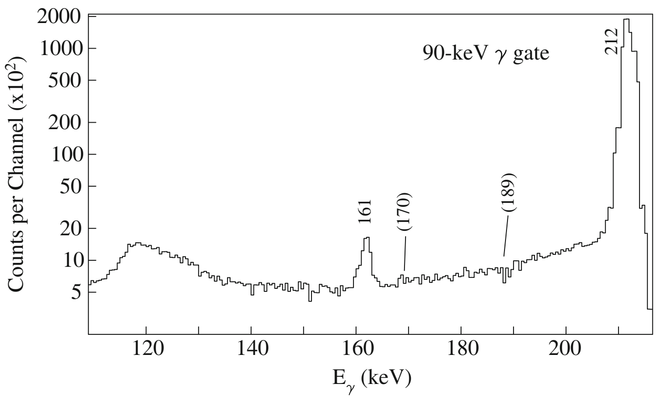

Fig. 7. Portion of the γ-ray energy spectrum gated on the 90 keV γ ray. The absence of a peak at 170 keV and 189 keV removes support for 42 keV and 22.5 keV transitions from the 212 keV level.

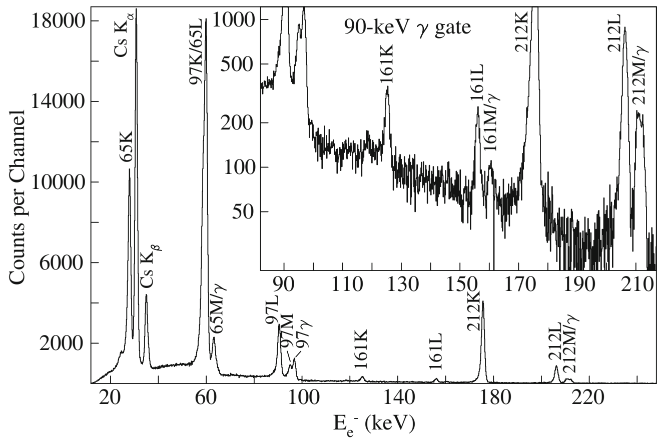

Fig. 8. Portion of the electron energy spectrum gated on the 90 keV γ ray. No evidence for the existence of a 22.5 keV transition, either directly or indirectly from the observation of conversion electrons from the 189 keV transition was found.

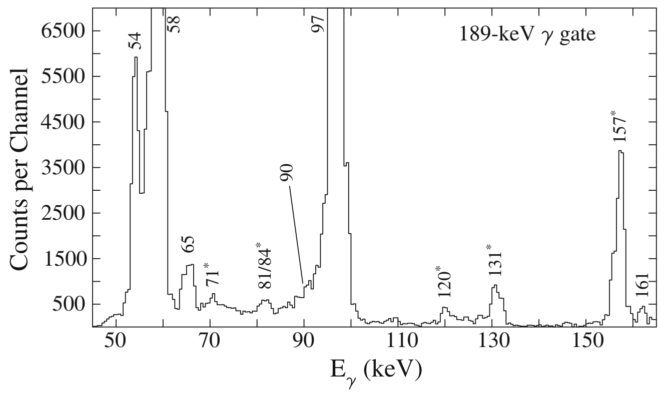

Fig. 9. Portion of the γ energy spectrum gated on the 189 keV γ ray. The 157 keV transition from the ^{124}Ba to ^{124}Cs decay can be seen and is labeled with an asterisk, as are other transitions from this decay.

the 212 keV and 189 keV levels was previously inferred in the $^{115}\mathrm{In}(^{12}\mathrm{C}, 3\mathrm{n}\gamma)$ fusion evaporation reaction [13]. The 189 keV γ ray from the 189 keV level to the ground state is not observed in coincidence with the 90 keV γ ray. The 90 keV γ-gated e^- spectrum in fig. 8 also shows no evidence for conversion electrons associated with the 189 keV transition. As a result, a 22.5 keV transition from the 212 keV level was not observed in the present data and was not placed in the level scheme.

The spectrum shown in fig. 7 was used to seek evidence for a possible 42 keV transition between the 212 keV and 170 keV levels. The 90 keV γ-gated γ-ray spectrum shows no visible peak at 170 keV that would have been fed by the 42 keV transition. Thus, the only observable transition from the 212 keV level is that to the ground state.

4.2 The 189 keV level

The 189 keV level exhibits two decay branches —a 189 keV branch directly to the ground state and a 19.5 keV transition that was previously inferred in the fusion-evaporation reaction $^{115}\mathrm{In}(^{12}\mathrm{C}, 3\mathrm{n}\gamma)$ [13]. An accurate branching ratio for this level is crucial since, as will be seen below, the 189 keV γ ray will be used as a gating transition to determine branching ratios of higher lying levels.

Fortunately, a small amount of ^{124}Ba was present as an isobaric contaminant in the beam delivered to the 8π spectrometer. The β-decay of ^{124}Ba to ^{124}Cs was identified through the observation of a 156.6(1) keV transition

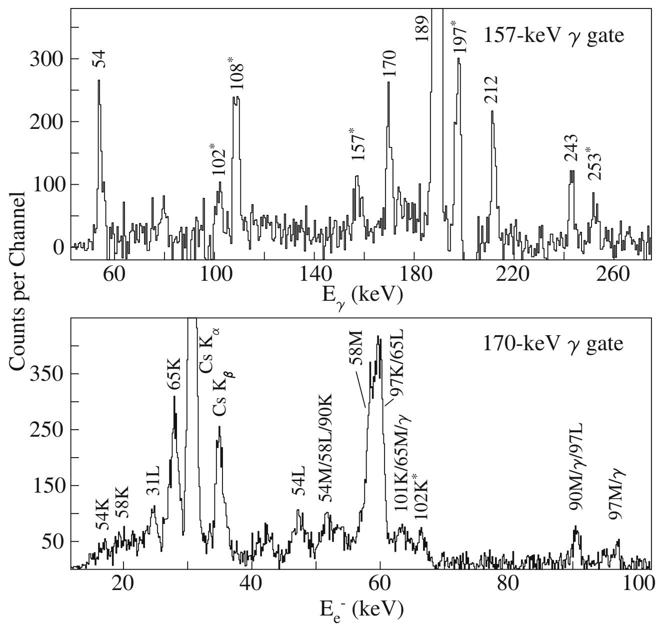

Fig. 10. (Top) A portion of the γ-ray coincidence spectrum gated on the 157 keV γ ray from the ^{124}Ba decay. (Bottom) A portion of the electron coincidence spectrum gated on the 170 keV γ ray from the isomer decay. Peak energies with an asterisk denote γ rays from the ^{124}Ba decay, or the result of Compton scattering of the intense 354 keV ^{124}Xe $2^+ \rightarrow 0^+$ γ ray. Both spectra display evidence for a 19.5 keV transition from the 189 keV level due to the 170 keV γ-ray in the top panel, and the 54K, L, and M electrons in the bottom panel.

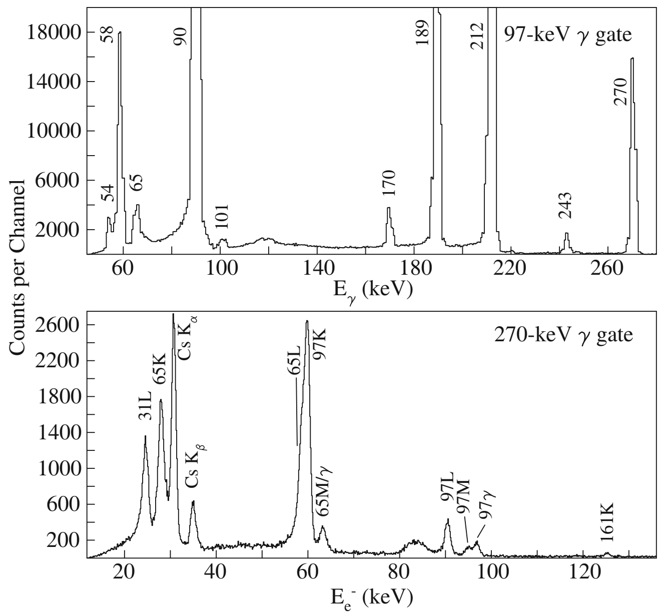

Fig. 11. Portion of the γ-ray coincidence spectrum gated on the 97 keV γ ray (top) and the electron energy spectrum gated on the 270 keV γ ray (bottom). The presence of the 270 keV γ-ray peak in 97 keV γ-ray gate indicates the presence of a 30.8 keV transition from the 301 keV level. This transition is directly observed in the bottom spectrum.

that had been previously assigned in a fusion-evaporation reaction study [13]. The 156.6(1) keV transition decays from the 399.6 keV level in ^{124}Cs, directly populating the 243 keV level. This is the first observation of the 156.6(1) keV transition in the β decay of ^{124}Ba, which can be seen in the ^{124m}Cs level scheme in fig. 5, and also in the 189 keV γ-gated spectrum shown in fig. 9. Several other transitions around 157 keV exist higher in the ^{124}Cs level scheme. In the 157 keV γ-gated γ-ray spectrum shown in the top panel of fig. 10, a γ ray at 170 keV from the 170 keV level can be seen. There are several cascades that could link the 157 and 170 keV transitions. The 31.3, 42 keV cascade is not possible, as explained in the previous section, because the 42 keV transition was not observed. A 74 keV transition could link the 243 and 170 keV levels. However, no peak at 74 keV can be seen in the 157 keV γ-gate in fig. 10.

Subsequently, a 19.5 keV transition fed by the 54 keV transition must exist to link the 189 and 170 keV levels. Further evidence for the existence of the 19.5 keV transition is seen in the 170 keV γ-gated e^- spectrum, shown in the bottom panel of fig. 10. The K, L, and M conversion electron lines of the 54 keV transition from the 243 keV level can be seen in this spectrum. As the entire intensity of the 170 keV peak in the 157 keV γ-ray coincidence spectrum flows through the 19.5 keV transition, the 19.5 keV:189 keV branching ratio was determined by the relative intensities of the 170 and 189 keV transitions measured in the 157 keV γ ray coincidence spectrum. The resulting branching ratios for the 19.5 keV and 189 keV transitions are 7.7(6)% and 92.3(6)%, respectively.

4.3 The 243 keV level

The top panel of fig. 10 shows two transitions decaying from the 243 keV level (54 and 243 keV) in coincidence with the 157 keV transition. A coincidence peak at 243 keV confirms that the 243 keV transition previously observed in the β-decay of ^{124}Ba [9] is also present in the isomeric decay. The presence of a 212 keV γ ray in fig. 10 requires a 31.3 keV transition to link the 243 keV and 212 keV levels. The intensity of the 54 keV transition feeding the 189 keV level could not be accurately determined in the 157 keV gated γ-ray spectrum due to uncertainties in the Ge-detector efficiency calibration at low energies. However, since the 54 keV transition is the only transition feeding the 189 keV level, its intensity in the 157 keV gate can be measured as the sum of intensities of the 170 and 189 keV transitions. Thus, the intensity ratio of the 212 keV:(170 + 189 keV):243 keV transitions measured in the 157 keV gate yield the 31:54:243 keV branches of 4.3(4)%, 90.9(7)%, and 4.8(5)%, respectively.

4.4 The 270 keV level

The 101 and 270 keV γ rays can be seen in coincidence with the 97 keV γ ray (fig. 11) that feeds the 270 keV level

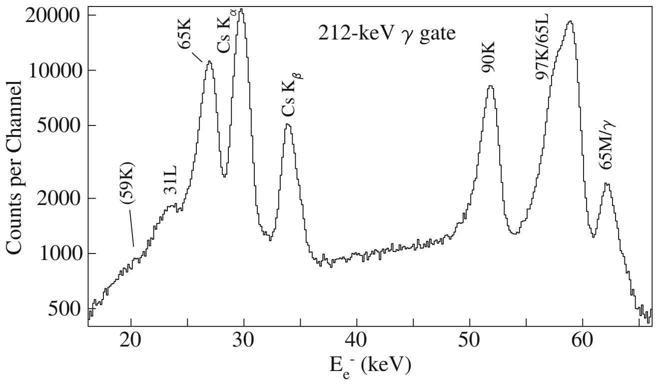

Fig. 12. Portion of the electron-energy spectrum gated on the 212 keV γ ray. The 59 keV K line is not observed.

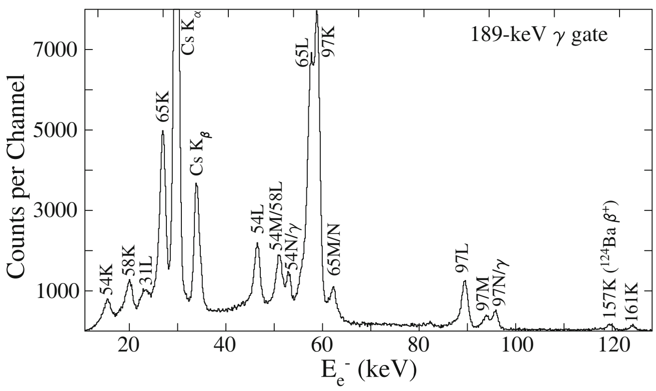

Fig. 13. Portion of the electron energy spectrum gated on the 189 keV γ ray. The presence of the 30.8 keV L line implies that a 27 keV transition from the 270 keV level.

through the 30.8 keV transition. An attempt was made to observe a new 59 keV transition from the 270 keV level into the 212 keV level. However, the electron-energy spectrum gated on the 212 keV γ ray (fig. 12) shows no evidence for the K conversion electron line of the 59 keV transition.

In the 189 keV γ-ray gated electron energy spectrum shown in fig. 13, the L conversion-electron line of the 30.8 keV transition from the 301 keV level can be seen. In order for the 30.8 and 189 keV transitions to occur in coincidence, a 27 keV transition from the 270 keV level must exist.

To determine the branching ratios for transitions from the 270 keV level, gates were taken from below on the 243 and 270 keV γ rays to fit the 97 keV transition. Equation (2) was used for both cases, with the 97 keV γ ray as the feeding transition and 243 keV and 270 keV γ rays as the respective draining transitions. A ratio of the two equations eliminates normalization constants, coincidence efficiencies, angular correlation attenuation factors and other unknowns. Subsequently, eq. (1) can be substituted to determine the total intensity of the 27 keV transition. Combining this intensity with the intensities of the remaining draining transitions from the 270 keV level, the branching ratios were measured to be 58(6)%, 4.6(8)%

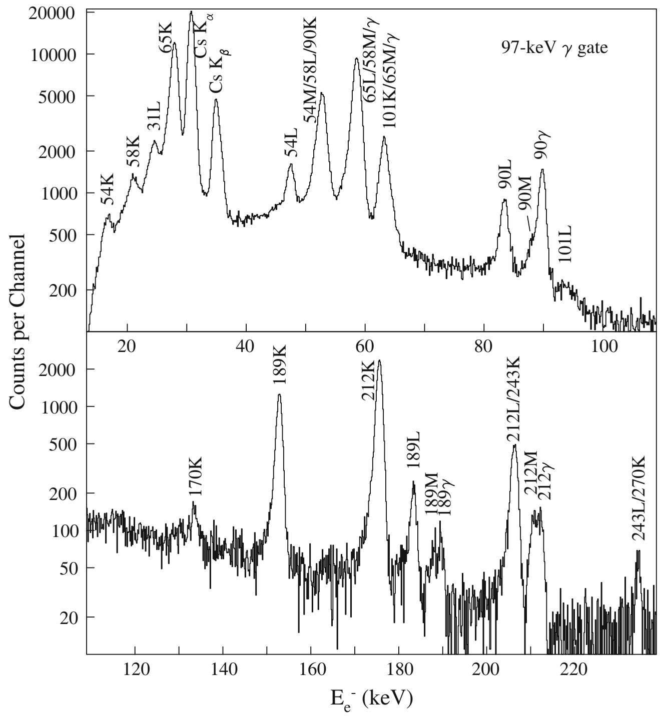

Fig. 14. Portion of the electron energy spectra gated on the 97 keV γ ray. There is a direct observation of the 30.8 keV L conversion electron line.

and 38(5)% for the 27, 101 and 270 keV transitions, respectively.

4.5 The 301 keV level

The 58 and 90 keV γ rays from the 301 keV level can be seen in coincidence with the 97 keV γ ray (fig. 11). The 270 keV γ ray from the 270 keV level is also seen in the coincidence spectrum, proving that a 30.8 keV transition exists between the 301 keV and 270 keV levels. Direct observation of the 30.8 keV transition is obtained from the γ-ray gated e^- spectra shown in fig. 11 and fig. 14. The bottom panel of fig. 11 displays the e^- spectrum gated on the 270 keV γ ray, whereas fig. 14 displays the e^- spectrum gated on the 97 keV γ ray. The 30.8 keV transition was previously inferred from the ^{115}In(^{12}C, 3nγ) fusion-evaporation reaction [13].

To determine the branching ratios for the transitions from the 301 keV level, a combination of γ-ray singles and γ-γ coincidence intensities were required. First, the coincidence intensities of the 58 and 90 keV γ rays were determined in gates taken from below on the 243 keV and 212 keV γ rays, respectively. The 58 keV γ-ray singles intensity could not be determined accurately since the peak is located in the region of the spectrum with a rapidly changing background (see, *e.g.*, fig. 1). Instead, the γ-ray singles intensity of the 90 keV γ ray was measured and the ratio of coincidence intensities between the 58 and 90 keV transitions was used to determine the singles intensity of the 58 keV γ ray.

The 31 keV transition feeding the 270 keV level is highly converted so it could not be measured directly in the γ-ray energy spectra. The method used for the 270 keV level was used again here: gates were taken from below the 301 keV level on the 90 and 270 keV transitions to fit the 97 keV transition. A ratio of eq. (2) with the two gating transitions was used to determine the total intensity for the 31 keV transition. The branching ratios for the 31, 58 and 90 keV transitions were measured to be 24(5)%, 23(3)% and 54(4)%, respectively.

4.6 The 463 keV level

The 65 and 161 keV transitions drain the 463 keV level. The 65 keV transition is highly converted, but occurs in direct coincidence with the 97 keV transition between the 398 and 301 keV levels as shown in fig. 6. To determine the branching ratios from the 463 keV level, the intensities of the 161 and 97 keV γ rays were measured in the 90 keV γ-ray gate taken from below. The branches are 98.8(2)% and 1.2(2)% for the 65 and 161 keV transitions, respectively.

5 Conclusions

The decay of the isomeric $(7)^+$ state at 463 keV in ^{124}Cs has been investigated using the 8π spectrometer and its auxiliary devices at the TRIUMF-ISAC facility. A new β^+/EC branch of 0.11(2)% to high-spin states in ^{124}Xe has been observed. Additionally, through the use of γ-γ, γ-e^-, and e^--e^- coincidences, the decay scheme of the ^{124m}Cs isomer has been modified with new transitions and measurements of the branching ratios.

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Author contribution statement

All the authors were involved in the preparation of the manuscript. All the authors have read and approved the final manuscript.

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