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^{124}In Levels Populated in the β-decay of ^{124}Cd

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The β-decay of ^{124}Cd into levels in ^{124}In was reinvestigated at the Holifield Radioactive Ion Beam Facility (HRIBF). Fifty MeV protons were bombarded on aranium targets and the induced fission products were mass separated and deposited on a moving tape in the center of an array of γ-detectors. The resulting γ-γ coincidences revealed appreciable disagreement with previous work and has resulted in a revised ordering of the low energy states in ^{124}In. The resulting partial decay scheme has four energy levels, three of which are new.

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I. INTRODUCTION

Beta-decay is one of the best ways to populate low-lying and low-spin levels far from stability. The low-lying states of the neutron-rich odd-odd In nuclei can be described as a $g_{9/2}$, or $p_{1/2}$ proton hole coupled to an $h_{11/2}$, $g_{7/2}$ $d_{3/2}$ $d_{5/2}$ or $s_{1/2}$ neutron particle (hole). In most cases the In ground and isomeric states are describable as $\pi(g_{9/2})^{-1} \otimes \nu(g_{7/2})$. The ground state J^{π} of the even mass In from 114 to 122 are all 1^{+} [1, 2], with the result that the β-decays of the 0^{+} ^{118,120,122}Cd [1, 2] nuclei have only been observed to decay to the ground states of the corresponding In isotopes (^{114,116}Cd are stable).

For the case of the β-decay of ^{124}Cd, Folgelberg *et al.* [3] reported observing a total of four γ-transitions de-exciting levels at 36.5 keV (1^{+}), 179.9 keV (1^{-}), and 242.7 keV (1^{+}) based on γ and conversion electron data. They assigned a J^{π} equal to 2^{+} to the ground state of ^{124}In. The resulting partial decay scheme of ^{124}Cd from Ref. [3] is displayed in figure 1. Later work [4] assigned a value of 3^{+} to the ground state of ^{124}In based on a $\pi g_{9/2} \otimes \nu d_{3/2}$ configuration. As the ground state of ^{124}Cd is 0^{+}, most of the β-decay strength would be expected to populate levels above the ground state.

A high-spin isomer was identified in ^{124}In [3, 5]. The assigned J^{π} of the isomer is (8^{-}) from collinear fast-beam LASER spectroscopy [6] and the systematics of odd-odd In isotopes. The large difference in spin-parity between the 0^{+} ground state of ^{124}Cd and (8^{-}) precludes any β-decay to this isomeric state. The only other studies that have provided any information on the excited states of ^{124}In have been from a ^{124}Sn(t,^{3}He) study [7] and a study of low-lying high-spin yrast states in ^{124}In from the reaction of 1.29 GeV ^{238}U beam on a Be target [8]. The former study reported levels at 122(15), 178(15), 365(20), and 555(20)-keV. It should be noted that the 178-keV peak in that work is not resolved from the larger peak at 122-keV (see figure 2 in Ref [7]). The yrast states study [8] reported high-spin states built on the high-spin isomer of ^{124}In and has no levels that would be expected to be populated in β-decay.

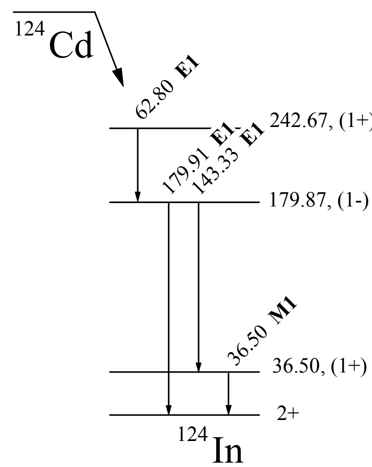

FIG. 1: Previously published partial decay scheme of the β-decay of ^{124}Cd [3]

As part of an investigation into the beta decays of ^{124,126}Ag [9], we produced a large amount of the isotope ^{124}Cd directly from the fission of uranium and as the β-daughter of ^{124}Ag [9]. This paper reports on the observed β-decay of this isotope. We report significant disagreements with the previously published decay scheme [3].

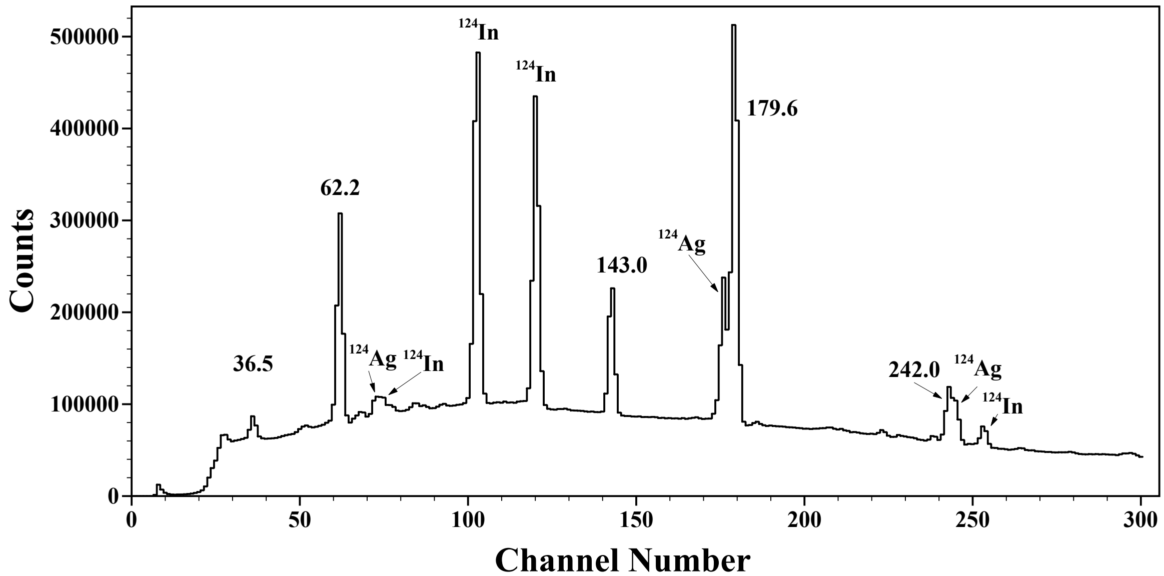

FIG. 2: Ungated γ-spectrum showing the five peaks assigned to the decay of ^{124}Cd. Peaks resulting from the β-decay of other nuclei are labeled as their respective β-decaying parent.

II. EXPERIMENTAL METHOD

Fission products were produced via the proton-induced fission of ^{238}U at the Holifield Radioactive Ion Beam Facility (HRIBF). Fifty MeV protons with an intensity of $\approx$15 μA from the ORIC cyclotron were used to bombard a $^{238}UC_x$ target [10] in a plasma ion source installed at the IRIS-2 [11]. The proton induced fission products were then mass-separated via a high resolution (Δm/m $\approx$10,000) magnet and delivered to the LERIBSS (Low-Energy Radioactive Ion Beam Spectroscopy Station) detector array, where they were embedded on a moving tape located in the center of the array [11]. The beam of mass 124 was pulsed via electrostatic plates with the beam on for the first 2 s, and then turned off for 1 s for a total of 3 s to allow the half-life measurements. The tape cycle time was chosen to enhance the observation of the short-lived ^{124}Ag isomers (144(20)ms and 191(28) ms for the high and low spin isomers respectively [9]). Cadmium-124 is present in this data set both from being deposited on the tape directly and as the β-daughter of ^{124}Ag.

At LeRIBSS the detector setup consisted of four segmented clover Ge detectors, and two plastic scintillators surrounding the tape. The γ-γ coincidences were used to construct the decay scheme in ^{124}In after β-decay. More details on the experimental setup may be found in Refs. [9, 12, 13]. Overall, very high statistics were collected for these nuclei compared to previously published results. The number of events observed in the 62-keV peak was $\approx$ 500,000 (more than an order of magnitude more than previously published work [3]) in the singles γ spectra.

III. EXPERIMENTAL RESULTS

We have observed a total of five γ-rays that are assigned to the decay of ^{124}Cd. The energies of the gamma-rays: 36.5(2), 62.2(1), 143.0(2), 179.6(1), and 242.0(3) keV observed in this work match well with those of Ref. [3]: 36.50(5), 62.8(1), 143.33(5), and 179.91(5) keV. The low-energy portion of the ungated γ spectrum is shown in Fig. 2. Peaks assigned to the decay of ^{124}Cd are labeled with their respective energies and peaks from the decays of ^{124}Ag and ^{124}In are labeled by parent nucleus.

Figure 3 (a-d) show the three spectra resulting from the γs coincident with the 179.9, 36.5, 143.0, and 62.2 keV γ-transitions respectively. The relevant part of the decay scheme from the previous work [3] is shown in the inset on the right side of each part.

Gating on the 179-keV transition (Fig. 3a) gives clear coincidence only with the 62-keV γ. Gating on the 36.5-keV transition (Fig. 3b) only shows a clear coincidence with the 62.2-keV γ, while the expected 143-keV γ-line is absent, indicating that the 36.5 - 62.2 cascade does not go through the intermediate 143-keV transition. Part c of figure 3 shows the γs in coincidence with the 143.0-keV γ transition. The 62.2-keV γ-line is clearly present, while the 36.5-keV γ-line is absent, indicating that the 179-keV γ can't be feeding a 36.5-keV level. Figure 3d shows the 179-keV γ is in coincidence with the 62.2 keV transition. The 36.5, 143.0, and 179.6 keV transitions are all in coincidence with the 62.2-keV γ. Gating on the 242.0-keV γ-ray produces no coincident γs. These discrepancies with the previous decay scheme [3] in the 36.5 and 143.0 keV γ-γ coincidence spectra indicate that the previous ordering of the γs and their consequent levels

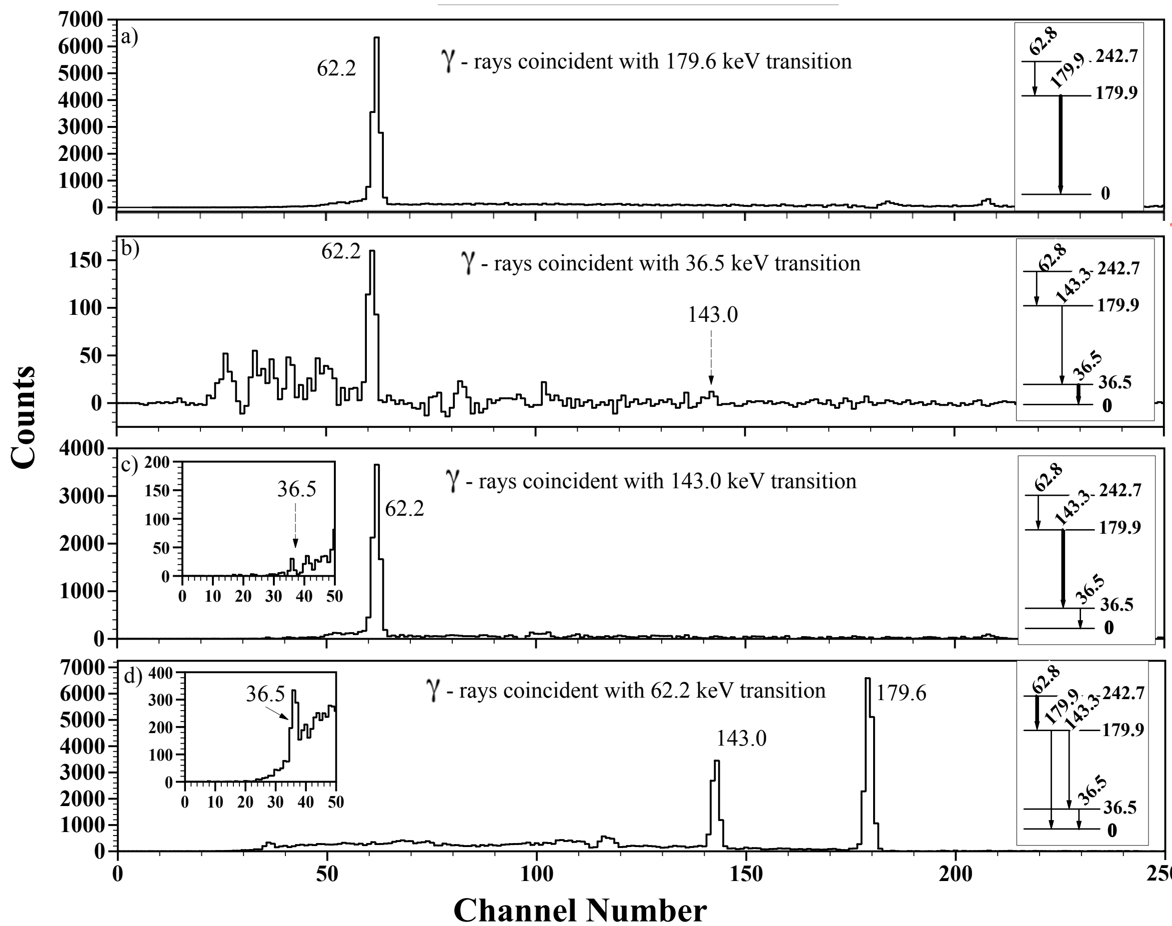

FIG. 3: The γ spectra coincident on the transitions a) 179.6-keV, b) 36.5-keV, c) 143.0-keV, and d) 62.2-keV. The insets on the right sides of the figure correspond to previous work [3], with energy values taken from that work. The insets on the left side of the figures are enlargements of the 0-50 keV portion of the respective spectrum.

TABLE I: List of γ-rays resulting from the beta decay of ^{124}Cd. The I_{tot} intensities in column 3 are normalized to 100%. Gamma intensities are based on singles. The I_γ values are uncorrected for α_{tot}, and the corrected I_{tot} values use the theoretical α_{tot} [14] based on the multipolarities reported in [3], except for the case of the 36.5-keV γ (see text).

E_γ (keV)	I_γ	I_{tot}	multipolarity	α_{tot}	E_i	E_f
36.5(2)	2.3(2)%	8.7(6)%	E1	2.85(6)	98.7(2)	62.2(1)
62.2(1)	28.2(5)%	47.0(10)%	E1	0.664(10)	62.2(1)	0.0
143.0(2)	7.8(5)%	8.3(5)%	E1	0.063	205.2(2)	62.2(1)
179.6(1)	29.2(5)%	30.3(4)%	E1	0.033	241.8(2)	62.2(1)
242.0(3)	5.3(2)%	5.7(2)%	E2	0.07	241.8(2)	0.0

are incorrect.

IV. DISCUSSION AND CONCLUSIONS

The observed γ transitions in the decay of ^{124}Cd are of low energy and have significant values of α_{tot} that must be taken into account in order to get the total intensity of a given transition. In the previous work [3], α_K values were determined by measuring conversion electrons in a Si(Li) detector. The values of 0.7(2), <0.07, and 0.028(10) were determined for the 62.8, 143.3, and 179.9-keV transitions, respectively. These values all compare well to the calculated values from the conversion coefffi-cient calculator BRICC [14] for E1 transitions. The corresponding conversion electron intensity for the 36.5-keV was not measured directly, instead its α_K was "obtained from the K X-ray intensity after correcting for the K-shell conversion of other transitions and for the fluorescence

TABLE II: List of levels populated in the β-decay of ^{124}Cd.

E_{level}(keV)	Branching ratio	J^{π}
0.0	0%	(3^+)
62.2(1)	0%	(2^-)
98.7(2)	<16.5(6)%	(1^+)
205.2(2)	<15.8(3)%	(1^+)
241.8(1)	<67.7(9)%	(1^+)

yield" [3], resulting in a value of 5.9(25). This value falls between the calculated values for E1 (2.9) and M1 (9.5). Fogelberg *et al.* assigned this transition a multipolarity of M1. In our data, using α_{tot} = 9.5 (or 5.9) results in more feeding into the 62.2-keV state than can be accounted for from the decay of a 62.2-keV E1 transition de-exciting this state. The possibility of the 62.2-keV state decaying by β-decay is excluded as the state that is de-excited by the 62.2-keV transition has been measured by Fogelberg *et al.* to have a lifetime of 50(6) ns [3]. We therefore assign a multipolarity of E1 to the 36.5-keV transition.

The properties of the observed transitions from the decay of ^{124}Cd are shown in Table 1. We use the calculated values from Ref. [14] for the α_{tot} values. A new partial decay scheme that satisfies the observed coincidences for the β-decay of ^{124}Cd is shown in figure 4. Note that the intensity balance of the 36.5, 143.0 and 179.6-keV γs feeding the 62.2-keV level minus the intensity of the 62.2-keV transition gives a value of 0 (within error bars) for the β feeding to this state. This is consistent with the assigned J^{π} value of 2^- that we assign to this level. For the higher-lying levels, the resulting beta branches to the 98.7, 205.2 and 241.8-keV states are 16.5(6)%, 15.8(3)%, and 67.7(9)% respectively. These values should be considered as upper limits as higher energy levels are likely to be weakly populated (the value for Q_{β} is 4170(40) keV [15]). The levels populated are listed in Table 2. The level J^{π} values are assigned as a result of the multipolarities of the observed transitions. It was not possible to observe any ground state to ground state decays in this experiment. However, if the assignment of 3^+ to the ground state of ^{124}In is correct, this decay would be a second forbidden decay with a very small branching ratio.

The resulting partial decay scheme has four levels, three of which are new. As noted above, the likely configuration of the 3^+ ground state is $\pi g_{9/2} \otimes \nu d_{3/2}$ [4]. The first excited state at 62.2 keV decays via an E1 [3] transition to the 3^+ ground state and is therefore assigned a J^{π} value of 2^-. This state likely based on a $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration. The three states at 98.7, 205.2, and 241.8 are apparently directly populated by β-decay and are observed to decay to the (2^-) 62.2-keV level. They are all assigned as 1^+ based on the observed E1 multipolarities from Ref. [4] to the 62.2-keV 2^- state. These states likely arise from $\pi g_{9/2} \otimes \nu d_{3/2}$ or $\pi g_{9/2} \otimes \nu s_{1/2}$ configurations.

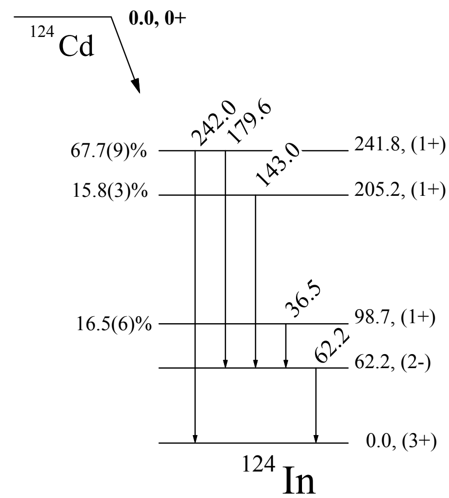

FIG. 4: Proposed partial decay scheme of ^{124}In.

In conclusion, we have reinvestigated the β-decay of ^{124}Cd into levels in ^{124}In. Significant disagreement with previous work has been observed resulting in a revision of the low energy states in ^{124}In.

Acknowledgments

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