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In-beam γ−ray spectroscopy in the ground-state proton emitter ^{113}Cs

C. J. Gross[1,2], Y. A. Akovali[2], C. Baktash[2], J. C. Batchelder[1], C. R. Bingham[3], M. P. Carpenter[4], C. N. Davids[4], T. Davinson[5], D. Ellis[3], A. Galindo-Uribarri[2], T. N. Ginter[6], R. Grzywacz[3], R. V. F. Janssens[4], J. W. Johnson[1], J. F. Liang[2], C. J. Lister[4], J. Mas[7], B. D. MacDonald[8], S. D. Paul[2], A. Piechaczek[9], D. C. Radford[2], W. Reviol[3], K. Rykaczewski[2], W. Satuła[7], D. Seweryniak[4], D. Shapira[2], K. S. Toth[2], J. Uusitalo[4] W. Weintraub[3], P. J. Woods[5], C.-H. Yu[2], E. F. Zganjar[9],

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[1] *Oak Ridge Institute for Science and Education, Oak Ridge, TN 37831, USA*
[2] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[3] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
[4] *Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*
[5] *Department of Physics, University of Edinburgh, Edinburgh EH9 3JZ, UK*
[6] *Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, USA*
[7] *Joint Institute for Heavy Ion Research, Oak Ridge, TN 37831, USA*
[8] *School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, USA*
[9] *Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, USA*

Abstract. Gamma-ray transitions in the ground-state proton emitter ^{113}Cs have been identified using the reaction ^{58}Ni(^{58}Ni,p2n) at a beam energy of 230 MeV and the recoil decay tagging technique. The first experiment was done using the Recoil Mass Spectrometer at the Holifield Radioactive Ion Beam Facility where γ−ray transitions were detected with 6 Clover and 5 Duet Ge detectors. A follow-up experiment using the GAMMASPHERE-FMA combination at Argonne National Laboratory was performed. Ninety-six Ge and 4 LEPs detectors were used to record recoil-$\gamma\gamma$ coincidences. Both experiments employed standard recoil mass separation techniques which resulted in the implantation of A=113 reaction products into a double-sided silicon-strip detector. By gating on the energy of the emitted proton and decay time, the correlation between γ rays and the implanted ^{113}Cs could be observed. Initial analysis and comparison with energy level systematics of the Cs isotopes reveal a decay sequence based on the $h_{\frac{11}{2}}$ bandhead. Further analysis is required to determine the decay of this sequence to the expected positive parity ground state.

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INTRODUCTION

Ground-state proton emitters are undergoing great scrutiny experimentally and theoretically [1–5]. Located beyond the proton drip line, these weakly bound systems are held together by the Coulomb and angular momentum barriers. Through the measurement of the proton decay energy and half-life, the valence configuration for spherical nuclei can be determined using such simple approaches as the WKB method [5].

There are, however, a few proton emitters such as ^{113}Cs which have anomalous half-lives and cannot be described using the spherical WKB approach. It has been suggested that deformation is the cause for these anomalies and the theoretical approach of Bugrov and Kadmenskii [4] which includes configuration mixing associated with deformation can be applied to these nuclei. Situated just above the $Z = 50$ closed shell, candidate valence configurations for the odd proton are $d_{\frac{5}{2}}$, $g_{\frac{7}{2}}$, $g_{\frac{9}{2}}$ (extruder), and $h_{\frac{11}{2}}$ (intruder). The 18-μs half-life [3,6] of the 0.96 MeV proton radioactivity is not adequately described by the calculated half-life of a spherical $d_{\frac{5}{2}}$ state shown in column 1 of table 1 taken from ref. [5]. The half-lives in columns 2 and 3 which include the possibility of deformation given in column 4 are from ref. [4]. Thus, the ground state of ^{113}Cs is interpreted to be built upon the $[422]\frac{3}{2}^+$ state with a deformation of $\beta_2 \approx 0.2$.

However, other experimental evidence of deformation that would support this conjecture is lacking. One way to determine the extent to which these nuclei are deformed is to study the excited states of these nuclei and compare the observed decay properties to simple, well established criteria for measuring collectivity. The technique known as recoil decay tagging (RDT) [7] is ideal for the detection of γ rays correlated with the proton radioactivity. To this end, we have performed two experiments to identify γ-ray transitions and their coincidence relationships in ^{113}Cs.

TABLE 1. Calculated half-lives for the $d_{\frac{5}{2}}$ orbitals ^{113}Cs from ref. [4,5]

$T_{\frac{1}{2}}$ WKB (μs)	$T_{\frac{1}{2}}[420]\frac{1}{2}^+$ (μs)	$T_{\frac{1}{2}}[422]\frac{3}{2}^+$ (μs)	Deformation β_2
0.51			0.0
	0.4-6.8	29-41	0.10
	0.3-1.1	16-17	0.20
		14-15	0.24
		12-14	0.27

EXPERIMENT DETAILS

The experiments used 230-MeV ^{58}Ni beams on ^{58}Ni targets. Identification of 10 γ rays was performed using the Recoil Mass Spectrometer (RMS) [8] and the new Clover Ge array presently being installed at the Holifield Radioactive Ion Beam Facility (HRIBF) and the cascade relationship between these transitions was achieved using the GAMMASPHERE [9] and Fragment Mass Analyzer (FMA) [10] combination at the Argonne Tandem Linear Accelerator System (ATLAS) facility. Cesium-113 is produced via the p2n channel and its production cross-section is on the order of 25 μb. Both experiments used standard recoil-γ coincidence techniques and thin, highly segmented, double-sided silicon strip detectors [11]. The time correlations between the γ rays detected at the target, the implantation of the recoiling nucleus, and its subsequent proton decay, permit a clean assignment of the γ rays to ^{113}Cs. The short half-life of this nucleus minimizes the chance of random correlations affecting our assignments.

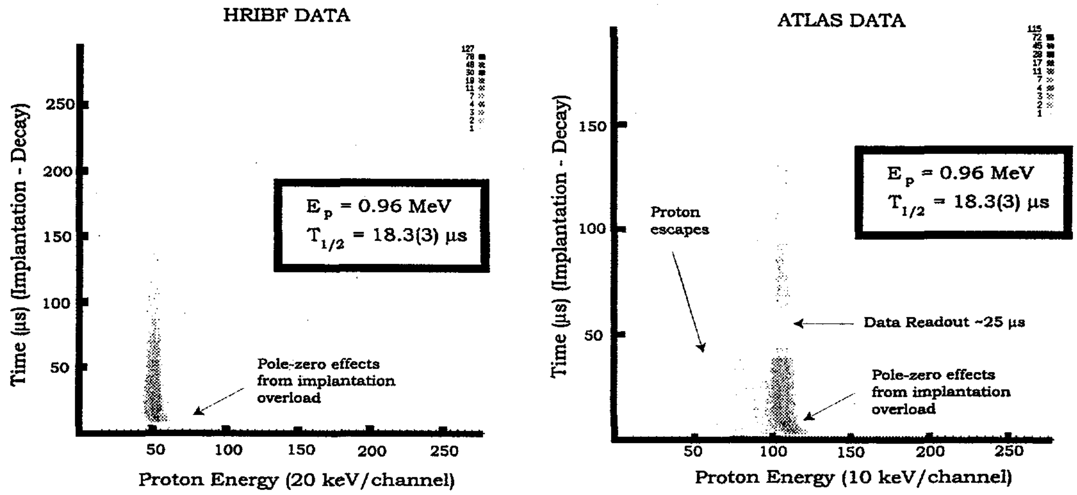

FIGURE 1. Total decay time versus proton energy spectra of ^{113}Cs from the HRIBF (left) and ATLAS (right). Note the "hole" in the ATLAS data arising from the limited delay range of the GAMMASPHERE data acquisition.

One critical aspect central to the success of these experiments is the the relationship between the readout of the data and the detection of the decay event. In both experiments, the data acquisition systems have a programmable time period to delay the readout of the implantation events. This is important since it takes several tens of microseconds for the data to be read out before new events may be accepted. During this time, decay events may not be recorded properly and are, therefore, suppressed at the end of the event. At HRIBF, the time delay was set to 80 μs before the first data were read. At GAMMASPHERE, the data acquisition was set to 50 μs, and this is the reason for the "hole" in the proton decay time vs.

energy spectrum shown on the right side of fig. 1. At the end of this experiment, the time was extended to 100 μs by replacing an integrated circuit delay chip in the data acquisition system.

DISCUSSION

From the 5500 proton decay events recorded in the HRIBF experiment, a half-life of 18.3 $\pm$ 0.3 μs was measured and is in agreement with previous measurements. The total γ-ray spectra gated by ^{113}Cs decay events are shown in fig. 2. Despite the lack of anti-Compton shields on the Clover Ge detectors and the lower overall detection efficiency, the HRIBF data contains almost all of the transitions detected by GAMMASPHERE. The largest discrepancy occurs below 200 keV where identification of the 92 and 166 keV transitions is hindered by the high background. However, these transitions can be observed in the data if one knows they are there. The 72 keV transition is not observed in the HRIBF data probably due to intensity and absorption associated with the temporary, thick-walled target chamber. A charge-state reset foil was not used at the HRIBF while one was used during the ATLAS experiment. Since all the strong γ-ray transitions are observed in both experiments we can conclude that these transitions have half-lives less than a few nanoseconds and have small electron conversion branches. Thus, we can confine ourselves to consider that all observed transitions are E1, M1, or E2. We note that under the above criteria, M2 radiation is possible above 250 keV and E3 radiation above 1 MeV [12].

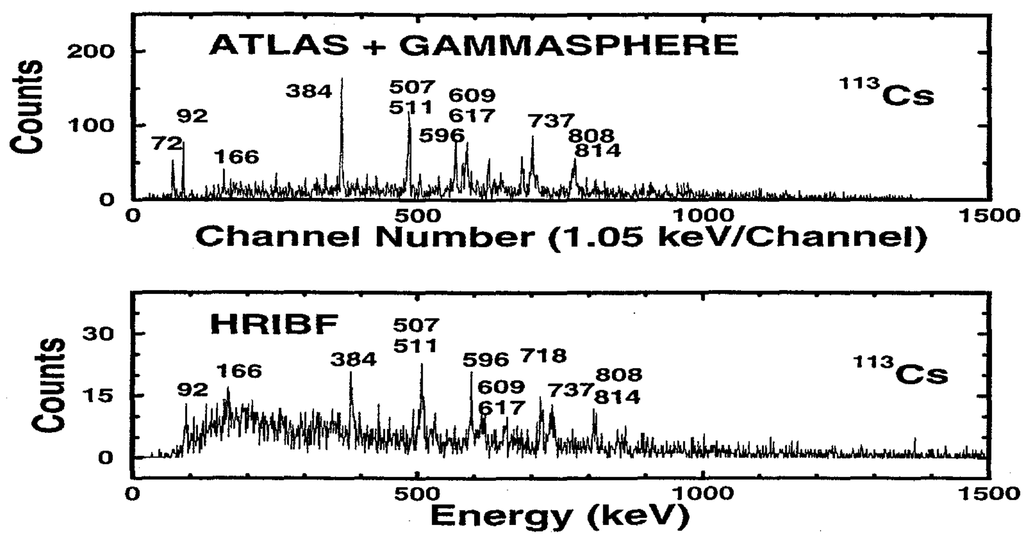

FIGURE 2. Total projection of $\gamma-$ray spectra of ^{113}Cs from both experiments.

An examination of the γ-ray coincidences recorded in the ATLAS experiment revealed a cascade relationship between the 384-596-737-814 keV transitions. A comparison of the energy level systematics [13,14] for the $h_{\frac{11}{2}}$ bands in the cesium isotopes is shown in fig. 3; it reveals a similar decay pattern and we tentatively assign this cascade to the $h_{\frac{11}{2}}$ bandhead. Further evidence supporting this assignment is that this is the most intensely populated cascade which is typical in this mass region for the $h_{\frac{11}{2}}$, high-j, intruder orbital. The decay of this band to the expected positive parity ground state is, at this time, unclear. It depends strongly on the location of the lowest energy $\frac{9}{2}^+$ state. Should this state lie above the $\frac{11}{2}^-$ state, then the decay would proceed through M2 or E3 transitions, and depending upon the energy and half-life, decay in flight outside the focus of the Ge array. Such a scenario does not necessarily lead to a large reduction in recoil-γ efficiency if the conversion electron branch of this decay is small.

The cesium isotope which most closely resembles ^{113}Cs is ^{125}Cs [14] which is only 4 neutrons above mid-shell (^{121}Cs$_{66}$). The similarity between these two isotopes can be explained by the deeper penetration into the single-particle energy spectrum of low-K intruder orbitals. In ^{125}Cs, the decay of the $h_{\frac{11}{2}}$ band is isomeric since the $\frac{9}{2}^+$ state lies above the $\frac{11}{2}^-$ state.

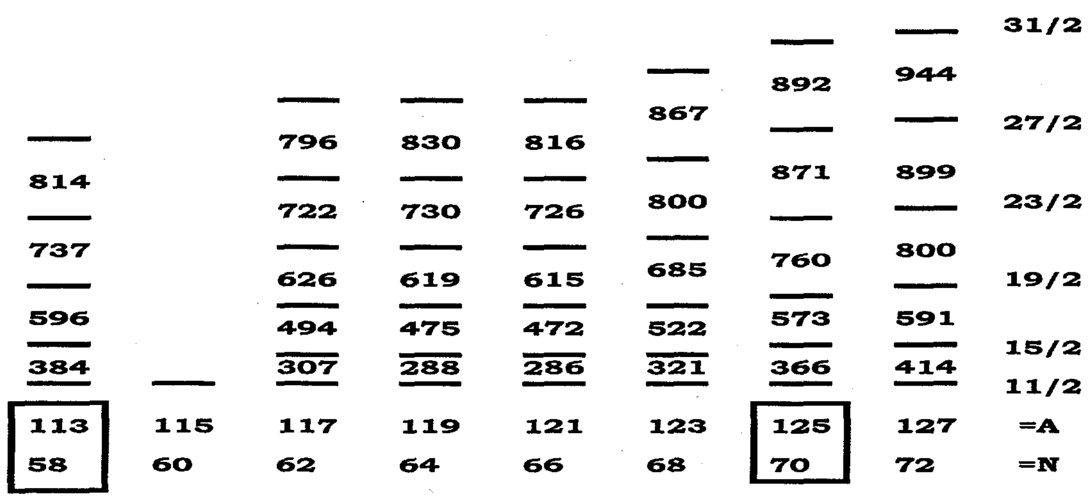

FIGURE 3. Energy level systematics for the $h_{\frac{11}{2}}$ bands in the cesium isotopes. The data were taken from Sun, *et al.* [12] and the present experiment.

SUMMARY

The method known as recoil decay tagging has been used successfully at the HRIBF. A subset of the new Clover Ge array currently being installed at the RMS target position has been used to identify up to 10 γ-ray transitions in the ground state proton emitter ^{113}Cs. In a follow-up experiment using the GAMMASPHERE-FMA combination, one cascade has been tentatively identified as the $h_{\frac{11}{2}}$ band using arguments based on the energy level systematics of the Cs isotopes. Further analysis is required to identify the decay out of this band and to characterize the other low spin states in the suspected deformed nucleus.

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