A High-Resolution Study of the ^{110}Tc → ^{110}Ru → ^{110}Rh → ^{110}Pd Decay Chain with the GRETINA Array

S. Jazrawi[1,2], D.T. Doherty[1], J.M. Allmond[3], P.H. Regan[1,2], R.V.F. Janssens[4,5], W. Korten[6], S. Zhu[7], M. Zielińska[6], D. Radford[3], S. Ansari[6], K. Auranen[7], B. Bucher[8], M.P. Carpenter[7], W.N. Catford[1], K. Hadyńska-Klek[1], J. Henderson[9], M. Hendricks[7], M. Komorowska[10], F.G. Kondev[7], T. Lauritsen[7], J. Li[7], G. Lotay[1], P.J. Napiorkowski[10], E. Padilla-Rodal[11], R.C. Pardo[7], B.C. Rasco[7,13], W. Reviol[7,12], D.G. Sarantites[12], D. Seweryniak[7], D. Santiago-Gonzalez[7], G. Savard[7], P. Singh[6], S.M. Stolze[7], R. Vondrasek[7], G. Wilson[7,14], C.Y. Wu[9], J. Wu[7]

[1] Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom
[2] National Physical Laboratory, Teddington, Middlesex, TW11 0LW, United Kingdom
[3] Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[4] Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, USA
[5] Triangle Universities Nuclear Laboratory, Duke University, Durham, North Carolina 27708, USA
[6] Irfu, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[7] Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA
[8] Idaho National Laboratory, Idaho Falls, Idaho 83415, USA
[9] Lawrence Livermore National Laboratory, Livermore, California 94550, USA
[10] Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
[11] Instituto de Ciencias Nucleares, UNAM, AP 70-543, 04510 Mexico, D.F., Mexico
[12] Department of Chemistry, Washington University, St. Louis, MO 63130, USA
[13] Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37966, USA
[14] Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA

E-mail: s.jazrawi@surrey.ac.uk

Abstract. Spectroscopic data, such as precise γ-ray branching and $E2/M1$ multipole-mixing ratios, provide vital constraints when performing multi-dimensional Coulomb-excitation analyses. Consequently, as part of our new Coulomb-excitation campaign aimed at investigating the role of exotic non-axial (triaxial) deformations in the unstable refractory Ru-Mo isotopes, additional beta-decay data was obtained. These measurements make use of ANL's CARIBU facility, which provides intense beams of radioactive refractory isotopes along with the excellent efficiency and angular resolution of the GRETINA γ-ray tracking array. In this article, we report on the analysis of the A = 110 decay chain, focussing on the identification of previously unreported states in ^{110}Ru following the decay of ^{110}Tc.

1. Introduction

As most nuclei are expected to show some degree of axial symmetry, the observation of triaxial deformation, where all three deformation axes have different lengths, has become a key topic of nuclear structure physics in recent years. In particular, it is not known whether such deformations are restricted to only a few nuclei or if it is spread over a larger area. Additionally, it is unclear whether triaxial deformation can represent both rigid and soft nuclear shapes. To this end, recent Coulomb-excitation results for the ^{76}Ge nucleus are particularly interesting [1] as, in this work, it is demonstrated in a model-independent way, that ^{76}Ge has a relatively rigid triaxial ground-state shape, albeit for a case where rich spectroscopic data is available.

A simple, but not definitive, signature of triaxial deformation, according to the Rigid Triaxial Rotor Model of Davydov et al. [2, 3], is the presence of low-lying 2^+_2 states. The Os-Pt nuclei are one such region where low-lying 2^+_2 states are observed, and evidence for low-lying triaxial deformation has been observed [4]. The other region where this key signature is observed is the neutron-rich Ru-Mo nuclei. However, despite longstanding interest, Coulomb-excitation measurements of these nuclei have not been possible, until recent years, due to the refractory nature of these nuclei whereby their physical properties prevent their release from traditional Isotope Separation Online (ISOL) targets.

Building upon our previous work, e.g. [5], and in order to take advantage of the improved experimental setup at ANL's ATLAS facility, we performed in 2018 a further series of Coulomb-excitation and decay experiments, focussed on the neutron-rich Ru-Mo region. A crucial improvement, which resulted in significantly cleaner beams, was the successful use of Electron Beam Ion Source (EBIS) charge breeder [6] instead of the Electron Cyclotron Resonance (ECR) source employed in previous studies. The results from the Coulomb-excitation studies are in the final stages of analysis and will be reported shortly. This article, therefore, focusses on the decay measurements which constituted the other half of the experimental campaign. The primary goal of performing decay measurements, in addition to Coulomb excitation, was to obtain precise γ-branching and $E2/M1$ multipole-mixing ratios by taking advantage of the angular sensitivity of the GRETINA array. Both quantities serve as valuable additional constraints in the multi-dimensional Coulomb-excitation analysis. In particular, knowledge of multipole-mixing ratios allow for $M1$ matrix elements to be determined in addition to $E2$ ones. However, as we can report, the available beam intensity and the excellent efficiency of the GRETINA detection setup have also enabled the ^{110}Ru level scheme to be extended.

2. Experimental Details

The experimental campaign took place at Argonne National Laboratory's ATLAS (Argonne Tandem Linac Accelerator System) facility. Beams of neutron-rich refractory isotopes were provided by the CARIBU facility [7], which consists of a $\sim$ 1.7 Ci ^{252}Cf source placed within a gas catcher which acts to efficiently thermalize the fission fragments in order to produce a beam of 1^+ ions. The ions of interest were selected with an isobar separator and then directed to the new EBIS [6] for charge breeding before being sent to the ATLAS linac for post acceleration. For the ^{110}Ru studies the beam consisted of ^{110}Tc, ^{110}Ru and ^{110}Rh ($t_{1/2}$=0.900(13) s, 12.04(17) s and 28.0(13) s, respectively) [8] with negligible stable contamination. For the Coulomb-excitation measurements the beam impinged on a 1.5 mg/cm^2-thick ^{208}Pb target at the centre of the GRETINA + CHICO2 experimental apparatus while for the decay measurement the ^{208}Pb target was replaced with a thick ^{197}Au foil. The GRETINA array [9] is composed of 11 modules with 4 segmented HPGe detectors per module, the CHICO2 heavy-ion counter [10] is not required for the beta-decay measurements and consequently, will not be discussed further here. Energy and efficiency calibrations of the GRETINA array were performed with standard ^{60}Co, ^{137}Cs, ^{152}Eu and ^{182}Ta sources with particular care taken to verify the γ-ray tracking and add-back algorithms used in the data analysis with the source data.

3. Preliminary Results

The data were sorted offline into $E_{\gamma,1} - E_{\gamma,2}$ coincidence matrices, from which level schemes could be constructed, and into $E_{\gamma,1} - E_{\gamma,2} - \theta_{1,2}$ cubes, which are used to determine the angular correlations of the emitted γ rays. An example coincidence spectrum, gated on the 241-keV $2_1^+ \rightarrow 0_1^+$ transition in ^{110}Ru is shown in Figure 1 below, while Figure 2 provides the spectrum obtained with a coincidence gate set on the newly observed 3188-keV transition. It is clear that the spectra are of excellent quality and, furthermore, that the obtained statistics are greater than that of other previously reported ^{110}Tc $\rightarrow$ ^{110}Ru beta-decay studies, [11, 12, 13].

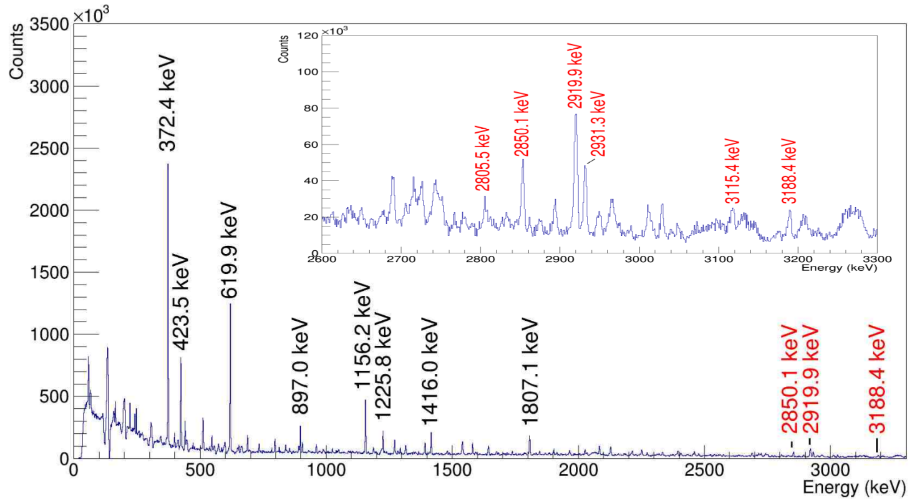

Figure 1. A γ-ray energy spectrum showing transitions in coincidence with the 241-keV $2_1^+ \rightarrow 0_1^+$ transition in ^{110}Ru following the beta decay of ^{110}Tc. The energies in red indicate previously unreported transitions with the inset showing a zoomed in portion of the high-energy region of the spectrum, where a number of new transitions were identified.

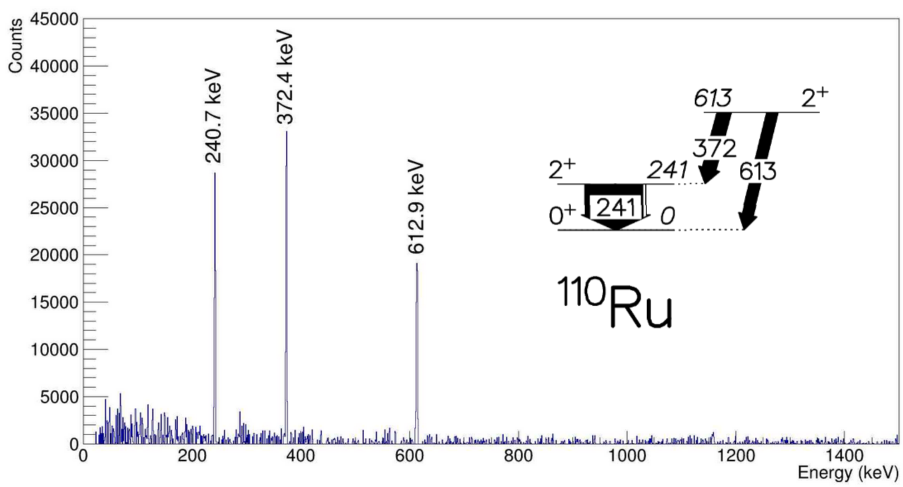

Figure 2. A background subtracted spectrum showing γ rays detected in coincidence with the new 3188-keV transition in ^{110}Ru, a partial decay scheme is shown in the inset.

The updated ^{110}Ru level scheme is displayed in Figure 3, where the new states are indicated with dashed lines.

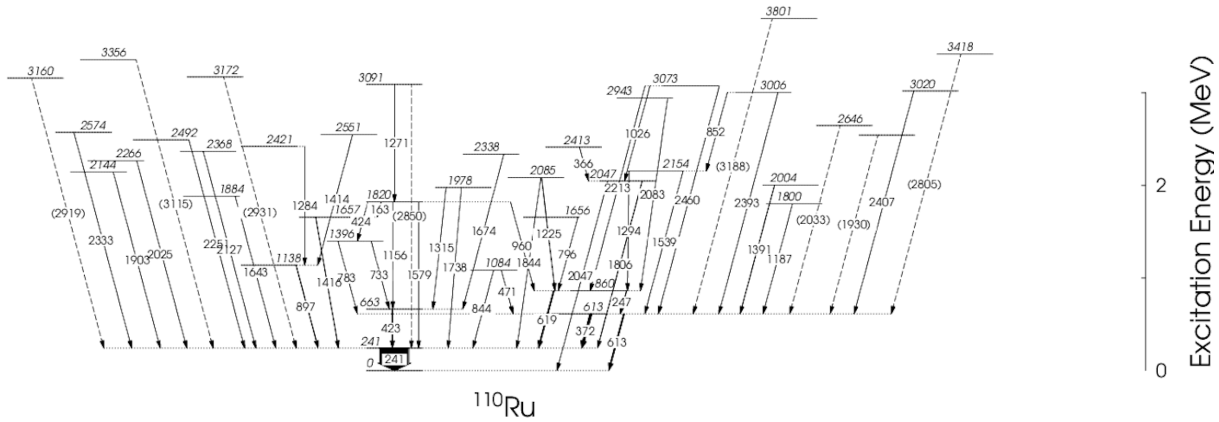

Figure 3. A preliminary level scheme with all the observed transitions in ^{110}Ru following the beta decay of ^{110}Tc. Previously unreported transitions are drawn as dashed lines.

4. Outlook

The ^{110}Ru level scheme has been extended by performing a high-resolution study of the ^{110}Tc $\rightarrow$ ^{110}Ru $\rightarrow$ ^{110}Rh $\rightarrow$ ^{110}Pd decay chain with beams of radioactive, refractory isotopes provided by ANL's CARIBU facility [7]. In addition, the high-statistics data allow for precise γ-ray branching ratios to be determined as well as for an angular-correlation analysis, aimed at extracting $E2/M1$ multipole-mixing ratios. Both the improved γ-ray branching ratios and the new multipole-mixing ratios serve as key additional constraints for the ongoing Coulomb-excitation analysis. In addition, the complementary nature of Coulomb-excitation and beta-decay measurements has been demonstrated; this will be particularly important as we move towards the next-generation of radioactive beam facilities, where Coulomb-excitation studies will be performed on nuclei where vital spectroscopic data is scarce.

Acknowledgments

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