In-beam and off-beam studies in ^{105}Ru via $(d, p\gamma)$ reactions

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Abstract

We propose to measure half-lives in ^{105}Ru by using $(d, p\gamma)$ reactions. At low energies, single-particle and seniority isomers emerge. The nucleus is placed in a region of triaxiallity, which often gives rise to sub-nanosecond isomers.

The present proposal is focused on the lifetime of the intruder state and single-particle low-spin states.

1 Motivation

^{105}Ru is located on the Segré chart between its heaviest stable isotope ^{104}Ru [1, 2] and the most exotic ^{117,118,119}Ru nuclei, produced in relativistic fission [3, 4, 5]. Being just on the edge of the line of β-stability, only few experimental methods can be used to populate its excited states. So far, the nucleus was studied in the ^{105}Tc β-decay [6], ^{104}Ru(d,p) reaction [8, 7] and n-capture on ^{104}Ru [10, 9]. However, these reaction mechanisms are highly selective and populate only low-spin states. In the 1990s the high-resolution high-granularity multidetector γ-ray arrays become available, which have enabled the use of induced fission reactions for γ-ray spectroscopy, providing the opportunity to fill in the gap of transitional nuclei situated between the line of beta stability and the most exotic neutron-rich nuclei produced in fission. By using induced fission reaction, the intruder negative-parity band in ^{105}Ru was observed for the first time and extended to $(31/2^-)$ [11].

1.1 Intruder states

Being the first neutron-rich odd-mass nucleus in the ruthenium isotopic chain, ^{105}Ru is crucial for the understanding of the structure of the more exotic ruthenium nuclei. For example, in [11] the spin/parity assignments of the yrast bands in all odd-mass ruthenium isotopes are based on the systematics. Thus, to test the spin and parity assignment to the 209-keV isomeric state in ^{105}Ru, we would like to measure the half-life of the 209-keV isomeric state. The half-life of this state is sensitive to is J^{π} value. If it is a $11/2^{-}$ state, as is assigned in [1], it would decay via $E3$ transitions to the lower-lying $5/2^{+}$ states, leading to isomer half-life of order of seconds. However, the $L = 5$ value from (d,p) reaction suggests that J^{π} could also be $9/2^{-}$. In this scenario, the state would decay via $M2$ transitions to the lower-lying $5/2^{+}$ states, leading to half-life of the order of few microseconds.

Recently [12], an isomeric transition with energy of 100-keV was observed in coincidence with the 108-keV transition in induced fission reaction, performed at HIL (Warsaw). The time structure of the beam, delivered by the HIL cyclotron, was used and data was taken only in the beam off periods. The half-life of the state was estimated to several microseconds suggesting that the state is indeed a $9/2-$ state. However, in this experiment a hundreds of nuclei were produced and both isomeric and beta delayed gamma rays are mixed and hard to disentangle. In order to determine unambiguously the isomeric transitions and the half-life of the isomeric state we would like to perform measurements in a more pure conditions.

1.2 Single-particle and seniority states

In addition, we would like to measure the half-lives of the low-lying positive parity states in ^{105}Ru, by using RoSphere. Some of these states are characterized by large spectroscopic factors, hinting at their single-particle nature. Others, having small spectroscopic factors, appear to have a more complex nature [13] involving seniority isomerism and triaxial collectivity.

Given that in the j^3 scheme of identical particles on the same orbit, the $M1$ transitions between the member of the same multiplet are forbidden [14], measurements of half-lives of low-lying states can hint at the persistence of such configurations away from the doubly magic nuclei. The decays of these states will be governed by the the $E2$ components of the respective transitions and their magnitude can be used to measure to what extent collectivity is present.

1.3 Collectivity

Also, a very successful theoretical description of the neighbouring even-even ^{104}Ru isotope has been obtained using the collective generalized Bohr Hamiltonian with all parameters calculated from a microscopic theory [2]. This opens possibility to treat the odd ^{105}Ru isotope in the frame of the Core-Particle-Coupling model in a way similar to that used in [15] for ^{111}Ru. Such approach allows for including the full quadrupole dynamics of the core, i.e. treating the vibrational (beta, gamma) and rotational degrees of freedom on the same footing.

2 Experimental Set up

2.1 Bunched beams

We propose to measure the half-life of the 209-keV isomeric state at RoSPHERE, comprising 11 $LaBr_3$:Ce and 14 HPGE detectors. Based on our previous experience [12], we would like to chop the d beam, to activate for about 50 μs and to measure off-beam the lifetime of the long lived isomer.

Given that the spectrum will consist only of few isomeric lines, we request one shift for this measurement. Additional two shifts are requested for $\gamma - \gamma(t)$ measurements from which we can determine the half-life of the $5/2^{+}$ at 108 keV. This state is supposed [13] to be a $\nu d^3_{5/2}$ multiplet member and hence to be an isomeric state. Typically, seniority isomers give rise to nanosecond isomers in the Ru isotopic chain. The lifetime of the level has not been measured before and RoSPHERE gives the opportunity to cover a wide range from few picoseconds up to several microseconds (in the case of the beam bunched setting). Thus, the half-life of the state should be measurable even if its wave function contains a large collective component.

2.2 Continuous beams

Also, ambiguity exists in the assignment of the 55-ns half-life, which is based on the $143\gamma(t)$ measurements and adopted for both the 159-keV and 163-keV states in ^{105}Ru [16]. This is not a simple typo, given that in the original source article [17] the decaying transition was ascribed to a $1/2^+$ level decaying via the 143-keV transition. However, the excitation energy of the state is not given by the authors and the present data evaluation shows that this transition de-excites a level at the 163-keV state and not the $1/2^+$ level at 159 keV. To solve the ambiguity we would like to use the RoSPHERE with a continuous d beam.

3 Experimental details

In order to obtain unambiguous assignment of the isomeric transitions in ^{105}Ru we will use a $(d, p\gamma)$ reaction, which is the most dominant channel of the ^{105}Ru+d reaction. According to the TALYS calculations, shown in Fig. 2 the (d, p) reaction cross-section is about 100 mb, which is consistent with the TANDL database value and with the 200 mb at 7 MeV from the EXFOR [18] database. The 7 MeV beam energy is just above the Coulomb barrier.

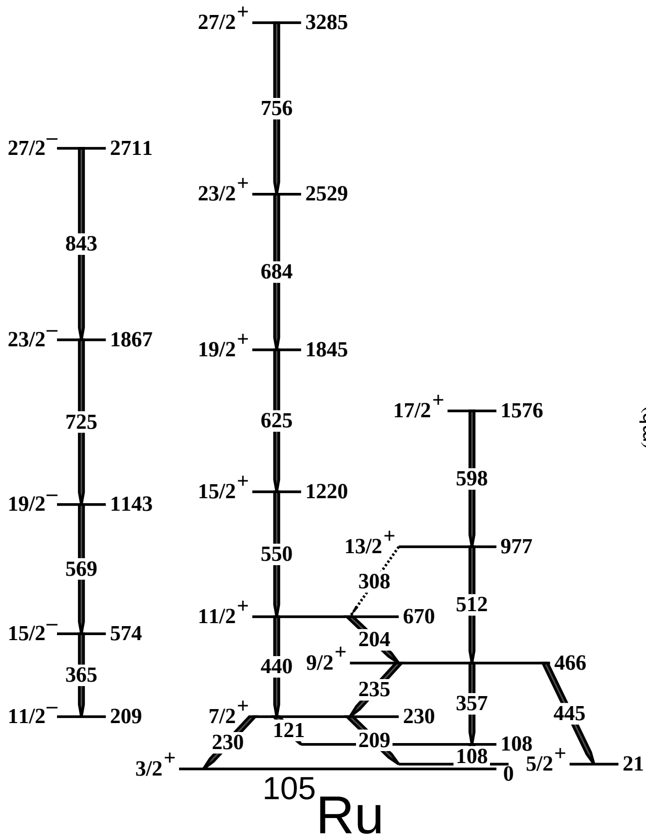

Figure 1: Partial level scheme of ^{105}Ru as observed in the present study.

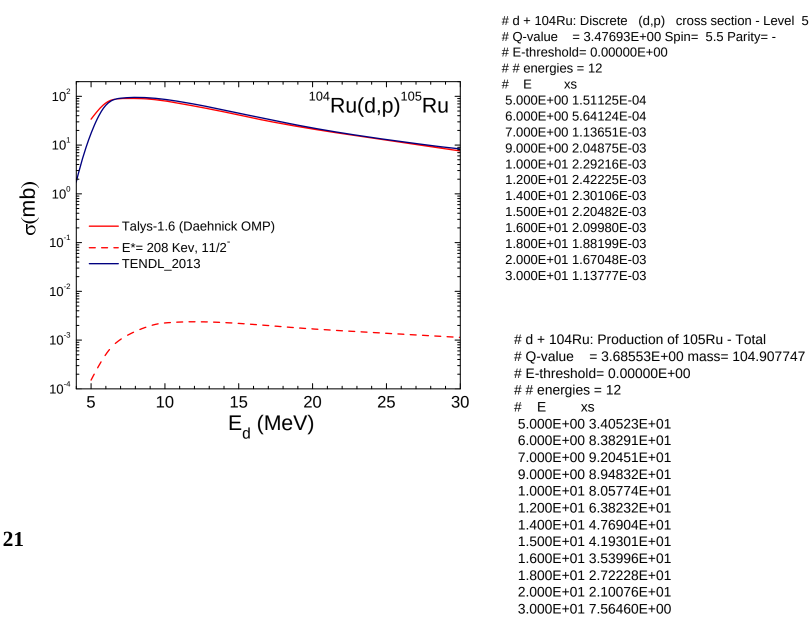

Figure 2: TALYS calculations [19].

12 mg/cm^2 thick target will be used, given that the Coulomb barrier for the reaction is ≈6.7 MeV and the stopping power of ^{2}H in ^{104}Ru is 0.034 MeV/mg.cm^{-2}. A target with thickness

of 9 mg/cm^2 will be thick enough to produce reactions in the entire volume and the additional 3 mg/cm^2 of ^{104}Ru will be used to stop the ^{105}Ru recoils, created at the back of the target.

The yield estimations are based on RoSphere efficiency of 2%, and assuming 10% isomeric ratio for the 209-keV isomer. This would lead to 2.35×10^5 counts in singles per shift or 2×10^3 coincidence per shift.

The isomeric ratio is estimated from the (d,p) data in [20] and it is determined with respect to the $\nu d_{5/2}$ state at 20-keV, which is the most dominant channel in this reaction.

We request additional three days of beam-time to measure the half-lives of the low-lying states by using delayed coincidences.

4 Summary

We propose to measure half-lives of the low-lying states in ^{105}Ru by using neutron striping reaction. In the focus of the proposal is the half-life of the 209-keV isomeric state. In addition, we would like to measure the half-lives of the low-lying $7/2^+$, $5/2^+$, $3/2^+$ and $1/2^+$ states, populated in-beam.

Experimental details:

- **Beam:** ^{2}H; bunched for the isomeric lifetime and continuous for the shorter half-lives
- **Target:** 12 mg/cm^2 thick, enriched in ^{104}Ru
- **Cross section:** 200 mb
- **Beam Current:** 1.5 nA
- **Detectors:** RoSphere

To perform suggested measurements **4 days of beam-time are requested**. One day will be used to measure the lifetime of the long-lived isomer at 209-keV. Three days of beam-time will be used to measure the half-lives of the low-spin isomers, placed close to the ground state.

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