Isomeric yield ratio measurements from $^{232}Th(\alpha,f)$ for investigation of the mechanism for angular momentum generation in fission

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One of the open problems in nuclear fission studies is the origin of the large angular momenta observed in fission fragments [1-3]. Wilson and co-workers recently published a study suggesting that the fragment spins are generated post-scission and independent of the fissioning system [4]. The latter finds partial support in a recent compilation and evaluation of isomeric yield ratios (IYR) [5]. However, the proposed un-correlated post-scission mechanism for the fragment spins also received some criticism. Randrup and Vogt argue that the nucleon-exchange mechanism, as it is implemented in the FREYA code, leads to collective rotational modes with highly correlated spins but still produces essentially uncorrelated fragment spins [6].

These findings and discussions motivate to use innovative experimental methods to study fission fragment spins, going beyond the traditional methods based on gamma spectrometry. We use the latest experimental advances in nuclear mass spectrometry to measure IYR by direct ion counting. The relative population of the different spin states is then used to extrapolate back to the angular momentum of the fission fragment right after scission has occurred [7].

The strength of this method is that the IYR do not depend on potentially incomplete or erroneous nuclear level schemes. A weakness of using mass measurement techniques lies in the required mass resolving power and the needed measurement time. However, recent advances, offered in particular by the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique [8], allow resolving metastable states with excitations energies as low as a few tens of keV. This opens the possibility for detailed studies of IYR over several neighboring isotopes, mapping, e.g., the region around ^{132}Sn.

We have already studied IYR resulting from $^{232}Th(p,f)$ and $^{238}U(p,f)$ at a proton energy of 25 MeV. So far, we have measured over 30 IYR in the ^{132}Sn region [9,10]. The measurements were done with JYFLTRAP at the IGISOL facility in Jyväskylä where the PI-ICR technique was recently implemented. A key finding is related to the deduced spins for Indium isotopes; J_{rms} for ^{127}In was found to be about 9.5 $\hbar$. The J_{rms} increases as one moves towards lower masses, reaching about 26 $\hbar$ for ^{119}In. This behavior is found to be strongly correlated with the isotopes' quadrupole moments.

In this paper, we present and discuss an extension of this work, aiming at disentangling the influence of the spin of the compound nucleus. To this end we have performed (planned for early spring 2022) IYR measurements from $^{232}Th(\alpha,f)$ with a beam energy of 32 MeV. Considering initial energy loss, and pre-fission neutron emission, the dominating fissioning system with about 80% is $^{234}U^*$ with an excitation energy of about 12 MeV. Fission of ^{233}U induced by thermal neutrons leads to the same compound system with an excitation energy close to 7 MeV. This means that the same system with comparable excitation energies is created in two different ways and with very different compound nucleus spins. For the ^{233}U(n,f) IYR we use existing data from the literature.

As an outlook, we plan to extend the available IYR dataset for ^{233}U(n,f) with new measurements performed at a reactor based Penning Trap, possibly TRIGATRAP in Mainz, Germany. A second extension of this work is measuring IYR from (n,f) at JYFLTRAP using the Be(p,n) as neutron source in IGISOL [11].

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