First direct mass measurements beyond the proton drip line at SHIPTRAP

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The Penning-trap mass spectrometer SHIPTRAP [1] at GSI Darmstadt has been set up to study nuclear ground state properties of heavy and transuranium elements. The nuclides are produced in fusion-evaporation reactions and kinematically separated in-flight at the velocity filter SHIP [2]. The reaction products are stopped in a buffer gas stopping cell, bunched in an RF quadrupole ion beam cooler and injected into a Penning trap system. There, after isobar purification, the mass is determined by a cyclotron frequency measurement. In the first stage precision mass measurements in the region of neutron-deficient rare-earth elements near the proton drip-line around A=150 were performed in 2005.

In this region the proton emission from the nuclear ground state was discovered in ^{147}Tm and ^{151}Lu almost 25 years ago [3]. Since then proton spectroscopy has proven to be a valuable tool for nuclear structure investigations beyond the drip line. However, at present many masses of these exotic nuclei as well as their daughter nuclei are still unknown even though some of them are rather long-lived. Several of these nuclides with half-lives above 100 ms can be investigated at SHIPTRAP profiting from the high primary beam intensities of the UNILAC in combination with the high transmission and background suppression of SHIP.

Two on-line experiments were performed in October and December 2005. The radionuclides of interest were produced in the reaction ^{58}Ni + ^{92}Mo, with primary beam energies of 4.3-4.6 MeV/u. The masses of 18 different nuclides were measured, 9 of them for the first time, with a relative mass uncertainty between $5 \cdot 10^{-8}$ and $1 \cdot 10^{-7}$. For ^{143}Dy and ^{147}Dy the isomeric states, which were also produced in the reaction, were resolved and their mass was measured in addition to the ground state. For the first time a direct mass measurement of ^{147}Tm was performed. In ^{147}Tm two proton decaying states are known [3]. The ground state decays with a half-life of 580 ms via proton emission into ^{146}Er, which was also measured. The production cross section of ^{147}Tm is known to be 30 μbarn [3], corresponding to a production rate of less than 100 ions/s for typical conditions. In a measurement time of 5 hours 900 ions were accumulated and a relative mass uncertainty of $8 \cdot 10^{-8}$ was achieved.

The results agree with the previous experimental data but have a lower uncertainty. In the cases, where the mass was measured for the first time, the nuclides deviate from the estimations given in the AME 2003 showing that these nuclides are in general less bound than predicted. The two-proton separation energies derived form the new data show now a smoother behavior in this region. The new values of the one-proton separation energies allow for a more precise determination of the proton drip line for the respective elements. For the four measured nuclides ^{144,145}Ho, ^{147,148}Tm a negative one-proton separation energy was obtained. However, only for ^{147}Tm proton decay is a relevant decay channel whereas the other nuclei decay by β-emission.

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