Mass measurements in the rare-earth region at TRIGA-TRAP

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The Penning-trap mass spectrometer TRIGA-TRAP is installed at the research reactor TRIGA Mainz to perform high-precision mass measurements of neutron-rich fission products as well as stable nuclides and long-lived actinoids [1]. It is part of the TRIGA-SPEC project which also comprises a collinear laser spectroscopy experiment. The coupling to the reactor is under construction. Off-line measurements have already been performed using a laser-ablation ion source which also provides carbon cluster ions as mass references [2]. Carbon clusters have been moreover used for a detailed characterization of the apparatus and an investigation of systematic uncertainties. Besides a mass-dependent shift of the frequency ratio between reference ion and ion of interest ($\varepsilon_m = -2.2(2) \times 10^{-9} \times (m\text{-}m_{\text{ref}})$ / u), the contribution of magnetic field fluctuations of the super-conducting magnet ($u_f(\nu_{\text{ref}}) / \nu_{\text{ref}} = 6(2) \times 10^{-11}$ / min$\times\Delta t$) has been determined. The accuracy of mass measurements at TRIGA-TRAP was verified using the stable nuclide ^{197}Au, since its mass was already known to an uncertainty of only 600 eV [3]. The TRIGA-TRAP result of $m(^{197}\text{Au})$ = 196.966 567 1(54) u is in agreement with the AME 2003 value of 196.966 568 7(6) u.

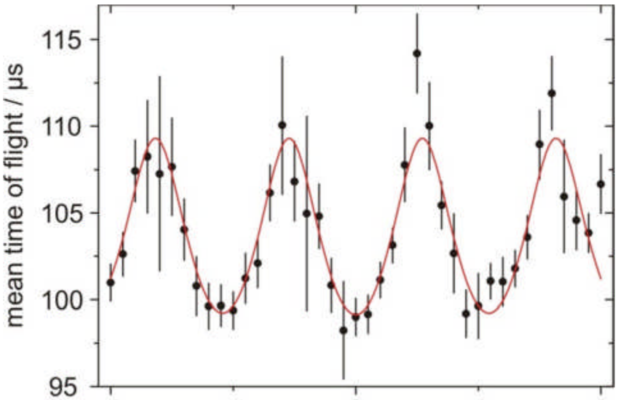

Figure 1: Time-of-Flight resonance for $^{160}\text{Gd}^{16}\text{O}^+$ ions. The solid line is a fit of the theoretical line shape to the data points leading to the center frequency ν_c = 610957.955(12) Hz.

The first series of mass measurements in 2009/10 concentrated on the rare-earth region. In total 15 stable nuclides of the elements europium, gadolinium, lutetium, and hafnium were measured. For the ion production a nitric acid solution of the element under investigation was dried on a carbon backing plate, desorbed and non-resonantly ionized by a laser in the ion source. The nuclide of interest was cooled and separated in a first Penning trap employing the mass-selective buffer-gas cooling technique prior to the transport to the precision trap, where the actual mass measurement took place. Here, the well-known Time-of-Flight Ion-Cyclotron-Resonance method was used with a Ramsey excitation pattern of one second total duration leading to time-of-flight spectra as shown in Fig. 1 for the case of $^{160}\text{Gd}^{16}\text{O}^+$ ions. In this way, relative uncertainties $\delta m/m$ of 2 - 6 × 10^{-8} could be achieved.

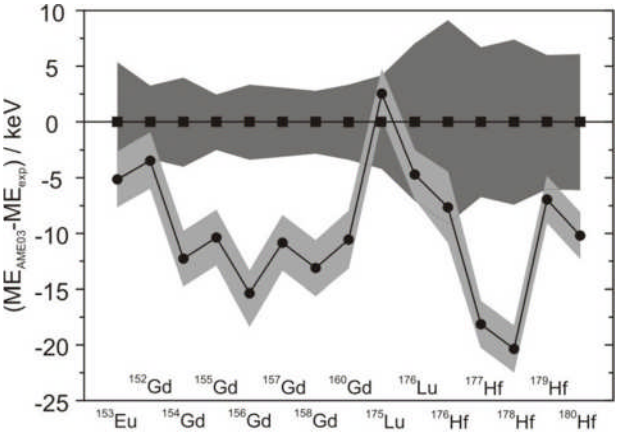

Figure 2: Differences (circles) between the mass excesses from the AME 2003 ME_{AME03} and the TRIGA-TRAP results ME_{exp} (squares). The bands indicates one standard deviation of the experimental (dark grey) and the AME data (light grey), respectively.

The oxide ions were the most abundant and thus, used for the mass measurements. Figure 2 displays the results in comparison to the latest published AME values from 2003. In some cases, deviations of 10 - 20 keV have been revealed [4]. The AME-2003 values are mainly determined by chains of (n,γ)-reaction energies which demands an independent check by direct mass measurements as performed with TRIGA-TRAP. In this respect, the experiments reported here provided the first direct links of the rare-earth nuclides under investigation (besides ^{179}Hf) to the atomic-mass standard ^{12}C. Clearly, such measurements are required for additional nuclides as planned at TRIGA-TRAP.

The mass values reported here are of importance concerning average proton-neutron interactions among valence nucleons. Looking at double-differences of binding energies, maxima occur exactly for those nuclides with equal number of valence protons and neutrons, e.g. for ^{160}Gd, which is explained [5] employing a modified Wigner energy similar to the case of $N \approx Z$ nuclides.

References

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Acknowledgement

This work is supported by the Stiftung Rheinland-Pfalz für Innovation (961-386261/854), the BMBF (06MZ91721), the Humboldt Foundation and the Alliance Program of the Helmholtz Association (HA216/EMMI).