First dedicated in-beam X-ray measurement at GARIS

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We report on an experiment aiming at in-beam X-ray spectroscopy of heavy and superheavy elements (SHE). The goal is to establish K-X-ray spectroscopy as a sensitive tool to identify SHE produced in fusion reactions. SHE are usually identified via the alpha-decay products, which have to be connected to well-known elements. However, various theories predict spontaneous fission as the dominant decay mode for the daughter nuclides. Additionally, half-lives of these elements are expected to increase to values1,2) impeding the identification of SHE solely by their decay. The in-beam identification of the characteristic X-rays would independently allow to identify the charge number of the produced SHE.

We performed dedicated experiments for in-beam X-ray recoil-decay-tagging spectroscopy at GARIS in order to study the dependence of the mean K-X-ray multiplicity $\langle M_K \rangle$ on the mass-number of the produced evaporation residue. $\langle M_K \rangle$ is predicted3) to increase to values well above one when approaching the SHE-region (see Fig. 1).

The fact that a single compound nucleus can emit more than one X-ray after formation is a consequence of the filling times of an empty inner atomic orbit (typically $10^{-13}$ ... $10^{-14}$ s) being significantly shorter than the typical lifetime of nuclear levels decaying by electron conversion (typically the picosecond range). Therefore many subsequent conversions are possible in the decay cascade of a compound nucleus.

Experiments were performed at the RIKEN Nishina Centre for Accelerator based Science by using the gas-filled magnet separator GARIS for superheavy element detection. A high-purity, low-energy planar germanium LEGe-detector3) was adapted to the GARIS system at the target place for the first time in order to measure the element-characteristic, prompt X-ray emission.

In September and October 2014, first tests concerning the rate-acceptance and resolution-deterioration of the LEGe-detector as well as background studies due to different targets in heavy-ion fusion reactions have been carried out. By measuring the $\gamma$-ray background during the reaction $^{248}$Ca$(^{48}$Ti,$xn)$$^{200}$Lv with f = 650 pmA average beam-intensity at a distance of 76 cm to the target the detector performance was excellent: Superior energy-resolution of $\Delta E_{FWHM} = 800$ eV ($@E_{x} = 74$ keV) at a trigger rate of 133 kcps. Additionally, neutron damage was measured to be negligible due to the thin and planar structure of the detector: Analysis of the neutron edges in the spectra showed a minimum detector lifetime of more than 40 days at full beam intensity before any visible neutron damage would influence the measurement.

Dedicated X-ray spectroscopy was performed in June, 2015: The reaction $^{139}$La$(^{48}$Ti,$xn)$$^{187}$−x Au was chosen to show the general feasibility of this new detection method. Due to space limitations, a fixed target of $^{139}$La with 300 µm/cm² on 3 µm Ti-backing had to be used. Therefore, intensity of the $^{48}$Ti beam (E = 242 MeV) was limited to 45 µA. The production cross-section of the compound nucleus $^{187}$−x Au was measured to be $\sigma = 18.5 \pm 4.6$ µb. As can be seen in Fig. 1, the measured value for the multiplicity-value reveals an excellent agreement with the semi-empirical prediction of $\langle M_K \rangle$ = 1.23 ± 0.29. Encountering the absolute detection efficiencies as well as the total dead-time of the electronics a detection-limit in cross-section can be estimated for in-beam X-ray spectroscopy using a whole array of LEGe-detectors to be 220 pb. This value - being nearly two orders of magnitude lower than the current limit for in-beam $\gamma$-ray spectroscopy - encourages for further studies.

References

Fig. 1. Experimental values for the mean K-X-ray multiplicity $\langle M_K \rangle$ as a function of the mass number $A_{CN}$. 