First dedicated in-beam X-ray measurement at GARIS

C. Berner,[*1,*3] H. Baba,[*3] R. Gernhäuser,[*1] S. Hellgartner,[*1] W. Henning,[*2,*3] D. Kaji,[*3] R. Lutter,[*4] L. Maier,[*1] K. Morimoto,[*3] K. Morita,[*3] D. Mücher,[*1] and Y. Wakabayashi[*3]

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 values[1,2)] 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 predicted[3)] 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 $10^{-13} \ldots 10^{-14}$ s[4)]) 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-detector[a)] 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 γ-ray background during the reaction $^{248}\mathrm{Cm}(^{48}\mathrm{Ca}, xn)^{296-x}\mathrm{Lv}^*$ with $I =$ 650 pnA 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.

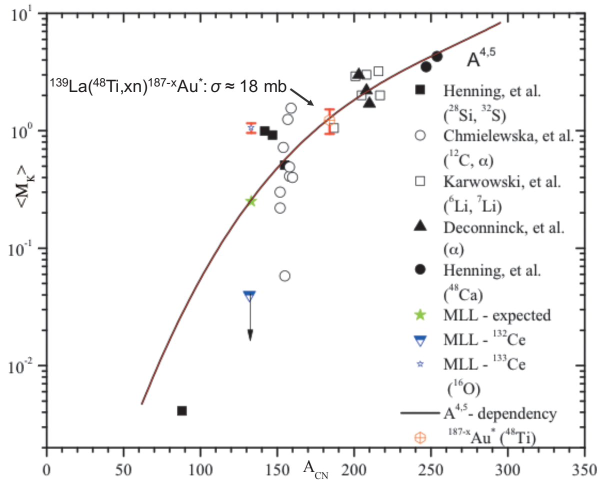

Fig. 1. Experimental values for the mean K-X-ray multiplicity $\langle M_K \rangle$ as a function of the mass number A_{CN}.

Dedicated X-ray spectroscopy was performed in June, 2015: The reaction $^{139}\mathrm{La}(^{48}\mathrm{Ti}, xn)^{187-x}\mathrm{Au}$ 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/cm^2 on 3 μm Ti-backing had to be used. Therefore, intensity of the ^{48}Ti beam ($E = 242$ MeV) was limited to 45 pnA. The production cross-section of the compound nucleus $^{187-x}$Au was measured to be $\sigma = 18.5 \pm 4.6$ mb. As can be seen in Fig. 1, the measured value for the multiplicity-value reveals an excellent agreement with the semi-empirical prediction of $\langle M_K \rangle = 1.23 \pm 0.29$. 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 γ-ray spectroscopy - encourages for further studies.

*1 Department of Physics, Technische Universität München
*2 ANL, Argonne National Laboratory
*3 RIKEN Nishina Center
*4 Faculty of Physics, Ludwig Maximilians Universität
a) Canberra Type LEGe1010

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