Observation of the extraction of Fr^{2+} from a cryogenic gas cell†

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The SHE-mass project is a joint effort between KEK and RIKEN with a long-term goal of identifying new superheavy element (SHE) isotopes produced via hot fusion. It makes use of cryogenic-capable, high-purity helium gas cell to convert the energetic (5∼50 MeV) evaporation products of fusion reactions into thermal ions. The evaporation products are separated from projectile-like fragments by use of the GARIS-II[1] gas-filled recoil ion separator. The thermalized ions are transferred to a multi-reflection time-of-flight mass spectrograph[2] (MRTOF) which can analyze the ions with a mass resolving power of $R_{\rm m} > 100\,000$. The SlowSHE system is described in some detail in[3].

To identify such low-yield species as new SHE will require an extremely low stable ion background rate. The primary source for stable background ions being charge exchange with contaminants in the gas cell, the gas cell has been designed to operate at cryogenic temperatures down to 50 K. At such temperatures, contaminants in the gas are expected to freeze out.

During the first commissioning runs of the SHE-mass project, masses of several isotopes of Fr, Rn, At, Po, and Bi were measured[3] as singly-charged ions. At that time the gas cell was operated near room temperature, as upon cooling the gas cell the radioactive ions ceased to be observed. One preliminary conjecture was that thermal contraction during cooling may be lead to misalignment of the gas cell extraction optics.

In December 2016, ions of short-lived Ac isotopes were produced with the reaction ^{169}Tm(^{48}Ca, xn)$^{217-x}$Ac with a bombarding energy of 232 MeV to study the gas cell system under cryogenic conditions, T≈150 K. As the 11.8 eV second ionization potential of actinium[4] is well-below the 24.6 eV first ionization potential of He, the system was optimized for Ac^{2+}. In the time-of-flight (ToF) spectrum, the intensity of the peak associated with a given Ac isotope could then be used to optimize the magentic field settings of GARIS-II and the thickness of the energy degrader between GARIS-II and the gas cell. Peaks were observed in the ToF spectra corresponding to a range of A/q, not all making the same number of laps in the MRTOF. By scaling the known period of circulation for a $^{133}Cs^{+}$ reference, it was possible to identify peaks corresponding to ions making different numbers of laps than the reference. Unexpectedly, fairly intense peaks were identified corresponding to $^{208-210}Fr^{2+}$, as shown in Fig. 1.

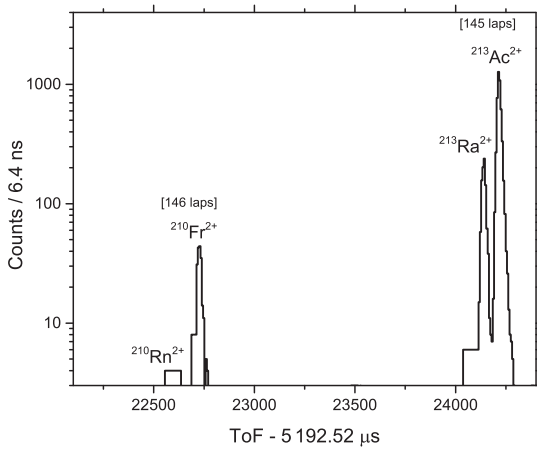

Fig. 1. Portion of observed ToF spectrum from the reaction ^{169}Tm(^{48}Ca, xn)$^{217-x}$Ac.

The production of Fr isotopes via ^{169}Tm(^{48}Ca, αxn)$^{213-x}$Fr is not unexpected[3]. However, francium being an alkali element with a second ionization potential of 22.4 eV[4], merely 2.2 eV below the first ionization potential of He, it was a surprise to observe Fr^{2+} ions. As the production yield of Fr could not be easily determined due to being the α daughter of Ac, the fraction of Fr ions extracted as doubly-charged could not be inferred from this measurement.

In a followup measurement with a ^{165}Ho target, Fr isotopes were directly produced. Preliminary analysis of these data indicate that Fr^{2+} was the dominant charge state. From this observation it can be inferred that in cryogenic operation, most elements should be expected to be extracted as 2+ or even 3+ ions.

References

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