Predicting the Retention Time of Nuclear Reaction Products in the PSI Recoil Chamber Using COMSOL Multiphysics

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Abstract

Introduction: The chemical properties of the heaviest elements (atomic number Z > 103) depend on the influence of the high nuclear charge to their electronic structure. Enhanced chemical stability of copernicium (Cn, Z = 112) and flerovium (Fl, Z = 114) was predicted already 40 year ago by Pitzer [1]. The challenge of chemical investigations of these elements is the tiny production rates of few atoms per week using 48Ca induced nuclear fusion reactions obfuscated with short half-lifes in the order of seconds and below (see e.g. [2]). The formed evaporation residues (EVRs) recoil out of the target and are thermalized in a recoil chamber (RC). Their retention time in the RC is comparable to the half-life of the produced isotopes. Recently performed experiments with Cn and Fl [3,4] showed that gas phase chemistry is suitable to meet all these requirements. In Figure 1 our experimental setup is schematically depicted. Detailed knowledge of the flow pattern and transport regime in the RC is essential to maximize the transport efficiency and the number of atoms available for chemical investigations. In contrast to the capillary transport, the dwell time prediction of reaction products out of the RC needs more efforts. Computational Methods: The steady state flow pattern of the carrier gas was calculated in a full 3D simulation using the CFD Module of COMSOL Multiphysics. The used geometry of the gas volume is based on a CAD model of the PSI-RC (Figure 2). Particular attention was paid to keep the original structure up to small details like imprints of skews or quartz columns. The final model consists of 504,298 mesh elements, and 466,377 degrees of freedom. In a following step the time dependence of the transport of a diluted species out of the RC was calculated, where the initial distribution of the EVRs was determined using the stopping range program SRIM-2011 [5]. Results: Due to the Z-limitations of the SRIM code uranium was used as target material and radon as EVR taken into account the known deviations from experimental results [6]. The obtained ion distribution was fitted using a Gaussian distribution in perpendicular direction to the recoiling EVRs and a Rayleigh type distribution along the direction of the recoiling EVRs, respectively.
The flow calculations were performed with a constant total carrier gas flow of 1.5 l/min, where the ratio of the flows entering inflow tube 1 (in1) and inflow tube 2 (in2) was varied. Figure 3 shows as an example of the isotope distributions after 75 ms if 20% and 80% flow passing inlet in1, respectively. Conclusions: These results were used to estimate the yield for interesting EVRs, in particular for the isotopes 287Fl (t1/2 ~ 0.5 s), 288Fl (t1/2 ~ 0.8 s), and 289Fl (t1/2 ~ 2.6 s). The results are depicted in figure 4. A flat yield maximum is predicted if 60% - 90% of the gas flow entering the inlet in1.

Reference

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[4] R. Eichler, et al.: „Indication for a volatile element 114" Radiochim. Acta 98, 133 (2010).
[5] J.F. Ziegler SRIM-2011, http://www.srim.org (2011).
[6] D. Wittwer, et al.: „Gas phase chemical studies of superheavy elements using the Dubna gas-filled recoil separator – Stopping range determination" Nucl. Instr. Meth. B 268, 28 (2010).

Figures used in the abstract

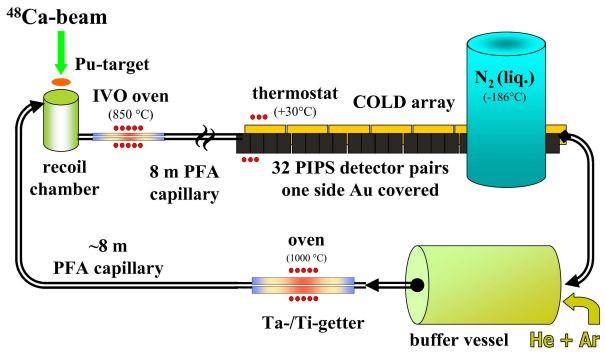

Figure 1: Scheme of the experimental setup consisting of the In-situ-Volatilization and On-line detection apparatus (IVO) and the Cryo On-Line-Detector (COLD). This system was used for chemical investigations of the elements copernicium (Cn Z=112) and flerovium (Fl Z=114).

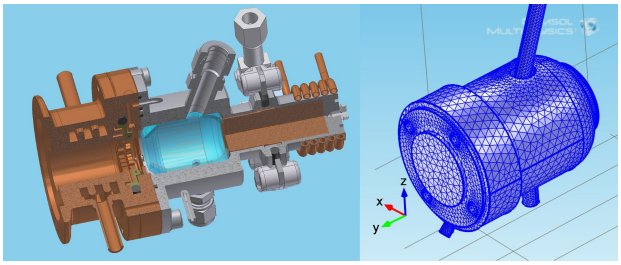

Figure 2: Left: CAD drawing of the PSI recoil chamber (RC). The beam enters from left and hits the target, which is placed close to the copper steel interface. The evaporation residues are recoiling into the gas volume of the RC enclosed by a quartz inlet. The gas inlet in2 (below the RC) and the gas outlet (on top of the RC) are visible. The gas inlet in1 is situated inside the copper part. Right: Mesh of the COMSOL Multiphysics® model of the inner gas volume of. Both gas inlets (below the RC) and the gas outlet (on top of the RC) are visible. The imprints of the screw heads of the target fixation (on the front) as well as the imprints of the outlet quartz tube (on top) are visible.

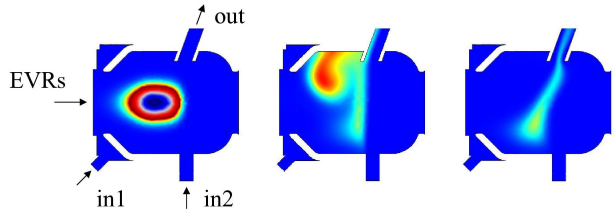

Figure 3: Evaporation residue (EVR) distribution for different flow conditions. The injection direction of the EVRs, both in-flow tubes and the out-flow tube are indicated. From left to right initial EVR distribution, EVR distribution after 75 ms with 20% and 80% flow passing inlet in1, respectively.

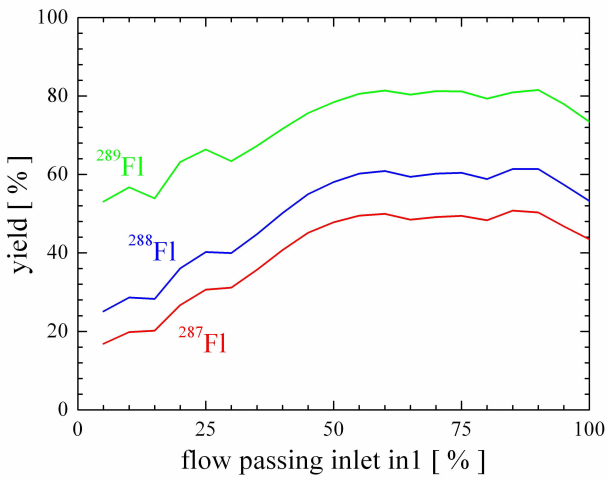

Figure 4: Total flushed out yield of different reaction products after 15 s. The results are given for different half-lives (t1/2) corresponding to the following isotopes 287Fl t1/2 = 0.5 s (red), 288Fl t1/2 = 0.8 s (blue), and 289Fl t1/2 = 2.6 s (green).