

Online coprecipitation experiment of ^{85}Zr and ^{169}Hf with Sm hydroxide for chemical study of Rf

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Elucidating chemical properties of transactinide elements with atomic numbers $Z \geq 104$ is an intriguing and important topic. Transactinide elements are produced at accelerators using heavy-ion-induced nuclear reactions. The production rates of these elements are low and their half-lives are short ($T_{1/2} \leq \sim 1$ min). Thus, chemical studies on these elements are conducted on a one-atom-at-a-time basis using rapid chemical separation techniques, and products transported online by a gas-jet system from a nuclear reaction chamber are used. For unambiguous identification of a single atom, detection of α or spontaneous fission decay is required. Owing to these difficulties, so far, simple partition methods such as gas-phase and aqueous-phase chromatographic experiments have been applied to the studies of transactinide elements.

Recently, the anion- and cation-exchange behaviors of rutherfordium (Rf, $Z = 104$) in HF and HF/HNO₃ solutions were successfully investigated at the Japan Atomic Energy Agency Tandem Facility, the behaviors of Rf was reported to be different from those of its homologues Zr and Hf.¹⁾ Detailed studies on Rf in various chemical systems are needed for a further understanding of its chemical properties. To establish a new chemical experiment for superheavy elements, thus far, we have developed a method to rapidly prepare a coprecipitated sample, which has good energy resolution in alpha spectrometry. For the coprecipitation study of Rf, we have studied coprecipitation properties of group-4 elements, Zr, Hf, and Th with Sm(OH)₃,²⁾ and also developed an apparatus for rapid preparation of precipitate samples. In this study, we performed online coprecipitation experiments of ^{85}Zr and ^{169}Hf using the developed apparatus, and determined the experimental conditions for Rf.

We produced carrier-free radiotracers ^{85}Zr ($T_{1/2} = 7.9$ min) and ^{169}Hf ($T_{1/2} = 3.25$ min) in the $^{nat}\text{Ge}/^{nat}\text{Gd}(^{18}\text{O}, xn)$ reactions using the RIKEN K70 AVF cyclotron. The reaction products were transported online by a He/KCl gas-jet system to the chemistry laboratory. They were deposited on the collection site of a dissolution apparatus, and then dissolved in 120 μL of a 0.46 M HNO₃ solution containing Sm ions (460 mg/L). Various compositions of basic solutions (dilute and concentrated aqueous NH₃, 0.15, 1, 6, and 12 M NaOH) were added into the sample solution. The resultant concentrations were 0.28 and 13 M NH₃,

and 0.08, 0.84, 5.3, and 11 M NaOH, respectively. After stirring the sample for 10 s, the coprecipitate sample was prepared by suction filtration on a polypropylene membrane filter (0.1 μm , $\phi 20$, Eichrom) using a semiautomatic filtration apparatus for repetitive experiments. The sample was dried using a heater at 100 $^{\circ}\text{C}$ and was subjected to γ -ray measurement using a Ge detector. On the other hand, radioactivities of the products dissolved using the dissolution apparatus were also determined. From the ratio of the measured radioactivities of the precipitate to those of the dissolved solution, precipitation yields of Zr and Hf were determined.

The dependence of the yield on the composition of the added basic solution is depicted in Fig. 1. It was found that almost the entire amounts of Zr and Hf were coprecipitated with Sm hydroxide when aqueous NH₃ and 0.1 M NaOH were used. This suggests that Zr and Hf form a neutral hydroxide complex and coprecipitate with Sm(OH)₃ precipitate in these basic solutions. For more concentrated NaOH solutions, the yields decreased as the concentration of the hydroxide ion increased, indicating that the Zr and Hf form anionic hydroxide complexes. These results are consistent with those obtained in the offline coprecipitation experiment using ^{88}Zr and ^{175}Hf .²⁾ It was found that the coprecipitation yields of Zr and Hf with Sm hydroxide in the rapid and online precipitation experiment can be obtained using the developed apparatus connected to the accelerator at RIKEN; the present experimental systems are applicable to Rf experiments.

Very recently, we indeed produced ^{261}Rf in a $^{248}\text{Cm}(^{18}\text{O}, 5n)^{261}\text{Rf}$ reaction and performed the first trial of coprecipitating Rf with Sm(OH)₃. Approximately 43 alpha events were detected in the energy region of ^{261}Rf .

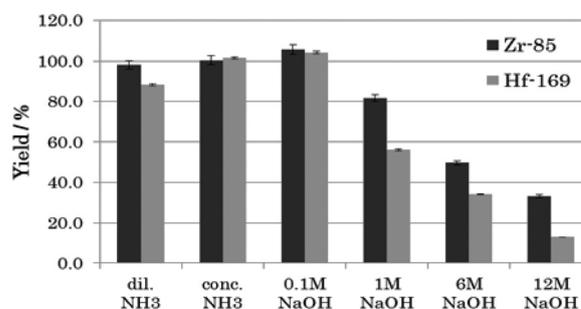


Fig. 1. Coprecipitation yields of ^{85}Zr and ^{169}Hf .

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