Production of $^{174}\text{Re}$ in the $^{258}\text{Gd}^{(23}\text{Na},\alpha x\gamma)$ reactions for future studies on Bh chemistry using GARIS


We have been developing a gas-jet transport system coupled to GARIS as a novel technique for superheavy element (SHE) chemistry.1 So far, isotopes of $^{280}\text{Rf}$ (atomic number $Z = 104$), $^{260}\text{Db}$ ($Z = 105$), and $^{260}\text{Sg}$ ($Z = 106$) have been produced in the $^{258}\text{Gd}^{(18}\text{O},5n)$, $^{248}\text{Cm}^{(19}\text{F},5n)$, and $^{248}\text{Cm}^{(23}\text{Ne},5n)$ reactions, respectively, and the production and decay properties of these isotopes have been investigated for chemical studies.2–5 Recently, the chemical synthesis and gas-chromatographic analysis of Sg(CO)$_{4}$ were successfully conducted with $^{280}\text{Rf}$.6 We plan to obtain a heavier element, Bh ($Z = 107$), by investigating production conditions of $^{266,267}\text{Bh}$ in the $^{248}\text{Cm}^{(23}\text{Na},\alpha n\gamma)$ reactions. In this work, as the first step, we optimized setting parameters of the GARIS gas-jet system using $^{174}\text{Re}$ produced in the $^{258}\text{Gd}^{(23}\text{Na},\alpha n\gamma)$ reactions. Since Re is a homologous element of Bh in the periodic table, the Re isotopes would be useful in fundamental experiments on Bh chemistry in the future.

The $^{258}\text{Gd}^{(23}\text{Na},\alpha n\gamma)$ target with a thickness of 340 $\mu$g cm$^{-2}$ was prepared by electrodeposition onto a 2-$\mu$m Ti foil. The $^{23}\text{Na}$ ion beam was extracted from RILAC. The beam energy was 130.6 MeV at the middle of the target, and the typical beam intensity was 1.4 particle $\mu$A. The evaporation residues (ERs) were separated by GARIS. Several magnetic rigidities were investigated ($B_{p} = 1.58–1.94$ Tm) at a He pressure of 33 Pa. Then, the ERs were guided into a gas-jet chamber of 100-mm depth through a 0.7-$\mu$m Mylar window. The ERs were transported by a He/KCl gas-jet to a chemistry laboratory. The He flow rate was 5 L min$^{-1}$, and the chamber pressure was 78 kPa. The KCl aerosols were then collected on a glass filter for 60 s and subjected to $\gamma$-ray spectrometry with a Ge detector after a cooling time of 60 s. A 20-$\mu$m Al foil was placed at the entrance of the gas-jet chamber to evaluate the gas-jet transport efficiency.

Fig. 1 shows a typical $\gamma$-ray spectrum observed in the $^{258}\text{Gd}^{(23}\text{Na},\alpha n\gamma)$ reactions at $B_{p} = 1.74$ Tm.

Fig. 2 shows the distribution of $^{174}\text{Re}$ as a function of magnetic rigidity. The dashed curve represents the result of the least-squares fitting with the Gaussian curve with a maximum yield at $B_{p} = 1.74 \pm 0.01$ Tm and a resolution of $\Delta B_{p}/B_{p} = 10.0 \pm 0.4\%$. This optimum $B_{p}$ agrees well with that ($B_{p} = 1.78 \pm 0.05$ Tm) deduced from our systematic trend for the low-energy recoil ions.8 The gas-jet transport efficiency was about 80%. The radioactivity of $^{174}\text{Re}$ available at the chemistry laboratory is $55 \pm 2$ kBq $\mu$A$^{-1}$ after the 60-s aerosol collection. This yield is high enough to allow development of chemistry apparatuses and investigation of chemical systems for the study of Bh chemistry in the future.

References