Production of $^{262}$Db in the $^{248}$Cm($^{19}$F,$\alpha$n)$^{262}$Db reaction and decay properties of $^{262}$Db and $^{258}$Lr


We have been developing a gas-jet transport system coupled to GARIS as a novel technique for superheavy element chemistry. So far, isotopes of element 104, 261Rf, and element 106, 262Sg, have been produced for chemical studies in the $^{248}$Cm($^{19}$O,$\alpha$5n) and $^{248}$Cm($^{22}$Ne,$\alpha$n) reactions, respectively. In this work, we produced element 105, 262Db in the $^{248}$Cm($^{19}$F,$\alpha$n) reaction and investigated its decay properties in detail for future chemical studies of Db.

$^{248}$CmO$_2$ targets with thicknesses of 230, 290, and 330 $\mu$g/cm$^2$ were prepared by electrodeposition onto a 2-$\mu$m Ti foil. The $^{19}$F$^+$ or $^{19}$F$^+$ ion beam was extracted from RILAC. The beam energies were 103.1 and 97.4 MeV at the middle of the target, and the typical beam intensity was 4 particle $\mu$A. The evaporation residues (ERs) separated by GARIS were guided into the gas-jet chamber through a 0.5-$\mu$m-thick Mylar window, which was supported by a grid with 84% transparency. Several magnetic rigidities were investigated in $Bp = 1.73$–2.09 Tm at a He pressure of 33 Pa; the optimal collection efficiency for 262Db was 81.1 ± 2.2% at $Bp = 1.89$ Tm. The ERs were then transported by a He/KCl gas jet to the rotating-wheel apparatus MANON for $\alpha$/SF spectrometry. In MANON, aerosol particles were deposited on a Mylar foil of 0.5-$\mu$m thickness, 40 of which were set on the periphery of a rotating wheel. The wheel was stepped at 15.5 s intervals to position the samples between 15 pairs of Si PIN photodiodes.

We searched for time-correlated $\alpha$-$\alpha$ event pairs in the time window of 58.5 s and in the energy range of 8.0 MeV $\leq E_x \leq 9.0$ MeV. As a result, 71 and 4 $\alpha$-$\alpha$ pairs were found at 103.1 and 97.4 MeV, respectively. By referring to the $\alpha$-particle energies ($E_\alpha$) and half-lives ($T_{1/2}$) adopted for $^{262}$Db and its daughter $^{258}$Lr, 74 $\alpha$-$\alpha$ pairs were reasonably assigned to $^{262}$Db $\rightarrow$ $^{258}$Lr. One exceptional $\alpha$-$\alpha$ pair at 103.1 MeV was $^{262}$Db $\rightarrow$ $^{257}$Lr $\rightarrow$ via the $^{248}$Cm($^{19}$F,6n) reaction. No $\alpha$-$\alpha$ pair on $^{262}$Db produced in the $^{248}$Cm($^{19}$F,4n) reaction ($^{262}$Db $\rightarrow$ $^{258}$Lr) was observed. We also observed two SF events that correlated with the $\alpha$ decays with energies and decay times of $^{262}$Db. This suggests that small SF and/or EC branches exist in $^{258}$Lr; the EC decay daughter of $^{258}$Lr, $^{258}$No, is a short-lived SF decaying nuclide with $T_{1/2} \approx 1.2$ ms and $b_{SF} = 100\%$.\(^3\) On the basis of the semi-empirical systematics of nuclear mass and half-lives, the EC decay would be favored in $^{258}$Lr next to the $\alpha$ decay.\(^4\)

The observed decay patterns of $^{262}$Db and $^{258}$Lr are shown in Fig. 1. The $\alpha$-particle energies of $E_\alpha = 8.46 \pm 0.04$ ($\alpha$ intensity $I_\alpha = 70 \pm 5\%$) and 8.68 $\pm$ 0.03 MeV (30 $\pm$ 5\%) were determined for $^{262}$Db, though three energies of $E_\alpha = 8.45$ (75\%), 8.53 (16\%), and 8.67 (9\%) had been adopted.\(^3\) The half-life of $^{262}$Db was measured to be $T_{1/2} = 33.8^{+4.4}_{-3.5}$ s, and this agrees well with $T_{1/2} = 34 \pm 4$ s in Ref.\(^3\). In this work, the SF activity with $T_{1/2} = 30.2 \pm 6.1$ s was also assigned to $^{262}$Db with a SF branch of $b_{SF} = 52 \pm 4\%$. This is larger than the currently adopted $b_{SF} = 33\%$.\(^3\) On the other hand, the $\alpha$-particle energies of $^{258}$Lr range from $E_\alpha = 8.43$ to 8.73 MeV and the average $\alpha$ energy of $E_\alpha = 8.61$ MeV agrees well with $E_\alpha = 8.605$ MeV deduced from the $\alpha$ energies and intensities of $^{258}$Lr in Ref.\(^3\). The half-life of $^{258}$Lr, $T_{1/2} = 3.54^{+0.46}_{-0.36}$ s also agrees with that in Ref.\(^3\) ($T_{1/2} = 3.9^{+0.4}_{-0.3}$ s). The EC branch in $^{258}$Lr was first determined to be $b_{EC} = 2.6 \pm 1.8\%$. The cross sections for the $^{248}$Cm($^{19}$F,5n)$^{262}$Db reaction were $2.1 \pm 0.7$ nb at 103.1 MeV and 0.23$^{+0.18}_{-0.11}$ nb at 97.4 MeV, while those for the $^{248}$Cm($^{19}$F,4n)$^{262}$Db reaction were the upper limits of $\leq 0.064$ nb at 103.1 MeV and $\leq 0.13$ nb at 97.4 MeV.

Fig. 1. Observed decay patterns for the chain $^{262}$Db $\rightarrow$ $^{258}$Lr $\rightarrow$ ($^{258}$No $\rightarrow$). The $\alpha$-particle energies and intensities ($I_\alpha$) of $^{258}$Lr and all decay data of $^{258}$No are taken from Ref.\(^3\).

References

4) H. Koura: private communication.