VI. 1. Investigation of Excitation Function for $^{238}\text{U}(^{12}\text{C},4-6\text{n})^{244-246}\text{Cf}$

Takamiya K.\(^2\), Kasamatsu Y.\(^3\), Ohtsuki T.\(^1\), Yuki H.\(^1\), Takabe T.\(^3\), Nakashima K.\(^3\), Hasegawa H.\(^3\), Shinohara A.\(^3\), Shibata S.\(^2\), Mitsugashira T.\(^4\), Sato N.\(^5\), Suzuki T.\(^5\), Miyashita Y.\(^5\), Shinozuka T.\(^5\), Kikunaga H.\(^6\), and Nakanishi T.\(^6\)

\(^1\)Laboratory of Nuclear Science, Tohoku University
\(^2\)Research Reactor Institute, Kyoto University
\(^3\)Department of Chemistry, Osaka University
\(^4\)Institute of Materials Research, Tohoku University
\(^5\)Cyclotron Radioisotope Center, Tohoku University
\(^6\)Department of Chemistry, Kanazawa University

The investigation for the excitation function of $^{238}\text{U}(^{12}\text{C},\text{xn})$ reaction has been carried out by on-line and off-line measurement system. An He-jet transport and a rotating-wheel measurement system was used for on-line experiments, and off-line experiments were carried out by radiochemical method. Furthermore, a simple and unique method of target preparation using a membrane filter of an Al\(_2\)O\(_3\) disk (25 \(\mu\)m/cm\(^2\) in thickness) that can be useful with precipitation after filtering the target material\(^1\) was applied in these experiments. The $^{238}\text{U}$ deposited on prepared Al\(_2\)O\(_3\) disk was irradiated with $^{12}\text{C}$ ions and the isotopes of Cf were produced with $^{238}\text{U}(^{12}\text{C},4-6\text{n})$ reactions. The obtained excitation functions of $^{244-246}\text{Cf}$ were compared with those obtained by other previous results.

The irradiation experiments were carried out using the 930-AVF cyclotron in the CYRIC. In order to measure isotopes which has various half-lives efficiently, two kinds of experiments, off-line and on-line experiments, were carried out. In the off-line experiments, uranium hydroxide collected on the membrane filter of an Al\(_2\)O\(_3\) was used as the targets (300 \(\mu\)g/cm\(^2\) in thickness). The target was mounted in an aluminum holder and placed in the reaction chamber on the end of a beam line as the sample side face to the upstream of ion beam. The energetic $^{12}\text{C}$ ions accelerated by the accelerator was irradiated to the target through a few aluminum degraders. The reaction products lost their kinetic energies in the target of filter and remained there. The irradiation time was varied from 20 - 40 min
according as the half-life of dominant isotope of Cf at the irradiation energy. The beam current was typically 150 particle-nA. After the irradiation, the target was dissolved in hydrochloric acid, and $^{252}$Cf and Fe$^{3+}$ ions were added as carrier materials. Sodium hydroxide solution was added to produce a precipitate. After repeating these procedures, the precipitate was dissolved in hydrochloric acid of 9 mol/L and poured into the anion exchange column (DOWEX 1X8, 200 - 400 mesh). Hydrochloric acid of 9 mol/L was injected to the column to elute the isotopes of Cf. Samarium was added to the eluent as a carrier material, and after that, ammonia water was added to precipitate as hydroxides of Cf and Sm. The precipitate was filtered and dried to prepare the measurement source for $\alpha$-particle spectroscopy using SSBD.

In the on-line experiments, the same precipitation targets (200 $\mu$g/cm$^2$ in thickness) or electrodeposited targets was used for the irradiation. The target was mounted in an aluminum holder and placed in the He-gas jet reaction chamber on the end of a beam course. The reaction chamber was connected to the He-gas (containing KCl clusters) jet transport system. He-gas (flow rate, 2 L/min) was applied through a KCl-cluster generator at 640°C. Reaction products were recoiled out from the targets by nuclear reactions, and kinetic energies were reduced in He-gas containing KCl clusters. The products adsorbed on the cluster were then transported with He-gas through a capillary tube to an automated rotating-wheel chamber placed in the room next door. Six $\alpha$-particle detectors equipped with PIN-photodiode were installed in the rotating-wheel chamber to measure the $\alpha$-particles emitted from the transported nuclides. The products transported by He-gas were blown onto polyethylene terephthalate films. The beam current was typically 150 particle-nA, that is almost the same as off-line experiments. Accumulation of the products on rotating-wheel and measurements of the $\alpha$-particles of Cf isotopes was repeated at 10 - 20 min intervals according as the half-live of dominant isotope of Cf.

The $\alpha$-particle spectra of $^{245}$Cf and $^{244}$CF, produced by $^{238}$U($^{12}$C, 5n) and $^{238}$U($^{12}$C, 6n) reactions, respectively, are shown in Fig. 1. The spectra illustrated in the upper and lower panels in this figure were obtained by off-line and on-line experiments, respectively, at the irradiation energy of 83 MeV. It was found that the energy resolution of the spectrum obtained by off-line experiment is better than that by on-line experiment. In the upper panel, the peak at 7.22 MeV of $^{244}$Cf and that at 7.15 MeV of $^{245}$Cf are clearly identified. On the other side, the spectrum obtained in the on-line experiments could be separated to several components by calculation with a computer; however, short-lived isotope of $^{244}$Cf could be measured with enough statistics. Finally, we have obtained the
cross section of the $^{238}\text{U}(^{12}\text{C},4\text{-}6\text{n})$ reactions in several irradiation energies on target. The excitation functions of $^{238}\text{U}(^{12}\text{C},4\text{-}6\text{n})$ $^{244\text{-}246}\text{Cf}$ are shown in Fig. 2 with those reported by Sikkeland et al.\textsuperscript{2} as a function of laboratory energy system. In this figure, open and closed symbols show the results by the present work and by Sikkeland, respectively. We found that the cross sections for the $^{238}\text{U}(^{12}\text{C},4\text{-}6\text{n})$ were estimated to be one order of magnitude lower than those reported.

In order to examine the discrepancy between the results by our work and Sikkeland et al., the maximum cross sections for 5n reaction of $^{238}\text{U}$ and $^{244}\text{Pu}$ as a function of the proton number of the compound nuclei are shown in Fig. 3. There seems that the cross section values of the previous reports\textsuperscript{3-6} decreases as the proton number increases in the both case of the targets of $^{238}\text{U}$ and $^{244}\text{Pu}$. It was found that our present result is consistent with the systematics although the result by Sikkeland is inconsistent.

References

1) Takamiya K., et al., to be published.