Coulomb breakup reactions of long-lived fission products, ^{79}Se, ^{93}Zr, and ^{107}Pd

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Nuclear transmutation of long-lived fission products (LLFPs) mixed in nuclear radioactive wastes is one of the candidate techniques for the reduction and/or reuse of LLFPs, and has been investigated since several decades. High-level radioactive wastes including LLFPs have to be kept in the deep and hard rock stratum to separate them from human environments with current disposal methods owing to their large radiations and high heats. Among the LLFPs, transmutations of ^{79}Se, ^{93}Zr, ^{107}Pd, and ^{135}Cs are important owing to their long half-lives of 0.3M, 1.6M, 6.5M, and 2.3M years, respectively. These LLFPs can be transmuted to be stable or short-lived nuclei; however the reaction rates relevant to these isotopes are not sufficient for transmutation techniques.

In order to accumulate nuclear reaction data for further developments, we performed nuclear reaction experiments using LLFPs as secondary beams[1]. In particular, we focused on (γ,n) and (n,γ) reactions for LLFPs and neighboring nuclei. The neutron capture (n,γ) for LLFPs is an important reaction for transmutation; however there are several difficulties to conduct these experiments. An alternative way may be by measuring photo-absorption (γ,n) cross sections (σ_{abs}) connected to (n,γ) cross sections via the principle of detailed balance. The σ_{abs} for LLFPs can be measured indirectly by Coulomb breakup reactions with fast RI beams of LLFPs in inverse kinematics. We focused on the measurements of Coulomb breakup reactions of ^{79,80}Se, ^{93,94}Zr, and ^{107,108}Pd to obtain σ_{abs}.

The secondary beams of ^{79,80}Se, ^{93,94}Zr, and ^{107,108}Pd with an energy of 200 MeV/nucleon were produced by in-flight fission reactions of a ^{238}U primary beam with 345 MeV/nucleon on a ^{9}Be production target and identified by BigRIPS[2]. In the experiment using the ZeroDegree (ZD) spectrometer[2], we performed inclusive measurements for Coulomb breakup reactions of ^{93,94}Zr and ^{107,108}Pd. Secondary targets of Pb and C with thicknesses of 0.52 g/cm^2 and 0.32 g/cm^2, respectively, were placed at the F8 focus and surrounded by DALI2[3] to detect de-excitation γ rays. The reaction products were analyzed and identified by the ZD spectrometer with the two Bρ settings. In the first setting, the Bρ value was adjusted to set non-reacted secondary beams to be centered (0% setting), which accepted momentum distributions up to -3% corresponding to three neutron removal channels for ^{107}Pd, for example. In another setting, the Bρ value was adjusted to be -3% relative to the 0% setting with the acceptance of six neutron removal channels for ^{107}Pd. Combining these two settings, Coulomb breakup cross sections will be obtained after subtracting nuclear components estimated by breakup reactions on the C target. Figure 1 shows the mass-to-charge distribution of reaction products in the ^{107}Pd + Pb reaction obtained by the ZD spectrometer with the -3% setting. By counting the yields for each isotope, Coulomb breakup cross sections will be deduced and converted to σ_{abs}.

Exclusive measurements were also made using the SAMURAI spectrometer[4] to obtain Coulomb breakup cross sections to be converted to the relevant excitation function. The secondary beams of ^{79,80}Se and ^{93,94}Zr were bombarded on Pb and C targets with thicknesses of 0.54 g/cm^2 and 0.26 g/cm^2, respectively. Charged particles produced in breakup reactions were analyzed by the SAMURAI spectrometer and neutrons were detected by NEBULA[4] and NeuLAND[5]. DALI2 was placed at the target area to detect de-excitation γ rays to identify reaction channels.

The analyses for both experiments are currently in progress. This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

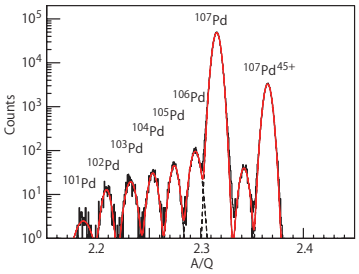

Fig. 1. Mass-to-charge ratio (A/Q) for Pd isotopes in the ^{107}Pd + Pb reaction.

References

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