Evaluation of ^{79}Se$(n,\gamma)^{80}$Se reaction by measuring ^{77,79}Se$(d,p)^{78,80}$Se reactions

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The first excited state at 95.7 keV in ^{79}Se, which is located on the path of the s-process nucleosynthesis, has a tiny branch of β decay to ^{79}Br. Depending on the temperature of the astrophysical site, some ground states of ^{79}Se can be excited to produce ^{79}Br. The ratio of ^{80}Se to ^{79}Se in a meteorite indicates the temperature of the site.[1] However, the neutron capture reaction on ^{79}Se which is the main reaction flow in the s-process has not been measured.

The nucleus is known as one of the long-lived fission products (LLFP) of nuclear waste. To design the facility to transmute the nucleus, a neutron capture cross-section on the nucleus was conceptualized. However, because both the neutron and LLFPs are unstable, the measurement of neutron-induced cross-section is quite challenging. Alternatively, the reaction cross-section can be indirectly determined through a surrogate reaction.

It is generally assumed that the (n,γ) cross-section is composed of two parts; the formation of compound state and the subsequent decay. The first term can be calculated using the optical model potentials with global parameterbcharres. In contrast, the theoretical estimates of the second process is quite challenging owing to high level density and complicated decay scheme, and need to be evaluated by the experiment.[2] This work aims to determine the γ emission probability, P_γ, from the unbound states of ^{80}Se populated by the (d,p) reaction as a surrogate for the ^{79}Se$(n,\gamma)^{80}$Se reaction. The method can be verified by comparing the cross-sections of ^{77}Se$(n,\gamma)^{78}$Se determined by directly measuring the ^{77}Se$(d,p)^{78}$Se reaction with the direct measurement at $E_n = 550$ keV.[3]

The experiment was performed by using the OEDO beam line[4] as one of the first physics experiments. The ^{77,79}Se beams produced by BigRIPS were energy-degraded at F5 and the beam was spatially focused on a 4-mg/cm^2 thick polyethylene deuteride target by OEDO. The beam energy was adjusted to be 20 MeV/nucleon at the target. The recoiled particles were identified by employing the six SSD-CsI(Tl) array called TiNA, which covered 100° to 150° in the laboratory frame. The excitation energies of the state populated in ^{78}Se (^{80}Se) were determined using TiNA and incident beam momentum. The momenta of the outgoing nuclei were analyzed by the first half of the SHARAQ spectrometer.

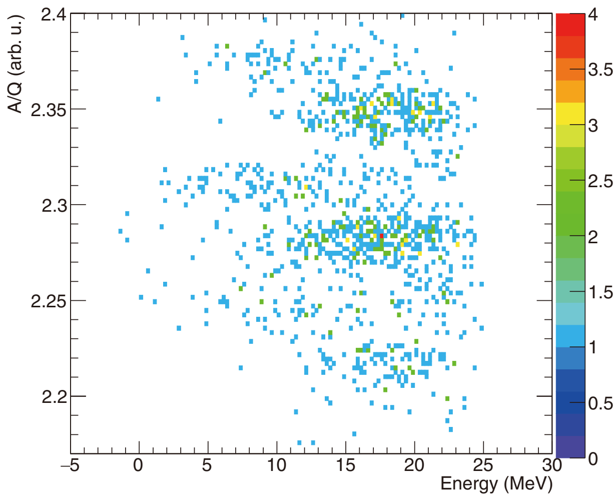

Fig. 1. A/Q measured at S1 focal plane as a function of the excitation energy in ^{80}Se. See the text for details.

Figure 1 presents the mass-to-charge (A/Q) ratio determined by the spectrometer as a function of the excitation energy of ^{80}Se. The locus at $A/Q = 2.3$ is the ^{80}Se^{33+} while $A/Q = 2.27$ is ^{79}Se^{33+}. The locus of ^{80}Se clearly indicates that ^{80}Se survived at an energy higher than 10 MeV of the one neutron separation energy of ^{80}Se. The fraction of $(N+1, Z)$ nuclei to (N, Z) residues allows us to determine P_γ as a function of excitation energy. Further analysis is ongoing.

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References

1) F. Kappler *et al.*, Rep. Prog. Phys. **52**, 945 (1989).
2) J. E. Escher *et al.*, Rev. Mod. Phys. **84**, 353 (2012).
3) S. Kawada, M. Igashira, T. Katabuchi, M. Mizumoto, J. Nucl. Sci. Tech. **47**, 643 (2010).
4) S. Michimasa *et al.*, Prog. Theo. Exp. Phys., accepted (2019).