Novel technique of the surrogate reaction for neutron captur rate with OEDO and SHARAQ†

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The neutron capture reaction cross-sections are important for understanding the origin of the elements in the universe as well as the nuclear engineering. In some cases, the target nuclei are radioactive so that the measurement of the cross section is not feasible.

To evaluate the cross section of ^{79}Se(n,γ), a surrogate ratio technique[1)] was employed. In general, the compound neutron capture reaction is considered to be composed of two factors: the formation cross section of the compound states and the γ decay probability from the unbound states. The energy-dependent formation cross section can be obtained by using the global optical potential. On the other hand, the γ emission probability strongly depends on the nuclear structure of the nucleus. Once the γ emission probability is obtained experimentally, the neutron capture cross sections can be determined. In the surrogate method, the same unbound states as those populated by the compound reaction are assumed to be excited by an alternative nuclear reaction such as (d,p) reaction. In the case of (d,p) reaction, the excitation energy can be determined by measuring the recoiled protons. Therefore, when γ emission channel at each excitation energy is identified, the neutron capture cross section can be determined.

So far, for the surrogate ratio method, the γ emission probability was determined by measuring deexcitation γ rays which requires the decay scheme from the unbound state. On the other hand, in our new method, the probability was determined by measuring reaction residues in coincidence with the recoiled proton, instead of measuring γ ray. The transfer reaction in the inverse kinematics made the measurement feasible. In this study, we also measured the ^{77}Se$(d,p)^{78}$Se reaction as well as ^{79}Se$(d,p)^{80}$Se. Since the ^{77}Se$(n,\gamma)^{78}$Se reactions were already measured at 550 keV, we can verify the method by ^{77}Se$(n,\gamma)^{78}$Se reaction cross section by using the surrogate method.

The energies of the secondary ^{77,79}Se beams were degraded to 20 MeV/nucleon at the secondary target by passing through the beam line detectors of parallel plate avalanche counters (PPAC)s. Two PPACs were installed upstream of the secondary target, FE12, to register the timing and the trajectory of the beams on the target. TOF between F5 and FE12 was measured to measure the respective beam energy. The RF deflector at OEDO[2)] decreased the beam spot in a diameter of 2 cm (σ) at a deuterated polyethylene CD_2 target of 4 mg/cm^2 thickness. The target size was 3 cm in diameter. The recoiled particles of (d,p) reactions were detected by six telescopes, each of which consisted of SSD at the first layer and two CsI(Tl)s detectors at the second layer. The telescope covered the scattering angles from 100 to 150 degrees in the laboratory frame. The momenta of the outgoing nuclei were analyzed by the first part of the SHARAQ spectrometer. At the exit of the D1 magnet of the spectrometer, two PPACs and an ionization chamber were installed as the focal plane detectors. PPACs gave us the TOF of ions. The trajectory obtained from PPACs also gave the $B\rho$ values of the residual nuclei. The ionization chamber yielded the energy loss (dE) and the range in the gas. The TOF-dE-range and $B\rho$ information enables us to identify the ions.

The neutron-capture cross-sections were evaluated from $E_n = 0.8$ to 4 MeV in 1 MeV steps by employing the surrogate ratio method. The cross-sections using the surrogate-ratio method support TENDL2019 rather than TENDL2017 and TENDL2021 which are lower than the presented results of the surrogate-ratio method.

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References

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