Deuteron activation cross sections for monitor reactions

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Structural materials in fusion energy devices like ITER are expected to be exposed to intense neutron flux. Therefore, material tests are important in fusion energy technology. The International Fusion Material Irradiation Facility (IFMIF) is a candidate facility for material tests. Intense neutrons consisting of a peak around 15 MeV are planned to be produced in IFMIF using the ^{7}Li(d,n) reaction with intense (125 mA + 125 mA) deuteron beams that are accelerated to 35 to 40 MeV by two linear accelerators[1)]. The prototype is under construction in Rokkasho, Japan within IFMIF Engineering Design Activities (IFMIF/EVEDA). In addition to generating high energy tail (d,n) neutrons up to 55 MeV, the deuteron beams also activate the surrounding materials of the test facility. To perform activation calculations[2)] for radiation safety, it is necessary to measure the radioisotope production cross sections for deuteron induced reactions. Accordingly, a deuteron induced reaction sublibrary was added to the latest version of the Fusion Evaluated Nuclear Data Library (FENDL-3.0)[3)]. Deuteron-induced reactions could also be useful for efficient radioisotope production. For various applications, we have started the measurements of radioisotope production cross sections for various deuteron-induced reactions by the AVF cyclotron of the RIKEN RIBF.

Radioisotope production cross sections for charged-particle induced reactions are often measured through monitor reactions. Recommended cross sections of various monitor reactions are distributed from the IAEA Nuclear Data Section[4,5)], and we have also adopted their recommended ^{27}Al(d,x)^{24}Na and $^{\mathrm{nat}}$Ti(d,x)^{48}V cross sections in our experimental studies[6,7)].

In addition to the best estimate of the cross sections, their uncertainties also become important for modern applications of nuclear reaction cross sections. This point has been stressed on for many decades for low energy neutron-induced reaction applications in relation to critical and radiation safety, and experimentalists are urged to perform error propagation and its documentation properly[8)]. This is also a common issue for people who report charged-particle induced reaction cross sections for applications. The recommended cross section for the monitor reaction is a major source of the correlated uncertainty in various experimental works, and its uncertainty must be well-known prior to the error propagation. For the standard neutron-induced reactions like ^{235}U(n,f), IAEA standard cross sections are provided with their uncertainties and covariance matrices[9)]. However, we currently assume an uncertainty of 5% in the IAEA recommended cross sections in its error propagation to our measured cross sections because their uncertainties are not provided. This issue is currently being discussed in an IAEA Coordinated Research Project[10)]. However, we decided to determine the uncertainties in the monitor reaction cross sections by ourselves for more appropriate error propagation in our future deuteron-induced isotope production cross section experiments. The purpose of this work is to determine the cross sections and their uncertainties for three monitor reactions ^{27}Al(d,x)^{24}Na, $^{\mathrm{nat}}$Ti(d,x)^{48}V, and $^{\mathrm{nat}}$Cu(d,x)^{65}Zn by using the stacked target activation technique.

A target stack consisting of Al foils (25 μm and 50 μm thick), Ti foils (20 μm thick), and Cu foils (12.5 μm and 25 μm thick) was prepared and irradiated by a deuteron beam (about 200 nA) extracted from the AVF cyclotron of the RIKEN RIBF for two hours. In order to determine the cross sections without reference cross sections for the monitor reactions, we provided an electric current of exactly 200 nA to the target holder and measured the electric current by a current integrator. We have confirmed that the current integrator may be calibrated by a very small correction factor (about 0.995). After the irradiation, the target stack was dissembled, and the gamma activity measurement was started 4.25 hours after the end of irradiation by using a germanium detector calibrated by a multiple gamma ray emitting point source covering the gamma energy range between 60 and 1836 keV. The off-line measurement is ongoing, and we plan to report the cross sections with well-determined uncertainties for the three monitor reactions (^{27}Al(d,x)^{24}Na, $^{\mathrm{nat}}$Ti(d,x)^{48}V, $^{\mathrm{nat}}$Cu(d,x)^{65}Zn) as well as other useful reactions like $^{\mathrm{nat}}$Cu(d,x)^{64}Cu for positron-emitter production application.

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