Thick-target transmission method for excitation functions of interaction cross sections†

M. Aikawa,[*1,*2] S. Ebata,[*1]and S. Imai[*3]

Nuclear transmutation is one of the promising technologies to dispose of nuclear waste with high-level radioactivity, such as long-lived fission products (LLFP). Although the nuclear data of transmutation reactions for LLFP are essential to develop the technology, the data are scarce in the present database because the experiments are restricted by the radioactivity and chemical instability of LLFP. To avoid these restrictions experiments in inverse kinematics are available for charged-particle-induced data. Indeed, the cross section data of nuclear waste composed of ^{90}Sr and ^{137}Cs have recently been measured at RIBF.[1)]

The excitation function of the interaction cross sections $\sigma_{\rm I}$, leads to the thick-target yields of LLFP transmutation. To measure $\sigma_{\rm I}(\varepsilon)$, we propose the thick-target transmission (T3) method, which extends the conventional transmission method to that with a thick target. In the T3 method, the target also plays the role of energy moderator and its thickness corresponds to the energy degradation $I(0)$ decreases to $I(x)$ after passing through a target with the thickness x. By using the attenuation ratios $I(x)/I(0)$ and $I'(x{+}\Delta x)/I'(0)$ of different runs, the $\sigma_{\rm I}(x)$ is derived as

$$\sigma_{\rm I}(x) = -\frac{1}{n_T \Delta x} \ln \left[\frac{I'(x+\Delta x)}{I'(0)} \frac{I(0)}{I(x)} \right], \qquad (1)$$

where n_T is the number density of target (cm^{-3}). When the LLFP beam is applied in the T3 method, $\sigma_{\rm I}(x)$ is the transmutation cross section.

To obtain $\sigma_{\rm I}(\varepsilon)$ by the conventional transmission method, it is necessary to change the beam energy for each cross section $\sigma_{\rm I}(\varepsilon)$. The T3 method is likely applicable with less efforts to stack a foil on the target than to change the beam energy.

To test the usefulness of the T3 method, we performed a simulation on the interaction cross sections for the ^{12}C-induced reaction on ^{27}Al with the Monte Carlo simulation code PHITS.[2)]In the simulation, the incident energy of the ^{12}C beam is set to 100 MeV/nucleon, which is stopped at approximately 1.23 cm from the surface of an Al target. The target of the maximum thickness consists of 21 foils with a thickness of 0.1 cm from 0.0 cm up to 1.0 cm and of 0.02 cm from 1.0 cm up to 1.22 cm. A beam intensity of 1000 pps and an irradiation time of 100 s are assumed and correspond to a trial number of 10^5 in the PHITS simulation.

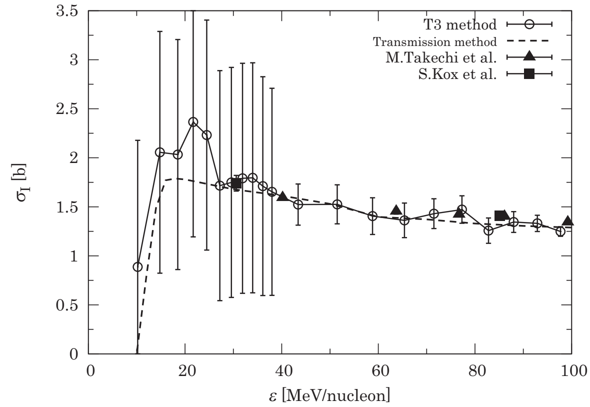

Fig. 1. Interaction cross section $\sigma_{\rm I}(\varepsilon)$ obtained from the T3 method (circles), conventional transmission method (dashed line), and experimental data (triangles and squares).[3,4)]

The results estimated by the T3 method are shown in Fig. 1 by circles. The dashed line is also obtained by the simulation but with the conventional transmission method. The filled symbols indicate the experimental data (triangles and squares).[3,4)] Our results well reproduce the tendency of experimental data, although they have large error bars owing to the low statistics at thin target foils and propagation of statistical uncertainties of $I'(x+dx)$ and $I(x)$. Thus, in spite of the small number of incident particles, such as 10^5, the interaction cross sections can be obtained. We emphasize that the experiments using the T3 method avoid the beam-energy re-adjustments, and time savings might be expected with these experiments.

The T3 method can derive the interaction cross sections through the iterative measurements of the beam attenuation ratio $I(x)/I(0)$. The energy dependence of $\sigma_{\rm I}$ is deduced by changing the target thickness. Our results calculated using PHITS simulation well reproduce the experimental data of the ^{12}C+^{27}Al reaction. The T3 method will contribute to accumulate fundamental data of the transmutation reaction for radiative targets including rare isotopes.

This work was funded by the ImPACT Program of the Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

References

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† Condensed from the article in Nucl. Instr. Meth. **B**383,156(2016)
*1 Faculty of Science, Hokkaido University
*2 RIKEN Nishina Center
*3 Institute for the Advancement of Higher Education, Hokkaido University