Development of a CCONE-based calculation system contributing to the consideration of nuclide production methods

S. Sakai,[*1] H. Otsu,[*1] O. Iwamoto,[*2] N. Iwamoto,[*2] S. Nakayama,[*2] H. Kikunaga,[*3] and T. Fukahori[*1,*2]

The SEKIGUCHI Three-Nucleon Force Project[1)] is developing a system for calculating and illustrating nuclide production cross-sections from various nuclear reactions to contribute to the consideration of nuclide production methods useful in the field of applied science. An overview of this system is given below.

- The projectile (n, p, d, t, ^{3}He, α, and γ), kinetic energy of the projectile (E_{proj}), target (including natural compositions), and nuclide produced can be selected.
- The nuclear reaction model calculation code CCONE[2)] (default calculation) is used for calculating nuclide production cross-sections.
- The CCONE calculated values are converted to the ENDF-6 format[3)] for comparison with existing nuclear data libraries.
- The sum of multiple nuclide production cross-sections (*e.g.*, ^{77}Br+^{77}Kr (decays to ^{77}Br with a half-life of 1.24 hours[4)])) can also be output.

This system can calculate the thick target yield[5)] (TTY), which is the yield for a target of infinite thickness. TTY is calculated by

$$\mathrm{TTY} = \int_0^{E_{\mathrm{proj}}} \frac{\sigma(E)}{S(E)} dE, \tag{1}$$

where $\sigma(E)$ and $S(E)$ represent the nuclide production cross-section and stopping power, respectively. The stopping power is calculated using stopping and range of ions in matter (SRIM).[6)] TTY is only calculated if the projectile is a charged particle. In addition, this system can confirm all residual nuclei that can be produced by a nuclear reaction under the following conditions.

- The maximum nuclide production cross-section exceeds 1 Mb in the CCONE calculation.
- EXFOR[7)] contains experimental values of the nuclide production cross-section.

As an example, this system is applied to ^{211}At, which is in rapidly increasing demand as an α ray emitter for nuclear medicine therapy.[8)] First, the reaction maximizing the ^{211}At production cross-section was confirmed under the following conditions.

- Projectile: n, p, d, α, and γ
- E_{proj}: 1–50 MeV
- Target: natural element target

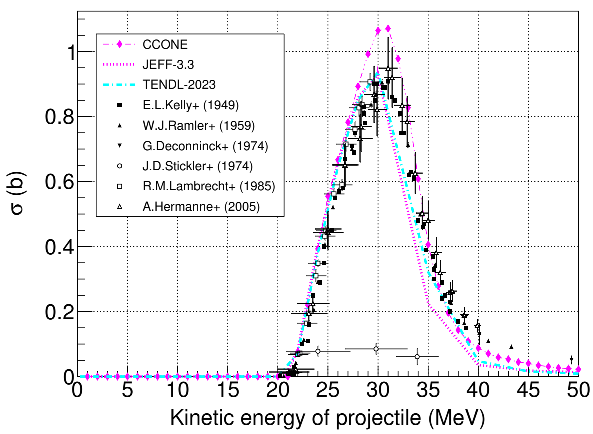

Fig. 1. ^{211}At production cross-section by α + ^{209}Bi. Nuclear data library values are given for reference.[9,10)] Experimental values are indicated by black symbols.

As triton and ^{3}He are practically difficult to use for projectiles, they have been excluded from this calculation. Consequently, the reaction that maximizes the ^{211}At production cross-section is found to be $\alpha + {}^{209}$Bi ($E_{\mathrm{proj}} \sim 31$ MeV). Figure 1 shows the ^{211}At production cross-section by $\alpha + {}^{209}$Bi. In addition, we found that $^{206,\,207,\,208,\,210}$Bi, $^{208–212}$Po, and $^{208,\,209,\,210,\,212}$At can be produced by $\alpha + {}^{209}$Bi other than ^{211}At.

*1 RIKEN Nishina Center
*2 Nuclear Science and Engineering Center, Japan Atomic Energy Agency
*3 Research Center for Electron Photon Science, Tohoku University

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