# Investigation of a new production and separation technique for RI beams at BigRIPS, "In-separator two-step method"

H. Suzuki,[*1] N. Fukuda,[*1] H. Takeda,[*1] Y. Shimizu,[*1] M. Yoshimoto,[*1] K. Yoshida,[*1] Y. Yanagisawa,[*1] and H. Sato[*1]

A new production and separation method of neutron-rich medium-heavy radioactive-isotope (RI) beams "in-separator two-step method" was proposed, and its usefulness was investigated. The beam intensities of such RIs produced by this new method are expected to be higher than those produced by the standard method, in-flight fission of a $^{238}$U beam, when its intensity reaches the goal value of 2000 particle nA in the RIBF upgrade project and RI-beam total rates are limited at 1 kHz by data acquisition (DAQ).

In the standard method, as shown in Fig. 1(a), an objective RI beam (*e.g.*, $^{128}$Pd) is produced by in-flight fission at the F0 Be target. When the magnetic rigidity ($B\rho$) of the first dipole is set at the momentum peak of $^{128}$Pd to maximize its yield, the total rate of the secondary beams becomes too high for DAQ or detectors even with the current $^{238}$U-beam intensity of 80 particle nA. To reduce the total rate below 1 kHz, the $B\rho$ setting should be higher than the momentum peak. The $^{128}$Pd yield decreases with such adjustment; however, the total rates can be decreased more efficiently. When the primary-beam intensity increases in the future, this $B\rho$-setting shift should be larger. Thus, the $^{128}$Pd yield will increase only by a factor of 9, although the $^{238}$U-beam intensity will be 25 times larger than the current.

To produce the RI beams more efficiently within the total-rate limit, the in-separator two-step method was proposed, as shown in Fig. 1(b). The Be target is divided into two at F0 and F2 for the first and second reactions, respectively. In the first step, less-exotic RIs (*e.g.*, $^{133}$Sn and neighboring RIs) relative to the objective RI are produced and roughly separated. In the second step, the objective RI is produced at the secondary target at F2 and separated.

Through a simulation, the $^{128}$Pd yield with the new method is expected to be ∼3 times larger than that obtained using the standard method with a 2000-particle nA $^{238}$U beam and 1-kHz total-rate limit.

A test experiment was performed at BigRIPS. The yield of $^{128}$Pd with the new method was measured with 2- and 3-mm Be targets located at F0 and F2, respectively, and 2- and 4-mm degraders at F1 and F5, respectively. The RI beams along the central trajectories in the first and second stages were $^{133}$Sn and $^{128}$Pd, respectively. The measured $^{128}$P (total) rate was 0.19 Hz (1 kHz) per 2000 particle nA. For comparison, the $^{128}$Pd yield obtained using the standard method was simulated with the LISE$^{++}$ code.[1] A 5-mm F0 Be target, 5-mm F1 degrader, and 1-mm F5 degrader were used. Here, the sums of thicknesses of the targets and degraders were the same in both the methods. The $^{128}$Pd rate was estimated to be 0.074 Hz per 2000 particle nA. From these results, an improved setting with the new method was obtained to produce $^{128}$Pd, under the conditions of the 2000-particle nA $^{238}$U beam and the 1-kHz total-rate limit.

The region in the nuclear chart where the new method is favorable will be searched using the LISE$^{++}$ simulation. However, we have found that some problems should be solved to perform reliable simulations. First, the momentum distribution and yields of fission products from $^{238}$U are not reproduced well. Second, the RI production cross-sections from RI beams are not well known, except for a $^{132}$Sn-beam case.[2] For further investigation, such basic data should be measured experimentally.

References

1) O. B. Tarasov, D. Bazin, LISE$^{++}$ site, `https://lise.nscl.msu.edu/lise.html`.
2) H. Suzuki *et al.*, Phys. Rev. C **102**, 064615 (2020).

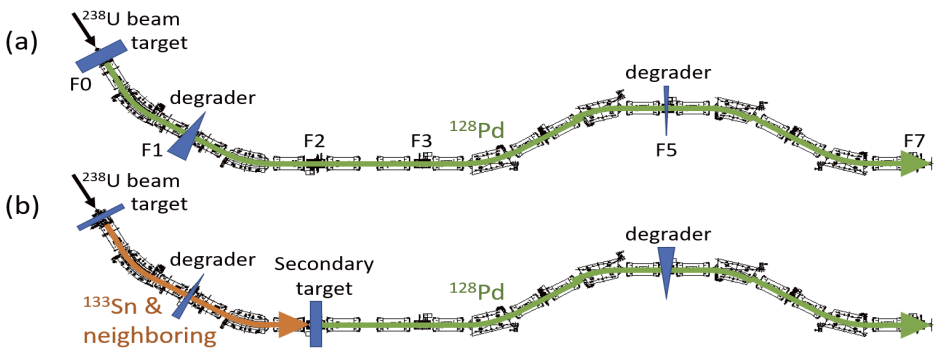


Fig. 1. Schematics of RI-beam productions at BigRIPS. (a) Standard method. An objective RI beam is produced from a $^{238}$U beam in one step. (b) New method, "In-separator two-step method." An objective RI beam is produced via less-exotic RIs with two targets in two steps.

*1 RIKEN Nishina Center