Development of carbon-isotope beams with solid target at CRIB

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The development of exotic carbon beams would enable more advanced studies to be conducted on the physics of light exotic nuclei. The interest in the negative parity states in ^{15,16}C has been recently revived by the observation of narrow resonances in the mirror ^{14}O + p scattering[1)] and in the ^{16}C$(d,t)^{15}$C reaction.[2)] Fusion cross sections involving halo nuclei, such as ^{15}C, have been measured in various systems, but a consistent conclusion regarding the reaction dynamics of halo nuclei near the barrier energy has not yet been obtained.[3)] By developing carbon isotope beams, we would be able to perform studies on these subjects.

In this context, we performed a beam production test with a 2-day beamtime (MS-EXP24-03) in May 2024. The standard RI beam production at CRIB uses a 2-body reaction of a primary-beam ion with a light-ion gas target.[4)] However, ^{15}C cannot be accessed directly by such reactions with any stable-nuclide beams. RI beams could also be produced with a solid target, and in fact, a ^{17}N beam was produced via the ^{18}O + ^{9}Be reaction in earlier studies at CRIB in 2003 and 2004.[5)] As a first step for the present development, we estimated the ^{15}C production rate by the fusion cross section via calculations with the PACE4 code, assuming 2-body kinematics and a nominal angular acceptance of 5.6 msr. We applied normalization (with a factor of 10–100, including the unknown transmission factor) to be able to reproduce the previous ^{17}N beam intensity with the same calculation method, and estimated the maximum ^{15}C rate by the ^{15}N + Be reaction to be 0.2–4.0 × 10^5 pps[a)], at the energy of 6.2 MeV/nucleon.

We tested the beam production by irradiating a ^{15}N primary beam onto a solid Be target. Particle identification (Fig. 1) confirmed production of secondary beams in the mass region of $A = 11$–16. We performed a magnetic-rigidity (Bρ) scan around the expected ^{14}C/^{15}C energy; however, we could not confirm production of ^{15}C. The $A = 15$ spot in the figure may have consisted of ^{15}C^{6+} and ^{15}N^{6+}, but by measurments of the energy loss in the materials at F2, it was shown that its dominant component was ^{15}N^{6+}, and that the production rate of ^{15}C would be 10^3 pps or smaller, even with the full-intensity (1 particle μA) primary beam.

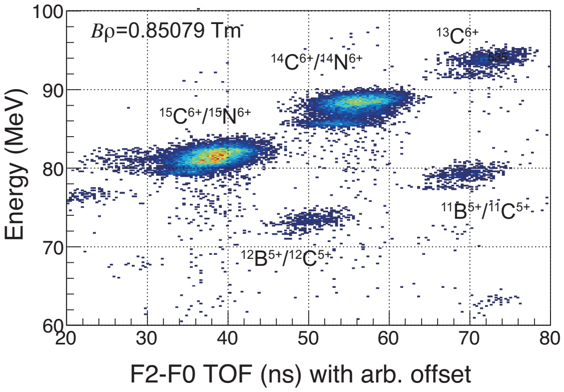

Fig. 1. Particle identification of secondary beams at F2, where particles with the same mass and charge are not separated. Each spot may appear as two components having slightly different energies, which is supposed to be an artifact of the detector response.

One possible explanation for the absence of ^{15}C is that the optimum Bρ for ^{15}C^{6+} was exceedingly close to that of ^{15}N^{6+}, where the scan was prohibited by the intense primary-beam component. Another possibility is that it is an indication of the significance of the direct reaction mechanism. ^{15}N at the ground state has an isospin $T = 1/2$, whereas ^{15}C has $T = 3/2$. It follows that the direct ^{15}N$(^{9}$Be$,^{9}$B$)^{15}$C reaction would not be a suitable reaction to change the isospin by $\Delta T = 1$. Our rate estimation was based on the fusion reaction, but if the direct mechanism was more essential, the yield could be much lower, as in the present work.

With regard to the ^{14}C, the beam production was optimized at 6.4 MeV/nucleon, corresponding to $B\rho$ = 0.87197 Tm. With the primary ^{15}N beam current of 1 particle μA and a Be target thickness of 3.3 mg/cm^2, we obtained a ^{14}C beam at 1.2 × 10^5 pps with a purity of 82% at F3. This was the first time ever that a ^{14}C beam was produced at CRIB at an optimized condition, which would be useful for future experiments.

References

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[a)] The difference in the values is due to the variation between the two earlier studies.

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