First production of ^{6}He beam at CRIB

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^{6}He is the second lightest unstable nuclide that could be used as a radioactive-isotope (RI) beam. In 2021, we performed a production test of ^{6}He beam at CRIB[1–4] for the first time, aiming to assess the feasibility of future experiments using this RI beam. The beam production was performed as a Machine Study beamtime in March, 2021. The primary beam was ^{7}Li^{3+}, accelerated with the AVF cyclotron up to an energy of 8.3 MeV/nucleon. The maximum beam current at the entrance of CRIB during the beamtime was 3 particle μA (= 9 electric μA (eμA)). The RI beam was produced with the ^{7}Li(d, ^{3}He)^{6}He reaction, which was also used in other in-flight facilities, such as RESOLUT of Florida State University.[5] At RESOLUT, a ^{6}He beam was produced with an energy range of 18–29 MeV (3–5 MeV/nucleon), an intensity of 10^4 pps, and a purity of 40%. The target gas we used at CRIB was D_2 at 730 Torr, confined in a cell, and cooled with the cryogenic gas target system.[3]

We tested the beam production at two magnetic rigidity conditions: 1) $B\rho$ = 1.227 Tm (^{6}He^{2+}: 7.99 MeV/nucleon) with the original primary beam, and 2) $B\rho$ = 1.032 Tm (^{6}He^{2+}: 5.66 MeV/nucleon) by degrading the primary beam energy to 6.5 MeV/nucleon with a 48-μm-thick Havar foil. Particle identification (PI) was performed by measuring the time-of-flight and energy of the secondary beam with the PPACs and silicon detectors at the F2 and F3 focal planes. The identified particles are ^{6}He^{2+}, ^{3}H^{1+}, and a small number of ^{7}Li^{2+}.

After the optimization at F2 to maximize the ^{6}He beam intensity, the beam was transported to F3 with a transmission efficiency of 28%. ^{7}Li^{2+} disappeared from the PI diagram, while ^{3}H^{1+} remained due to its charge-to-mass ratio identical to ^{6}He. Table 1 summarizes the purities of secondary beam particles in each condition. The purity of ^{3}H^{1+} appeared to be higher at F3 compared to F2, however, this is supposed to be from the limited detection efficiency of the PPAC, which triggered the measurement at F2, against the light ^{3}H^{1+} ion. The ^{6}He energy after one PPAC (thickness equivalent to 9.5 μm Mylar) was measured as (47.80 ± 0.44) MeV or (7.943 ± 0.073) MeV/nucleon, where the energy loss in the PPAC (0.29 MeV) was in a good agreement with a calculated value (0.28 MeV).

We increased the primary beam current to confirm the highest intensity ^{6}He beam we can obtain. The ^{6}He rate increased almost proportional to the primary beam current with a ratio of 370 kcps/μA. The detection efficiency of the PPAC was 70–80% or better, when the secondary beam rate was 300–400 kcps. The intensity test was performed up to the primary beam current of 2 electric μA (eμA), at which the PPAC efficiency dropped down to 42% for the secondary-beam intensity of 630 kcps, even though we applied the possible maximum voltages on the PPAC electrodes.

The beam production test in the low-energy condition was performed basically in the same procedure as the high-energy case. Due to the contamination ions of ^{7}Li^{3+} and ^{4}He^{2+}, we had a lower ^{6}He purity of about 60%, as shown in Table 1.

In conclusion, we succeeded in producing ^{6}He RI beams at 7.99 MeV/nucleon and 5.66 MeV/nucleon with an intensity of the order of 10^5 pps, superior to the beam at RESOLUT,[5] satisfying the requirement by the proposed ^{6}He+p experiment.[6] The practical beam intensity is presently limited to about 2×10^5 pps by the low detection efficiency of the PPAC for such a light-ion beam. To make the efficiency higher, we are planning to use wire chambers (MWDC) in the main experiment.

Table 1. Summary of the secondary beam purity. Note that the F2 data were taken with the PPAC trigger, and F3 were with the SSD.

Ion	High $B\rho$ (1.227 Tm)		Low $B\rho$ (1.032 Tm)	
	F2	F3	F2	F3
^{6}He^{2+}	85%	73%	60%	61%
^{3}H^{1+}	15%	27%	17%	23%
^{7}Li^{2+}	0.2%	–	22%*	5.9%
^{4}He^{2+}	–	–		9.7%

* Summed purity of ^{7}Li^{2+} and ^{4}He^{2+}.

References
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