Development of ^{216}Th and ^{220}Th beams at the BigRIPS separator

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We report the status of the development of ^{216}Th and ^{220}Th beams that are to be used in the recently proposed nuclear-reaction experiment at SAMURAI. The goal of this development is to determine the BigRIPS separator settings that completely meet the requirements for the beams used in the experiment.

The Th (^{216}Th or ^{220}Th) beam is produced by means of the projectile fragmentation of a 345 MeV/nucleon ^{238}U beam and separated using the BigRIPS separator. The essential requirements for the beam are as follows:

(1) Th-beam rate $\geq 10^4$ Hz
(2) Total beam rate at BigRIPS-F7 $\leq 5 \times 10^4$ Hz
(3) Beam energy $\geq$250 MeV/nucleon

In order to meet the requirments of (1) and (2) simultaneously, the purity of the Th beam must be 20% or heigher. Meanwhile, to achieve a higher beam energy (requirement (3)), the thicknesses of the production target and degrader must be small, which could result in insufficient isotope separation and thereby make it difficult to obtain high purity. Another concern is the particle identification (PID) of heavy fragments. In BigRIPS, in-flight PID based on the TOF-$B\rho$-ΔE method[1] has successfully been performed for heavy fragments with $Z = 82$–90 and beam energies of approximately 200 MeV/nucleon.[2] However, for fragments with higher beam energy ($\geq$250 MeV/nucleon in the present case), PID might be more difficult because of the deterioration in Z resolution caused by possible energy-loss straggling due to charge-state fluctuations.[3]

A test of the Th-beam production was conducted as a machine study (MS-EXP20-02) in November 2020. In consideration of the limited beam time of 12 h, we focused on the evaluation of PID performance and the investigation of contaminants. The RI beams around ^{220}Th were produced by the projectile fragmentation of a ^{238}U beam impinging on a 1-mm-thick beryllium target. The setting of the BigRIPS separator was nearly optimized for the production of a ^{220}Th beam, in which the magnetic rigidity $B\rho$ values at D1, D2, and the second stage (D3–D6) of BigRIPS were tuned for He-like, H-like, and He-like ^{220}Th ions, respectively, to remove huge contaminants from large fission-fragment yields. A 1-mm-thick aluminum degrader was installed at F5, while there was no suitable (sufficiently thin) degrader installed at F1. Instead, the parallel-plate avalanche (PPAC) detector at F1 served as a charge-exchange foil to reduce the amount of contaminants.

Figure 1 shows the Z vs. A/Q PID plot for fragments produced (a) without and (b) with the F5 degrader. The A/Q values of the fragments were deduced under the assumption that the charge states of the ions did not change at F5. The relative A/Q resolution is evaluated to be 0.08% in 1σ. No significant amounts of contaminants were observed in either setting. In the presence of the F5 degrader, fragments in the region of $Z = 85$–95 were extracted as intended, showing that a thickness of 1 mm is sufficient for the aluminum degrader. The expected location of ^{220}Th^{88+} is indicated by the red solid circle, in which no blobs of isotopes are found in each setting. This is probably because most of the ions transmitted to F7 changed their charge state at F5, and consequently, their A/Q values could not be deduced correctly under the present assumption. Therefore, charge-state identification based on accurate $B\rho$ analysis is required to achieve correct PID. It should also be noted that the relative Z resolution is as poor as 0.69% (1σ). Elaborate data analysis is currently in progress.

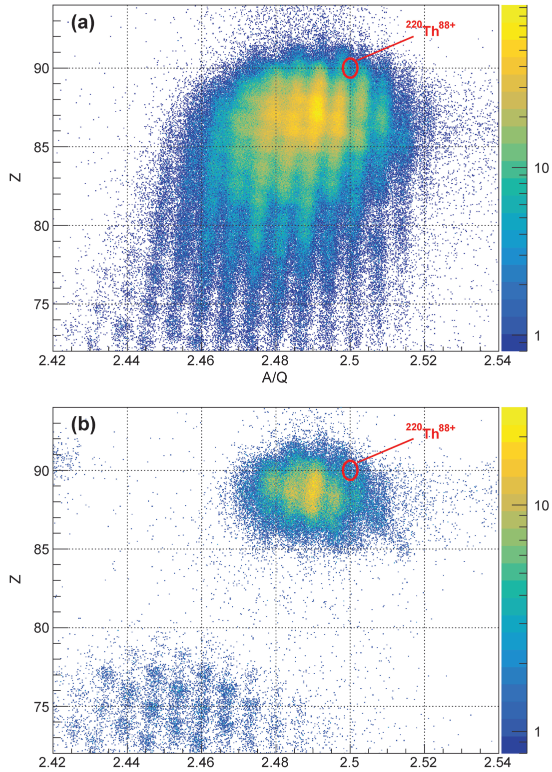

Fig. 1. Particle identification plot of Z vs. A/Q for fragments produced in the ^{238}U+Be reaction a) without energy degraders and b) with an energy degrader (1-mm-thick Al) was used at F5. The red solid circle indicates the expected location of ^{220}Th^{88+} ($A/Q = 2.5$, $Z = 90$).

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References

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