Acceleration test of ^{235}U

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Transmutation of long-lived fission products included in the radioactive waste into short-lived or stable nuclei is one of the fundamental issues for future nuclear energy. In order to design a reasonable process for transmutation, fundamental data on nuclear reactions, such as the neutron capture cross section over a wide energy range, are crucial. Acceleration of such radioactive nuclei would help in obtaining the fundamental data through nuclear reaction studies using radioactive beams.

The biggest obstacle in the acceleration of such nuclei is their high radioactivity, which limits the available amount of radioactive material in an ion source. The solution to this problem is to mix a very small amount (several tenths of micrograms) with the usual ion source materials, and accelerate them by pilot-beam acceleration. In this machine study, the feasibility of pilot-beam acceleration was investigated for ^{235}U, which is included in natural uranium (natural abundance of 0.7204%), using ^{238}U as the pilot beam. As shown in Fig. 1, the ^{235}U isotope is present in such minute quantities that it is impossible to be identified by the analyzing system of the RIKEN 28-GHz Superconducting Electron Cyclotron Resonance Ion Source (28-GHz SC-ECRIS).[1)]

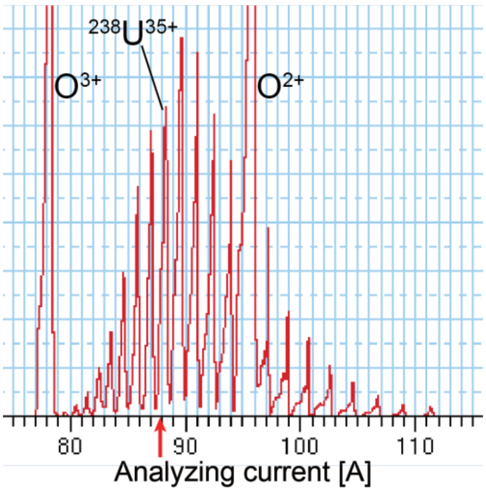

Fig. 1. Charge distribution of the uranium ions with a slit aperture of ±0.1 mm. ^{235}U ions are expected to appear at the position indicated by the red arrow, but they cannot be identified.

As the first step of the machine study, the $^{238}U^{35+}$ beam, which was used as a pilot beam, was extracted from the RIKEN Ring Cyclotron (RRC).[2)] Next, the aperture of the slit installed at the exit of the 28-GHz SC-ECRIS (SL-U10) was decreased, and the excitation current of the analyzing magnet of the 28-GHz SC-ECRIS was swept. Then, a small peak speculated to be due to $^{235}U^{35+}$ was identified by the profile monitor installed at downstream of SL-U10 (PF-U10b). The extraction voltage of the 28-GHz SC-ECRIS and acceleration voltage of the RIKEN Linear Accelerator 2 (RILAC2)[3)] were multiplied by 235/238 to extract and accelerate the particles comprising the peak. The $^{235}U^{35+}$ beam was successfully observed downstream of the RILAC2 (B61).

Since the $^{235}U^{35+}$ beam with an intensity of several electric nA was observed with the main differential probe (MDP) moved to the injection region, we tried to accelerate $^{235}U^{35+}$ by tuning only the phase of RF and the excitation current of the main coils of the RRC, while keeping the signal of the MDP as constant as possible. However, because of our insufficient tuning skill, it was difficult to go beyond the radii of 2 m; hence, we gave up this acceleration procedure.

Therefore, the SL-U10 was fully opened. A beam intensity of about 100 electric nA was observed with the MDP, which was enough to obtain the signal from the phase probe (PP). By tuning the isochronism, we achieved acceleration of the $^{235}U^{35+}$ beam in the RRC. The turn pattern of the circulating $^{235}U^{35+}$ beam measured by the MDP is shown in Fig. 2. The extraction efficiency was about 75%.

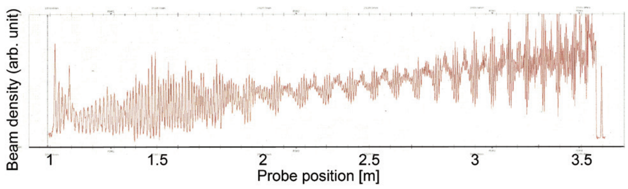

Fig. 2. Turn pattern of the circulating $^{235}U^{35+}$ beam in the RRC.

Besides our insufficient operational ability, the difficulty in the acceleration test mentioned above stemmed from the fundamental fact that isochronism cannot be achieved by changing only the main coil current. The magnetic field calculation revealed that several trim-coil currents should be changed over a wide range to accommodate the mass difference of more than 1% of the uranium ions. In our subsequent study, we plan to accelerate $^{234}U^{35+}$ by using $^{235}U^{35+}$ as the pilot beam, based on an accurate magnetic field calculation.

References
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