Development of a production technology of ^{211}At at the RIKEN AVF cyclotron: (i) Production of ^{211}At from the ^{209}Bi(α,2n)^{211}At reaction

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Astatine-211 (^{211}At, $T_{1/2}$ = 7.214 h) is one of the promising radionuclides for the α-particle therapy of diseases. The 5.9- and 7.5-MeV α-particle emissions occur with intensities of 42% and 58%, respectively, associated with the ^{211}At decay.[1)] Owing to the proper ranges of these α-particles in tissue (60–80 μm), the ^{211}At-labeled medicine is effective in killing focus cells. For the pre-clinical and clinical trials, a large amount of ^{211}At-labeled compounds is needed.

We have started to produce ^{211}At from the ^{209}Bi(α,2n)^{211}At reaction at the RIKEN AVF cyclotron and to distribute it to researchers in universities and institutes in Japan. Figure 1 shows the irradiation system for the ^{211}At production. An 18-μm beryllium window was placed to separate the vacuum beam line and the He-filled ^{211}At production chamber. A metallic ^{209}Bi target (chemical purity: >99.999%, typical thickness: 20 mg/cm^2) was prepared by vacuum evaporation onto an Al backing plate of 1-mm thickness. The Bi target was placed at an angle of 15° with respect to the beam axis. A 29.36-MeV α beam was delivered from the AVF cyclotron; the beam energy on the center of the target surface was calculated to be 28.4 MeV with the SRIM-2013 program.[2)] To obtain ^{211}At with a high radionuclidic purity, the α-beam energy was controlled at 28–29 MeV to prevent the production of ^{210}At ($T_{1/2}$ = 8.1 h), which decays to a highly toxic α emitter ^{210}Po ($T_{1/2}$ = 138 d); the threshold energy for the ^{209}Bi(α,3n)^{210}At reaction is 28.6 MeV. Thus, electrostatic pickups were used for an accurate evaluation of the beam energy.[3)] The target was cooled with circulating water (1.5 L/min) and He gas (30 L/min) during the irradiation. A beam wobbler system was used to rotate the beam spot on the target and to prevent heat concentration. The Bi targets were irradiated for 20–30 min at beam intensities between 1 and 10 particle μA. After the irradiation, the targets were subjected to γ-ray spectrometry with a Ge detector.

Figure 2 shows the thick-target yield of ^{211}At as a function of the α-beam energy on the target. Our experimental data almost agree with the IAEA recommended values.[4)] The deduced yield of ^{211}At was 7.2 ± 0.5 GBq/C at 28.4 MeV, which was nearly constant upto 10 particle μA. According to this work, about 500 MBq of ^{211}At could be obtained under 10 particle μA irradiation for 1 h. The atomic ratio of ^{210}At/^{211}At at the end of bombardment (EOB) was estimated to be $< 1 \times 10^{-5}$, which satisfied the medical requirement of $< 1 \times 10^{-3}$ at EOB.[5)] After the irradiation, ^{211}At was purified by a dry distillation method, which is reported in our succeeding paper.[6)]

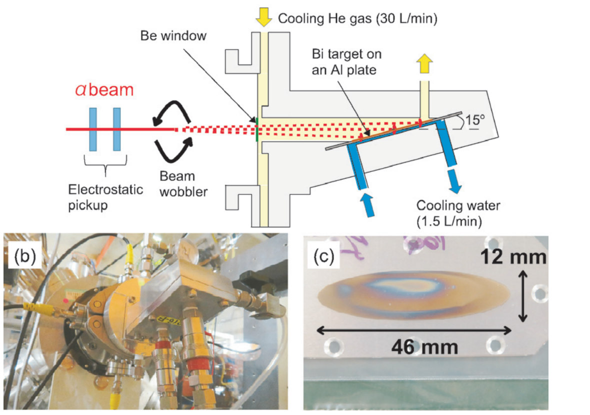

Fig. 1. (a) Schematic view of the irradiation system. (b) Photograph of the ^{211}At production chamber. (c) Vacuum-evaporated Bi target on an Al plate (after irradiation).

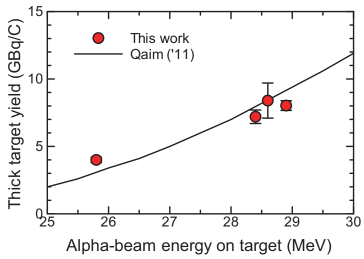

Fig. 2. Thick target yield of ^{211}At as a function of α-beam energy. The solid curve indicates the IAEA recommended value.[4)]

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