Present status of ^{211}At production at the RIKEN AVF cyclotron

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^{211}At is one of the most promising radionuclides for targeted alpha radiotherapy owing to its suitable half-life of $T_{1/2} = 7.214$ h and high alpha-particle emission probability of 100%.[1] We have been producing ^{211}At via the ^{209}Bi$(\alpha, 2n)^{211}$At reaction at the RIKEN AVF cyclotron.[2,3] In this paper, we report improved production technologies of ^{211}At, which could reduce the separation time from 2 h to 1 h and yield a neutral dry ^{211}At product instead of the confused ^{211}At species in the solution.

Figure 1 shows the production process for dry ^{211}At. A metallic ^{209}Bi target (> 99.999%, 20 mg/cm^2) was prepared through vacuum evaporation on an Al plate (thickness: 1 mm). As shown in Fig. 1(a), the Bi target was placed at an angle of 15° with respect to the beam axis. The target was cooled with water (10°C, 1.5 L/min) and He gas (30 L/min) during the irradiation. An alpha beam with an energy of 29.0 ± 0.2 MeV was delivered from the RIKEN AVF cyclotron. The precise beam energy was measured using a time-of-flight detector.[4] A beam-wobbling system was used to rotate the beam spot on the target and to prevent heat concentration. After the beam passed through a Be window (18.1 μm) and He cooling gas (65 mm, 1.1 bar), the beam energy on the target was 28.0 ± 0.2 MeV, as calculated with LISE (ver. 11.0.72). The beam intensity (4–32 μA) and irradiation time (2 to 8 h) was varied to meet the users' requirements. Subsequently, ^{211}At was separated from the Bi target by using a dry distillation technique (see Fig. 1(b)). The irradiated Bi target was placed on a copper tray in a quartz tube and heated up to 850°C in 10 min, following which it was kept for another 15 min and finally cooled down naturally. ^{211}At sublimated from the target was transported from the quartz tube through a quartz capillary (*i.d.* = 2 mm, length = 13 cm) to a PFA cold trap (*i.d.* = 1 mm, length = 100 cm) by oxygen gas (10 mL/min). The PFA cold trap was cooled to −96°C to collect the gaseous ^{211}At. As shown in Fig. 1(c), after the distillation, the capillary and the PFA trap tube were washed with chloroform (FUJIFILM Wako Pure Chemical Corporation, Cat. No.: 033-15721, Infinity Pure, 200–400 μL). The eluate collected in a 1-mL V-shaped glass vial was then dried up by dry N_2 gas (100 mL/min) at room temperature (see Fig. 1(d)). The chemical yields of the dry ^{211}At products were determined by measuring the 687 keV γ-ray ($I_\gamma = 0.261\%$) with a Ge detector. The chemical purity of the products and the decontamination factor of ^{209}Bi from ^{211}At were evaluated with chemical analysis using inductively coupled plasma mass spectrometry (ICP-MS).

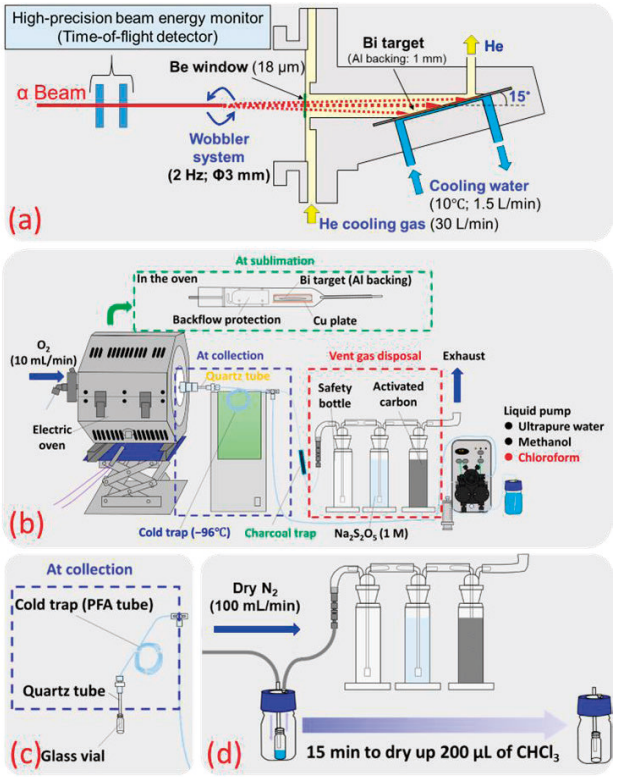

Fig. 1. Production process of dry ^{211}At.

We confirmed that the radioactivities of ^{211}At produced in the targets agreed well with those estimated from thick target yields in the literature.[5] The atomic ratio ^{210}At/^{211}At was determined to be less than 2.1×10^{-6} at the end of bombardment (EOB), which satisfied the medical requirement of $< 1 \times 10^{-3}$ at EOB.[4] The typical chemical yield was 80%. The chemical impurities (> 1 ng) in 200 μL of chloroform were Cu (43.84 ng), Al (38.90 ng), Zn (23.55 ng), and Bi (6.70 ng). The decontamination factor of ^{209}Bi for dry ^{211}At was determined to be 8.3×10^{-8}.

By using the current production technology of ^{211}At, 1 GBq of ^{211}At can be produced through 1.5-h irradiation with a 32-μA alpha beam (27.8 MeV on target). Dry ^{211}At can be prepared 4 h after EOB. We have been distributing ^{211}At to 14 users in Japan for the research and development of nuclear medicine.

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References

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