Production cross sections of ^{211}Rn *via* ^{7}Li-induced reaction on ^{209}Bi

N. Ukon,[*1,*2] K. Washiyama,[*1] M. Aikawa,[*3,*2] G. Damdinsuren,[*4,*2] S. Ebata,[*5,*2] and H. Haba[*2]

Astatine-211 possesses a half-life of 7.214 h and is a promising radionuclide for targeted α-particle therapy.[1] ^{211}Rn ($T_{1/2}$ = 14.6 h) is the longer-lived parent nuclide of ^{211}At and is expected for a ^{211}Rn/^{211}At generator.[2] One possible reaction to produce ^{211}Rn is Li-induced reactions on the mononuclidic element ^{209}Bi. Thus, we focused on the ^{7}Li-induced reaction on ^{209}Bi. Based on our survey, three experimental studies were found, and their data were scattered.[2–4] Therefore, we conducted experiments on the ^{209}Bi(^{7}Li, $5n$)^{211}Rn reaction to measure cross sections and thick target yield.

We conducted three experiments, *i.e.*, two for excitation functions and one for the thick target yield, using 72-MeV ^{7}Li beams at the RIKEN AVF cyclotron. γ-ray spectrometry was used to identify radioactive products. The stacked-foil activation technique was employed to measure the excitation functions.

To measure the excitation functions (#1 and #2), independent stacked targets were prepared. For the targets, small pieces of Bi (purity: 99.999%) and three Al foils (purity: >99%, thickness: 10, 18, and 5 μm, size: 100 × 100 mm) were purchased from Nilaco Corp., Japan. The 10-μm and 18-μm Al foils were used as backing foils for targets #1 and #2, respectively, and the 5-μm Al foil was used to cover the deposited Bi layer. The lateral size and weight of the Al foils were measured, and their average thicknesses of the 10-, 18- and 5-μm Al foils were 2.17, 4.79, and 1.21 mg/cm^2, respectively. The Al backing foils were cut into a size of 25 × 25 mm for the vacuum evaporation method. The Bi pieces were evaporated and deposited on a circular area with a diameter of 20 mm of the Al backing foils. The weight of the Al backing foils before and after the deposit process were measured, and the thicknesses of the Bi layers ranged from 5.46 to 10.9 mg/cm^2. The Bi layers on the Al backing and cover foils were cut into a size of 8 × 8 mm to fit target holders served as Faraday cups. Two stacked targets comprised 20 sets of Al(5 μm)/Bi/Al(10 μm) for target #1 and 16 sets of Al(5 μm)/Bi/Al(18 μm) for target #2.

To measure the thick target yield (#3), a Bi sheet (purity: 99.999%, thick: 1 mm, size: 25 × 25 mm, Goodfellow Co., Ltd., UK) was used. The Bi sheet and 5-μm Al cover foil were cut into a size of 10 × 10 mm to fit another target holder.

Targets #1, #2, and #3 were irradiated with the ^{7}Li beams for 60, 57, and 20 min, respectively. The average beam intensities measured using the Faraday cups were 147 (#1), 147 (#2), and 142 nA (#3). The beam energy common in the three experiments was 71.9 MeV. The energy degradation in the targets was calculated using stopping powers obtained from the SRIM code.[5] Target #3 was sufficiently thick to stop the beam.

γ rays emitted from the irradiated foils and sheet were measured using a high-purity germanium detector with different cooling times ranging from 1.0 h to 33 d.

The production cross sections of ^{211}Rn ($T_{1/2}$ = 14.6 h) were determined using the γ line at 674.1 keV (I_γ = 45.4%). The γ line overlapped with others at 672.82 keV (I_γ = 3.27%) from ^{209}At ($T_{1/2}$ = 28.5 min) and 675.15 keV (I_γ = 6.8%) from ^{207}At ($T_{1/2}$ = 1.80 h). The measurements with cooling times of 1.4–2.3 d were adopted to neglect the contributions of the γ lines from the shorter-lived co-products.

The preliminary results with the previously studied experimental data[2–4] are shown in Fig. 1. The results obtained from targets #1 and #2 are slightly scattered but consistent. The peak amplitudes of the previously studied experimental data are lower than those of the data of this study.

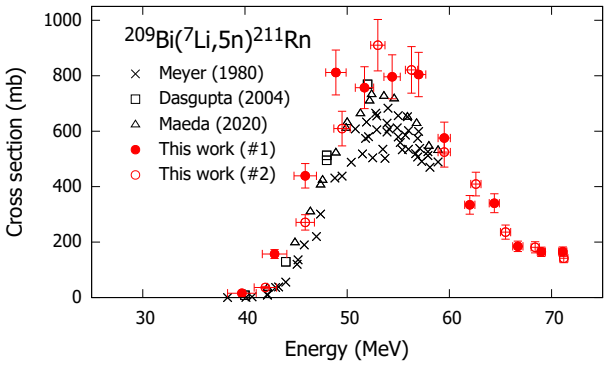

Fig. 1. Measured cross sections of the ^{209}Bi(^{7}Li, $5n$)^{211}Rn reaction with the literature data.[2–4]

Hereafter, we will determine the production cross sections of ^{211}Rn. The thick target yield will be calculated using the measured cross sections and compared with the experimental result.

*1 Advanced Clinical Research Center, Fukushima Medical University
*2 RIKEN Nishina Center
*3 Faculty of Science, Hokkaido University
*4 Graduate School of Biomedical Science and Engineering, Hokkaido University
*5 Graduate School of Science and Engineering, Saitama University

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