Study on background suppression of charged particles 
using GARIS-II filled with He-H\textsubscript{2} mixture

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The performance of a gas-filled recoil ion separator (GARIS-II) has been evaluated using various asymmetric fusion reactions\textsuperscript{1-3}. The feasibility of a high transmission under a low-background condition is a key issue for superheavy elements (SHEs) produced with a low cross section of pb-order. In previous work\textsuperscript{1,3}, it was found that GARIS-II filled with a He-H\textsubscript{2} mixture as a filled gas is promising to suppress background particles. To aid future study of SHEs, the usefulness of a He-H\textsubscript{2} mixture was investigated further in this work. As a typical example, the results for \textsuperscript{218,217}Pa, which were produced via the reaction of \textsuperscript{197}Au(\textsuperscript{24}Mg,xn) [x=3,4], are given here.

The products of \textsuperscript{218,217}Pa were separated in-flight from projectiles and other by-products using the GARIS-II, and then they were guided into a double sided silicon detector after passing through a time-of-flight detector. The separator was filled with a He-H\textsubscript{2} mixture with various \textsuperscript{2}H mixing ratios (0, 10, 20, and 30\%). The gas pressure was maintained at 53 Pa. Recently, a new gas-mixing system, shown in Fig. 1, was developed as the previous system used a commercial gas with fixed mixing ratio. This system enables the mixing ratio to be tuned under constant pressure. The system was well calibrated by a gas analyzer.

The reaction products of \textsuperscript{218,217}Pa, which were assigned to \textalpha-transitions of 9.616 and 8.337 MeV with half-lives of 113 μs and 3.8 ms respectively as shown in Fig. 2, were measured by varying the fraction of \textsuperscript{2}H composition from 0 to 30\%. The reaction products of \textsuperscript{217,218}Pa including long-lived isotopes of \textsuperscript{215,214}Ac are clearly identifiable with an increasing mixing ratio. The values of the equilibrium charge state \textseven, which are deduced from the optimum magnetic rigidity \textit{Bp} values, are plotted against the \textsuperscript{2}H composition in Fig. 3. The \textseven in pure \textsuperscript{2}H\textsubscript{2} is estimated to be 3.80 using empirical systematics, obtained using a Dubna gas-filled recoil separator DGFRS\textsuperscript{4}. Interpolated values of \textseven between 4.47 and 3.80 in the case of pure \textsuperscript{2}He and \textsuperscript{2}H\textsubscript{2} are indicated as a broken line in Fig. 3. It seems that the measured \textseven values agree well with the linear interpolation of the DGFRS.

![Fig. 1. New gas control system for GARIS-II filled with He-H\textsubscript{2} mixture.](image)

![Fig. 2. Two-dimensional scatter plots, obtained by a time-position correlation analysis, of decay time against decay energy. Fractions of \textsuperscript{2}H\textsubscript{2} composition are (a) 0\%, (b) 10\%, and (c) 30\%.](image)

![Fig. 3. Equilibrium charge state of \textsuperscript{217}Pa ions moving in a He-H\textsubscript{2} mixture. The broken line is the linear interpolation between the experimentally obtained \textseven of 4.47 and the estimated \textseven of 3.80 from the DGFRS's work\textsuperscript{4}.](image)

References
2) D. Kaji et al., RIKEN Accel. Prog. Rep 47, 213 (2014).
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