We developed a new gas-filled recoil ion separator (GARIS-II) to study asymmetric actinide-target based fusion reactions\(^1\). As the first step, we measured the solid angle of the separator offline using a standard \(\alpha\)-source of \(^{241}\)Am, and it was determined to be 18.2 msr\(^1\). As the second step, we performed online testing to evaluate the separation capability of GARIS-II from background particles, and its transmission using \(^{40}\)Ar-induced fusion reactions. These reaction products were collected onto a focal plane detection (FPD) system with high efficiency under extremely low background conditions\(^2\).

As the third step of commissioning #3, we performed online operating tests on GARIS-II using \(^{22}\)Ne-induced fusion reactions of \(^{197}\)Au, \(^{205}\)Tl, \(^{208}\)Pb, \(^{209}\)Bi, \(^{232}\)Th, and \(^{238}\)U. The reaction products were separated in-flight from projectiles and other by-products using GARIS-II, and then they were guided into the FPD system after passing through the time-of-flight detector\(^3\). The separator was filled with He gas at the pressure of 10, 33, 80, and 173 Pa. For further background rejection using GARIS-II, we tested He-H\(_2\) mixture as the filled gas at the same gas pressure. Figure 1(A) shows the intensity distribution of \(^{215}\)Ac, which is produced via the \(^{197}\)Au\(^{(22}\)Ne,4n\) reaction, at FPD in the case of filling at 33 Pa He gas and 33 Pa He-H\(_2\) mixture (He:H\(_2\)=2:1). The optimum \(B\rho\) was shifted up to 11\% and the transmission was increased from 11.4\% to 14.6\%. The \(B\rho\) shift implies that the average equilibrium charge state of recoil ions moving in a filled gas becomes small. The improvement of transmission is due to a decrease in the multiple scattering between the recoil ion and filled gas atom. Figure 1(B,C) shows a comparison of background (BG) level at each peak of the recoil ion and filled gas atom. Figure 1(B,C) shows the intensity distribution between the He and the He-H\(_2\) mixture. The BG level was significantly changed, and the beam-like particles were strongly suppressed.

As the fourth step of commissioning #4, we performed online operating tests on GARIS-II using \(^{48}\)Ca-induced fusion reactions of \(^{208}\)Pb \(\rightarrow\) \(^{208}\)Pb. We measured an excitation function of \(^{208}\)Pb\(^{(48}\)Ca,2n\)\(^{204}\)No and the transmission of GARIS-II for \(^{254}\)No. The maximum transmission was 73\% assuming \(\sigma = 2.05\ \mu \text{b}\)\(^3\) when the separator was filled with He gas at a pressure of 73 Pa, and the magnetic rigidity \(B\rho\) was set to 2.064 Tm. The maximum transmission of GARIS-II is two times higher than that of GARIS, which is 36\%. Further, it is better than design value of 61\% for GARIS-II. Transmission data are summarized in Fig. 2.

![Image](image.jpg)

**Fig. 1.** (A) Intensity distribution of \(^{215}\)Ac at FPD. (B, C) Two-dimensional views of energy measured by Si detector vs. recoil velocity measured using the timing counter.

![Image](image2.jpg)

**Fig. 2.** Transmission curve. Velocity regions of interest for the reactions of both cold fusion and hot fusion are given by the blue and red stripes, respectively. \(\bigcirc, \nabla: \text{GARIS}, \times: \text{GARIS-II}\). Solid and dashed curves are estimated by considering multiple scattering with the filled gas for GARIS and GARIS-II, respectively.

### References