

Production of new neutron-rich isotopes near the $N = 60$ isotones ^{92}Ge and ^{93}As by in-flight fission of a 345 MeV/nucleon ^{238}U beam[†]

Y. Shimizu,^{*1} T. Kubo,^{*1} T. Sumikama,^{*1} N. Fukuda,^{*1} H. Takeda,^{*1} H. Suzuki,^{*1} D. S. Ahn,^{*1} N. Inabe,^{*1} K. Kusaka,^{*1} M. Ohtake,^{*1} Y. Yanagisawa,^{*1} K. Yoshida,^{*1} Y. Ichikawa,^{*1} T. Isobe,^{*1} H. Otsu,^{*1} H. Sato,^{*1} T. Sonoda,^{*1} D. Murai,^{*2} N. Iwasa,^{*3} N. Imai,^{*4} Y. Hirayama,^{*5} S. C. Jeong,^{*5} S. Kimura,^{*5} H. Miyatake,^{*5} M. Mukai,^{*5} D. G. Kim,^{*6} E. Kim,^{*6} and A. Yagi^{*7}

The production of very neutron-rich isotopes in the region with atomic numbers $Z \approx 32\text{--}33$ and neutron number $N \approx 60$ was investigated using the in-flight fission of a ^{238}U beam, in which we searched for new isotopes near the $N = 60$ isotones ^{92}Ge ($Z = 32$) and ^{93}As ($Z = 33$). Neutron-rich nuclei with $Z = 34\text{--}42$ are known to exhibit a sudden shape change at $N \approx 60$ as N increases (sudden onset of nuclear deformation). The present work was aimed at expanding the frontiers of accessible nuclei in such an interesting region.

The experiment was performed with a $^{238}\text{U}^{86+}$ beam at 345 MeV/nucleon. A 4-mm-thick beryllium target was used. Fission fragments emitted from the target were separated and identified in flight using the large-acceptance two-stage separator BigRIPS.¹⁾ Aluminum energy degraders were placed at the first and second stages of the BigRIPS separator for isotope separation. The ^{238}U beam intensity was typically ≈ 11 particle nA on target.

The particle identification (PID) was performed in the second stage of the BigRIPS separator by measuring the time of flight (TOF), magnetic rigidity ($B\rho$), and energy loss (ΔE), from which the mass-to-charge ratio A/Q and Z values of the fragments were derived.²⁾ The TOF was measured between two thin plastic scintillators placed at the entrance (F3) and exit (F7) foci of the second stage. The $B\rho$ was determined via the trajectory reconstruction method using the positions and angles measured at the F3, intermediate (F5), and F7 foci with parallel plate avalanche counters, which allowed a high-resolution $B\rho$ measurement. The $B\rho$ was determined in both the first (F3 to F5 foci) and second (F5 to F7 foci) halves of the second stage. These TOF and $B\rho$ measurements allowed us to derive the fragment velocity before and after the energy degrader placed at the F5 focus. The ΔE was measured at the F7 focus using a multi-sampling ionization chamber.

The A/Q and Z values were calculated from the $B\rho$, fragment velocity, and ΔE , after which a Z versus A/Q

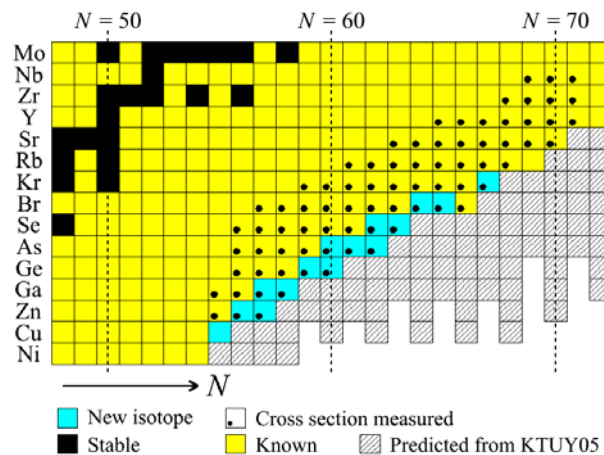


Fig. 1. Section of nuclear chart showing 15 new isotopes discovered and isotopes whose cross sections were measured in this work. Hatched squares indicate unknown isotopes whose existence was predicted from the KTUY05 mass formula.

plot was made for the PID. Furthermore, an independent measurement of Z , called Z_{F5} , was derived from the energy loss in the F5 degrader, which was calculated from the $B\rho$ and velocity values before and after the degrader. The Z_{F5} was used to remove background events through a Z versus Z_{F5} correlation plot. Background events were also removed by investigating various correlations of detector pulse-height and time signals, beam phase space, and ion trajectory. The PID was verified and calibrated using the isomer tagging method, in which delayed γ rays emitted from known microsecond isomers among the fragments were measured at the F7 focus using germanium detectors.

The achieved PID resolution and background removal allowed us to discover a total of 15 new neutron-rich isotopes: ^{84}Cu , $^{86,87}\text{Zn}$, $^{88,89}\text{Ga}$, $^{91,92}\text{Ge}$, $^{93,94,95}\text{As}$, $^{96,97}\text{Se}$, $^{99,100}\text{Br}$, and ^{103}Kr , and measure cross sections for isotope production, as shown in Fig. 1. The total irradiation time was 97.2 hours. The frontiers of known isotopes were significantly expanded, including ^{92}Ge and ^{93}As with $N = 60$. Experimental studies of the properties of these $N = 60$ nuclei and their neighbors will be an important future challenge. The measured production cross sections were compared with predictions from abrasion fission model calculations with the LISE⁺⁺ code,³⁾ and overall a fairly good agreement was obtained.

[†] Condensed from the article in Phys. Rev. C **109**, 044313 (2024) DOI: 10.1103/PhysRevC.109.044313

^{*1} RIKEN Nishina Center

^{*2} Department of Physics, Rikkyo University

^{*3} Department of Physics, Tohoku University

^{*4} Center for Nuclear Study, University of Tokyo

^{*5} Wako Nuclear Science Center (WNSC), IPNS, KEK

^{*6} RISP, Institute for Basic Science (IBS)

^{*7} Department of Physics, Osaka University

References

- 1) T. Kubo, Nucl. Instrum. Methods Phys. Res. B **204**, 97 (2003).
- 2) N. Fukuda *et al.*, Nucl. Instrum. Methods Phys. Res. B **317**, 323 (2013).
- 3) O. B. Tarasov, D. Bazin, Nucl. Instrum. Methods Phys. Res. B **266**, 4657 (2008).