Nuclear Science and Transmutation Research Division
Superheavy Element Research Group
Superheavy Element Production Team

1. Abstract

The elements with atomic number $Z \geq 104$ are called as trans-actinide or superheavy elements (SHEs). Superheavy Element Production Team synthesizes SHE nuclei including new elements and investigates synthesis mechanisms of SHE nuclei, nuclear properties of SHE nuclei, and chemical properties of SHEs in collaboration with Superheavy Element Devise Development Team and Nuclear Chemistry Research Team of RIKEN Nishina Center.

2. Major Research Subjects

(1) Search for new superheavy elements
(2) Decay spectroscopy of the heaviest nuclei
(3) Study of reaction mechanisms for production of the heaviest nuclei
(4) Study of chemical properties of the heaviest elements

3. Summary of Research Activity

(1) Search for new superheavy elements

In November 2016, the 7th period of the periodic table was completed with the official approval of four new elements, nihonium (Nh, $Z = 113$), moscovium (Mc, $Z = 115$), tennessine (Ts, $Z = 117$), and oganesson (Og, $Z = 118$) by International Union of Pure and Applied Chemistry. We have started to search for new elements to expand the chart of the nuclides toward to the island of stability and the periodic table of the elements toward the 8th period. In January 2020, RIKEN heavy-ion Linear ACcelerator (RILAC) was upgraded as Superconducting RIKEN heavy-ion Linear ACcelerator (SRILAC). We installed the new gas-filled recoil ion separator GARIS-III on the beam line of SRILAC. In June–July 2020, we conducted the commissioning of SRILAC and GARIS-III using the ^{169}Tm + ^{40}Ar, ^{208}Pb + ^{40}Ar, and ^{208}Pb + ^{51}V reactions. Since October 2020, we have been conducting a synthesis experiment of isotopes of new element 119 in the ^{248}Cm + ^{51}V reaction under the nSHE collaboration.

(2) Study of reaction mechanisms for production of the heaviest nuclei

SHE nuclei have been produced by complete fusion reactions of two heavy nuclei. However, the reaction mechanism of the fusion process is still not well understood both theoretically and experimentally. In 2022, the quasielastic barrier distribution of the ^{51}V + ^{248}Cm reaction was extracted by measuring the excitation function of quasielastic backscattering using GARIS-III at SRILAC. The result was utilized to estimate the optimal incident beam energy for production of isotopes of new element 119 in the ^{248}Cm(^{51}V, xn)$^{299-x}$119 reactions. We also measured the excitation functions for the evaporation residues and the quasielastic scattering of the ^{51}V + ^{159}Tb reaction to deepen our understanding of the ^{51}V-induced reaction on the deformed target.

(3) Study of chemical properties of the heaviest elements

Chemical characterization of newly-discovered SHEs is an extremely interesting and challenging research subject in modern nuclear and radiochemistry. In collaboration with Nuclear Chemistry Research Team of RIKEN Nishina Center, we are developing SHE production systems as well as rapid single-atom chemistry apparatuses for chemistry studies of SHEs. We installed a gas-jet transport system to the focal plane of GARIS at RILAC. This system is a promising approach for exploring new frontiers in SHE chemistry: the background radiations from unwanted products are strongly suppressed, the intense primary heavy-ion beam is absent in the gas-jet chamber, and hence the high gas-jet extraction yield is attained. Furthermore, the beam-free conditions make it possible to investigate new chemical systems. In 2022, we continued to develop an ultra-rapid gas-chromatograph apparatus, which consists of an RF carpet gas cell and a cryo-gas-chromatograph column with a Si detector array, at the focal plane of GARIS for the gas chemistry of SHEs. To realize aqueous chemistry studies of Sg ($Z = 106$) and Bh ($Z = 107$), we have been developing a continuous and rapid solvent extraction apparatus which consists of a continuous dissolution apparatus Membrane DeGasser (MDG), a Flow Solvent Extractor (FSE), and a liquid scintillation detector for α/SF-spectrometry. In collaboration with Osaka University, co-precipitation behavior of No ($Z = 102$) with $BaSO_4$ and CaC_2O_4 was also investigated with ^{255}No produced in the ^{248}Cm(^{12}C, $5n$)^{255}No reaction at the AVF cyclotron.

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List of Publications & Presentations

Publications

[Original Papers]

A. Yakushev, L. Lens, Ch.E. Düllmann, J. Khuyagbaatar, E. Jäger, J. Krier, J. Runke, H. M. Albers, M. Asai, M. Block, J. Despotopulos, A. Di Nitto, K. Eberhardt, U. Forsberg, P. Golubev, M. Götz, S. Götz, H. Haba, L. Harkness-Brennan, R.-D. Herzberg, F. P. Heßberger, D. Hinde, A. Hübner, D. Judson, B. Kindler, Y. Komori, J. Konki, J. V. Kratz, N. Kurz, M. Laatiaoui, S. Lahiri, B. Lommel, M. Maiti, A. Mistry, Ch. Mokry, K. J. Moody, Y. Nagame, J. P. Omtvedt, P. Papadakis, V. Pershina, D. Rudolph, L. G. Samiento, T. K. Sato, M. Schädel, P. Scharrer, B. Schausten, D. A. Shaughnessy, J. Steiner, P. Thörle-Pospiech, A. Toyoshima, N. Trautmann, K. Tsukada, J. Uusitalo, K.-O. Voss, A. Ward, M. Wegrzecki, N. Wiehl, E. Williams, and V. Yakusheva, "On the adsorption and reactivity of element 114, flerovium," Front. Chem. **10**, published online (August 25, 2022). DOI: 10.3389/fchem.2022.976635 .

M. Tanaka, P. Brionnet, M. Du, J. Ezold, K. Felker, B. J. P. Gall, S. Go, R. K. Grzywacz, H. Haba, K. Hagino, S. Hogle, S. Ishizawa, D. Kaji, S. Kimura, T. T. King, Y. Komori, R. K. Lemon, M. G. Leonard, K. Morimoto, K. Morita, D. Nagae, N. Naito, T. Niwase, B. C. Rasco, J. B. Roberto, K. P. Rykaczewski, S. Sakaguchi, H. Sakai, Y. Shigekawa, D. W. Stracener, S. VanCleve, Y. Wang, K. Washiyama, and T. Yokokita, "Probing optimal reaction energy for synthesis of element 119 from ^{51}V + ^{248}Cm reaction with quasielastic barrier distribution measurement," J. Phys. Soc. Jpn. **91**, 084201-1–11 (2022).

A. C. Berriman, D. J. Hinde, D. Y. Jeung, M. Dasgupta, H. Haba, T. Tanaka, K. Banerjee, T. Banerjee, L. T. Bezzina, J. Buete, K. J. Cook, S. Parker-Steele, C. Sengupta, C. Simenel, E. C. Simpson, M. A. Stoyer, B. M. A. Swinton-Bland, and E. Williams, "Energy dependence of p + ^{232}Th fission mass distributions: Mass-asymmetric standard I and standard II modes, and multichance fission," Phys. Rev. C **105**, 064614-1–18 (2022).

H. Sakai, H. Haba, K. Morimoto, and N. Sakamoto, "Facility upgrade for superheavy-element research at RIKEN," Eur. Phys. J. A **58**, 238-1–15 (2022).

[Review Article]

羽場宏光, 「人工元素合成」, 科学 **92**, 846–851 (2022).

[Books]

羽場宏光, 「元素探索と RI 製造」 in 「量子ビーム科学の基礎と応用」, NSA/Commentaries **27**, 一般社団法人日本原子力産業協会 原子力システム研究懇話会, 195 ページ, 2023 年 3 月 24 日, p. 26–39.

桜井弘（編), 荒野泰, 小谷明, 高妻孝光, 佐治英郎, 鈴木晋一郎, 中山祐正, 根矢三郎, 羽場宏光, 廣田俊, 藤井敏司, 「ブルーバックス 元素 118 の新知識 第 2 版」, 講談社, 2023 年 3 月 20 日, p. 560.

[Proceeding]

H. Sakai, H. Haba, K. Morimoto, and N. Sakamoto, "Facility upgrade for SHE research at RIKEN Nishina Center," Acta Phys. Pol. B Proc. Suppl. **16**, 4-A10-1–12 (2023).

Presentations

[International Conferences/Workshops]

H. Haba (invited), "Production and applications of radioisotopes at RIKEN RI Beam Factory—Search for new elements through diagnosis and therapy of cancer—," Laser Solutions for Space and the Earth 2022 in OPTICS & PHOTONICS International Congress 2022 (OPIC 2022), Yokohama, Japan & Online, April 18–22, 2022.

M. Tanaka (invited) for nSHE Collaboration, "Quasielastic backscattering measurement for ^{51}V + ^{248}Cm reaction toward element-119 synthesis at RIKEN," 19th Workshop on Recoil Separator for Superheavy Element Chemistry & Physics (TASCA 22), Darmstadt, Germany & Online, May 10–12, 2022.

H. Haba (invited), "Production and applications of radioisotopes at RIKEN RI Beam Factory—Search for new elements through diagnosis and therapy of cancer—," IAEA/RCA RTC on Good Manufacturing Practice (GMP) and Radiation Safety Aspects of Radiopharmaceutical Production Using Medical Cyclotron, Online, May16–20, 2022.

H. Sakai (invited), H. Haba, K. Morimoto, and N. Sakamoto, "Facility upgrade for SHE research at RIKEN," Zakopane Conference on Nuclear Physics, "Extremes of the Nuclear Landscape," Zakopane, Poland, August 28–September 4, 2022.

M. Tanaka (oral) for nSHE Collaboration, "Optimal energy for element 119 synthesis via ^{51}V + ^{248}Cm reaction probed by quasielastic barrier distribution measurement," Zakopane Conference on Nuclear Physics, "Extremes of the nuclear landscape," Zakopane, Poland, August 28–September 4, 2022.

S. Sakaguchi (poster) and M. Tanaka for nSHE Collaboration, "Probing optimal energy for synthesis of element 119 from ^{51}V+^{248}Cm reaction," The 28th International Nuclear Physics Conference (INPC 2022), Cape Town, South Africa, September 11–16, 2022.

A. Takamine (invited), D. Kaji, H. Haba, M. Wada, P. Schury, H. Koura, H. Wollnik, H. Miyatake, H. Ishiyama, K. Morimoto, M. Rosenbusch, S. Kimura, T. Niwase, Y. Hirayama, Y. Ito, Y. Watanabe, and P. Brionnet, "Multi-reflection time-of-flight mass spectroscopy of superheavy nuclides," 19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS 2022), Daejeon, Korea, October 3–7, 2022.

M. Tanaka (oral), "Optimal reaction energy for synthesis of element 119 via ^{51}V + ^{248}Cm reaction probed by quasielastic barrier distribution measurement," 19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS 2022), Daejeon, Korea, October 3–7, 2022.

P. Brionnet (poster), R. Grzywacz, D. Kaji, T. King, T. Niwase, K. Morimoto, and K. Rykaczewski, "Development and optimization of the digital electronic for the search of new super heavy element at RIKEN on GARIS-III," 19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS 2022), Daejeon, Korea, October 3–7, 2022.

H. Haba (invited), "Production and distribution of radioisotopes at RIKEN RI Beam Factory," PRISMAP Workshop on Emerging Infrastructures and Technical Developments, Padova, Italy & Online, November 21–22, 2022.

H. Haba (invited), "Production of radioisotopes for application studies at RIKEN RI Beam Factory—Search for new elements through diagnosis and therapy of cancer," The Fifth International Conference on Application of RadiotraCers and Energetic Beams in Sciences (ARCEBS 2023), Purulia, India, January 31–February 5, 2023.

[Domestic Conferences/Workshops]

永井歩夢 (口頭発表), 細川浩由, 中島朗久, 坂口綾, 南部明弘, 重河優大, 羽場宏光, 横山明彦, 「^{232}Th + ^{7}Li 核反応によって生成する U 同位体の ICP-MS による定量」, 日本放射化学会第 66 回討論会 (2022), 文京区, 2022 年 9 月 15–17 日.

渡邉瑛介 (口頭発表), 笠松良崇, 横北卓也, 中西諒平, 大髙咲希, 板倉悠大, 益田遼太郎, 王瑞麟, 重河優大, 南部明弘, 殷小杰, 羽場宏光, 高宮幸一, 篠原厚, 「クラウンエーテルを用いた 102 番元素ノーベリウムの硝酸系固液抽出実験」, 日本放射化学会第 66 回討論会 (2022), 文京区, 2022 年 9 月 15–17 日.

中西諒平 (口頭発表), 渡邉瑛介, 大髙咲希, 王瑞麟, 板倉悠大, 速水翔, 羽場宏光, 南部明弘, 篠原厚, 笠松良崇, 「Rf の共沈実験に向けた Zr, Hf, Th のシュウ酸, マロン酸系でのフロー式共沈実験」, 日本放射化学会第 66 回討論会 (2022), 文京区, 2022 年 9 月 15–17 日.

羽場宏光 (依頼講演), 「新元素でがん治療〜理研 RI ビームファクトリーがつくるラジオアイソトープ〜」, 放射線安全フォーラム第 75 回放射線防護研究会, 「短寿命核種の利用の拡大に向けて」, 文京区 & オンライン, 2022 年 10 月 29 日.

山ノ内邑希 (ポスター発表), 坂口聡志, Pierre Brionnet for nSHE Collaboration, 「新元素合成のための最適反応エネルギー推定に向けた ^{51}V + ^{159}Tb 融合反応の励起関数測定」, 日本物理学会 2023 年春季大会, オンライン, 2023 年 3 月 22–25 日.

深津巧光 (ポスター発表), 坂口聡志, Pierre Brionnet for nSHE Collaboration, 「新元素合成のための最適反応エネルギー推定に向けた ^{51}V + ^{159}Tb 融合反応の障壁分布測定 I」, 日本物理学会 2023 年春季大会, オンライン, 2023 年 3 月 22–25 日.

道本優也 (ポスター発表), 坂口聡志, Pierre Brionnet for nSHE Collaboration, 「新元素合成のための最適反応エネルギー推定に向けた ^{51}V + ^{159}Tb 融合反応の障壁分布測定 II」, 日本物理学会 2023 年春季大会, オンライン, 2023 年 3 月 22–25 日.

Outreach Activities

羽場宏光 (依頼講演), 「新元素でがん治療—RIBF がつくるラジオアイソトープ—」, 理研と未来を創る会第 28 回講演会, 和光市, 2022 年 9 月 6 日.

羽場宏光 (依頼講演), 「ニホニウム発見への道のり」, 山梨県立吉田高等学校理研見学会, 和光市, 2022 年 11 月 16 日.