Nuclear Science Research Division
Superheavy Element Research Group

1. Abstract

The elements with atomic number $Z \geq 104$ are called as trans-actinide or superheavy elements (SHEs). Superheavy Element Research Group 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 Group 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

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) Decay spectroscopy of the heaviest nuclei

In collaboration with High Energy Accelerator Research Organization (KEK), mass of neutron-rich isotopes produced via spontaneous fission of ^{252}Cf were measured using a multireflection time-of-flight mass spectrograph. The mass of ^{155}Ce was determined experimentally for the first time. A discrepancy between the experimental and literature values was found for the mass of ^{127}Sb. In comparison with several theoretical predictions, both the values and the trend of the mass excesses of $^{152–155}$Ce could not be consistently explained. The wide-range and simultaneous mass measurements of the multireflection time-of-flight mass spectrograph enabled us to crosscheck the existing mass data, and the conflict between the measured time-of-flight ratio and the extracted mass would imply the necessity of re-examining them.

(3) 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 2024, we investigated the ^{51}V + ^{159}Tb $\rightarrow$ ^{210}Ra* reaction through measurements of both the entrance-channel barrier distribution and detailed excitation functions for the *xn*, *pxn*, and αxn channels over a wide energy range. This research extended systematic studies of reactions involving beams heavier than ^{48}Ca on deformed heavy targets, linking cross section measurements to the side-collision configuration effects observed in superheavy nuclei synthesis. The analysis, interpretation, and comparison with theoretical calculations were performed using the CCFULL code and a statistical model.

(4) 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 Group 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 2024, 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, the solid-liquid extraction of No ($Z = 102$) with the Eichrom Sr resin was conducted using ^{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]

S. Kimura, M. Wada, H. Haba, H. Ishiyama, S. Ishizawa, Y. Ito, T. Niwase, M. Rosenbusch, P. Schury, and A. Takamine, "Comprehensive mass measurement study of ^{252}Cf fission fragments with MRTOF-MS and detailed study of masses of neutron-rich Ce isotopes," Phys. Rev. C **110**, 045810-1–9 (2024).

P. Brionnet, T. Cap, M. Forge, T. Fukatsu, H. Haba, D. Kaji, S. Kimura, K. Morimoto, Y. Michimoto, T. Niwase, M. Tanaka, S. Sakaguchi, H. Sakai, and Y. Yamanouchi, "Investigation of entrance-channel barrier distribution and charged-particle emission in the ^{51}V + ^{159}Tb reaction," Phys. Rev. C **110**, 064601-1–19 (2024).

Y. Shigekawa, A. Yamaguchi, N. Sato, A. Takamine, M. Wada, and H. Haba, "Development of an RF-carpet gas cell coupled to the RIKEN gas-filled recoil ion separator for chemistry of superheavy elements," Nucl. Instrum. Methods Phys. Res. A **1075**, 170421-1–13 (2025).

[Review Articles]

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[Proceedings]

H. Sakai and P. Brionnet for the nSHE Research Group, "SHE research at RIKEN Nishina Center," Acta Phys. Pol. B Proc. Suppl. **17**, (2024), 3-A21-1–11.

R. Koyama, T. Watanabe, H. Haba, and A. Kamoshida, "Application to beam current measurement using electrostatic pickups at RIBF," Proceedings of the 21st Annual Meeting of Particle Accelerator Society of Japan, July 31–August 3, (2024), pp. 89–93.

P. Brionnet, H. Haba, D. Kaji, S. Kimura, K. Morimoto, T. Niwase, S. Sakaguchi, and H. Sakai, "Reaction parameter study of the ^{51}V beam onto deformed targets: ^{51}V + ^{159}Tb reaction," EPJ Web Conf. **322**, (2025), 02006-1–3.

Presentations

[International Conferences/Workshops]

R. Grzywacz (oral) for RIKEN SHE Collaboration, "Report from RIKEN and Oak Ridge National Laboratory," The FRIB-Theory Alliance Topical Program: The Path to Superheavy Isotopes, East Lansing (Michigan State University), Michigan, USA, June 3–7, 2024.

P. Brionnet (poster), D. Kaji, H. Sakai, H. Haba, K. Morimoto, S. Sakaguchi, S. Kimura, and T. Niwase, "Reaction parameter study of the ^{51}V beam onto deformed targets: ^{51}V + ^{159}Tb reaction," The 7th International Workshop on Compound-Nuclear Reactions and Related Topics (CNR*24), Vienna (International Atomic Energy Agency), Austria, July 8–12, 2024.

H. Sakai (poster), P. Brionnet, T. Cap, H. Haba, K. Morimoto, and N. Sakamoto for nSHE Research Group Collaboration, "SHE facility at RIKEN, construction, commissioning and present status," The 7th International Workshop on Compound-Nuclear Reactions and Related Topics (CNR*24), Vienna (International Atomic Energy Agency), Austria, July 8–12, 2024.

H. Haba (invited), "Production and applications of radioisotopes at RIKEN RI Beam Factory—Search for new elements through therapy of cancer—," XIth DAE-BRNS Symposium on Emerging Trends in Separation Science and Technology (SESTEC-2024), Mumbai (HSNC University), India, July 10–13, 2024.

S. Sakaguchi (invited), "Probing optimal energy for synthesis of element 119 from ^{51}V + ^{248}Cm reaction and fusion reaction studies for producing new elements and isotopes," The 14th International Conference on Nucleus Nucleus Collisions (NN2024), Whistler (Whistler Conference Centre), British Columbia, Canada, August 18–23, 2024.

H. Haba (invited), "Present status and perspectives of superheavy element research at RIKEN," International Conference on Shapes and Symmetries in Nuclei: from Experiment to Theory (SSNET'24), Orsay (IJCLab), France, November 4–8, 2024.

H. Haba (invited), "Synthesis of superheavy elements at RIKEN," International Conference "50 Years of Cold Fusion," Yerevan (National Academy of Sciences of the Republic of Armenia and Ramada Hotel & Suites by Wyndham Yerevan), Republic of Armenia, November 20–23, 2024.

Y. Watanabe (oral), S. Michimasa, H. Haba, T. Ohnishi, N. Imai, H. Yamaguchi, and Y. Hirayama, "Diverse RI production techniques at RIBF," Korea-Japan Symposium on TOPTIER Platform in Extreme Rare Isotope Science, Seoul (Seoul National University Hoam Faculty House), South Korea, December 15–17 2024.

[Domestic Conferences/Workshops]

羽場宏光 (依頼講演), 「がんの治療に新元素合成で貢献」, 第 1 回 R-COMS 技術支援ネットワーク・現場の会, 和光市 (理化学研究所), 2024 年 6 月 4–5 日.

羽場宏光 (招待講演), 「がんの治療に新元素合成で貢献」, 第 28 回日本がん分子標的治療学会学術集会, 江東区 (有明セントラルタワーホール&カンファレンス), 2024 年 6 月 19–21 日.

羽場宏光 (依頼講演), 「ラジオアイソトープの製造と応用〜新元素の探索からがん治療まで〜」, 理化学研究所仁科加速器科学研究センター第 3 回原子核研究に関する記者勉強会—宇宙の起源解明から応用研究まで—, 和光市 (理化学研究所), 2024 年 7 月 19 日.

小山亮 (口頭発表), 渡邉環, 鴨志田敦史, 羽場宏光, 「理研 RIBF における静電誘導型ピックアップによるビーム電流測定への応用」, 第 21 回日本加速器学会年会, 山形市 (山形テルサ), 2024 年 7 月 31– 8 月 3 日.

庭瀬暁隆 (口頭発表), 和田道治, Schury Peter, 木村創大, Brionnet Pierre, Chaoyi Fu, 羽場宏光, 平山賀一, 石山博恒, 伊藤由太, 加治大哉, 宮武宇也, 森本幸司, Rosenbusch Marco, 高峰愛子, 渡邉裕, 「MRTOF 質量分光器を用いたイオン計数による蒸発残留核の励起関数測定」, 日本物理学会第 79 回年次大会 (2024 年), 札幌市 (北海道大学札幌キャンパス), 2024 年 9 月 16–19 日.

王瑞麟 (口頭発表), 金子政志, 永田光知郎, 風間裕行, 渡邊瑛介, 横北卓也, 板倉悠大, 紺野未夢, フルトエニー, 柴本恭佑, 橋場奏, 羽場宏光, 重河優大, 南部明弘, 清水弘通, 笠松良崇, 「ジチオリン酸系における 102 番元素ノーベリウムの固液抽出オンライン実験」, 日本放射化学討論会第 68 回討論会 (2024), 静岡市 (グランシップ), 2024 年 9 月 23–25 日.

板倉悠大 (口頭発表), 金子政志, 風間裕行, 永田光知郎, 王瑞麟, 紺野未夢, Khult Enni, 柴本恭佑, 羽場宏光, 金山洋介, 重河優大, 南部明弘, 笠松良崇, 「Rf の化学的性質解明に向けたソフトドナーによる Zr, Hf の溶媒抽出」, 日本放射化学討論会第 68 回討論会 (2024), 静岡市 (グランシップ), 2024 年 9 月 23–25 日.

柴本恭佑 (ポスター発表), 金子政志, 風間裕行, 王瑞麟, Khult Enni, 板倉悠大, 紺野未夢, 重河優大, 殷小杰, 金山洋介, 南部明弘, 羽場宏光, 塚原聡, 笠松良崇, 「Rf の化学研究に向けた DGA を用いた 4 族元素の固液抽出実験及び機械学習手法の応用」, 日本放射化学討論会第 68 回討論会 (2024), 静岡市 (グランシップ), 2024 年 9 月 23–25 日.

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王瑞麟 (ポスター発表), 渡邉瑛介, 紺野未夢, 板倉悠大, フルトエニー, 柴本恭佑, 高宮幸一, 羽場宏光, 重河優大, 南部明弘, 金山洋介, 金子政志, 風間裕行, 永田光知郎, 笠松良崇, 「102 番元素ノーベリウムの化学研究に向けた二族元素のジチオリン酸/Sr レジン系固液抽出実験」, 第 59 回京都大学複合原子力科学研究所学術講演会, 熊取町 (京都大学複合原子力科学研究所) & ハイブリッド, 2025 年 1 月 30–31 日.

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E. Khult (oral), M. Kaneko, H. Kazama, R. Wang, K. Shibamoto, M. Konno, Y. Itakura, R. Kikuchi, K. Mori, K. Kawamoto, H. Haba, A. Nambu, K. Takamiya, M. Inagaki, and Y. Kasamatsu, "Solid-liquid extraction of group 2 elements with DGA-resin towards the chemical study of element 102, nobelium," 日本化学会第 105 春季年会 (2025), 吹田市 (関西大学千里山キャンパス), 2025 年 3 月 26–29 日.

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会, 和光市 (理化学研究所), 2024 年 10 月 5 日.
羽場宏光 (招待講演),「ニホニウム発見への道のり」, 茨城県立並木中等教育学校理化学研究所見学会, 和光市 (理化学研究所), 2024 年 10 月 8 日.
『科学者に聞いてみよう「ニホニウムってなんだ！？」〜誕生 20 周年記念講演会〜』開催, 和光市 (理化学研究所), 2024 年 11 月 3 日.
森田浩介,「ニホニウムってなんだ！？」, 科学者に聞いてみよう 「ニホニウムってなんだ！？」 〜誕生 20 周年記念講演会〜, 和光市 (理化学研究所), 2024 年 11 月 3 日.
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