Partner Institution
Wako Nuclear Science Center, IPNS (Institute of Particle and Nuclear Studies)
KEK (High Energy Accelerator Research Organization)

1. Abstract

The Wako Nuclear Science Center (WNSC) of KEK aims to promote low-energy nuclear physics and nuclear astrophysics research and interdisciplinary studies using short-lived radioactive nuclei. WNSC operates the KEK Isotope Separation System (KISS), an electro-magnetic isotope separator featuring elemental selectivity from resonance laser ionization in a gas catcher. The KISS facility provides various neutron-rich nuclei via multinucleon transfer reactions. Of particular significance is its provision of nuclei in the vicinity of the neutron magic number $N = 126$. Optical and β-γ spectroscopy have been applied to these neutron-rich nuclear beams for nuclear structure and nuclear astrophysical studies. In addition, several new developments—a rotating target, a donut-shaped gas cell, and an in-jet laser ionization scheme—have been performed to improve the performance of the KISS facility. The WNSC has also developed multi-reflection time of flight mass spectrographs (MRTOF-MS) for precision mass measurements of short-lived nuclei in collaboration with the RIKEN SLOWRI team and the Institute of Basic Science (IBS), Korea. After successful mass measurements combined with the GARIS-II at RILAC, the existing MRTOF-MS setup has been renewed for use with the GARIS-II relocated after the ring cyclotron for high precision mass measurements of superheavy nuclides. Furthermore, additional MRTOF-MS setups have been placed at KISS and F11 of the ZeroDegree Spectrometer for comprehensive mass measurement.

The Wako Nuclear Science Center (WNSC) of KEK aims to promote low-energy nuclear physics and nuclear astrophysics research as well as interdisciplinary studies using short-lived radioactive nuclei. WNSC operates the KEK Isotope Separation System (KISS) which is an electro-magnetic isotope separator featuring elemental selectivity from the use of resonance laser ionization in a gas catcher. The KISS facility provides various neutron-rich nuclei via multinucleon transfer reactions. Of particular significance is its provision of nuclei in the vicinity of the neutron magic number $N = 126$. Optical and β-γ spectroscopy have been applied to these neutron-rich nuclear beams, for nuclear structure and nuclear astrophysical studies. Several new developments—a rotating target, a donut-shaped gas cell, and in-jet laser ionization scheme—have been performed to improve the performance of KISS facility. The WNSC has also developed multi-reflection time of flight mass spectrographs (MRTOF-MS) for precision mass measurements of short-lived nuclei in collaboration with the RIKEN SLOWRI team and the Institute of Basic Science (IBS), Korea. After successful mass measurements in combination with the GARIS-II at RILAC, the existing MRTOF-MS setup has been renewed for use with the GARIS-II relocated after the ring cyclotron for high precision mass measurements of superheavy nuclides, and additional MRTOF-MS setups have been placed at KISS and at F11 of the ZeroDegree Spectrometer for comprehensive mass measurements of more than one thousand nuclides.

2. Major Research Subjects

(1) Production and manipulation of radioactive isotope beams for nuclear experiments.
(2) Explosive nucleosynthesis (r- and rp-process).
(3) Heavy ion reaction mechanism for producing heavy neutron-rich nuclei.
(4) Development of MRTOF mass spectrographs for short-lived nuclei.
(5) Comprehensive mass measurements of short-lived nuclei including superheavy elements.
(6) Development of KISS-II.

3. Summary of Research Activity

The Wako Nuclear Science Center (WNSC) provides low-energy short-lived radioactive ion beams to researchers from universities using the KEK isotope separator system (KISS). Research activities in RIKEN RIBF were restricted due to the COVID-19 pandemic for more than half of the JFY2020. During the governmental "stay home" period, the WNSC researchers worked on writing research papers and technical development at home. Five physics papers were published for the experiments conducted at KISS, including two experiments right before a national state of emergency was declared. A press release was announced on one of the experiments to advertise the KISS uniqueness that can provide low-energy neutron-rich isotopes of refractory elements. These nuclides are essential ones for the study of the origin of gold in the universe.

In late September, a part of the activities was restarted at the laboratory. Modification of the KISS beamline has started to perform decay spectroscopy of pure isobaric or isomeric nuclides by placing the detector array behind a multi-reflection time-of-flight (MRTOF) mass spectrograph. When the modification is completed in JFY2021, simultaneous spectroscopy of multiple species will be realized thanks to the spectrographic future of the MRTOF device and a gamma-ToF detector that is under development.

The WNSC is conducting a campaign of comprehensive mass measurements of all available nuclides at RIKEN RIBF in collaboration with RIKEN's SLOWRI team. A new combined gas cell and MRTOF device were installed in front of the beam dump of the BigRIPS in-flight fragmentation separator. A series of online commissioning experiments were conducted using parasitic beams of the in-beam gamma-ray spectroscopy experiments (HiCARI campaign) in November–December 2020. The energetic radioactive ion beams passing through the upstream experiments' target were guided to the gas cell and converted to trapped ions for precision mass measurements using the MRTOF mass spectrograph.

The total system efficiencies were studied with various elements. While some species were diverse across molecular sidebands (*e.g.*, ScOH), more than 1% efficiencies were obtained for heavier nuclides (*e.g.*, Te and Sb). In sum, the commissioning campaign was highly successful, with more than 70 atomic masses measured with the parasitic beams. The masses of three nuclides (88As,

89As, 112Mo) have been measured for the first time, and eleven other nuclear masses improve the present uncertainty significantly.

The WNSC plans to extend the present KISS facility to investigate the nuclides in the neutron-rich region of uranium using the multi-neutron transfer reactions of actinide targets to study the origin of uranium. The primary studies of the future facility are in progress.

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List of Publications & Presentations

Publications

[Original Papers]

H. Watanabe, Y. X. Watanabe, Y. Hirayama, A. N. Andreyev, T. Hashimoto, F. G. Kondev, G. J. Lane, Yu.A. Litvinov, J. J. Liu, H. Miyatake, J. Y. Moon, A. I. Morales, M. Mukai, S. Nishimura, T. Niwase, M. Rosenbusch, P. Schury, Y. Shi, M. Wada, and P. M. Walker, "Beta decay of the axially asymmetric ground state of ^{192}Re," Phys. Lett. B, **814**, 136088 (2021).

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H. Choi, Y. Hirayama, S. Choi, T. Hashimoto, S. C. Jeong, H. Miyatake, J. Y. Moon, M. Mukai, T. Niwase, M. Oyaizu, M. Rosenbusch, P. Schury, A. Taniguchi, Y. X. Watanabe, and M. Wada, "In-gas-cell laser ionization spectroscopy of ^{194,196}Os isotopes by using a multireflection time-of-flight mass spectrograph," Phys. Rev. C **102**, 034309 (2020).

A. V. Chudinov, M. Rosenbusch, V. I. Kozlovskiy, V. V. Raznikov, P. Schury, M. Wada, and H. Wollnik, "Model independent peak fitting and uncertainty assignment for high-precision time-of-flight mass spectrometry," Analyst **145**, 3401–3406 (2020).

Y. X. Watanabe, M. Ahmed, Y. Hirayama, M. Mukai, J. H. Park, P. Schury, Y. Kakiguchi, S. Kimura, A. Ozawa, M. Oyaizu, M. Wada, and H. Miyatake, "Deexcitation γ-ray transitions from the long-lived $I^{\pi} = 13/2^{+}$ metastable state in ^{195}Os," Phys. Rev. C **101**, 041305(R) (2020).

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Presentations

[International Conferences/Workshops]

Michiharu Wada (invited), "MRTOF development and status @ RIKEN-RIBF," NUSTAR Annual Meeting, Online, February 24, 2021.

[Domestic Conferences/Workshops]

Marco Rosenbusch (口頭発表), "New mass measurements of exotic nuclides by the first MRTOF setup at BigRIPS/RIKEN," 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

飯村俊 (口頭発表), 「理研 BigRIPS SLOWRI における RF カーペットガスセルの開発—オンライン実験と質量測定—」, 日本物学会第 76 回年次大会, オンライン開催, 2021 年 3 月 12–15 日.

渡邉裕 (招待講演), 「KISS, MRTOF を用いた核分光実験の現状」, 令和 2 年度専門研究会「短寿命 RI を用いた核分光と核物性研究 VII」, オンライン開催, 2021 年 1 月 15 日.

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Toshitaka Niwase (口頭発表), "First direct mass measurement of superheavy nuclide via MRTOF-MS +α-TOF," KEK Student Day, Online, November 17, 2020.

和田道治 (招待講演), 「何故, 如何に原子質量を測るのか?」, 日本物理学会 2020 年秋季大会, オンライン開催, 2020 年 9 月 14–17 日.

渡邉寛 (口頭発表), 「非軸対称変形核 ^{192}Re の基底状態からのベータ崩壊」, 日本物理学会 2020 年秋季大会, オンライン開催, 2020 年 9 月 14–17 日.

飯村俊 (口頭発表), 「理研 BigRIPS SLOWRI における RF カーペットガスセルの開発」, 日本物理学会 2020 年秋季大会, オンライン開催, 2020 年 9 月 14–17 日.

[Seminars]

Peter Schury (invited), "Use of multi-reflection time-of-flight mass spectrometry to study SHE," Virtual SHE seminars, Online, January 12, 2021.

Press Releases

「中性子過剰なタンタル核異性体で探る原子核形状の多様性—原子核構造の研究から重元素合成の起源天体解明に迫る—」, 2020 年 11 月 11 日. https://www.kek.jp/ja/press/ipns_pr20201111-2/.