Accelerator Applications Research Division
Nuclear Transmutation Data Group

1. Abstract

The Nuclear Transmutation Data Group, which had been established in 2014, was reformed in 2023. The Group was orginally designed to conduct a part of the ImPACT project entitled "Reduction and Resource Recycling of High-level Radioactive Waste through Nuclear Transmutation." In the project, nuclear reaction data for Long-lived Fission Products (LLFP) were systematically obtained via inverse kinematics with radioactive isotope beams delivered at the RIBF facility. The data obtained were utilized to construct a new nuclear reaction database of JAEA "JENDLE/ImPACT-2018." In parallel, experiments of muon capture reaction for LLFP's were conducted at RCNP Osaka University, RAL and J-PARC.

After the ImPACT project finished in 2019, the Group continues to provide the nuclear reaction data to solve the raioactive waste problem as well as to meet other nuclear engineering needs and social demands.

2. Major Research Subjects

(1) Study of nuclear reactions via inverse kinematics with long-lived nuclear beams at RIBF and development of its applications.
(2) Study of muon capture reaction and development of its applications.
(3) Development of new radioactive isotope beams and of new methods in reaction studies.

3. Summary of Research Activity

(1) Nuclear data with fast radioactive isotope beams

The ImPACT project boosted up reaction study with LLFP's and physics runs for study of spallation reaction were successfully organized at RIBF in 2015–2017. The reaction data obtained with both fast and energy-degraded beams at RIBF encouraged the nuclear data group of JAEA, and a new database called "JENDLE/ImPACT-2018" has been released. The new database has been generated by a newly developed reaction model "DEURACS" which treats deuteron-induced reactions. DEURACS reproduces very well cross section data, and much better than other reaction models. A simulation code "PHITS" has been re-coordinated to use the database information.

Our activity has been demonstrated and recognized internationally. In December 2018, Hideaki Otsu, was invited to join Technical Meeting of IAEA, "Novel Multidisciplinary Applications with Unstable Ion Beams and Complementary Techniques." In November 2020, Hideaki Otsu organized a domestic conference of "RIKEN Sympoium on Nuclear Data 2020."

At the end of fiscal year 2021, the spallation reaction data with ^{99}Tc beam was obtained and a secondary beam test for ^{237}Np production was conducted. The data analysis is in progress. In the experiment campaing, a new ion-chamber with Xe based gas, which was proposed by the Group, was successfully operated to identify heavy secondary beams.

Two new projects have been discussed with JAEA. One is DPA measurement to develop radiation resistant materials, where heavy ion primary beams such as a uranium beam will be irradiated to give a high LET to the materials. The other is study of the Pb/Bi spallation reactions in inverse kinematics with Pb/Bi beams, of which data is useful in development of Pb/Bi targets for ADS.

Collaboration with the Super-Kamiokande group has been formed to obtain the spallation data for ^{16}O, which is necessary to precisely estimate backgrounds in detecting supernova relic neutrino. Intensive discussions have been made under the collobation including reaction theorists. A reaction workshop dedicated to the neutino-induced nuclear reaction was organized in 2024. An experiment proposal was submitted to the RIBF PAC in 2024, and was approved with rank-A.

The Group has joined JST ERATO "Sekiguchi Three Nuclear Force Project" since October 2023, and has been in charge of the nuclear data applications for society, in collaboation with JAEA nuclear data group.

(2) Muon capture reaction

The muon capture reaction is a unique "tool" for nuclear transmutation and other applications, as well as for study of dynamics in hot nuclei.

In the ImPACT project, the muon capture program started at RCNP, Osaka University in 2016 and the data for Pd isotopes were successfully obtained in 2017–2019 via in-beam method with c.w. beams, and via activation method with pulsed beams at J-PARC and ISIS-RAL/RIKEN facilities. In 2023, the ISIS data was published in Physical Review C. In this work, the in-beam activation method was firstly employed. The reults of he muonic X-ray measurement for the Pd isotopes were published in Physical Review C 2025.

Lifetime of muonic atoms is essenially important in deducing muon capture rate. The isotope depencence of the lifetime muon capture reaction was studied at J-PARC MLF in 2023–2024. The measurement was based on an achievement of detector development for muonic X-ray and de-excitation gamma-ray measurements. A new calibration method and a digital electronics system for Ge detectors were successfully developed and the results were published in PTEP 2023 and in NIM A 2024. The first lifetime paper for ^{27}Al and ^{28,29,30}Si is in press in Physical Review C. In parallel, isotope dependence of final states in the muon capture reaction was studied for ^{27}Al and ^{28,29,30}Si. The results are submitted to Physical Review C.

Muon capture reaction can be uniquely applied to radioactive isotope production. Compared with other reactions, the range of final reaction products in the muon capture is rather limited and their proton numbers are different from those in target. Hence, high specific activity and simple chemical separation treatment are achieved. The applications for production of ^{99m}Tc and ^{225}Ac were discussed in Journal of Radioanalytical and Nuclear Chemistry in 2024.

To create a muon capture database is being proposed by the Group and being discussed with the nuclear data community in Japan. As a new project, a test-experiment to observe muon-induced fission was proposed at TRIUMF and was approved in 2025.

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List of Publications & Presentations

Publications

[Original Papers]

X. H. Sun, H. Wang *et al.*, "Production of neutron-rich nuclei in the vicinity of ^{78}Ni: Fragmentation reactions of unstable ^{81}Ga and ^{82}Ge beams," Phys. Lett. B **858**, 139081 (2024).

Y. Shimizu *et al.*, "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," Phys. Rev. C **109**, 044313 (2024).

T. T. Yeung *et al.*, "First exploration of monopole-driven shell evolution above the $N = 126$ shell closure: New millisecond isomers in ^{213}Tl and ^{215}Tl," Phys. Rev. Lett. **133**, 072501 (2024).

B. Moon *et al.*, "Triaxial deformation of neutron-rich Zr nuclei explored by high-resolution in-beam γ-ray spectroscopy," Phys. Lett. B **858**, 139047 (2024).

E. Querel *et al.*, "Overcoming the probing-depth dilemma in spectroscopic analyses of batteries with muon-induced X-ray emission (MIXE)," J. Mat. Chem. A **13**, 2275 (2025).

L. Antwis *et al.*, "A comparative study of target fabrication strategies for microgram muonic atom spectroscopy," Sci. Rep. **15**, 6939 (2025).

H. Iwamoto, M. Niikura, and R. Mizuno: "Comprehensive Bayesian machine learning approach to estimating the total nuclear capture rate of a negative muon," Phys. Rev. C **111**, 034614 (2025).

T. Y. Saito *et al.*, "Muonic X-Ray measurement for the nuclear charge distribution: The case of stable palladium isotopes," Phys. Rev. C **111**, 034313 (2025).

T. Matsuzaki and H. Sakurai, "^{255}Ac production via ^{226}Ra$(\mu^-, n\nu)^{255}$Fr reaction with ^{226}Ra target," J. Radioanal. Nucl. Chem. **333**, 6047–6056 (2024).

[Proceedings]

M. Niikura *et al.*, "Muon nuclear data," JAEA-Conf. **2024-002**, (2024), p. 29.

R. Mizuno, M. Niikura, T. Matsuzaki, S. Abe, M. Amitani, M. Hashimoto, K. Ishida, S. Kawase, N. Kawamura, F. Minato, D. Nishimura, T. Y. Saito, H. Sakurai, A. Sato, K. Shimomura, P. Strasser, S. Takeshita, M. Tampo, D. Tomono, I. Umegaki, and Y. Yamaguchi, "Search for 2-alpha emission from nuclear muon capture reaction on Ni, Zn and Ca isotopes," KEK-MSL Prog. Rep. 2023, to appear (2025).

Presentations

[International Conferences/Workshops]

M. Niikura (invited), "Measurement of radio-isotope production probability by muon capture using the in-beam activation method," Muon User Meeting 2024, Abingdon, UK, September 5–6, 2024.

S. Sakai (invited), "Inverse-kinematics experiment using oxygen beams at the RIBF: Toward the observation of diffuse supernova neutrino background at the SK-Gd project," Advancing Physics at Next RIBF (ADRIB25), Wako, Japan, January 22–23, 2025.

R. Mizuno (oral), "Study of nuclear reaction using muonic atom," KEK-TRIUMF Scientific Symposium 2025, Tsukuba, Japan, January 29–30 2025.

R. Mizuno (oral), "Muon induced fission experiment using germanium detector array," 8pi Workshop, Osaka, Japan, February 5, 2025.

[Domestic Conferences/Workshops]

大津 秀暁 他 (口頭発表),「関口三体核力プロジェクト（2）応用科学への展開と核データ研究」,「オージェ電子放出核種の生成法の検討に資する計算システムの開発」, 日本原子力学会 2024 年秋の大会, 仙台市（東北大学川内キャンパス）, 2024 年 9 月 11–13 日.

大津 秀暁 (招待講演),「逆運動学法を用いた核分光実験」, シグマ調査専門委員会将来の核データワークショップ「残留核の反跳」, 東京工業大学 (大岡山), 2024 年 8 月 5 日.

新倉潤 (招待講演),「ミューオン核データ」, 日本原子力学会 2024 年春の年会, 東北大学, 2024 年 9 月 11–13 日.

新倉潤 (招待講演),「ミューオン核データと EXFOR」, EXFOR ワークショップ, 京都大学 (熊取), 2024 年 11 月 13 日.

新倉潤 (招待講演),「ミューオン核データの開発」, ミューオン核物理と核データ研究会, 大阪大学核物理研究センター, 2025 年 1 月 16–17 日.

新倉潤 (招待講演),「ミューオン原子核物理」, 第 10 回「極低放射能技術」研究会, 富山大学, 2025 年 3 月 6–8 日.

酒井聖矢 (招待講演),「ERATO プロジェクト」, 第二回瀬戸内ニュートリノ研究会, 小豆郡土庄町（豊島エスポワールパーク）, 2024 年 8 月 22–24 日.

酒井聖矢 他 (口頭発表),「関口三体核力プロジェクト (3) オージェ電子放出核種の生成法の検討に資する計算システムの開発」, 日本原子力学会 2024 年秋の大会, 仙台市（東北大学川内キャンパス）, 2024 年 9 月 11–13 日.

酒井聖矢 他 (ポスター発表),「オージェ電子放出核種の生成法の検討に資する計算システムの開発」, 2024 年度核データ研究会, 熊取町（熊取交流センター すまいるズ 煉瓦館）, 2024 年 11 月 14–15 日.

酒井聖矢 他 (口頭発表),「CCONE ベースの計算システムを用いた医療用 RI に関する核データの現状把握」, 令和 6 年度北関東支部 若手研究者・技術者発表会, 東海村（東海村産業・情報プラザ（iVil））, 2025 年 1 月 31 日.

酒井聖矢 (口頭発表), "Measurement of the neutrino-oxygen neutral-current quasielastic cross section and study of nucleon-nucleus interaction model using atmospheric neutrino data in the SK-Gd experiment", 2024 年度第一回 CRC タウンミーティング, 柏市（東京大学柏キャンパス）, 2025 年 3 月 10–11 日.

酒井聖矢 他 (口頭発表),「関口三体核力プロジェクト (4) CCONE ベースの計算システムを用いたオージェ電子放出核種 ^{77}Br の最適な生成法の検討」, 日本原子力学会 2025 年春の年会, オンライン, 2025 年 3 月 12–14 日.

水野るり惠 (招待講演),「ミューオン原子核捕獲反応後の残留核分岐比測定」, 核反応の時間発展ダイナミクスの解明に向けて, 和光市（理化学研究所）, 2024 年 9 月 25–26 日.

水野るり惠 (口頭発表),「ミューオン原子を利用した原子核研究とその展望」, Stop and Slow RI 12th meeting (SSRI), 福岡市（九州大学）, 2025 年 2 月 20–21 日.

水野るり惠 (口頭発表),「Si ミューオン原子核捕獲反応による核変換分岐比の測定」, 日本物理学会第 79 回年次大会, 札幌市（北海道大学）, 2024 年 9 月 16–19 日.

水野るり惠 (口頭発表),「ミューオン原子核捕獲率の同位体依存測定」, 日本物理学会春季大会, オンライン, 2025 年 3 月 18–21 日.

Award

令和 6 年度東京大学理学系研究科研究奨励賞,「^{27}Al, $^{28, 29, 30}$Si におけるミューオン原子核捕獲反応」, 水野るり惠.