先端基礎研究センター長
岡 眞

始めに

国立研究開発法人「日本原子力研究開発機構」（JAEA）は、我が国における唯一の原子力研究開発に関する Center of Excellence (COE) として、基堀・基盤研究と原子力に関するプロジェクト研究を推進していく機関です。

現代社会を支える科学技術は、私達の夢を実現し生活を豊かにするプラスの面と同時に、福島第一原子力発電所の事故で明らかになったように、負の面も持っています。そのために、原子力の今後を既存に解決しながらも、原子力機構が将来担うべき科学技術の新しい原理を見出していくことが必要です。

「先端基礎研究センター」(ASRC) は、原子力機構の基礎研究を担うために 1993 年 4 月に設立されました。現在は「アクチノイド先端基礎科学」分野 (3 グループ) と「原子力先端材料科学」分野 (3 グループ) に、分野を横断する先端物理研究グループを加えた、7 研究グループを設定し、先端原子力科学における未踏分野の開拓を進め、新現象、新原理の発見、新物質の創生、新技術の創出を目指しています。また、JAEA が世界に謳る研究施設である J-PARC や TANDEM などを利用した最先端研究や、それを活かした人材育成を通じて JAEA の他部門との連携を図り、JAEA の将来を展望する先導的役割を果たすことを目指します。

さらに、これらの研究分野での国際的な研究連携を強め、COE としての役割を果たすべく、当センターが推進する国際共同研究プログラム「黎明研究」制度を充実して、国際黎明ワークショップの開催や外国人研究者の積極的な登用等、国際的に開かれた研究体制を築いています。関連分野の国内外の研究者が集まれ ASRC に集まって、自由に研究を進める環境を構築することを目指して、今後も改革を進めていきたいと考えています。
Makoto OKA  
Director General  
Advanced Science Research Center

The Japan Atomic Energy Agency (JAEA), as the Center of Excellence for the research and development of nuclear science in Japan, promotes both fundamental science and atomic energy related research projects.

Science and technology, which are now essential parts of the infrastructure of modern society, enrich our lives but, at the same time, have negative aspects as shown by the accident at the Fukushima nuclear power plant. Therefore, the task of JAEA is to establish the new future role of atomic energy while solving current issues concerning atomic energy.

The Advanced Science Research Center (ASRC) was established in April 1993 with the mission of conducting research on basic science related to atomic energy. Currently, the center consists of three groups in the area of “Advanced Actinides Science,” three groups in the area of “Advanced Nuclear Materials Science,” and a newly-formed Advanced Theoretical Physics group that employs a cross-disciplinary research approach. We explore yet-undiscovered disciplines and study advanced atomic energy sciences. Our aim is to develop new theories and investigate novel phenomena, materials, and technologies. In addition, by making full use of the most advanced facilities at JAEA, such as the J-PARC and TANDEM accelerators, we perform cutting-edge nuclear and material science research. We further cultivate human resources for this purpose, develop cross-disciplinary collaborations with other sections of JAEA, and aim to play a leading role in the future planning of JAEA.

To promote the ASRC as a center for international collaboration in these research fields, we encourage international collaborative research programs making effective use of the “Reimei Research Program” driven by the ASRC and aim to become an internationally open and leading research center by regularly holding international “Reimei” workshops and by recruiting foreign researchers. To this end, we continue our efforts to reform and further develop the center.
Study of nuclear and electronic structure in heavy nuclei and atoms.

Studies on the chemical properties of the heaviest elements and determination of the limits of nuclear stability are among the most interesting but also the most challenging topics in modern chemistry and nuclear physics. The research of this group strongly addresses these fundamental questions.

In nuclear physics, our core program is related to fission, which is a unique physical process observed only in nuclear matter, and which provides the basis for numerous atomic energy applications. We work on fission studies in the regions of exotic nuclides, including neutron-rich fermium nuclei. We also promote studies of nuclear structure and accurate mass measurement to explore neutron-rich super-heavy nuclei. These programs are supported by strong collaborations between theorists and experimentalists worldwide.

In nuclear chemistry, our work is concentrated on the heaviest elements, whose chemical properties are determined crucially by relativistic effects, which rule the ordering of electronic orbits. The first ionization potential of elements in the region of super-heavy elements (SHE) will be studied to determine the energy and orbitals of their valence electrons. The chemical properties of SHEs such as complex formation and adsorption behavior of the compounds will be investigated to find any deviations from lighter homologues and to thus understand the influence of relativistic effects on the electronic structure.

To achieve these goals, we take full advantage of the JAEA infrastructure, such as tandem accelerator, J-PARC, and supercomputers. Applications, such as measurement of nuclear data needed for nuclear transmutation projects, will be promoted as well.
界面化学反応場における重元素の新奇な反応の探索

Quest for novel reactions of heavy elements at interfacial chemical reaction fields

水と接する固体の表面、つまり固液界面は、水に溶けている元素及び固体に含まれる元素の反応場となる。水と混ざり合わない有機溶媒等との界面、つまり液液界面も元素の反応場となる。本研究では、様々な固液界面、液液界面における重元素等の新奇な反応の探索を行う。

固液界面反応に関する研究では、鉱物などの無機表面反応場及び微生物細胞表面反応場における反応の探索及びそれを利用した技術開発を行う。細胞表面のバイオ反応場は、鉱物などの無機表面反応場よりもはるかに複雑な反応場である。例えば、細胞表面はタンパク、脂質など複数の生物分子が存在する。それらは重元素の吸着反応場となるだけでなく、微生物が分泌する生体分子を触媒として重元素の酸化還元反応場となる場合もある。実際の地球環境、無機物と微生物が混ざる条件ではさらに複雑な反応場（ハイブリッド反応場）となる。ハイブリッド反応場は、微生物、生体分子、鉱物群の無機物と重元素が複雑な相互作用をすることで、特異的な反応が発現する可能性がある。

本研究ではさらに、鉱物や微生物と元素の相互作用の研究を通じて得た知見を利用し、福島第一原子力発電所事故で環境中に放出された放射性物質の移行挙動や除染技術の研究開発を行うとともに、有機系加速化のための技術開発を行う。

液液界面反応に関する研究では、放射性廃液等の処理方法の高度化あるいは有価元素・希少元素の回収による資源利用に資するため、重金属等を選択的に抽出する有機抽出剤を開発するとともに、抽出効率の高い抽出システムの開発を行う。さらに、液液反応場を利用した物質創成に関する基礎研究を行う。

Solid surfaces in water, that is, liquid-solid interfaces, are reaction fields for elements. A liquid-liquid interface between water and a liquid phase immiscible in water is also a reaction field for elements. We explore novel chemical reactions of heavy elements at various liquid-solid and liquid-liquid interfaces.

In terms of liquid-solid interfacial chemical reactions, we explore novel reactions at inorganic surface (e.g. mineral surface) reaction fields and microbe cell surface reaction fields and develop novel technologies through basic research. Microbe cell surfaces are far more complicated and reactive than inorganic surface reaction fields. Complex biological molecules are present on cell surfaces. They act as sorption reaction fields for heavy elements, biomolecule-catalyzed redox reaction fields, and more. There are far more complicated reaction fields in which both inorganic substances and microbes are present, such as the soil environment. Such hybrid reaction fields are treasures of unexplored novel chemical reactions. We also face environmental contamination problems owing to radionuclides emitted by the Fukushima Daiichi Nuclear Power Plant (FDNPP) Accident, and we aim to contribute to acceleration of the FDNPP decommissioning program through technological development.

In the research on liquid-solid interfacial chemical reactions, we aim to develop organic extractants with high selectivity and capacity for specific elements and extraction systems with high extraction efficiencies to use them for radioactive waste liquid treatment and recovery of valuable elements. In addition, we conduct basic research on synthesizing new materials by using liquid-liquid reaction fields.
多彩なフレーバーを含むハドロンと原子核の研究

Study of hadrons and nuclei with various flavors and densities

大強度陽子加速器 J-PARC において、地球上に存在しない重いクォークを持つ粒子と原子核に関する研究を推進する。

J-PARC において世界最高強度の \( \pi, K \) 中介子や陽子ビームを用いて、ストレンジクォークやチャームクォークを含む未知のハドロン（強い相互作用をする粒子）や原子核を探索してその構造や相互作用を調べ、クォーク・ハドロン・原子核の階層構造を明らかにする。特に大強度ビームに対応した粒子検出器の開発によって、6 個のクォークを持つ新しい粒子「H ダイバリオン」の発見、3 個のクォークを持つ重粒子（バリオン）の励起状態の研究、ストレンジクォークを 2 個持つ重粒子（Ω）と原子核からなるΩ原子核の研究、ストレンジクォークを 2 個持つ原子核（ダブルΛハイパー核）の発見等を目指す。また J-PARC の将来計画（J-PARC-HI）として、重イオン入射器の導入により重イオンビームを加速し、中性子星中心部に存在する原子核の 5-10 倍の宇宙最高密度の物質を生成し、その相転移現象や、ストレンジクォークを多数含む新たな粒子や原子核の生成の研究を目指す。

一方、理論研究については、先端基礎研究センターの先端理論物理グループや国内外の実験、理論グループと連携して、J-PARC に関連するハドロン物理研究を、強い相互作用の基礎理論である量子色力学 (QCD) に基づいて進める。

We study particles and nuclei which have heavy quarks that do not exist in the earth at the high-intensity proton beam facility J-PARC.

We will study new hadrons and nuclei which include strange and charm quarks to ultimately elucidate the hierarchical structures of quarks, hadrons, and nuclei, by making use of one of the most intense hadron beams in the world such as the \( \pi \) and \( K \) mesons, and protons. Especially, by developing particle detectors for high-rate beams to discover a new six-quark-state particle “H dibaryon”, to study excited states of 3 quark particles (baryons), to study the structure of an atom with a nucleus and a baryon with two strange quarks (Ω), and to study nuclei with two strange quarks (double Λ hypernuclei). As a future project of J-PARC, we will develop a project to accelerator heavy-ion beams (J-PARC-HI) by introducing a heavy ion injector. We aim at producing the densest matter in the universe with the density of 5-10 times as high as the nuclear density, which exists in neutron stars. We will study the phase transition, and production of new particles and nuclei with many strange particles.

On the other hand for theoretical studies, we collaborate with Advanced Theoretical Physics Group in ASRC, and other international theoretical and experimental groups, related to the J-PARC hadron experiments, by conducting studies based on the fundamental theory of strong interaction, QCD.
重元素化合物の電子物性解明と高機能原子力材料開拓
Materials physics for heavy element systems and basis for high performance nuclear materials

Heavy element compounds based on actinides and lanthanides are not only important as nuclear fuels but have also been widely used in high performance materials such as magnets or catalysts. This research group contributes to the development of the condensed matter physics of heavy element systems and to the development of basic nuclear science, including high-performance materials such as radiation-resistant devices. In addition, an aim of our project is the development of human resources responsible for research on nuclear radiation science.

Owing to the strong spin-orbit interactions found in heavy elements, novel electronic properties are discovered in their compounds and are studied intensively. Among these effects, we focus on the development and evaluation of nuclear materials, as well as new superconductors and magnetic materials. In collaboration with Bristol University, UK, we have succeeded in fabricating thin films of uranium compounds for radiation-resistant devices based on spintronics technology.

Our research methods include synthesis of advanced materials, measurement of physical properties, and the development of relevant theory. Along with the development of new materials, high-purity single crystals can be grown, which facilitates evaluation of intrinsic physical properties. These include, in addition to thermal and transport properties, microscopic properties such as NMR and $\mu$SR in extreme environments, for example, high pressure. The studies described here are also augmented through domestic and international collaboration with many institutions.
効率的なエネルギー利用をめざしたスピン変換科学
Spin transformation science toward high energy efficiency

エネルギーの効率的利用は、今後より重要になる社会的課題である。本研究グループでは、新しいエネルギー変換技術への応用が期待される物理性や物理現象について、J-PARCなど原子力機構が有する研究施設と密接に連携をとり、理論および実験の両面から研究を進めている。なかでも、物質中の電子が持つ「スピン」を積極的に利用する新しい電子技術（スピントロニックス）を基軸に据える。磁気の源であるスピンの流れ（スピン流）は、大幅に消費電力を低減した不揮発性磁気メモリーやスピンを用いたエネルギー変換技術など、多様な応用が期待されている。その根拠に、一方向に回転運動が制限されるというスピンに特有な性質があり、熱などの物質中のランダムな運動を一定方向に揃える機能（整流性）などが期待される。これを基礎として、スピンを用いた力学的・電磁気的・熱的エネルギーロの流れの制御を目指す。更に、物質中のミクロなスピンを記述する量子力学を、物体の回転や振動などの力学的運動を扱えるように拡張することで、物性理論における新しいパラダイムを創成する。これらの研究により、新たなスピン変換の概念や、力学運動を組み込んだスピントロニクスデバイスの創出、従来のエレクトロニクスでは不可能と考えられていた機能性デバイスを実現する。以上のスピン変換科学は、新しい熱電発電の仕組みを可能にし、原子力エネルギーロの効率を高め、外部電源喪失時における安全維持に寄与する。また、これらスピン物性を基礎としたデバイスは、放射線環境下にあっても機能する技術の礎になると期待される。

The most important and urgent problem of our society is energy efficiency. In this research group, new materials and phenomena applicable to energy transformation will be studied theoretically and experimentally in collaboration with J-PARC. Especially, new technologies based on electron spin (spintronics) will be the key to realizing our project. A spin current, which is a flow of magnetism, will be used in non-volatile magnetic memory and energy conversion technology. This will dramatically reduce energy consumption because of the particular property of spin, whose rotational motion is limited in one direction. Hence, we can expect some interesting functionalities, such as rectification of heat flow. By exploiting this advantage of spins, we will pursue new principles to control mechanical, electromagnetic, and thermal energy flows. Furthermore, we will create a new paradigm of condensed matter theory by extending quantum mechanics to mechanical motions such as rotation, vibration, and so on. These studies will help realize new concepts related to spin transformation, new spintronics devices with mechanical motion, and new functionality never achieved by conventional electronics. Our spin-transformation science will lead to the creation of a new method of thermoelectric power generation, which will increase energy efficiency and contribute to the security of nuclear power plants. In addition, the devices based on spin materials will be the basis of technology in radiation environment.
Study of novel phenomena in nano-scale region of advanced material

The internal and external characteristics of a person do not always coincide, and it is difficult to understand the person’s character based only on the external characteristics. It is necessary to make fully use various means to holistically understand the character of a person. This is true for materials research as well. A thermodynamic property usually depends on the normal bulk state, while novel state and structure are realized by a break in translational symmetry at a surface. In addition, different states are formed around defects and impurities, and these states influence bulk property. Hence, the study of local states is quite important in materials research.

Macroscopic properties of matter based on local states could be understood by investigating a nanoscale region of the sample. An experimental technique that can be used to selectively investigate a surface, bulk, impurity/defect, or ultrathin film can extend the field of materials research.

Existing technical developments enable us to efficiently produce high-intensity beams, especially beams of synchrotron light, electrons, neutrons, muons, and positrons, which are useful for studying various atomic structures and dynamics of functional materials at the length scale of advanced beams. In addition, experimental techniques that can obey local states such as surface, interface, and impurity have been developed as well, and they can be used to obtain new scientific insights.

Our objective is to develop these new advanced measurement technologies and study the nanoscale structures of functional devices and materials to clarify the essential properties of matter.
Quantum many-body systems and nonequilibrium dynamics

Originating from the TPI (Theoretical Physics Institute), the Research Group for Advanced Theoretical Physics was launched in 2019 at ASRC/JAEA to conduct theoretical research on basic physics related to atomic energy. Our missions are to support experimental research at JAEA and promote interdisciplinary research with novel ideas. Further, we serve as the base for an international research network to exchange new ideas, build active international collaborations, and foster young researchers. To achieve these aims, we welcome and invite researchers, including students, from a variety of backgrounds.

The group members’ interests cover the theoretical physics of hadrons and nuclei and strongly interacting systems. In addition, the recent addition of condensed matter physicists working on spintronics makes our group unique compared to other research organizations.

The common basis of these physics fields is the quantum many-body theory, which governs the dynamics at wide scales from the fermi world of quarks to the nanosystems of condensed matter. To directly access these systems with experiments, we put an emphasis on reactions through which we can study the various properties of many-body systems of interest.

In addition to our regular meetings, our main activities involve holding seminars, lectures, and workshops, which are open to all ASRC members, to exchange mutual ideas. We are also actively engaged in international collaborative research projects, such as the “Reimei research programs”, to accomplish our purposes.
先端基礎研究センターにおける研究推進
Promotion of Basic Research at Advanced Science Research Center (ASRC)

理事長
President

先端基礎研究センター長
Director General of ASRC

アドバイザー
Advisors

先端基礎研究・評価委員会
ASRC Research Evaluation Committee

黎明研究評価委員会
REIMEI Research Evaluation Committee

共同研究（国内・国外）
Cooperative Research

テーマ発掘
（黎明研究等）
Theme Exploration
(REIMEI Research etc)

アクチノイド先端基礎科学
Advanced Actinides Science

原子力先端材料科学
Advanced Nuclear Materials Science

大学・研究機関
（国内・国外）
Universities and Research Institutes

原子力機構
Japan Atomic Energy Agency

産業界
（国内・国外）
Industries

国際協力協定
Agreement of International Cooperation

<核物理研究所技术協力
(ANL, ORNL)
Japan & U.S. Science & Technology Cooperation in Nuclear Physics
(ANL, ORNL)

イオンビーム照射
利用分野の
研究開発（GSI）
Research and Development in the Field of Ion Beam Application
(GSI)

CEAグループとの
基礎研究に関する
研究協力
(CEA-INAC)
Implementing Arrangement in the Field of Basic Research
(CEA-INAC)

ハドロン原子核物理に
関する研究協力
(ソウル大学)
Joint Research Arrangement on Nuclear and Hadron Physics (Seoul Univ.)
福島第一原動力発電所事故による放射性核種汚染に関する研究
Study on radioactive contamination due to Fukushima Daiichi NPP accident

We have been working on the radioactive contamination problems caused by the Fukushima Daiichi NPP accident. Our research includes i) elucidation of environmental behavior of radionuclides and ii) technical developments for in-situ immobilization of radionuclides in soil, decontamination of soil, and treatment methods for the long-lived anionic radionuclides in contaminated water.

For elucidation of environmental behavior of radionuclides, we have been investigating 1) the functions of mushrooms on the environmental circulation of radium (Cs), 2) chemical states of Cs in soil, 3) characterization of Cs-bearing particles in rivers, 4) Cs uptake by plants, and 5) chemical states of Cs in sewage sludge ashes.

To immobilize radioactive strontium (Sr) in the soil at the NPP site and the sea-bottom soil in the port of the NPP, we developed methods using minerals produced by microorganisms (biominerals) and organic-modified fine mineral particles under cooperation with Materials Sciences Research Center, Shibaura Institute of Technology, and three other universities.

For technical development of anionic radionuclide treatment, we are working on solving challenging problems, selective extraction (collection) and inorganic stabilization of long-lived anionic radionuclides ($^{90}$Tc, $^{131}$I, $^{75}$Se), to establish measures for disposal of spent sorbents stored at the contaminated water treatment facility in the NPP.
"黎明研究" は、国際的視野での新たな発想に基づく新たな研究テーマの発掘を目的とし、国内外の研究者からアイデアを募集し、日本原子力研究開発機構先端基礎研究センターと共同で研究を進める制度です。

原子力科学の分野で革新的な原理や現象の発見を目指す先端基礎研究で、独創性、新規性、発展性、挑戦性などに富み、既存の科学・技術のパラダイムシフトや将来の原子力の革新に発展する可能性を秘めた研究テーマを募集対象としています。

The Reimei Research Program set out with the aim of cultivating frontier research in diverse fields such as atomic energy and related disciplines throughout the world, as well as to promote research collaboration with ASRC. ASRC seeks research themes that explore novel principles and phenomena in the field of atomic energy and related disciplines. The themes are expected to change the paradigm of existing science and technology, and to develop the future of innovation in atomic energy. Inventive, expansible, and challenging ideas are welcome.

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