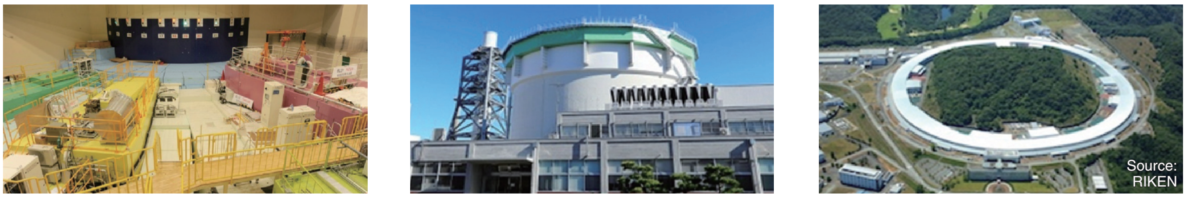
5 Neutron and Synchrotron Radiation Research

Contributions to Innovative Achievement in Science and Technology

In accordance with the Science and Technology Basic Plan formulated by the Government of Japan, we have aimed to contribute to the advancement of science and technology and the promotion of industry through innovative research into neutron and synchrotron radiation. This includes using the high-intensity proton accelerator at the Japan Proton Accelerator Research Complex (J-PARC) and the high-performance and multipurpose research reactor JRR-3 and JAEA's synchrotron radiation beamlines at the Super Photon ring-8 GeV (SPring-8) (Fig.5-1), upgrading neutron facilities and devices, and pursuing world-leading research in fields that use neutron and synchrotron radiation, such as nuclear energy and materials sciences.


Source: RIKEN

Materials and Life Science Experimental Facility (MLF) of J-PARC

JRR-3

SPring-8

Fig.5-1 Facilities used for neutron and synchrotron radiation research

(1) Research and development of performance improvement of J-PARC

J-PARC comprises three proton accelerators, including a linear particle accelerator (linac), a 3-GeV rapid-cycling synchrotron (RCS), and a main ring synchrotron, and three experimental facilities. The facilities include the Materials and Life Science Experimental Facility (MLF) for a wide range of research fields using neutron and/or muon beams, the Hadron Experimental Facility for nuclear and particle physics experiments using K-mesons and other particles, and the Neutrino Experimental Facility for T2K particle physics experiments using neutrinos. These experimental facilities are open to researchers worldwide.

In FY2021, accelerator studies were conducted with a rated beam power of 1 MW; the beam loss at RCS was successfully reduced from 0.2% to 0.15%. At linac, a gas sheet beam monitor was developed as a nondestructive monitor with the aim of reducing beam loss and improving the beam quality of the existing wire-scanning-type profile monitor (Topic 5-1).

During FY2021, the proton beam power delivered to the MLF was increased from 600 kW to 700 kW, and the user program was carried out for 151 days. A wide range of experiments related to materials and life sciences were conducted at MLF with 21 neutron spectrometers and 3 muon instruments. With regard to neutron experiments, a deep-learning method was developed to remove statistical noise effectively from measured data in the structural analysis of the surface and/or interface of materials by learning about 1 million datasets acquired at a neutron reflectometer. This method yielded reliable structural analysis results without sacrificing resolution even when the data acquisition time was substantially shortened by one-tenth (Topic 5-2).

Furthermore, in the development of a neutron-polarizing super mirror for obtaining polarized neutrons that are useful for studying the microscopic magnetic structure of a sample, we found a specific condition of the Fe/Ge multilayer of the polarizing super mirror under which the saturation magnetization does not decrease even if layer thickness of the multilayer is reduced to a value less than the current minimum of 6 nm. Thus, the ratio m of the critical momentum transfer of the supermirror to that of natural Ni was improved from the existing value of $m = 5$ to $m > 6$ (Topic 5-3). This technique is expected to promote the research on the magnetic structure of a magnetic body.

(2) Research and development at the Materials Sciences Research Center (MSRC)

Researchers at the MSRC aim to provide innovative results and seed research in a wide range of scientific, technological, and academic fields by developing and improving neutron and synchrotron radiation instruments for advanced structural and functional analysis in Tokai (JRR-3 and J-PARC) and in Harima (SPring-8).

In FY2021, in our research using neutron beams, we discovered that the domain motion of proteins controlled the local molecular structures that were the core of the catalytic reactions in proteins (Topic 5-4). This study revealed that the structure and fluctuation of amino acid residues contributing to the activity of the enzyme protein MurD were well controlled by the cooperative fluctuations of the domain structure. We also clarified the effect of additives on the hierarchical structure of borosilicate glasses, which are a type of host materials for high-level radioactive liquid waste (HLLW) (Topic 5-5). This study revealed that the size of the periodic structure composed of the SiO_2-rich and B_2O_3-rich nanodomains in the glasses were strongly affected by the amount of Na_2O additive, and the formation and suppression of the nanoscale structures in the glasses were also affected by the CaO/ZnO and Li_2O additives. These findings are expected to contribute to the development of vitrification techniques for HLLW.

In our research on synchrotron radiation, we clarified the polarization mechanism of bismuth sodium titanate (BNT), which is expected to be a candidate for lead-free piezoelectric material (Topic 5-6). The result indicated that the displacement of Bi ions produced a large polarization in the high-temperature phase of BNT, and it provides an important clue to develop environment-friendly high-performance piezoelectric materials by controlling the size and shape of the ferroelectric domains. In addition, we revealed the energy band structure of $EuNi_2P_2$, which is the first heavy electron system among the Eu-based compounds (Topic 5-7). The result confirmed the presence of Eu 4*f* electron states at the Fermi level, indicating that the electronic and thermodynamic properties of this compound are markedly affected by the Eu 4*f*–derived heavy electrons. Further study is expected to contribute to a material design for developing new rare-earth-based superconducting materials.