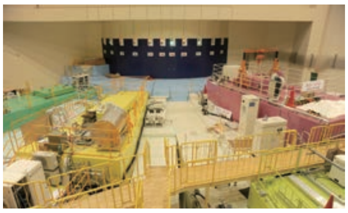
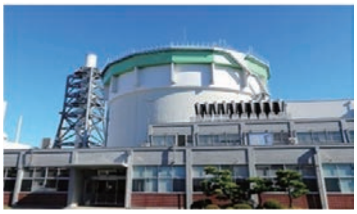
5 Neutron and Synchrotron Radiation Research

Contributions to Innovative Achievement in Science and Technology

In accordance with the Science, Technology and Innovation Basic Plan formulated by the Government of Japan, we aimed to contribute to the advancement of science and technology and the promotion of industry through innovative research into neutron and synchrotron radiation. This included the use of the high-intensity proton accelerator at the Japan Proton Accelerator Research Complex (J-PARC), 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.1), upgrading of neutron facilities and devices, and the pursuit of world-leading research in fields that use neutron and synchrotron radiation, such as nuclear energy and materials sciences.



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



JRR-3

SPring-8

Fig.1 Facilities used for neutron and synchrotron radiation research

(1) Research and development at 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) that enables research in a wide range of 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.

Reducing the beam loss in accelerators is important for ensuring stable operation at the target proton beam power of 1 MW. The mechanism of an event in which negative hydrogen ions are replaced by hydrogen atoms during acceleration in the linac was elucidated; this event is one of the causes of beam loss (Topic 5-1). Based on the result, we are planning to study countermeasures to further reduce the beam loss.

During FY2022, the proton beam power delivered to MLF was increased from 700 kW to 830 kW and a user program was conducted for 144 days. A wide range of experiments related to materials and life sciences were conducted at MLF using 21 neutron spectrometers and three muon instruments. For neutron experiments, a remarkable experimental environment that can apply a pressure of 21 GPa, the highest among inelastic neutron scattering experiments worldwide, has been established. Experiments conducted in this environment clarified that in hydrides with fluorite-type structures ($ZiH_{1.8}$, $TiH_{1.84}$), hydrogen atoms preferentially shrink to a greater extent than metal lattices under high-pressure conditions (Topic 5-2). This high-pressure experimental environment is expected to be used to develop future studies on the dynamics of various materials under high pressure.

Furthermore, as a major contribution to research on the evaluation of magnetic structure of materials under high magnetic fields by neutron diffraction, a unique compact pulse magnet system has been developed. This system can generate a high magnetic field of over 30 T by using silver–copper alloy wires as coils (Topic 5-3). It is expected that new magnetic properties of magnetic materials will be explored by using the world's most intense pulsed neutrons provided by the MLF.

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

At the MSRC, we aim to provide innovative results and to 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 analyses. We also operate the neutron instruments in Tokai (JRR-3) and the synchrotron radiation instruments in Harima (SPring-8).

In FY2022, in our research using neutron beams, we proposed a new method to determine the magnitude of the electron magnetic moments in magnetic materials (Topic 5-4). Neutron diffraction at cryogenic temperatures allows us to observe not only the electron magnetic moment but also the nuclear magnetic moment with only a single magnetic reflection. The electron magnetic moment is evaluated simply by comparing it to the observed nuclear magnetic moment, the magnitude of which can be accurately determined by calculation. We successfully evaluated the neodymium electron magnetic moment of $Nd_3Pd_{20}Ge_6$. We also captured the movement of lithium ions in an all-solid-state lithium-ion battery during charging in real time (Topic 5-5). By measuring the α-ray and tritium energy generated by the $^{6}Li(n,\alpha)T$ reaction, the position of the lithium ions in the battery was visualized for the first time in the world. This technique is expected to advance the development of all-solid-state batteries in the future.

In our research using synchrotron radiation, we demonstrated the principle of a new method for separating and recovering radioactive elements from spent nuclear fuel (Topic 5-6). This method was used to extract and separate americium, which is highly toxic, from among the elements present in spent nuclear fuel. The element was extracted by selectively oxidizing it using a laser beam. This new method will help reduce the burden of radioactive waste management. In addition, we clarified the mechanism of oxidation reactions occurring on silicon surfaces—knowledge of these reactions is the key to control the performance of semiconductor devices (Topic 5-7). This study proposes a new reaction mechanism in which the oxidation reaction at the interface proceeds via molecular adsorption at defects associated with carriers from the substrate. The result is expected to lead to a dramatic improvement in performance of semiconductor devices through higher-density integration.