SPring-8 BL09XU Evaluation Report

Chairman: Kazumichi Namikawa (Tokyo Gakugei University)

Committee members: Masataka Umeno (Fukui University of Technology)

Yorihiko Tsunoda (Waseda University)

Yutaka Maeda (Kansai Gaidai University)

Rudolf Rueffer (ESRF)

1. Preface

The SPring-8 BL09XU is a beamline for nuclear resonant scattering experiments. Scientists, however, continued to utilize it for experiments on surfaces and interfaces and for precision X-ray measurement experiments until the BL13XU surface interface beamline was completed. In this Evaluation Report, we review the technological and scientific results that have been achieved since the construction of this beamline. Every committee member studied the reference materials sent to each member of the Evaluation Committee before the meeting. All committee members except the overseas committee member attended the meeting, and were given descriptions based on the reference materials by the person in charge of the facilities. After that, the committee members participated in a question-and-answer session. When making the Evaluation Report, the domestic members considered the overseas member's opinion regarding the following evaluation items.

2. Technological state of beamline and experimental station

In the summer of 2001, the multiaxis diffractometer for surface and interface structure analysis experiments was moved to the BL13XU, although this beamline BL09XU was used for different types of experiment, that is, nuclear resonant scattering experiments as well as surface and interface structure analysis experiments and precision X-ray measurement experiments. At present, in the special bunch mode, nuclear resonant scattering experiments are conducted; whereas, in the multi bunch mode, precision X-ray measurement experiments are conducted for the effective use of this beamline.

The beamline BL09XU definitely has low emittance in a wide-energy region because SPring-8 has a long ring circumference and a high operation energy. Such a low emittance is advantageous to users of BL09XU for nuclear resonant scattering experiments, in comparison with similar beamlines of other third-generation light sources ESRF and APS. An in-vacuum undulator with a period of 32 mm provides 14.4 keV for the most important nuclide ^{57}Fe and fundamental waves for Ta, Tm, Kr, and other nuclides, to produce the highest brilliance. The undulator provides third-order harmonics for other isotopes that have a transition energy of 30 keV or less. The undulator provides five-order harmonics for nuclides that have a transition energy of 60 keV or more, to produce brilliance decreased by a factor of 10.

This beamline has a spectroscope of the Si pin-post type, which has a high heat-load resistance; however, such a device is not suitable for this high-brilliance beamline because the beamline may increase heat load, and because scientists desire higher resolutions. In a high-energy region, the mismatch between the longitudinal divergence of a synchrotron radiation beam and the acceptance angle of a spectroscopic crystal is a problem.

On the other hand, scientists have developed high-resolution monochromator important for nuclear resonant scattering experiments, using two types of goniometers with an air pad system. According to the experimental requirements, scientists select an appropriate type of monochromator for each nuclide to be used. Thus, they can use an increased number of nuclides as samples. A system selects an energy resolution of 2.5 meV or 3.5 meV at 14.4 keV by translating the crystal. Such an effective system contributes greatly to the effective use of measurement time. People may pay attention to scientists' attempts to build a low-temperature cooling system for 29.6 keV of the ^{40}K isotope that will be a standard in a higher-energy region. Scientists have developed an appropriate avalanche photodiode detector for the feature of each experiment because no detector can have both a high time resolution and a high detection efficiency. The experimental station is equipped with peripheral devices: a continuous-flow cooler and a diamond anvil cell. These are effectively used for experiments.

To make effective use of the excellent synchrotron radiation beam of BL09XU, it is necessary to improve optical elements. High-resolution X-rays will be intensified by replacing the water-cooled spectroscope of the Si pin-post type which has a high heat-load resistance, with a monochromator of the liquid-nitrogen-cooled type. The high-resolution monochromator has a sufficient resolution for time-domain Mossbauer spectroscopy; for nuclear resonant inelastic scattering experiments, however, scientists desire to improve the resolution from the present 1.6 meV to 0.5 meV or less at 14.4 keV. Concentrating the beam is needed to conduct an experiment using a diamond anvil cell. Energy of the concentrated beam is to be scanned in nuclear resonant inelastic scattering experiments; therefore, a monochromator is further needed which has a stationary beam source.

3. Research results

Before this beamline was built, nuclear resonant scattering experiments were verification rather than application. The primary achievement of this beamline is to apply nuclear resonant scattering experiments to a variety of research fields. Nuclear resonant scattering applications are classified roughly into two research fields: hyperfine-interaction research using nuclear resonant scattering as main experimental means, and molecular-dynamics research using nuclear resonant inelastic scattering and quasi-elastic scattering as main experimental means.

Hyperfine-interaction research is referred to as time-domain Mossbauer spectroscopy. It should be aimed at developing experimental techniques that would be difficult if normal Mossbauer spectroscopy using radioactive isotopes were conducted. With this beamline, scientists are carrying out research based on the features of the synchrotron radiation source, such as high brilliance, high directivity, polarization, and time division property. Scientists are developing new experimental techniques, such as the measurement of physical properties at high pressures, and a stroboscopic method of detection. The stroboscopic method of detection has the potential to detect long-life excitation level nuclei (such as ^{181}Ta and ^{67}Zn) that have been difficult to detect.

Molecular-dynamics research includes research regarding the phonon state density and phonon diffusion of targeted elements, and dynamics research regarding a targeted sample that does not have a nuclear resonance element due to the nuclear resonance energy analysis.

With this beamline, scientists are eagerly measuring the phonon state density of targeted elements, such as deposit and minor elements in metals. With this beamline, scientists analyze the movement of a particular ion in solution that contain macromolecules. Research that analyzes the vibration mode inherent in a particular element, by utilizing nuclear resonant scattering, opens a new field of nuclear resonant scattering experiments using synchrotron radiation. With research results based on this beamline, scientists are leading the world.

Using this beamline, scientists conducted a verification experiment on ^{197}Au for the NEET phenomenon. Many scientists in the world continued to conduct a large number of experiments, after the NEET phenomenon was theoretically predicted 30 years ago. A successful experiment using this beamline terminated the history of the NEET phenomenon controversy.

The phonon state density of a particular atom obtained from the nuclear resonant inelastic scattering experiment is important because such a phonon state density provides findings regarding the behavior of particular impurities and additives that have a strong influence on the physical properties of a material. A nuclear resonant inelastic scattering experiment on magnetite has recently been conducted using this beamline. In such an experiment, scientists have analyzed both the time domain and energy region to the produce phonon state density of a particular site identified by a hyperfine interaction. This experiment is a pioneering experiment material research, based on the advantage of SPring-8 featuring the highest brilliance in the world. Its future development is expected.

Because nuclear resonant scattering is a unique method, BL09XU cannot simply be compared with other beamlines. Regarding nuclear resonant scattering, some research results have not yet been reported or published although part of the past research carried out with this beamline produced remarkable results.

From the second half of 1997 to the first half of 2001, until the multiaxis diffractometer was moved to the BL13XU in the summer of 2001, surface and interface structure analysis experiments were conducted under conditions where instrumentation could not create an ultra high vacuum. Those experiments included those using the X-ray standing wave method, CTR scattering, X-ray holography and multiple scattering, and other important research subjects for surface and interface structure analysis. Nevertheless, the surface and interface structure analysis group published fewer results than expected considering the adequate allocated beam time.

4. Support system for sharing

Equipment and research methods for nuclear resonant scattering experiments have been developed and improved using both this beamline BL09XU and the JAERI beamline (BL11XU). At the same time, nuclear resonant scattering applications have been researched. Present and future developmental research studies are important. Presumably, it is necessary to increase personnel and machine time. It is also necessary to give the public the number of access to beamline research results, to expand application fields into other areas of sciences, and to increase users. For future developments, the systematic and effective operation of the BL09XU beamline will be necessary so that BL09XU and other beamlines (BL35XU and BL11XU) can coexist.

Considering the high allocation rate of beam time, we mention that the recent adoption rate of research subjects is acceptable.

However, the number of publications of research results is not equal to the number of research subjects to which the beam time was allocated. Research results have not yet been published regarding one-fourth of the research subjects to which the beam time was allocated. We suspect that the adoption rate of research subjects varies significantly depending on the bunch mode, although the reference materials do not describe the adoption rate of research subjects for each bunch mode.

Developmental research requires a system for strong promotion under the internal staff's leadership, and for close cooperation with external research organizations and staff. To increase users, we suggest that a system should be provided which enables independent groups to conduct experiments without assistance by the internal staff or an external skilled researcher.

It is important to provide peripheral sample-preparation equipment for the beamline, to increase users' research results. It is essential to increase the beamline staff, and to enable the beamline staff themselves to carry out research activities so that the beamline staff can discuss any problems with users, give them advice, and assist them in organizing the experimental data.

5. Future developments

We mention an excellent proposal that the monochromator of high heat load and the high-resolution monochromator should be separated and placed in two independent optical hutches so that users can provide and adjust, in advance, several high-resolution monochromators which have various energy resolutions, and which users can select according to a variety of nuclides. We mention another excellent proposal that the experimental hutch should be separated into two so that users can adjust the fixed sample environment in advance.

The staff should change the high-heat-load monochromator from the present water-cooled type to the liquid-nitrogen-cooled type as soon as possible. To make full use of the newly developed high-performance APD, we suggest that the staff improve the performance of electronics. To develop high-pressure experiments using the diamond anvil cell, it is necessary to improve the condenser optical system. To expedite application developments, it is also necessary to improve the superconducting electromagnet, high-pressure apparatus, UHV system, laser heater, and peripheral equipment associated with samples.

A large number of experiments based on the features of SPring-8 those of have been conducted, to produce numerous excellent results that include nuclear resonant inelastic scattering. Scientists around the world pay attention to such research results. For future developments, scientists should strongly promote research on the applications of nuclides other than ^{57}Fe the nuclear excitations of which have been observed so far. Under new regulations, the use of an increasing number of nuclides in radiation sources will be strictly controlled. Thus, the synchrotron radiation sources are really expected to serve as an alternative.

Combining nuclear resonant inelastic scattering with time-domain Mossbauer spectroscopy that provides phonon state density related to a particular atom or site, presumably, is important to research aimed at elucidating the functions of biopolymer or the like which has a metal ion as the active center.

Research on the physical properties of surfaces and interfaces and on functional materials of nano structures is a field in which synchrotron radiation shows its abilities. It is anticipated, therefore, that nuclear reflectivity measurement and other applications will be developed. It is essential to study nuclear small-angle scattering used as a means of studying a mesoscopic objects. X-ray optics based on the nuclear resonant scattering of large coherence lengths is also an important research subject.

6. Summary

(1) Technological state of beamline and experimental station

The technological state of the beamline and experimental station is good on the whole. The high-resolution monochromator and the detector are high level equipment. The pin-post type obstructs progress in the monochromator of high heat-load. It is necessary to clear such an obstruction.

(2) Research activity

The number of published papers is smaller than the number of adopted subjects. BL09XU has a lower rate of published papers with respect to the adopted subjects than other beamlines. However, such a rate is acceptable because of the large number of developmental research subjects using this beamline, and because of the steady progress in research. NEET (nuclear excitation by electronic transition) research and research regarding phonon state density, based on nuclear resonant inelastic scattering, were excellent attempts at research and development. From the completion of R&D, the applications of NEET and phonon state density are expected for future developments. We hope that the number of papers will increase as applications research develops.

(3) Support for users

BL09XU is not adequately equipped with peripheral equipment needed for the use of the beamline for research. It is necessary to provide two or more compatible devices for future developments in research regarding physical properties. It is desirable to provide instruction manuals. The staff should provide on-site treatment of samples. BL09XU lacks support personnel. The systematic and effective operation of BL09XU should coexist with the BL11XU and BL35XU.

(4) Future developments in science and technology

Technological problems to be solved are itemized below in priority order: [1] improving a monochromator of high heat-load, [2] concentrating the beam, [3] separating the optical hutch, and [4] separating the experimental hutch. For scientific problems, [1] it is necessary to increase the number of detectable nuclides, and to include nuclides detectable in Mossbauer spectroscopy (so that scientists can ordinarily use Fe, Eu, Sn, Sm, I, and Au). [2] It is necessary to add physical properties, soft materials (synthetic polymer, biopolymer), and other materials to objects of research. It is necessary to consider the applications of the most advanced research (for example, the stroboscopic method for ^{181}Ta, ^{67}Zn, and other long-life nuclides) for future developments. It is also necessary to assist academic exchange among scientists using BL09XU, BL11XU, BL35XU, and other beamlines (to provide a forum for scientific discussion). It is necessary to publicize the use of established technology (to organize groups for workshops and for scientific research expenses).