Vol.2 No.2

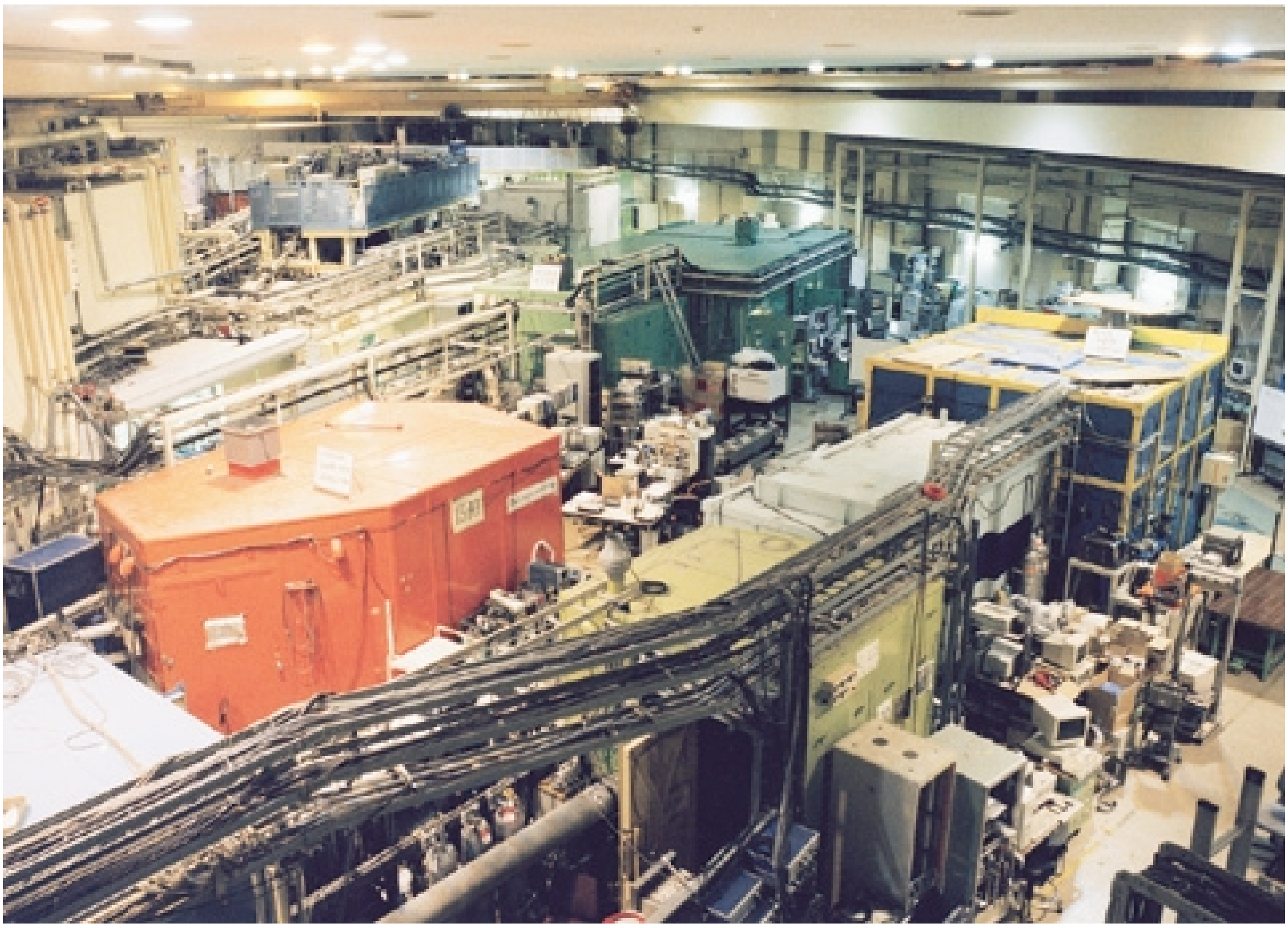
KEK News

Photon Factory Story

The Australian National Beamline Facility at the KEK Photon Factory

High Energy Accelerator Research Organization

PHOTON FACTORY STORY



PF station #14 through #17 at the 2.5 GeV Ring

While high energy particle accelerators have been the major tool for nuclear and elementary particle researches, electron / positron accelerator rings have taken an other important role to provide a very powerful radiation (called as synchrotron radiation : SR). KEK Photon Factory (PF) has two electron (positron) accelerator rings dedicated for generating the SR. The first ring (2.5 GeV) has been in operation since 1982 and the second ring (6.5 GeV) since 1986. SR is emitted along tangent directions when trajectory of electrons traveling near the speed of light are bent under a magnetic field. It has very unique properties such as (1) high brightness (several orders of magnitude brighter than conventional X-ray sources), (2) a continuous spectrum covering from infrared to X-rays, (3) linearly polarized and (4) pulse width of sub-nanoseconds. Because of these, SR has been used as a tool for observing positions, motions and behaviors of atoms and electrons in various kinds of materials.

Synchrotron Radiation as a microscopic probe

Since SR is a microscopic probe with a resolution to see the size of atoms and molecules, area of its application is very broad such as in physics, chemistry, materials science, biology, medical science, pharmaceutical science / engineering, electronics and so forth. The technique used in those studies are also full of varieties: diffraction, scattering, absorption, fluorescence, secondary emission, radiation effects. To accommodate wide variety of researches, we have about 60 experimental stations. The first picture shows a view of beamlines and experimental stations in 2.5 GeV ring experimental hall.

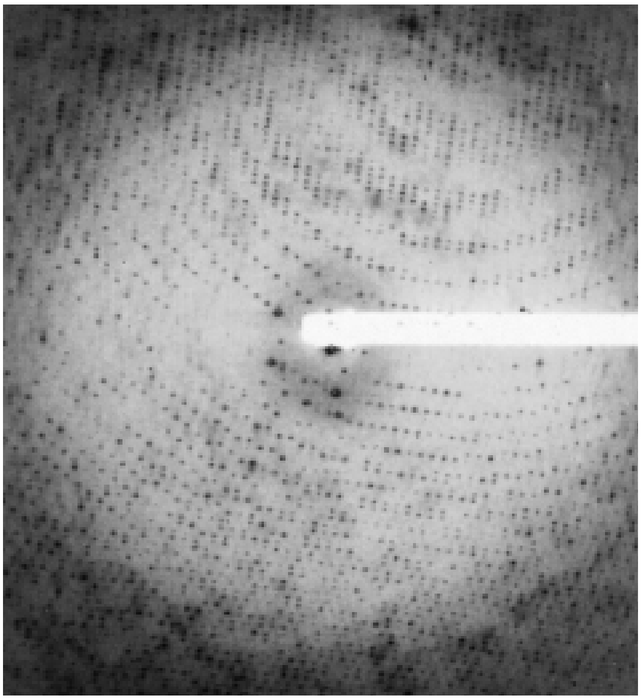
More than 2,000 researchers visit and stay at the Photon Factory to conduct their experiments to determine precise structure of proteins, viruses, high-temperature superconductors, materials under high pressure and high temperature (to find out what is happening in the inner core of the earth) and to study radiation-induced chemical reactions, atomic level mechanism of catalytic reaction, atomic level analysis of the mechanism of muscle contraction, trace element analysis of metals in biological samples, and so forth. Following examples are to give you a closer look at what we do here.

(1) Synchrotron radiation to study molecular structures

SR enables us to study an atomic level structure of a protein molecule. It is well known that proteins play very important roles in any life forms. Since the nature of proteins is originated from their atomic structures, determination of atomic structure of proteins is one of the most important areas of study in biology.

The protein crystal scatters the SR according to its atomic structure resulting a very regular diffraction pattern (right). This pattern was obtained from a protein (Cytochrome C Oxidase) which plays an important role in the respiration mechanism.

The nutrition taken in by a living body is oxidized to generate energy. This protein works as a proton (Hydrogen ion) pump to create a gradient of proton concentrations across a cell membrane.



Diffraction pattern of a protein (Cytochorome C Oxidase)

Such a gradient is essential in the process of synthesizing adenosine 5’-triphosphate which is the most versatile forms of energy in cells. However, the mechanism of proton pumping is not fully understood at an atomic level.

A picture below shows a ribbon-model representation of a molecular structure of Cytochrome C Oxidase resulted from an analysis of almost five million diffraction spots in previous picture.

Revealed fine structure of a Cytochrome C Oxidase from a cow’s heart (ribbon model representation)

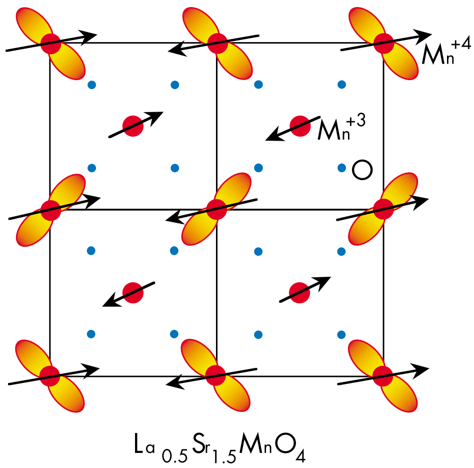
Such studies of proteins are widely appreciated owing to contributions of synchrotron radiation and we have one of the best facilities for the structural study of macromolecules.

(2) Synchrotron radiation to study arrangement of electrons in crystals

Some manganite crystals show drastic changes in electrical conductivity when exposed to a magnetic field. This phenomenon draw much attention from scientists and engineers because it reflects correlation effects of electrons in solids and could lead to an invention of new magnetic devices.

Such effect is strongly related to a spatial ordering of charge, spin and orbit of electrons. Neutron diffraction technique enables to observe the spin ordering directly, but not the charge and orbital orderings.

However, a successful observation of the charge and orbital ordering of a manganite was made here for the first time using the resonant effect of the SR. The result of such studies also stimulated theoretical discussions on resonant X-ray scattering.



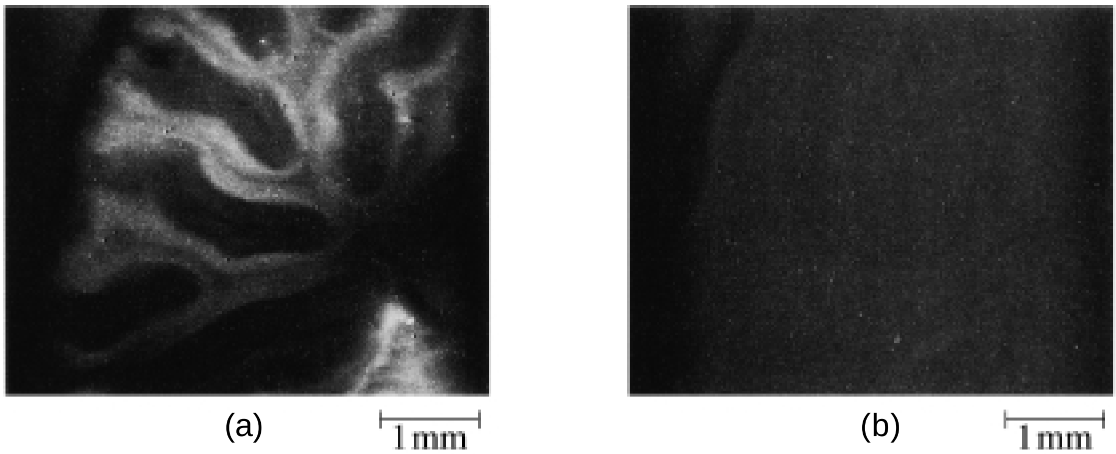
Charge and orbital ordering in a manganite crystal

(3) Synchrotron radiation to study soft biological tissues

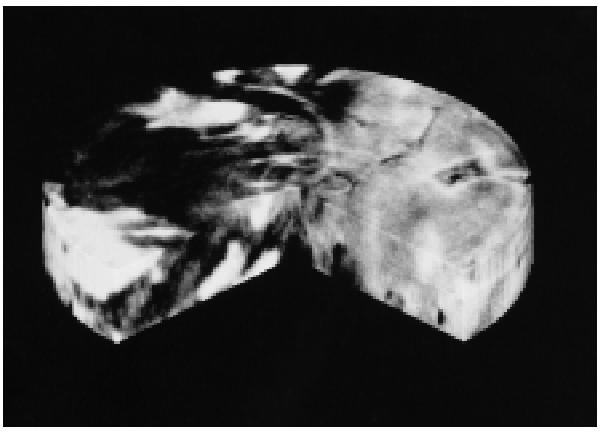
X-ray images such as taken at hospitals show difference in absorbing power of different parts of your body. Another way to see internal structure of a living body (without cutting open your body) is making use of the difference in traveling speed of X-rays (phase contrast) through different parts of body. In light element materials, the phase contrast is thousands of times more sensitive than the contrast resulted from a difference in absorption so that we can see internal structure much clearer.

A collaborative team of Hitachi Ltd., the PF and Tsukuba University developed a computational tomographic imaging method based on the phase contrast of X-rays utilizing a special type of X-ray interferometer. Figures below show a brain of a rat observed through two techniques. Comparing the pictures one can see a clear superiority of the phase contrast technique over the conventioal method.

The superiority was also demonstrated when a liver of a rabbit was observed (bottom picture). A cancer in the liver was clearly visible with the phase contrast technique, but would be hard to spot when conventional method is employed. The research group is now trying to develop a new clinical imaging system using this method.



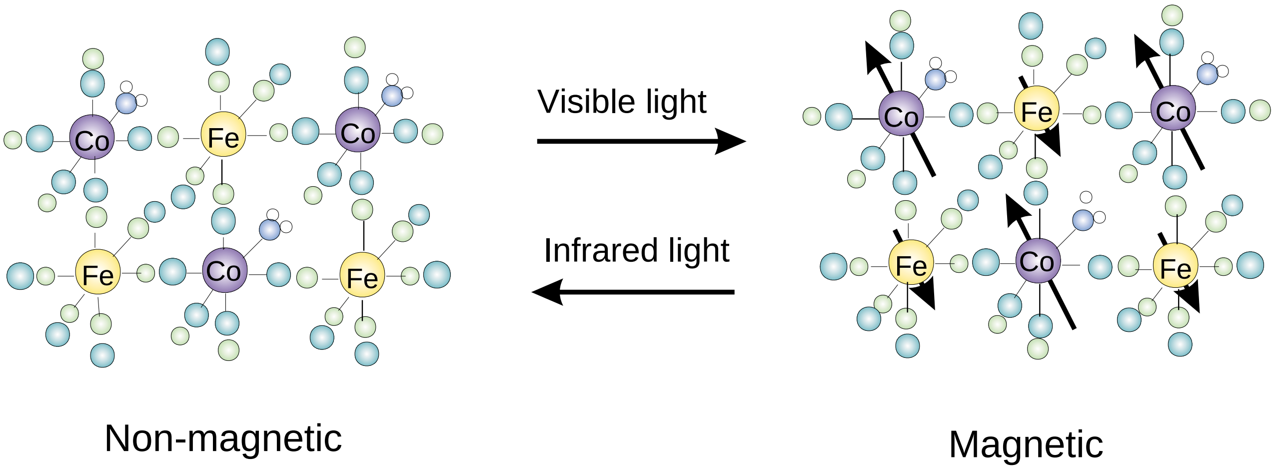
Cross-sectional image of a rat's brain
(a) Phase contrast method (b) Absorption contrast method



Phase contrast image of a rabbit's liver.
Dark area indicates liver cancer

(4) Synchrotron radiation to study a molecule-based magnet

Magnetic materials are widely used for recording as in tape recorders where changing magnetic field controls the amount of magnetization on the tape. It is known that an electrical process induced by a light irradiation can also control magnetic properties of some materials (optical switching). A group of metal cyanide complexes has attracted a great interest because light irradiation converts their magnetic property quite easily: visible light converts the material to a ferromagnetic state while infrared light converts back to a non-magnetic state in a reversible way. However, the detailed mechanism has not been elucidated yet. X-ray absorption spectra of one of such materials was studied. In the spectra, there exists oscillatory structures called an X-ray Absorption Fine Structure (XAFS) which is a result of interference between emitted photo-electron wave and back-scattered photo-electron wave from neighboring atoms. This structure reflects chemical states of absorbing elements and distances to the neighboring atoms.



Optical switching of a molecule-based magnet
Iron (Fe) and Cobalt (Co) atoms in $Na_{0.4}FeCo_{1.3}(CN)_6$ molecules are magnetized by visible light and are demagnetized by infrared light. Arrows in the right figure show magnitudes of magnetization of Fe and Co atoms.

By analyzing XAFS spectra, the efficiency of light switching was quantitatively estimated. Furthermore, detailed atomic structure change around metal atoms was quantitatively determined. Such information is very helpful in the further development of new molecule-based magnetic materials.

Radiation sources and beam handling techniques

Continuous efforts have been put in to improve this facility for all sorts of applications. Followings are some examples of improvements we have accomplished in recent years.

Radiation source

Continuous efforts have been made in developing and improving the SR source since its initial operation in 1982. The recent, most notable accomplishment in this area was the emittance upgrade of the 2.5 GeV ring in 1997-1998 after 4 years of preparation and construction of necessary components of the ring. With the improvement, the electron beam size was made much smaller than before (approx. 280 µm (horizontal) x 80 µm (vertical)) and the brilliance of the ring was increased by a factor of approximately 5.

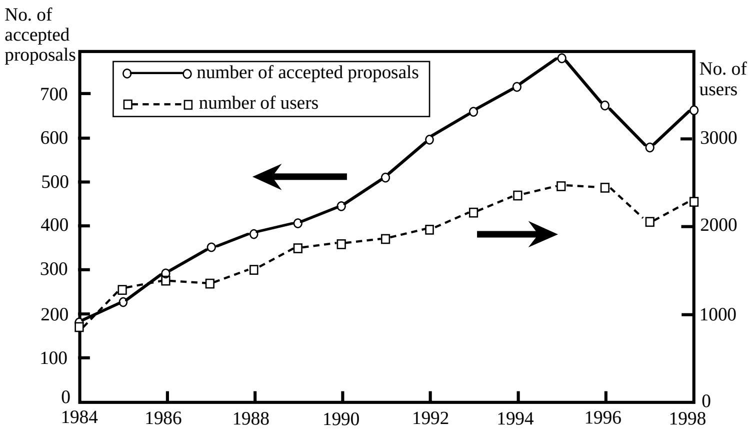
Insertion Devices

For even higher radiation intensity as well as to control polarization of the SR beam, several types of Insertion Devices were developed and installed. They have many arrays of alternating magnetic field to force the electron beam to spatially oscillate. SR is emitted at every flip of the magnetic field when electron beams pass through. The SR overlaps with each other, generating much more intense radiation. There are 6 insertion devices in the 2.5 GeV ring and 2 in the 6.5 GeV ring. Two major technical contributions from the PF Insertion Device Group are : (1) Insertion Devices for generating circularly-polarized soft-X-rays or elliptically polarized X-rays by making electron beam travel along a spirally shaped trajectory and (2) in-vacuum undulater which is useful for generating X-rays several orders of magnitude brighter than that from bending magnets.

SR beam handling technique

It is also important to efficiently transport synchrotron radiation to the sample position for experiments since we would otherwise waste the intense photon beam before it reaches the experimental station. Transporting the SR is done through a beamline that consists of many optical elements and beam transport pipes. Our PF Optics Group developed a transmission type diamond crystal X-ray phase plate that can control polarization state of X-rays very efficiently. Such phase plates are so efficient that they are now widely used at many synchrotron radiation facilities worldwide.

Users of our Synchrotron Radiation Facility



Activities per year
(dip in 1996~97 : reduced beam time due to a major upgrading work)

700-800 experimental proposals are submitted to Program Advisory Committee and reviewed annually. Approximately 500 scientific papers are published and 30-40 doctoral theses are written every year from experiments carried out at our facility.

We are open to outside institutions to construct their own beamlines at their costs. Organizations which have built and are operating such beamlines are the Australian Nuclear Science and Technology Organization (see next article in this issue) , 4 industrial companies (NTT, NEC, Hitachi and Fujitsu), Institute of Solid State Physics of the University of Tokyo, Spectrochemistry Laboratory of the University of Tokyo and Tsukuba Advanced Research Alliance of Tsukuba University. We are one of the most active centers for SR research and any users from any countries are most welcome. Professors of the Photon Factory have joint appointments with the Graduate University of Advanced Studies so that a number of graduate students and post-doctoral fellows are studying and working on synchrotron-radiation-related science. Any students who have interests and enthusiasm are most welcome.
Please visit our web pages at : **http: / / pinecone.kek.jp**

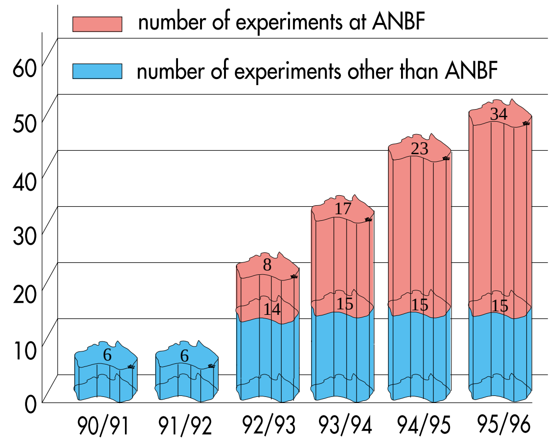
The author of this article,
Professor Tadashi Matsushita, is the head of the KEK Photon Factory since 1997 and is the deputy director of Institute of Materials Structure Science.

The Australian National Beamline Facility at the KEK Photon Factory

Towards the end of the 1980s, a core group of Australian researchers who made regular use of synchrotron radiation (SR) in their research programmes began devising a plan which would for the first time open the field of SR to all Australian researchers by providing a mechanism for routine access to a state-of-the-art facility such as the Photon Factory here at KEK (KEK PF). Through their efforts in lobbying the Australian government and the generosity of the Photon Factory management, the Australian National Beamline Facility (ANBF) came into being. The ANBF in its current form is a collaborative research project between the KEK PF and the Australian Synchrotron Research Program (ASRP). The ASRP is funded by the Australian government directly under the Major National Research Facilities programme and includes with the ANBF an Australian involvement with three Collaborative Access Teams (CATs) at the Advanced Photon Source (APS) at Argonne National Laboratory in Chicago, USA.

The ANBF has two full-time staff members based permanently at KEK - Dr. Garry Foran, the Project Leader (picture right) Dr. James (call me Reg) Hester (picture left) who recently joined the ANBF after four years working at another institute in Tsukuba (NIRIM). Reg replaced the much-loved Dr. David Cookson who is still working for the ASRP but is now part of the ChemMat CARS CAT at the APS.

The ANBF has been operational at KEK since 1993 and currently hosts about 40 experimental groups per year at beamline BL-20B. The groups cover a wide range of scientific interests including physics, chemistry, materials science, mineralogy, biology and biomedicine (See below for more details). In addition, the ANBF collaboration with KEK has led to an increased usage of other beamlines at KEK PF by Australian research groups. Currently about 15 experimental teams per year make use of the Photon Factory beamlines other than the ANBF.



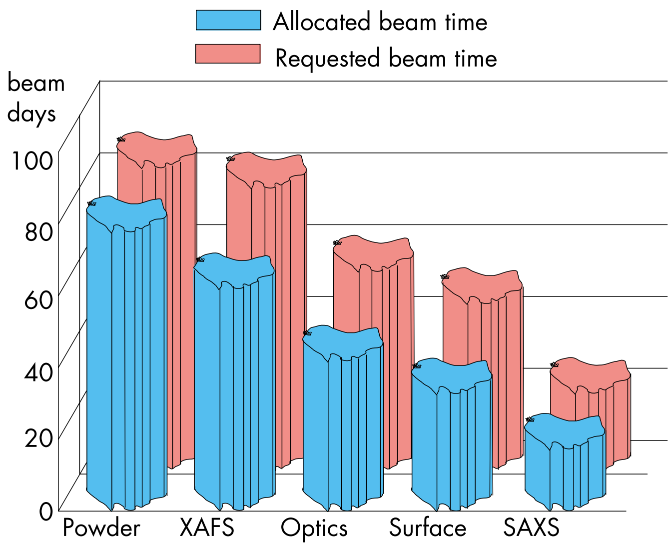
Number of Australian experiments conducted at KEK PF by financial year.

Beamline Description

Because the ANBF serves such a wide range of scientific disciplines with many and varied demands, it is by nature a multi-purpose facility providing monochromatic or “white beam” photons in the Hard X-ray range (4 - 25 keV) for use by the experimenters. Two experimental stations are available at the ANBF. The main station is a multi-configuration two-circle diffractometer which is mounted inside a large vacuum chamber. The instrument is designed to operate in a conventional scanning mode of data collection but is optimized for high-speed data collection using X-ray imaging plates (IPs). The main technique for which this instrument is used is high-resolution powder diffraction in which the X-ray diffraction patterns of powdered, polycrystalline materials are measured and then used to determine atomic level structure. A complete high-resolution data set for a single sample can be collected in a matter of minutes using this instrument, compared to the many hours of scan time required for a conventional laboratory-based diffractometer.

In addition, the diffractometer can be operated in a time resolved mode which makes it suitable to study dynamic processes and phase transitions. The unique combination of IP detection and vacuum operation of the diffractometer makes it suitable for a number of other techniques. It can be configured for grazing-incidence diffraction to study thin films and surfaces, triple-axis diffraction and small angle scattering which has found popular application in the study of natural fibres of animal and human origin.

The second experimental station at the ANBF is an optical table which is used primarily for X-ray absorption experiments (XAFS) but can be configured also for optics and imaging experiments. An extensive range of detection equipment is available for XAFS experiments including a 10 element germanium solid-state advanced array detector. A recently-acquired closed-cycle helium refrigeration system has increased our capabilities further in this active application of SR. Currently, XAFS and powder diffraction make up about two thirds of the experiments performed at the ANBF.



Beamtime allocation by experimental technique in 1995 and 1996.

Back to the Future

After more than five years of operations at the ANBF, the facility continues to mature and attract new and interesting scientific problems both to BL-20B and the PF as a whole. While demand for beamtime at the ANBF is now considerably beyond what can be supplied, it is hoped that the ANBF can continue to grow by concentrating effort into “untapped” Australian markets such as those research groups that require SR in the vacuum ultraviolet (VUV) and soft X-ray ranges.

Thanks to the hard work of the ANBF staff members and the support of the research, administrative and, not the least, the technical staff of KEK, the project has proved to be a great success and stands proud as a model for fruitful and mutually beneficial international scientific collaborations. The ANBF maintains it’s own office at the PF and can be contacted anytime by the following media.

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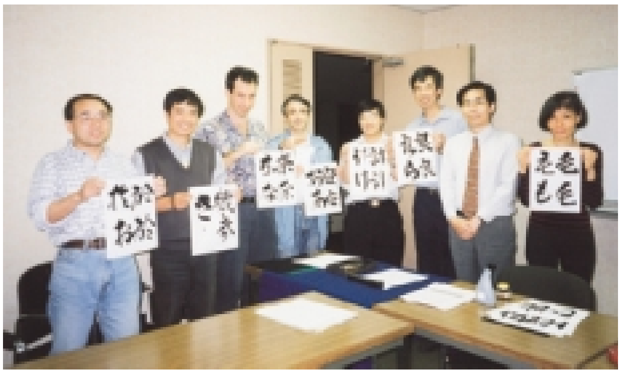
The author or this article,
Dr. Garry Foran, first came to Japan in 1982 as a high-school student and has made many trips to Japan since. He has been living in Tsukuba and working for the ANBF since the construction began in 1992.

The 20th US/Japan Committee meeting for Cooperation in High Energy Physics

The meeting to discuss on research plans for FY1998 was held on May 31 and Jun. 1. Since this meeting was held in Japan last year, it took place in USA (SLAC) this year.



Visit of Minister of Education, Science, Sports and Culture, Mr. Machimura

Mr. Machimura visited KEK for a tour on Jun. 24. He has gone through BELLE, Long-baseline Neutrino facility and Photon Factory.

"Introduction to Japan" class

KEK is now offering "Introduction to Japan" and "Japanese for beginners" classes to assist newly arrived scientists (and their families) from outside of Japan to start their life in Japan. The former provides basic knowledge on Japanese language and culture while the latter language lesson. Tuition free. Photo shows the first "Introduction to Japan" class held between May 13 and July 15.

Meeting of the KEK Council

KEK Council meeting took place on Jun. 26. Major discussion was on the KEK research plans for FY 1999. All proposed plans were approved by the Council.

1 k-ton water tank was installed

On July 21, a 1 k-ton water tank joined in the on-site near-detector system which had only iron plates for muon ranger and lead glass blocks. The preparation of the long-base-line neutrino oscillation experiment linking 250 km from KEK to Kamioka is in its final stage towards the start scheduled in early 1999.

By the end of next January, they will get a beam with slow spill and after some beam line alignments, they will start the targetting study with fast spill in the begining of February, then install the horn system in the beginning of March. (See previous issue of KEK News for more detail.)

International Science School

5th International Science School for high school students (ISS) was held between July 23 and 30. This has been the annual event at KEK since 1994.

22 students from 12 countries attended the school. This year, photon factory hosted the school under the direction of Prof. Y. Azuma. It is gratifying to know that most students who had attended past ISS at KEK have been engaged in scientific careers and some have offered their help at ISS.

KEKB main ring major milestone

There was a celebration on completion of most KEKB magnet installation on Aug. 21.

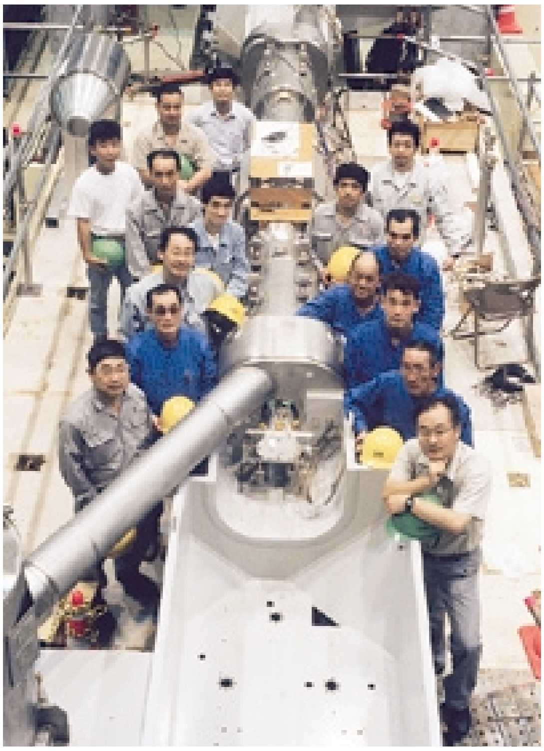
Work to convert the TRISTAN ring into the KEKB started Feb. 26, 1997 by KEK Magnet group led by Prof. Ryuhei Sugawara. Since then, 1,625 main magnets and 1,709 correction dipole magnets have been installed in the two KEKB rings. Those magnets were conveyed by hover-craft type magnet transporters through the narrow path of 1.2m wide and 2.3 m high. Now, precise alignment of them is in progress.

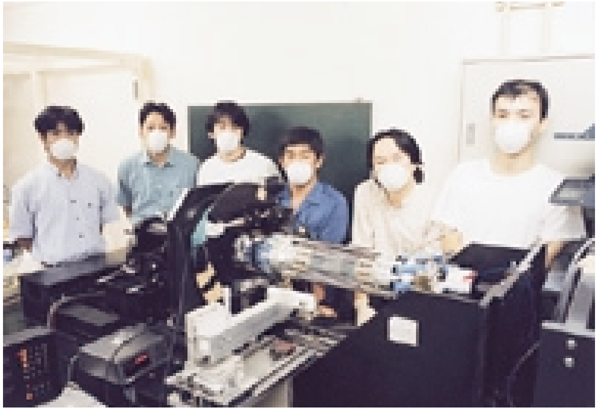
KEK Open House

Annual KEK Open House on Sept. 15 was different from previous years. A beautiful actress, Ms. Michiko Hada, came to KEK as the “Director-General of the Day”. Over 3,300 visitors came to KEK for the Open House.

KEKB beam chamber milestone

Over 80% of 2,000 beam chambers for KEKB rings have been installed by the end of September. Most are made of oxygen-free copper to cope with the very high beam intensity. Specially designed are chambers for the interaction region that has a middle connection flange in the bore of a superconducting magnet cryostat. On Sept. 18, the KEKB Vacuum group led by Prof. K. Kanazawa succeeded to joint this difficult connection and passed an important milestone to construct the interaction region.





BELLE CsI calorimeter detector assembly completed and installed

BELLE CsI calorimeter was completed and carried into Tsukuba experimental Hall on Sept. 25. Installation into the BELLE detector took place on the 30th. Its diameter of 3.3 m and length of 3.7 m is quite impressive, beside its weight is over 40 tons. It contains 6,624 CsI crystals in it.

KEKB SVD assembled

Assembly of the 32 sensor units of the Silicon Vertex Detector (SVD) was completed by Sept. 28. After the completion of support structure, it will be tested with a full-size readout system in October and then will be integrated into BELLE detector in November.

The SVD has 81,920 channels with a spatial resolution of about 10 micometers.

Picture on front cover shows a Japanese firework called "senko hanabi".
It is a small firework at 25 cm long and 2 mm in diameter, producing tiny flashes. Since it is quite safe, it is a popular firework children are allowed to play with. For the special article on photon factory, the editor thought this is appropriate as it is also a photon factory.

Picture on the back cover shows the Osaka castle. You may visit this castle when you come to ICHEP2000 in Osaka. (20 minutes from the conference site)
Picture: courtesy of Osaka Castle
Special thanks to Mr. Takeshi Watanabe, the curator of Osaka Castle.

KEK International Collaboration Office (KIC-Off) is offering an information package for people planning to come to Japan. It covers life in Tsukuba city as well as basic Japanese language/culture.
Visit the web site of KIC-Off:
http://ccwww.kek.jp/iad/fink/

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