REVIEW

OF THE

NEUTRON SCIENCE

LABORATORY KENS

IN THE

HIGH ENERGY ACCELERATOR

RESEARCH ORGANIZATION

KEK, JAPAN

Summary and Recommendations

of the KENS Review Committee

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The KENS Review Committee Member

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Executive Summary

KENS started its operation in 1980 as the first spallation pulsed neutron source dedicated for condensed matter science and neutron physics in KEK. Since the beginning of the operation, the KENS facility has successfully performed pioneering contributions to the science and technology of pulsed neutron scattering and presented much high quality research to the world's physics, chemistry and biology scientific communities.

The situation has significantly changed since KENS started seventeen years ago. The users of pulsed neutron scattering have increased enormously in not only universities but also in industry. Following the example of KENS, large-scale spallation pulsed neutron sources have now been installed in Europe and the USA.

It is a timely opportunity for KEK to survey the status of the KENS facility whilst planning a powerful next-generation pulsed spallation neutron source - the Neutron-Arena of the JHF project. At the request from the Director General of KEK, the KENS Review Committee has extensively evaluated the scientific and technical activities of the current KENS facility through both written and oral presentations from KENS.

The KENS Review Committee concludes that the scientific and technical achievements of the work carried out at KENS has contributed significantly to the progress of materials research and neutron physics in the world and the quality of the research is at a very high international standard. However, the Committee observed that the number of KENS staff is far too small to support the increasing level of university users and to implement the future plans for the N-Arena in the JHF.

The KENS Review Committee strongly recommends that the N-Arena in the JHF project be realized as a key strategy for Japanese scientists to continue the scientific contribution through pulsed neutron scattering for the peaceful progress of the world. To achieve this, the number of in-house staff in KENS (both scientific researchers and technicians) must be increased by at least a factor two over the present levels in the next few years.

Introduction of KENS Review

The KENS neutron scattering facility was established in 1978 as a division of the Booster Synchrotron Utilization Facility (BSF) in the National Laboratory for High Energy Physics (KEK), Tsukuba, Japan. In 1980, the first users' research program using a pulsed spallation neutron source dedicated to neutron scattering material sciences started in KENS. Such a short realization time is the result of the extreme dedication of research and technical staff, as well as the users involved in KENS. To date, a number of scientific and technical achievements have been realized under the outstanding leadership of KENS, operating as an inter-university research facility.

In April 1997, the KEK was rearranged to a new organization named as High Energy Accelerator Research Organization (KEK), by joining Institute for Nuclear Study of the University of Tokyo and Meson Science Laboratory of the University of Tokyo. There are three main groupings in the new KEK: the Institute of Particle and Nuclear Sciences: the Institute of Materials Structure Science; and the Accelerator Laboratory. KENS now belongs to the Institute of Materials Structure Science within KEK.

The new KEK is responsible for the Japan Hadron Facility (JHF) project which has been a long time goal for the neutron scattering community in Japan. The construction of JHF will most likely start in 1998. It is therefore an excellent time for KEK to evaluate the scientific and technical achievements of the KENS facility.

The KENS Review Committee is composed of the external reviewers listed on a previous page. The Committee members were selected according to the seven fields of KENS activities:

neutron source;
instruments;
structure of materials;
dynamics of condensed matter;
soft materials;
fundamental neutron physics; and
JHF neutron-arena plan.

Six members attended the Review Committee meeting held on July 10, 1997 in KEK, and one member joined by a television route, for reviewing directly the presentations from KENS staff and users groups. The two members of the Review

Committee presented their evaluation reports on the basis of the documents published by the KENS facility.

The evaluation points of the Review Committee are as follows:

- Quality of scientific research;
- Technical development;
- International collaboration and competition;
- Inter-university users program;
- Education and training;
- Prospect of Neutron-Arena in JHF project.

Each reviewer presented to the chairman of the Review Committee his review report of the field charged to him concerning the evaluation points mentioned above. The final report of the KENS Review Committee was completed by collecting the reviewer's reports and arranging them under the responsibility of the chairman. This evaluation report will be presented to the Director General of the new KEK.

General Survey of KENS Activities

History of KENS

Pulsed neutron scattering for condensed matter science in Japan started in Tohoku University and Hokkaido University utilising electron linear accelerators in the late 1960s. Based on the pioneering experiences in these universities and also that of Argonne National Laboratory, KENS was constructed as the first spallation pulsed neutron source in Japan and began the operation of a 500 MeV and 1 μA proton beam in June 1980.

The KENS-I' upgrade project was realized in 1985 by replacing tungsten target with depleted uranium one, together with intensifying the proton beam current, to result in increasing neutron beam intensity more than four times. This target operated successfully until 1996 when it was replaced with a tantalum target. The proton beam current was gradually increased and has maintained the continuously high level of about 5 μA since 1992.

The beam time allocated to KENS has reached saturation at 1989, but dropped by about 30 % for the last two years of 1995 and 1996 because of the operation break of KENS due to the construction of a new experimental hall.

When KENS started operation in 1980, there were only five spectrometers available for users. In 1997, seventeen spectrometers are operational in the present KENS. Eight spectrometers have been installed at four beam holes looking at a cold moderator, while the nine spectrometers have been located on nine thermal neutron beam holes. Three spectrometers have been discontinued.

Budget

The budget for upgrading the neutron source and constructing the new spectrometers have been approved in 1987, 1990 and 1995. However, running costs for operating the neutron source and instruments and for performing experiments has shown essentially no fluctuation around 330 million Japanese Yen since starting the operation of KENS. This means that the average maintenance cost for each spectrometer currently has decreased to less than half of that in the beginning of KENS operation, because the number of spectrometers available for users is more than twice at the present moment.

KENS staffs have continuously received the Grant-in-Aid for Scientific Research from Monbusho since 1990. In particular, the travelling fund for Japanese scientists to visit the ISIS under the Japan-UK contraction has been raised by KENS until 1996. KENS has also accepted payment from industry continuously since 1988, when industrial researchers use the KENS facility.

Personnel

The activities of KENS are supported by in-house staff and users. The total number of KENS in-house staff has been almost constant (14 to 16) including professors, associate professors, research associates and technicians since 1988, despite the increase in neutron beam intensity and the number of the spectrometers. A current difficulty is the decrease in the number of young research associates, who should play a central role in the practical work and also in the future development of KENS. Personnel exchanges between university researchers and KENS staff is very important and should further be encouraged.

KENS had 350 registered users in 1996. This is a substantial increase over the 50 users when KENS started operation in 1980. Almost all users of KENS come from outside as visiting scientists and research students from universities and institutes in Japan. Users from overseas are still relatively small in numbers.

Inter-University Users Program

KENS users do not simply use the KENS facility, but are organized to join machine groups which are responsible for the design, operation, maintenance and improvement of instruments together with the in-house staff. In exchange for the obligation, a half of total machine time is preferentially allocated to these groups, in addition to the money for supporting the research to be carried out using the spectrometer. According to the different function and degree of collaborations, the groups are classified into four categories. The leader of the group is very often an outside user. The groups and spectrometers in KENS correspond to each other.

Since the number of neutron beam holes and the funds for spectrometer construction are limited, severe competitions is unavoidable among the groups. Such a mechanism for the collaboration and competition in KENS, which has worked quite successfully, may be a unique feature in the Japanese neutron community.

The number of research proposals from university users has been linearly increasing from the beginning of operation of KENS. Since the neutron beam time at KENS has not increased since 1991, oversubscription now reaches a factor three. The users proposals are concentrated on the subject of crystal structure and excitations including liquids and glasses. The Review Committee is strongly appreciative of the fact that the shortage of beam time for crystal structure researchers has been substantially reduced by constructing the new powder diffractometers VEGA and SIRIUS.

Education and Training

KENS staff give lectures as visiting professors at universities and also act as supervisors to 12 research students in PhD courses to 1997. In addition, as registered users of KENS facility, 73 students worked and completed their doctoral theses through their university programs. KENS has made significant contributions to the education and training of young scientists who are essential to carry out the future plans of KENS.

Proper development of young scientists is crucial to the well-being of any field and this is especially so in neutron scattering where limited experimental resources are available. KENS is an appropriate place to host, e.g., training schools and financial support for such purposes is highly recommended.

International Collaboration

In the Japan-UK collaboration in neutron scattering research, KENS has had the major responsibility for the exchange of scientists and engineering of instruments, particularly for the construction of MARI spectrometer at ISIS. KENS scientists have played a key role in developing advanced techniques for measuring excitations in single crystals at pulsed sources The development of such techniques at ISIS is an essential step towards the realisation of next generation pulsed neutron sources world-wide.

KENS is a founder member of ICANS - the International Collaboration on Advanced Neutron Sources - which has done so much to stimulate the development of spallation sources world-wide. KENS has served as the host of ICANS meeting in 1980 and 1990, and significantly contributed to the every meeting of ICANS since 1980. As a part of ICANS collaboration, there have been more than twenty scientists exchanged in long term stay between KENS and foreign pulsed neutron facilities.

International collaborations are vitally important for continuing the scientific activity of neutron communities. The present close relationship with ISIS should be maintained and developed further. At the same time the future possibility of collaborations with Grenoble and Asian countries should be kept in mind, so that KENS becomes really international. Regular scientific meetings should be held in KENS to publicise its activities to broader international communities.

KENS Neutron Source

KENS is the first pulsed spallation source constructed for the purpose as a full-blown research facility. KENS has operated successfully from its beginnings and done much to prove the effectiveness of the concept, both world-wide and in the scientific community of Japan. A distinguishing feature of KENS is its high efficiency in converting protons to slow neutron beams, exploiting a very tightly coupled target-moderator geometry which sets a standard not met elsewhere and demonstrates a goal to which other designs must aspire. The use of only two moderators enhances this efficiency, notwithstanding the fact that the moderators serve a large number of beams and instruments. KENS also set new standards in neutron facilities development by the early use of a solid methane moderator and guide tubes.

Starting from 1 to 2 μA proton current, KENS has steadily improved in performance and has reached 5 μA over the course of the years. This, together with continuous improvements on the existing instruments and addition of new innovative ones, allowed KENS to become an important user-oriented facility, attracting scientists not only from all over Japan but also from around the world. While the beam time allocated to KENS has remained roughly unchanged over the years, the number of research proposals accepted and completed successfully has grown almost linearly throughout the whole period and has reached an impressive number of 150 in recent years. This has become possible not only by adding new instruments to the existing suite, but also by upgrading earlier ones or replacing them with more efficient ones.

The continuing close collaboration with the Hokkaido University group and Prof. Watanabe is a great benefit to KENS and to the larger world effort in target-moderator-reflector systems development. Collaborations set up within the framework of ICANS and with ISIS, PSI and INR will similarly be very helpful in accomplishing a highly efficient facility in the N-Arena of the JHF

All these development and activities serve exceedingly well to position the KENS group to arrive at highly refined, efficient design for the N-Arena of the Japan Hadron Facility. Furthermore, the recently formed collaboration with the KUR group on target thermal, hydraulic and mechanical engineering provides an excellent mechanism for N-Arena target development.

KENS Neutron Scattering Instrumentation

KENS now has a suite of instruments that is able to cover a broad range of energy and momentum transfer, with suitable resolution. Several diffractometers (HIT, HRP and SAN) provide information on the static structure of materials over a range of length scales from sub-angstrom to fractions of a micron, and a suite of spectrometers (LAM-40, LAM-80, LAM-D, CAT, MAX and RAT) allow atomic and magnetic dynamics to be studied over a wide range of time scales.

Several of the neutron scattering instruments at KENS are based on innovative designs whose value can be judged by the fact that they have been imitated at other neutron sources. Examples includes MAX (which is the forerunner of PRISMA at ISIS) and CAT and RAT (the forerunners of TFXA and EVS at ISIS). In other cases, clever instrument design has enabled scientists at KENS to make measurements in some fields of science that are fully competitive with those made at the world's best facilities. A case in point is the LAM-80ET instrument which, for measurements of Q-independent scattering, provides both similar resolution and similar count rates to the IRIS spectrometer at ISIS, which has about 60 times greater proton beam power.

In the area of powder diffraction, one of the world experts in this field, Dr. J. Jorgensen of Argonne National Laboratory, has informed us that the KENS instrumentation is now more advanced than any in the world. A special symposium will be organized at this year's International Conference of Neutron Scattering to examine first results from SIRIUS and to plan an international strategy for advancing the state of the art even further. That new diffractometer sets a new standard for large solid angle detectors and their implementation through data acquisition and calibration.

WINK and SWAN are unique instruments designed in KENS and they simultaneously provide very wide Q-scan range of 10^{-2} to 10^{2} nm^{-1}. Such a wide Q-scan will be surely a key strategy for exploring the overall structure of complicated amorphous systems between organic and inorganic materials.

Until recently, the KENS facility has suffered somewhat from the restrictions of space in the experimental area. While this has been largely overcome by a clever arrangements of instruments in the crowded room, the new cold neutron hall completed in 1996 will enhance the effectiveness of the facility and its service to the scientific community.

Japanese scientists at KENS have recognized the importance of advanced neutron technology and novel sample environments and have systematically moved forward in these areas. For example, the PEN instrument was one of the first (if not THE first) in the world to perform generalized polarization analysis by carefully controlling the magnetic fields around the sample. In another area, scientists in Europe and the USA are now beginning to emulate their Japanese colleagues by constructing high-field magnets, but it will be several more years before there is any serious competition to the 30 Tesla magnet that is available at KENS for the studies of the structure of magnetic materials.

Scientists associated with KENS have also advanced the state of the art in the area of neutron detection, by developing a linear position sensitive detector package with compact, integrated amplifier having excellent positional resolution. This same technology, applied to increase the large-Q range in the small angle diffractometer SWAN, exemplifies KENS's leadership in the push to larger numbers of data pixels in advanced time-of-flight instrumentation. On-going research on helium scintillation detectors is aimed at producing detectors that can handle 100 times the counting rate of present-day detectors and that will therefore be well-suited for development at more intense neutron sources, such as that envisaged for future construction at the N-Arena in the JHF project.

The Review Committee recognizes the importance of the chopper spectrometer developments pursued jointly between KENS and ISIS. MARI and the forthcoming MAPS spectrometers not only provide access for the Japanese scientific community to state-of-the art spectrometers, but also represent important experience on which to build new instruments for the N-Arena.

An important feature of the instrument construction activity at KENS has been the way in which students and professors from Japanese universities have been involved. Not only has this contributed strongly to the education of students, but it has proved to be a very efficient way to construct many instruments without unduly augmenting the in-house staff. This method of involving the national community in the construction of instrumentation has not been widely used in the rest of the world, but is now being attempted in different guises at centres in other countries, partly because of the success that it has had at KENS. Observers from foreign centres conclude that there is much in this model that can profitably be applied in instrumentation programs at new facilities developing outside Japan, not only in the provision of instruments but also in governance of their utilization through the external instrumentation groups.

Opening his presentation to the Review Committee, Dr. M. Arai noted that "Our unique instrumentation has made KENS competitive with other more intense sources". The Review Committee fully concurs with this view and congratulates the scientists who have been involved with instrument construction at KENS on their innovation and efficiency in building a suite of instrumentation which is truly world class.

Scientific Achievements

Structure of Materials

Probably the most remarkable achievement at KENS in structural study of solids is the world's earliest determination of the High-T_c superconducting material in 1987. As soon as the crystalline $YBa_2Cu_3O_7$ was reported to undergo a transition to the superconducting state at 90 K, almost all of the solid state researchers began to address the problem. Among such the world-wide movements, the scientists at KENS pioneered in the determination of detailed crystal structure of this substance using the HRP spectrometer. It is worthwhile mentioning that the achievement was brought in by an *ad hoc* 3 days extension of the operation of the proton accelerator at KEK. This pioneering work has been followed by a large amount of structural data of various class of High-T_c superconducting materials, which has contributed to broad understanding of novel mechanism of superconductivity.

The hydrogen bond is one of the chemical bonds which plays an important role in life science as well as materials science since various biological functions are associated with the hydrogen bonding in proteins, DNA, etc.. In this context, neutron scattering study of hydrogen-bonded systems developed by KENS group is worth noting. On the one hand, the world's finest energy resolution of LAM-80 spectrometer has been utilized to observe the energy level splitting of tunnelling protons with energy separation as small as a few nano-eV. On the other hand, observing Compton scattering with RAT/CAT spectrometers, they succeeded to determine directly the ground state wave function of the protons forming the hydrogen bonds in solid systems such as KH_2PO_4. Systematic investigations on this line will open up new research field aiming at microscopic study of biological functions played by hydrogen bonds in biomolecules.

Considering future development of materials science, one of the most important research fields is the study of materials under extreme conditions such as ultra-high magnetic field, ultra-low temperature, ultra-high pressure, etc.. This research field is most favorably developed by the use of pulsed neutron source when incorporated with pulsed generation of the extreme conditions. KENS has achieved pioneering works in this direction, particularly by combining pulsed magnetic field (30 Tesla) with the pulsed probe neutrons where the timing of the application of both pulses is properly synchronized. The observation of field induced phase transition in $CsCuCl_3$ crystal at 12 Tesla has clearly demonstrated the power of the pulsed neutron scattering study in the research of materials under extreme conditions.

Polarized neutrons play important roles both in fundamental physics and the condensed matter physics. Therefore, it is very important to have neutron spin polarizers and analyzers. The KENS group has developed the polarized proton filter, and have succeeded for the first time to polarize the neutron spin more than 70% over a wide energy region. They have also developed the polarized ^3He filter and obtained 40% ^3He polarization at high pressure of 3.5 atm ^3He gas. These neutron spin polarizer and analyzer have been successfully applied to the above studies.

Another notable tendency in materials science in recent decades is the movement from 'simple and regular' systems to 'complex and irregular' systems. Recent developments in the study of quasi-crystals, amorphous materials, systems in percolation limit and etc., illustrate this tendency. From this viewpoint, the achievements by the scientists at KENS in the study of magnetic systems at the percolation limit, as well as of various amorphous materials, are highly regarded.

The structural study of the percolated magnetic system $Rb_2Co_cMg_{1-c}F_4$ clearly shows that the system is characterized by a fractal system with the fractal dimension of D_f=1.89. It should be noticed that the fractal nature has been directly observed by the line profile of the scattered neutron spectrum S(Q). This situation will be extended to include energy spectrum. In other words, the energy-momentum spectrum S(Q, E) would show time-wise fractal nature as well as space wise. The first observation of 'fractons' at KENS in the same system is quite attempting and certainly suggests future developments of neutron scattering study in the new research field of 'complex systems'.

Liquid and amorphous solids are a large part of the structure studies carried out in KENS. Separation of center-center correlation and orientational correlation of molecules existing in the liquid state is a noteworthy success due to the use of short wavelength neutrons provided efficiently by the KENS neutron source. The high-Q measurement using the short wavelength neutrons also gives the highly resolved short-range structure in the radial distribution function. This point has been fully applied to assign the atom-atom correlations in various kinds of multicomponents glasses to find the role of chemical bonds in the topologically disordered materials.

Dynamics of Condensed Matter

In condensed matter studies, neutron scattering experiments play unique roles by its capability of extracting the information of atomic and spin structures, S(Q, E) and

$\chi(Q, E)$, respectively, in a very wide range of momentum Q and energy E. Frontiers of the neutron scattering research are then in large and small Q and high and low E together with the higher resolution in both variables Q and E. To pursue these frontiers the higher intensity has to be constantly pursued. At the same time combination of neutron scattering experiment with the high magnetic field, high pressure and low temperature have resulted in even more important findings.

The dynamics of solids, liquids and particularly of magnetic materials is one of the strongest research area in KENS. One measure of the strength of this research program is the ease with which Japanese scientists obtain beam time on inelastic scattering spectrometers such as MARI and HET at ISIS. Time on these machines is awarded purely on the basis of peer review of scientific proposals, a competitive procedure which results in Japanese scientists obtaining almost twice as much beam time than would be obtained pro rata.

The studies of magnetic dynamics by KENS staff and users are in forefront areas, such as high temperature superconductivity and low-dimensional magnetism, where there is considerable international competition. A notable study in these frontiers areas carried out in KENS is the exploration of the fractal structure of percolating magnetism realized in diluted antiferromagnets. The high Q-resolution experiments have confirmed unambiguously the scaling nature of these systems. At the same time the nature of anomalous spin diffusions in percolating magnets have been clarified by the experiments carried out at very low energy transfer.

A unique spectrometer MARI, which can scan a wide range of Q and E, has clarified spin dynamics of antiferromagnetism in the high T_c oxide parent La_2CuO_4 and its Sr doped compounds, and the qualitative differences of the width of the spin wave in the limit of low temperature between S=3/2 ($CsVCl_3$) and S=3 ($CsCrCl_3$). Similarly the experimental data obtained for a wide range of Q and E have identified the location of hydrogen atoms in $KHCO_3$ and hence led to the effective potential for hydrogens. A good example of combined experiments is the exploration of phase transitions in $CsCuCl_3$ in the magnetic field, pointing to the existence of new type of phase transition caused by the quantum fluctuations.

Another area that has been pioneered by scientists from KENS is that involving investigations of short-range correlations of dynamical nature in a variety of materials (dynamical pair correlation functions). Although this technique is logical extension of the elastic partial distribution function, it represents a different way of thinking about the dynamics of materials and has already shed new light on a number of problems, including the dynamics of high T_C superconductors. As an example, one may cite the work performed on the dynamics of SiO_2 and $GeSe_2$ glasses. In the former case, inelastic neutron scattering was used to extract the information about Si-O-Si bond angle and dihedral angle between SiO_4 tetrahedra, which was very difficult to obtain by other methods. In case of $GeSe_2$ glass, results observed by MARI showed that there is no need to modify the generally accepted continuous random network model for the structure of this glass.

High-Q experiments contributed to the clarification of the short- and medium-range order such as atomic distance and the co-ordination number in metallic glasses. For example, the existence of the trigonal prismatic packing of six Ni atoms in Ni-B amorphous alloys was found. Inelastic neutron scattering measurements using the LAM-40 clearly represents the identification of the so-called Boson peak (excess spectral weight in medium energy range (several meV)) in $Pd_{79}Ge_{21}$ amorphous alloy as due to the hinge-like motion between trigonal prismatic units.

Soft Materials

The importance of neutron scattering for studying soft materials has arisen first from the labelling possibilities offered by the large difference in the coherent scattering length between hydrogen and deuterium, and secondly from the available Q-range, which concedes exploration of distance scales from a few repeat molecular units up to the dimensions of whole molecules. A great advantage in the usage of pulsed neutron facility for the study of soft materials is to allow the simultaneous measurements in the wide range of both momentum and energy space at the same sample conditions, because several phenomena observed in soft materials are resulted in complex conformational and morphological changes at different circumstances. These powerful neutron scattering techniques have been successfully applied in the studies of several polymer systems at the KENS facility.

A typical example is the investigation of structure and mechanism of physical gels using atactic polystyrene as a sample. When the crosslinking of polymers is of a physical nature, thermoreversible gels are formed. On cooling the polymer solution, a sol to gel transition is observed. The neutron scattering experiments of atactic polystyrene solution in carbon dioxide revealed that two mechanisms of physical gelation existed in different molecular conformations of polymer segments. Another scientific highlight done at KEK is the study of glass transition dynamics and relaxation processes of polymers. Using a quasielastic neutron scattering technique, the dynamics of amorphous polybutadiene was investigated as a function of temperature. A very fast motion of picosecond order was found at the so-called Vogel-Fulcher temperature T_0, suggesting that the fast process is a precursor of the glass transition. This fast process was assigned to a damped vibrational motion in the C-C tortional potential well. In addition to the fast process, a slow motion of 0.1 nanosecond order was observed above the glass transition temperature T_g. This slow process was assigned to an elementary process of conformational transition in a polymer chain, leading to structural relaxation above T_g. These experiments have been performed in the close collaboration among many scientists from several universities under the inter-university program of KENS.

Currently inorganic ceramics and often transient materials between inorganic and organic state have been prepared from organic polymers specially designed as a precursor material. The KENS neutron instruments LAM-40, SAN and WINK have worked efficiently to find that a very high mechanical strength of Si-C-O-(Ti) fibres (a kind of semi-soft material) is not simply related to an anisotropic fibre structure induced by the organic-to-inorganic conversion, but essentially originated from the formation of critically sized b-SiC crystalline nanoclusters embedded in Si-C-O amorphous matrix. Such a new category processing, which lies across conventional disciplines of organic and inorganic materials, might be a merging and promising area for pulsed neutron scattering characterization of dynamics and medium-range structure at the KENS facility.

Neutron scattering is also one of the useful tools to investigate the structures and dynamics of biomaterials. However, the neutron intensity of the present facility at KENS seems to be too low to elucidate the biological phenomena in details, although a few preliminary experiments related with biomaterials have been carried out. This would be realized in the near future by the use of high neutron flux of N-arena in JHF Project.

Fundamental Neutron Physics

The neutron is a unique probe to search for the parity- and/or T-violating effects in nuclei. Masuda and his colleagues have contributed significantly to the progress in the above fundamental physics; the works by them are of very high quality and of world-wide interest. One of the outstanding work is the establishment of mechanism of the parity violation enhancement in compound nucleus of ^{139}La. The first observation of the longitudinal asymmetry as large as about 10% was made at Dubna in the p-wave radiative capture resonance, and later at KENS with a sophisticated instrument. The mechanism of this large parity-nonconserving (PNC) effect, however, was not clear at that time. Recently, Masuda et al. have succeeded for the first time to observe the parity-violating neutron spin rotation in the same p-wave resonance, which played a key role to understand the mechanism. Furthermore, their results could provide us a very useful information to estimate the effects of the T-reversal invariance in the same reaction. It should be stressed here that these works have been carried out by developing the sophisticated and sensitive techniques of the dynamically polarized proton filter and the polarized ^{3}He filter.

International collaboration was rather poor in the past, most likely due to a very small number of the permanent staff. Recently, however, the collaboration becomes active, and actually Masuda et al. are doing the above experiment with scientists from various countries at Los Alamos; this change might be due to the well organization of the inter-university program. Here it should be mentioned that the polarized ^{3}He filter developed at KENS has enabled them to start the above experiment of the parity violating neutron spin rotation at Los Alamos. While, the polarized proton filter developed at KENS has attracted the scientists at Los Alamos, and thus, they made great efforts to improve the performance of the filter. Furthermore, the experiment of the polarized neutron diffraction of polarized biological material was for the first time carried out at KENS, which stimulated the GKSS group in Germany.

The outstanding works mentioned above have been carried out in collaboration with scientists from a several number of universities, and therefore an inter-university program seems to operate well in this field. However, the numbers of PhD course students and post-doctoral fellows are small. Since not only the research but also the education must be an important part of the activities of the KENS, it would be very important to extend the inter-university program further by increasing the number of positions for the experimental group, and by developing a new system to strengthen the connections between the KENS in-house staff and the outside group. Increasing the number of positions for the experimental group and the support staff is strongly recommended, and furthermore, it is highly desirable to provide funds for post-doctoral positions and for supporting foreign visitors.

It is extremely interesting to extend the studies such as the p-wave radiative capture resonance of ^{139}La further to search for the T-violation effects in nuclei. The measurements of the electric dipole moment and the life time of the neutron are very important not only in fundamental physics, but also in cosmology. For the measurements, however, one should make a great efforts to increase the number of the UCN, and for the development it is strongly recommended to strengthen the international collaboration. It should be added that the spallation neutrons in the keV region can be a unique probe in the interdisciplinary fields, such as the nuclear astrophysics.

Future Research Plan -Prospect of N-Arena in JHF Project-

The scientific and technical success of KENS make it obvious that as a long term strategy Japan would need at least one facility with significantly higher performance to fulfil the demand of its scientific community and to attract a larger international user clientele.

In 1983, immediately after the successful start-up of KENS-I, a next project KENS-II aiming at 0.4 MW pulsed spallation neutron source was planned. In 1986, KENS-II was merged into the original Japanese Hadron Project (JHP), which comprised an 1 GeV and 400 μA linac and a 200 μA compressor/stretcher ring to be constructed on the basis of completely new infrastructure. However the total cost of this JHP project was estimated to be rather expensive.

In 1995, taking into account the plans Europe and USA have for building megawatt class spallation neutron sources, new requirements were reconsidered as a Neutron -Arena in Japan Hadron Facility (JHF) as follows; i) proton beam power: 1 MW class, ii) energy: between 1 and 3 GeV, iii) repetition rate: between 10 and 50 Hz and iv) harmonics: not critical. Finally, the plan for the N-Arena of JHF project represents a highly cost-effective use of existing infrastructure and shared use of accelerator facilities built within JHF project for its other application.

The JHF project comprises three accelerators, a 200 MeV linac, a 3 GeV booster synchrotron and a 50 GeV main ring. While the main ring will operate on 0.3 Hz repetition rate, the linac and booster can run at 25 or -with some upgrade- at 50 Hz. Although the beam power is more than a factor of 200 up from the current KENS facility, it is still at the medium range of the parameter other pulsed source projects world wide are now aiming at (AUSTRON, 0.25-0.5 MW; NSNS 1-4 MW; ESS 5 MW). Therefore, there is not completely no technical risk that the facility can be built and operated, although ISIS has been running at 0.2 MW for several years and the continuous spallation neutron source SINQ is now successfully running at 0.5 MW.

Upgrade options will be discussed below:

The energy of 3 GeV is higher than what is normally considered the optimum for spallation targets, but it also has its advantages, since the desired power can be reached at a lower current and hence less radiation damage in critical component such as the target window. The frequency of 25 Hz is an excellent compromise allowing also slow neutron measurements to be carried out with good efficiency.

The general design of the target station for the N-Arena follows the concept which is now widely accepted as the most viable and cost efficient one: horizontal beam injection and removal of the target into a downstream hot cell area. While some other projects chose to make the target removable independent of the moderator-reflector assembly, the N-Arena design group prefers a single target-moderator-reflector assembly (TMRA), thus saving on remote handling equipment and associated cost on the possible expense of longer maintenance and repair periods.

The project being in a rather early stage at present, several decisions are still pending and cannot be evaluated at present. However, the KEK design group is actively involved in several national and international collaborations and is fully aware of developments going on elsewhere, in particular also through the long standing tradition of KEK in participating in the International Collaboration on Advanced Neutron Sources (ICANS).

While, as mentioned above, the N-Arena can be expected to run at roughly 0.6 MW in routine operation, the design power of the target station has been specified as 1 MW. This is in view (a) of the possibility of running the N-Arena target without sharing beam with the M-Arena over periods of time and (b) of an upgrade potential of the accelerator facility.

Two possible routes of upgrading the facility in terms of beam power are being discussed: (1) increasing the repetition rate to 50 Hz and (2) increasing the linac energy to 400 MeV to allow injection of a larger number of protons into the booster at each pulse. It is important to note that these two options are not equivalent in terms of the neutron generation and utilization. Once the instruments are optimized for a certain (e.g. 25 Hz) repetition rate, doubling the frequency will benefit many of them only little or not at all. Increasing the number of neutrons per pulse will raise the instantaneous load on the target and suitable design provisions must be made. Both routes are viable, however and either one of them would make the N-Arena in JHF project a truly world class facility. Using existing buildings to house the facility enables substantial cost savings and a clever way has been worked out by the design team to accomplish this.

Finally, efforts are going on to enhance international participation in JHF, which should also apply to the N-Arena. The problems hindering or making such international presence at KEK difficult at the moment have been recognized by the management and suitable proposals to alleviate them have been put forward. With improved accessibility and working conditions for foreign visitors, the N-Arena in JHF project could become a truly international centre of excellence in the Asian-Pacific region and a focal point for scientific and technological research using neutrons which will continue to be an indispensable tool even in the era of increased significance of light sources and other novel techniques.

The instrumentation program for the N-Arena will be more demanding of available resources than has been the program for developing instruments for KENS. Innovation at KENS over the past two decades owes much to the vision, foresight and leadership of Professors Ishikawa and Watanabe. Similar strong leadership will need to be identified and nurtured to make the N-Arena project a success.

Conclusions and Recommendations

The KENS facility has performed a remarkably successful function as the first pulsed spallation neutron source dedicated for condensed matter sciences and neutron physics since the beginning of operation in 1980. Pioneering works for the design and construction of neutron sources and instruments still continue at KENS. Much high quality research of a high international standard has been given from KENS to the scientific communities of physics, chemistry and biology in the world.

However, the situation has been significantly changed from when KENS started seventeen years ago. The user community of pulsed neutron scattering in Japan has been enlarged, in not only universities but also in industries, to approximately ten times compared with the start-up of KENS. Outside of Japan, large-scale spallation pulsed neutron sources were installed at the IPNS in Argonne National Laboratory and the ISIS in Rutherford Appleton Laboratory after KENS. Furthermore, Europe and USA are actively planning new megawatt-class spallation neutron sources.

On the basis of the historical situation mentioned above, the KENS Review Committee has surveyed extensively the scientific and technical activities of the current KENS facility by hearing the presentation and/or by reading the written reports submitted from KENS. The KENS Review Committee concludes the evaluation and presents the recommendations as follows:

- The scientific and technical achievements carried out in KENS have contributed significantly to the progress of materials research and neutron physics in the world. These researches are of very high quality in the world-wide standard. The productivity of the achievements has been maintained at a significantly high level despite of the shortage of neutron beam time and in-house man-power at KENS.

- There is the difficult problem of the reduction of numbers of young scientists on the KENS staff. The numbers of KENS staff is far too small to support the rapidly increasing number of university users. The Review Committee strongly suggests that the number of the KENS in-house staff has to be increased at least to the twice of the present number for both the researchers and technicians over the next few years.

- The inter-university users program has been efficiently organized. The machine group system has functioned quite efficiently so far, as a unique mechanism for the maintenance and development of new instruments in KENS. However, it must be carefully considered that this mechanism will be still promising in the future of KENS. The personnel exchange between universities and KENS is extremely effective.

- The Neutron-Arena in the Japan Hadron Facility is a most necessary and timely project for developing the neutron scattering activity indispensable to materials science and technology in Japan.

- The Review Committee strongly recommends that the N-Arena in JHF project must become a key strategy for Japanese scientists to continue the scientific contribution through pulsed neutron scattering to the peaceful progress of the world. In particular, KENS must be a Centre-of-Excellence for neutron scattering science in the Asian-Pacific region.