Progress at the pulsed-spallation neutron facility KENS

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1. Outline

The world's smallest pulsed-spallation neutron facility KENS is still active and has been successfully operated since the last ICANS with increasing proton-beam intensity. Scientists of the proton accelerator group at KEK have convinced themselves that a beam intensity of 2 x 10^{12} protons per pulse came within range.

The beam time allocated to neutron-scattering experiments was about 1150 hours per year, which is saturated since 1981. Visiting scientists spent about 3500 man-days at the KENS facility in the last year from about 40 different institutes to perform experiments. Fig. 1 shows the total number of registered users in each fiscal year since FY 1981.

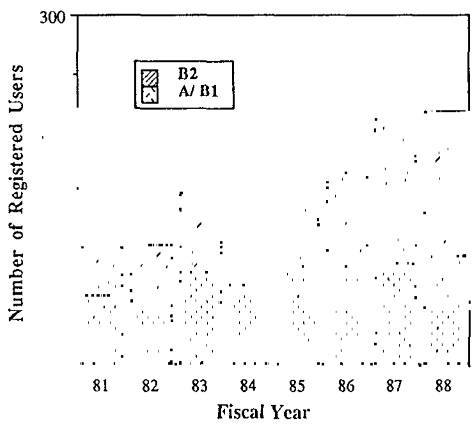


Fig. 1 Number of registered users

Figure 2 shows the number of proposals accepted each year. About 60 proposals including test experiments were accepted each recent year from more than 65 proposals, and about 55 experiments were successfully completed. At KENS we have two categories of proposal. Proposals by large groups responsible for construction, operation, maintenance and improvement of the instruments which they are concerned with are classified in the first category A/B1 and they can use up to 60% of the beam-time. On the other hand, proposals by small groups of pure users are in the second category, B2, and they have to share the remaining 40% beam-time in competition. We intend to increase the B2 fraction: for example, in the case of the small angle scattering instrument SAN, more than 60% of the beam time is allocated to B2.

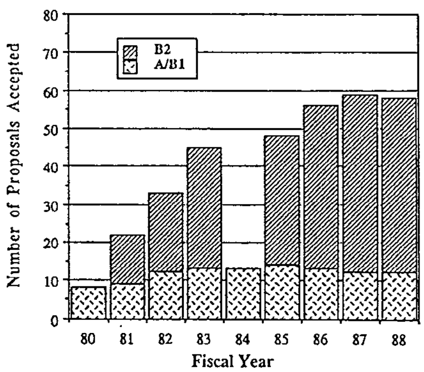


Fig. 2 Number of proposals accepted

Figure 3 shows a beam-time distribution of each instrument used in various research fields in recent years.

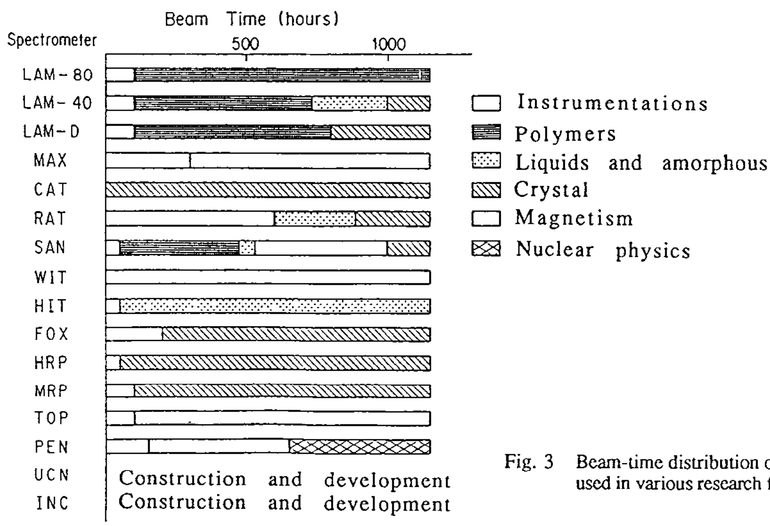


Fig. 3 Beam-time distribution of each instrument used in various research fields

The budget for KENS has also been saturated since FY 1985. Table I shows, in round numbers, the budget in FY 1988 after adjustments at KEK. Costs for manpower and for accelerator operation are not included. Laboratory overhead and various costs for radiation safety, electricity, water, air-conditioning etc. have been subtracted. KEK supports full expenses for travel and stay of outside visitors.

Table I Budget for KENS in FY 1988

(unit is ¥M)

Operation of facility		Neutron scattering experiments	
KENS	Beam line	Experiment	Travel and lodging
85	51	96	16

Table II shows the number of scientists and engineers in the Booster Synchrotron Utilization Facility (BSF).

Table II Number of Scientists and Engineers in BSF

	Scientists	Engineers
Director	1	
Neutron scattering	6	2
Beam-line	3	4

The number of publications for research at KENS are shown in Figs. 4 and 5. The total number of papers published in journals and conference proceedings came to about 250, including reviews, status reports, accelerator/beam-line development for KENS, and publications in Japanese, in addition to neutron scattering results..

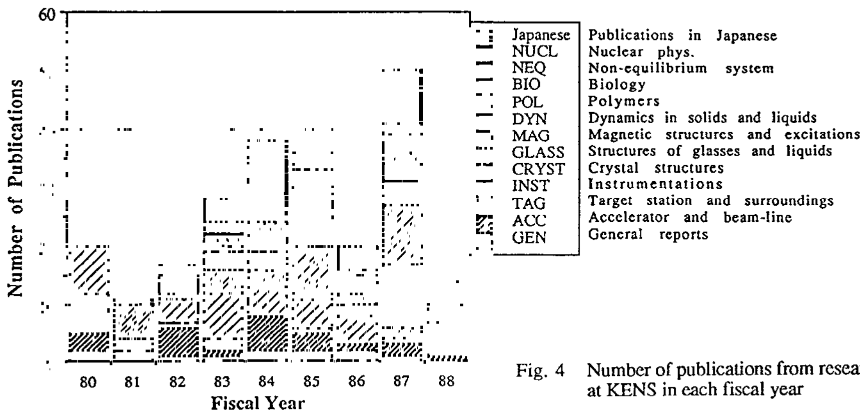


Fig. 4 Number of publications from research at KENS in each fiscal year

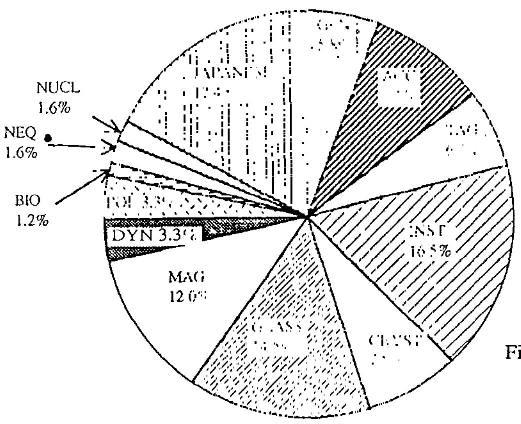


Fig. 5 Proportions of publications in each field

2. Target and Moderators

The neutron-production-target system of depleted uranium[1] has worked quite well with great stability during these years. In Fig. 6 the measured temperature rise at the center of the first target block (the block with the heaviest heat-load) is plotted as a function of proton beam current at a rated coolant-flow (60*l*/min). The temporal change in the temperature rise is probably due to fluctuations of the proton-beam position on the target. Error bars indicated in the figure represent the maximum and the minimum of the temperature distribution. The temperature rise per μA was thus determined as 15.6± 3.2°C/μA. The maximum temperature of the target block is, therefore, estimated to be 177±32°C at the designed proton-beam current of 10 μA with a coolant temperature of 21°C. The estimated temperature is significantly lower than the highest safe value estimated in the safety analysis report.

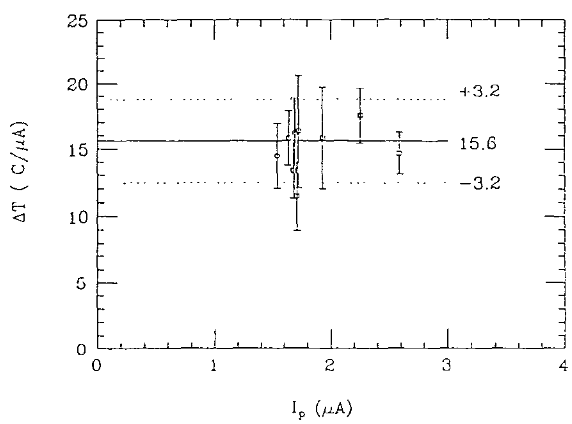


Fig. 6 Measured temperature rise at the center the first Target block

It was recently found that the polyethylene moderator at room temperature suffered from serious radiation damage due to the increased proton-beam-current and the use of the depleted uranium target. We therefore, decided to replace the polyethylene with circulating light water. Full installation of the new moderator system was completed September 1988.

Some improvements were performed on the hardware of the KENS cold neutron source[2]. The vacuum-pump system was improved by replacing the previous diffusion pump with a turbo-molecular pump (RTP-300 RIGAKU, 320*l*/sec). The control system was also improved so that the vacuum can be held in the event of an electric power failure and the pump starts automatically on recovery.

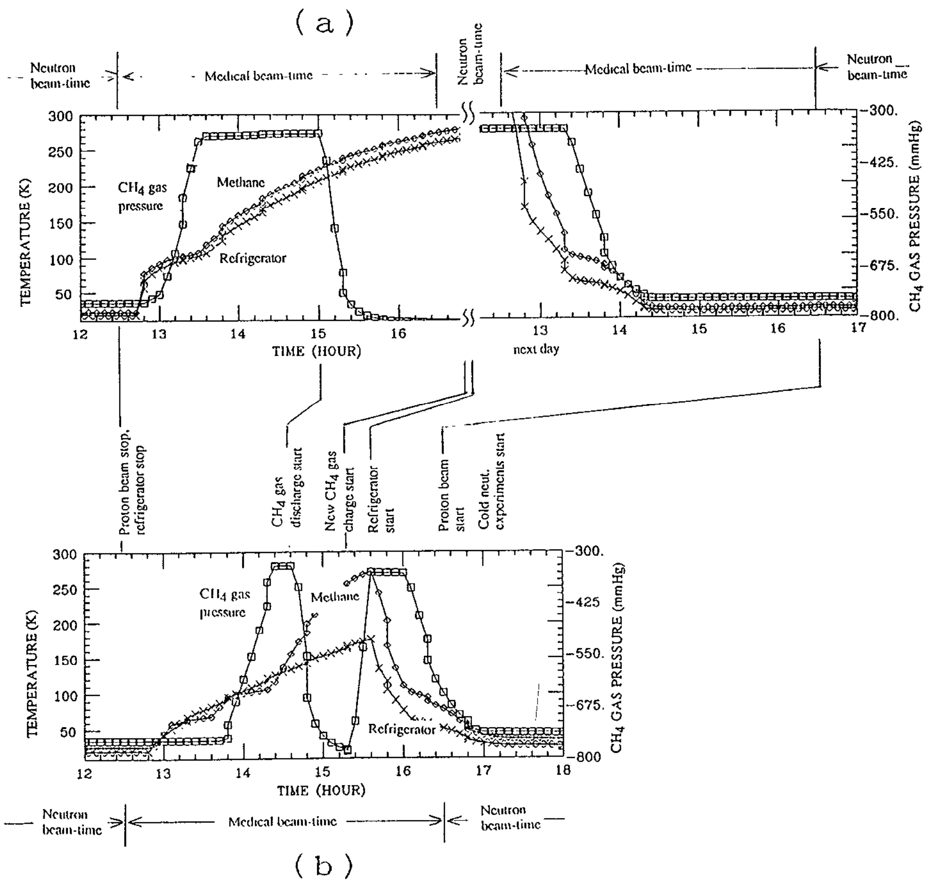


Fig. 7 Operational records on renewing solid methane moderator: standard operation until June 1988 (upper), quick operation (lower)

We, however, have serious problems on the solid methane moderator. We experienced a so-called "burp" three times and the cryogenic moderator chamber suffered from serious damage[2]. The chamber was replaced by a new one in September 1987. Although the "burp" problem has not been overcome, we can avoid the burp by renewing solid methane before reaching a critical value of integrated protons on the target, which is empirically determined to be about 6×10^{18}. Therefore after the installation of the new chamber we renewed solid methane at the midpoint of the beam cycle before reaching the critical dose. We had to waste almost one day of cold neutron beam-time in each cycle for renewing as shown in Fig. 7(a). In order to minimize the wasteful time, we tried to renew the solid methane as quickly as possible. Every working day of beam-time about 4 hours in the afternoon is allocated to the medical group, Particle Radiation Medical Science Center, university of Tsukuba, for cancer therapy using protons. If we can complete the renewing within the medical beam-time, we have no loss. The result of the first quick renewing is shown in Fig. 7(b). We confirmed that we can restart experiments with the solid methane moderator immediately after the end of the medical beam-time.

Another important problem is cryostat trouble. Since December 1985 we use a new-type cryostat in which the heat exchanger is embedded into the side walls of the moderator container. The performance of the second cryostat of this type, which was installed in September 1987, became poor since April 1988: sometimes the methane temperature went up to 40 K associated with poor vacuum. We found that it was, at least partly, due to a leak of coolant helium to the vacuum space of the cryostat. Even though the second cryostat had no experience of burp, it suffered from damage. It is not clear what is the major mechanism of such damage, but we guess that a welded part between the wall-heat-exchanger and the external piping of coolant-helium cracked by the stress associated with the volume increase of solid methane by radiation. Similar cryostat trouble at IPNS was reported by Carpenter.[3] They avoided burp by raising the methane temperature periodically, but the life of the cryostat was rather short. September 1988 we replaced the second cryostat by a third one. We, however, have to develop a new type of cryostat in due course.

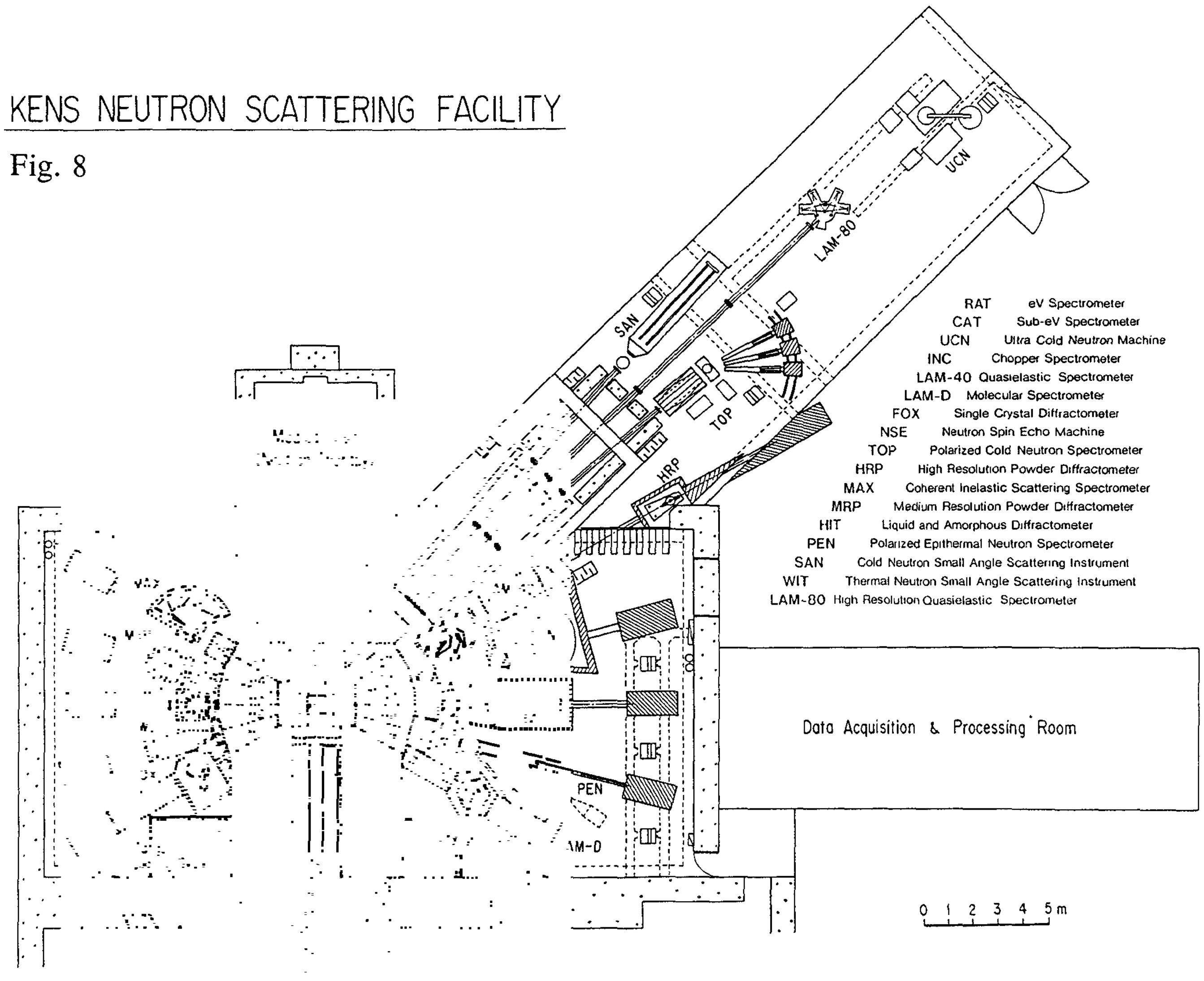
3. Development of Neutron Scattering Instruments

In the KENS facility there are sixteen instruments : Fourteen are in operation, a chopper spectrometer INC is under construction and an ultra cold neutron generator test UCN is still under development. Recent layout of these instruments is shown in Fig. 8.

INC was designed for complementary use with a sister instrument MARI which is under construction at ISIS. The mechanical chopper of INC is almost the same as that of MARI. Since INC has shorter flight path lengths than MARI, the

KENS NEUTRON SCATTERING FACILITY

Fig. 8



counting rate can be made comparable by relaxing the energy and momentum resolutions slightly. A vacuum scattering chamber and a spectrometer shield were installed in place. Data acquisition electronics and computer are ready. About 170 He-3 detectors will be installed within this year. A fast Fermi chopper was supplied from the Rutherford Appleton Laboratory. The construction of INC will be completed by the end of FY 1988. Details will be presented at a Poster Session by Arai.

The energy resolution of the high-resolution quasielastic spectrometer LAM-80 [4] was improved by use of mica instead of pyrolytic graphite as analyzer crystals.[5] The energy resolution attained is about 19 μeV with 6.6 Å and 8 μe V with 9.9 Å neutrons. LAM-80 has an incident flight path about 31 m long which makes a contributioh to the energy width $\Delta E_i \sim 13$ μeV for 6Å incident neutrons. Energy resolution of the analyzer crystal has to be matched with ΔE_i. Pyrolytic graphite (PG) with any mosaic spread is too bad and perfect crystal of silicon is too good for this. Mica crystal seems to be the best in this energy-resolution range. In Fig. 9, the third order Bragg reflection from a mica crystal (1.83 meV) is compared to the 002 reflection from a PG with mosaic spread of 0.4°. Those are measured with analyzer angle $\theta_A=87°$ at the exit of the 31 m long neutron guide (C2) from the solid methane moderator. The peak shape of the mica is superior, especially in the rising side. Note that the faint intensity on the both sides of the peak observed with PG is completely eliminated. Neutron scattering spectra from a vanadium sample on the LAM-80 using the third order reflection of the mica crystal (6.6Å at $\theta_A=80°$) is also shown in Fig. 9.

The performance of the coherent inelastic scattering spectrometer MAX [6] was also improved. By use of vertically focused analyzers instead of previous flat ones, the counting efficiency was increased by a factor 1.7 and the signal to background ratio by about 1.5 times as shown in Fig. 10.[7] Each analyzer mirror consists of 16 pieces of pyrolytic graphite (6mm x 50mm) aligned on a curved holder which is a part of a simple cylinder instead of an ellipsoid. Since the essential feature of MAX is that the curvature of the analyzer varies with θ_A, many holders with different curvatures were prepared. Further improvement on analyzers is in the planning stage.

The characteristics of the MAX are most suitable for measurements of spin wave excitations in two-dimensional magnets, because simultaneous constant - q scans by many analyzer-detector sets become possible. Typical TOF spectrum and measured dispersion relations for a two-dimensional random antiferromagnet $Rb_2Co_{0.14}Ni_{0.86}F_4$ are shown in Fig. 11 for reference.[8]

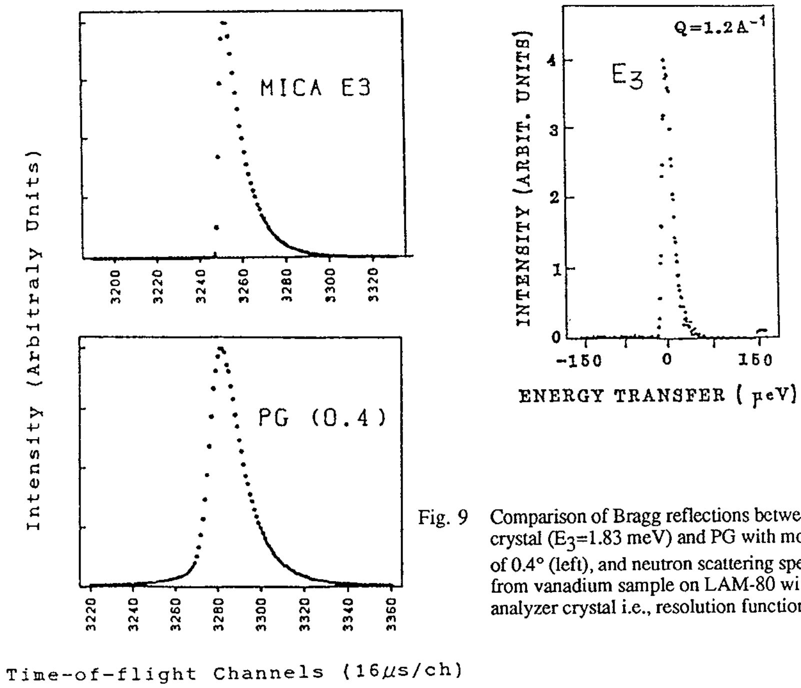


Fig. 9 Comparison of Bragg reflections between mica crystal (E_3=1.83 meV) and PG with mosaic spread of 0.4° (left), and neutron scattering spectrum from vanadium sample on LAM-80 with mica analyzer crystal i.e., resolution function (right)

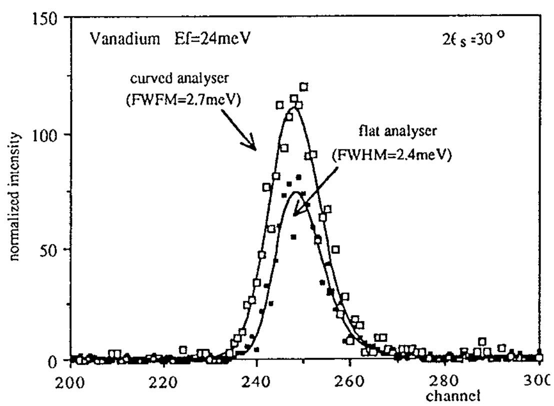
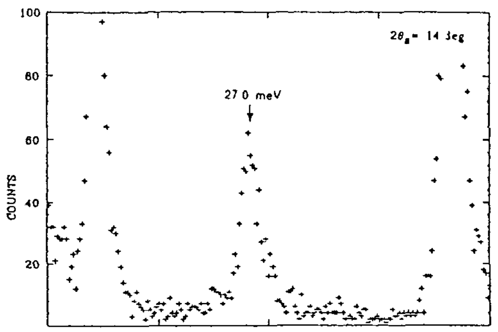


Fig. 10 Comparison of Intensities between curved and flat analyzer



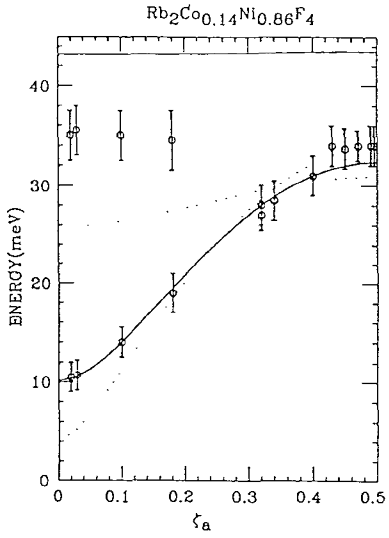


Fig. 11 Typical constant-q spectrum (left) and dispersion relations (right) of two-dimensional random antiferromagnet $Rb_2Co_{0.14}Ni_{0.86}F_4$ at 15K obtained on MAX. Measuring time was 2.5 days

The performance of the polarized epidermal neutron spectrometer PEN was also improved.[9] A polarized proton filter is used as a neutron polarizer and proton polarization more than 80% was achieved by microwave pumping in a ^4He bath at 0.5K. Epithermal neutron polarization of more than 70% was obtained, with a neutron transmittance about 25%.

The polarized cold neutron spectrometer TOP[10] has been modified. By the installation of PSD's at small angle region with a newly constructed vacuum chamber, small angle scattering using polarized cold neutrons has become possible.[11]

The number of backward neutron detectors of the high resolution powder diffractometer HRP[12] was increased to improve counting efficiency. A new computer program[13] has been developed for the Rietveld analysis of time-of-flight neutron diffraction data on the HRP. KENS is a low repetition pulsed-neutron-source (2OHz) which makes it easy to enlarge the d-spacing accessible. Powder diffraction in larger d-spacing region becomes possible by adding lower angle counter banks. Results of a test experiment to detect 001 diffraction from $Ba_2Y(CuZn)_3O_{7-x}$ (d=11.626Å) and 002 diffraction from $Tl_2Ba_2Ca_2Cu_3O_{10}$ (d~17.8Å) are shown in Fig. 12 with Rietveld refined profiles. The installation of lower-angle-counter banks is under progress. The data acquisition electronics of the HRP was also upgraded: a new electronic time-focussing hardware was developed at KENS, which can accept neutron signals in much higher rate than the computer focussing.

The medium resolution powder diffractometer MRP is being converted to a multi purpose diffractometer. In addition to the original function as a

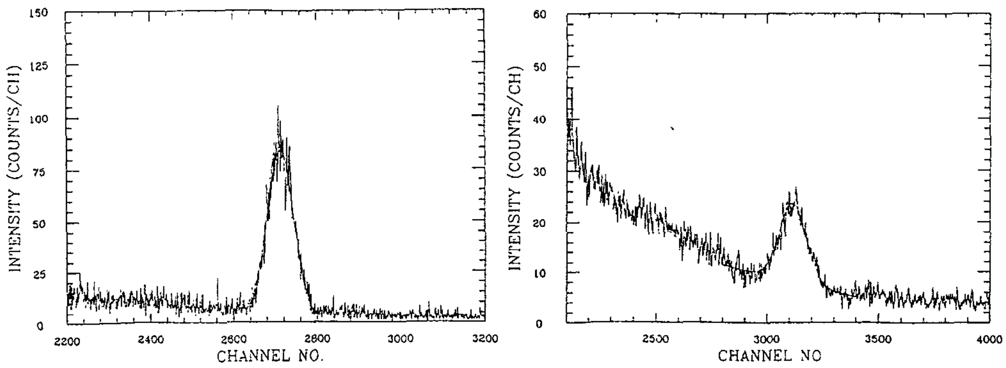


Fig. 12 001 diffraction from $Ba_2Y(CuZn)_3O_{7-x}$ (d=11.626A) (left) and 002 diffraction from $Tl_2Ba_2Ca_2Cu_3O_{10}$ (d~17.8A) observed by a low angle test counter on HRP

conventional powder diffractometer, options for single crystal diffraction and epithermal neutron diffraction are built in. For the former option, MRP is equipped with 1D-PSD's and a sample goniometer table which allows the use of a heavy helium cryostat, and for the latter, with a high-efficiency small-angle counter bank to detect epithermal neutrons from neutron-absorbing samples.

The down-scattering crystal spectrometer LAM-D, designed mainly for molecular spectroscopy, was moved from the H-6 beam hole to the H-9 after upgrading. The number of analyzer-detector arms was increased from one to four to realize larger analyzer solid-angle.[14)]

4. Data Acquisition and Processing System

The installation of the KENS new data acquisition and processing system based on the VAX has been completed. A VAX 8350 was chosen as a hub computer and eight VAX station II's were introduced as data acquisition computers with many Macintosh front end computers. The data-acquisition software ICP/GENIE developed at RAL was introduced to our new system by M.W. Johnson (RAL) under UK-Japan collaboration. Details of the new system will be presented at Poster Session by Furusaka.

5. Activities in Neutron Scattering

One of the highlights of the research achieved in these periods was the first successful determination of the crystal structure of a high-Tc superconductor $Ba_2YCu_3O_{7-x}$. It is already historical, but highly exciting at that time of the "High-Tc fever". Early March 1987 our colleagues in National Institute for Research in Inorganic Materials, Tsukuba, informed us that they were just successful in preparation of a high-quality single-phase powder-sample of $Ba_2YCu_3O_{7-x}$.

Proton accelerators at KEK were already shut-down finishing the scheduled operation in that fiscal year. Director General, professor T Nishikawa, decided to restart the proton-accelerators and immediately carry out the diffraction experiment on this sample with the high resolution powder diffractometer HRP. The sample was in fact not a single-phase one but a mixture of orthorhombic and tetragonal forms, but fortunately we were successful to determine the crystal structures of both phases simultaneously. It was almost the same time with three other independent experiments performed at IPNS, ISIS and ILL with their high resolution powder diffractometers. In succession, we studied the crystal structure of various 123 compounds $RBa_2Cu_3O_{7-\delta}$ (R : Y or lanthanide elements) using the HRP and showed that the variation of the long apical Cu-O bond distance of the CuO_5 pyramid must have a crucial role in forming Cooper pairs of O-2p holes between CuO_4 layers. We also studied various nonstoichiometric compounds $R_{1+x}Ba_{2-x}Cu_3O_{7-\delta}$ and showed that $[Cu\text{-}O]^+$ concentration controls T_c.

The crystal and magnetic structures of $(LaSr)_2CuO_4$ system were also studied. Powder diffraction on the HRP showed that the space group of La_2CuO_4 is Cmca. Since the superconductivity is believed to be strongly related to the magnetism of these systems, the magnetic contribution to small angle neutron scattering is being measured using large single crystals on the small angle scattering instrument SAN.

New superconductors of Tl- and Bi-systems were also measured on HRP. Structural parameters of $La_{1.9}Ca_{1.1}Cu_2O_x$, which does not show superconductivity, were also refined. The results will be useful in the examination of theories.

As an interesting application of an eV-spectrometer utilizing a nuclear resonance, a combined method of high Q scattering spectroscopy with resonance absorption spectroscopy was developed on RAT (resonance detector spectrometer). This method is useful to determine the mean kinetic energies, i.e., effective temperatures of specific elements in multi-component systems such as high Tc superconductors. Ikeda found that the effective temperature of oxygen atoms is unchanged in various oxides, while that of copper atoms changes significantly; the effective temperature of copper atoms in the La_2CuO_4 system is higher than those in metal Cu and CuO, and the $YBa_2Cu_3O_{7-x}$ system has much higher efective temperature of copper atoms than those mentioned above. A technical aspect of this application will be presented at a Workshop Session by Ikeda.

A parity-nonconserving (PNC) effect in neutron radiative capture was extensively studies using polarized epithermal neutrons from PEN. A new γ-ray annular detector made of BaF_2 scintillators was constructed and the γ-ray detection efficiency was increased. Simultaneous measurements of capture γ-rays and neutron transmission with positive and negative helicity states gave consistent results on the p-wave resonance of ^{139}La at 0.734 eV.

Kinetics of first order phase transitions has been examined on Al-Li alloys by use of SAN. Experimental results show a peculiar behavior at very early stages of the phase transition; the exponent n in the scattering law q^{-n} changes with time. It is explained by a competition between phase separation process and order-disorder transformations.

In addition to the above topics, many experiments in various fields, for example, precipitation in Nb-Ti multifilamentary superconducting composites, magnetic excitation in the two-dimensional random antiferromagnets $Rb_2Co_xNi_{1-x}F_4$, magnetic structure of the reentrant spin glass Fe-Al alloy system, structure and dynamics near the glass transition, dynamics of fractal structure, and so on have been extensively carried out in these periods.

6. Japan-UK Collaboration

This is the third year of the UK-Japan collaboration on neutron scattering. The construction of the chopper spectrometer MARI, which is provided by KEK for installation on ISIS in Rutherford Appleton Laboratory, is going well. A vacuum scattering chamber is ready for installation. A fast Fermi chopper is almost ready; The computer for the data acquisition system and associated electronics are ready as well. The construction of MARI is expected to be completed in FY 1989 on schedule.

The workshop of the collaboration "Neutron Scattering Research with Intense Spallation Neutron Source-Today and Tomorrow- was held at KEK on Oct. 6-7, 1987. About fifty participants attended at the meeting. The proceedings of the meeting has been completed and will be distributed soon.

In FY 1987 a Japanese scientist stayed RAL for a long term and three visited RAL for a short term to perform neutron scattering experiments and collaborate on the construction of MARI.

7. KENS-II

The future program of the pulsed spallation neutron source KENS-II was included in the Japanese Hadron Facility Project as an important part of four major fields. The project was already authorized by the Science Council of Japan, and is now under examination by the government

Details on the KENS-II project will be presented by Endoh at a succeeding Session. Here I give only very brief comments on some technical aspects. Proton-beam energy is still not fixed: 1 GeV with a 1 GeV proton linac and a storage ring, or 2 GeV (or less) with a 1 GeV linac and a synchrotron. Time-averaged proton-beam-current is expected to be 200 μA.

We are thinking of adopting a coupled cold moderator, probably a composite moderator of liquid hydrogen with light water at room temperature, in order to obtain higher time-averaged cold neutron flux albeit in longer pulses. One idea of the target-moderator-reflector assembly is a combination of a coupled cold moderator with decoupled moderators at ambient and reduced temperatures. The former could hopefully be located in a large D_2O tank above the target. The latter would serve short-pulse uses similarly to the present operation of other spallation neutron sources (ICANS laboratories).

We performed some neutronic calculations for the KENS-II with higher proton energies, say 2 GeV. A result will be presented at a Workshop Session.

References

1) N. Watanabe, M. Misawa, S. Ikeda, Y. Masuda, M. Arai and S. Satoh : KENS Report-VI, KEK Progress Report 86-2 (1987) 11
2) S. Ikeda, N. Watanabe, S. Satoh, M. Furusaka and K. Inoue: ibid 24
3) J. M. Carpenter: private communication
4) K. Inoue, Y. Ishikawa, N. Watanabe, K. Kaji, Y. Kiyanagi, H. Iwasa and M. Kohgi: Nucl. Instrum. Methods A238 (1985) 401
5) K. Inoue, S. Ikeda, Y. Kiyanagi, K. Shibata, T. Kanaya, H. Iwasa, H. Niizeki, K. Kobayashi and T. Yoshihara: KENS Report-VII. (1988) 17
6) K. Tajima, Y. Ishikawa, K. Kanai, C.G. Windsor and S. Tomiyoshi: Nucl. Instrum. Methods 201 (1982) 491
7) Y. Todate, H. Ikeda and K. Tajima: KENS Report-VII (1988) 16
8) K. Tajima, Y. Todate and H. Ikeda: presented at ICNS '88, to be appeared in Physica B
9) Y. Masuda, S. Ishimoto, A. Masaike, Y. Ishikawa and M. Kohgi: Nucl. Instrum. Methods A264 (1988) 169
10) Y. Endoh, S. Ikeda, S. Mitsuda and H. Fujimoto: Nucl. Instrum. Methods A240 (1985) 115
11) S. Itoh and Y. Endoh, KENS Report-VII(1988) 18
12) N. Watanabe, H. Asano, H. Iwasa, S. Satoh, H. Murata, K. Karahashi, S. Tomiyoshi, F. Izumi and K. Inoue: Jpn. J. Appl. Phys. 26(1987) 1164
13) F. Izumi, H. Asano, H. Murata and N. Watanabe J. Appl. Cryst. 20 (1987) 411
14) K. Inoue, to be published