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STATUS AND NEUTRON SCATTERING EXPERIMENTS AT KENS

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ABSTRACT

This paper reports present status of the KENS facility, progress in neutron scattering experiments and instrumental developments, and status of the KENS-I' program. A design study of a high intensity rapid-cycle 800 MeV proton synchrotron for proposed new pulsed neutron (KENS-II) and meson source is also described.

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1. PRESENT STATUS OF KENS

In FY 1981 (April 1, 1981 - March 31, 1982), the booster synchrotron at KEK has been operated for 3280 hours, 88 per cent of which has been delivered to the Booster Synchrotron Utilization Facility (BSF). The spallation neutron source KENS has been operated successfully throughout this period. Total operation time for KENS was about 1450 hours, because we shared the machine time with Booster Meson Facility (Boom) of Meson Science Laboratory, University of Tokyo.

Many research programs were proposed for FY 1982. Number of proposals are listed in Table 1. Among the existing spectrometers, the small angle scattering spectrometer SAN is the busiest. In order to relieve machine time congestion, the construction of a new small angle scattering machine has been proposed, which will be authorized in the next fiscal year. The machine will be equipped with a 2-dimensional PSD made of Li-6 glass scintillators, and installed at a beam hole viewing the room temperature moderator. Shortage in neutron machine time becomes more serious this year, because the BSF has started to deliver proton beams to the new facility, Particle Radiation Medical Science Center, University of Tsukuba, which is located in the next door of KENS. Furthermore, the proton accelerators at KEK will be shut down for about one year probably in 1984, due to the TRISTAN tunnel construction under the existing accelerators.

Table 1 Number of Proposals

Type	Definition	Total machine time (%)	No. of proposals accepted/No. of proposals	
			FY 1981	FY 1982
A1	Big project for the construction of a new spectrometer with instrumental development	100	2/2	3/3*
A2	Program for instrumental development	100	4/4	4/4**
B1	Big research program using a existing spectrometer by the instrument group responsible for the spectrometer	70	5/5	5/5**
B2	Small research program using existing spectrometers	30	9/20	13/19

* Two proposals are the continuation from the FY 1981.
** All proposals are the continuation from the FY 1981.

The tungsten target was renewed at the end of this period, because the outer-surface of the target container and the coolant pipe suffered from serious erosion, even though the material was SUS-316. This is probably due to the high concentration NO_x gas formation in the final section ($\sim$ 2 m long) of the proton beam line where air is confined instead of helium gas. Change to helium atmosphere is necessary.

There has been a considerable improvement in the remote handling devices for the active target-moderator-reflector assembly. A robot arm crane was constructed which enables the precise mounting or the demounting of the assembly or the cold neutron moderator system on (from) the target station with full remote mode. An iron cell has been built which is necessary for the maintenance of the assembly, and also for the reconstruction of the KENS-I' advanced system. A photograph of the robot arm crane is shown in Fig. 1.

2. NEUTRON SCATTERING EXPERIMENT WITH EXISTING SPECTROMETERS

Neutron scattering experiments with the existing five spectrometers HIT, LAM, MAX, SAN and TOP were very active during the last fiscal year. Many results have already been obtained. We will briefly summarize some of these research activities. (All of the experimental results which have been achieved last year are being published as KENS Report-III, KEK Internal (1982).)

1. High Intensity Total Scattering Spectrometer (HIT)

More than hundred samples have been measured with HIT last year. Short-range structures of metal-metal alloy glasses such as Ni-Ti and Cu-Ti, and those of archetypical metal-metalloid alloy glass of Ni-B have been determined, and it was concluded that (i) the atomic arrangement of alloy glasses preserves the chemical short-range order analogous to that found in the corresponding crystalline compounds, (ii) glass formation composition ranges are likely to be dominated by the nature of the chemical short-range order inherent in these alloy glasses. As an example of measured data, S(Q)'s and g(r)'s of Ni-B alloy glasses are shown in Fig. 2. Atomic sites of deuteriums in deuterided metallic glasses such as $Pd_{0.35}Zr_{0.65}D_X$; structure changes of Pd-17at%Si alloy glass by cold rolling; and structures of silicate glasses, binary amorphous alloys and amorphous As-chalcogenids were also studied. Nuclear and magnetic structure of Fe-B alloy glasses has been measured. Instrumental improvement is also in progress; annulus detectors of Li-6 glass scintillator at small angles are under construction.

2.2 Large Analyzer Mirror Spectrometer (LAM)

Several improvements were made on the LAM since last ICANS. One of them, the increase of the number of analyzers from four to eight (see Fig. 3), provided more information about the Q dependence of the quasielastic spectral profile, and the evacuated housing of the whole spectrometer improved drastically the S/N ratio. Fig. 4-a gives some raw data of the quasielastic spectrum of chloroprene. We can definitely distinguish the quasielastic and the elastic parts in the spectrum. Fig. 4-b shows the measured elastic incoherent structure factor (EISF) where the solid line is a theoretical curve of EISF in a model describing migration of kinks in the rubber polymer. Many other low energy fluctuational motions involved in molecular and spin systems were studied. In the case of the former, diffusion in liquids such as water, methanol aqueous solutions, cycrohexane, benzene, etc; rotational diffusion in plastic crystals; micro-Brawnian motion of polymer chains; and diffusion of hydrogen in TiH_x were studied. Similar studies concerning poly- and oligo-ethers, α-lactalbumin solution and polyelectrolyte solutions were also done. Concerning spin systems, experiments were performed to measure the temperature and magnetic field dependence of crystal field splitting in CeBi.

2.3 Multi-Analyzer Crystal Spectrometer (MAX)

One of the progress MAX made last year was the success of the intensity mapping of the magnetic excitations over the whole Brillouin zone. An example is shown in Fig. 5 where the magnetic excitations in a $\gamma Fe_{0.7}Mn_{0.3}$ alloy at various temperatures up to $1.5T_N$ are displayed as the contour maps of the scattering intensity. The data show clearly that the low energy excitations are renormalized near T_c, while the higher energy excitations remain almost unchanged even above T_N.

2.4 Small Angle Scattering Spectrometer (SAN)

The SAN, small angle scattering machine has also been improved further this year. The large external memory bank of 2 M bite was attatched to it in order to make the measurement of the time dependent phenomena possible. The measurements under various circumstances as at different temperatures ($10 \leq T \leq 1,000$ K) or in a magnetic field ($H \leq 5$ kG) become also possible. The subjects studied by this spectrometer included the magnetic systems, phase separation in alloys as well as polymer and biological problems. A complete study of the magnetic correlation was carried out on a single crystal of $0.88FeTiO_3$-$0.12Fe_2O_3$ at different temperatures ($10 \leq T \leq 300$ K) in various magnetic fields. Two dimensional displays of the scattering profiles at low temperatures are shown in Fig. 6. A significant change of the profiles occurs between 40 K and 45 K corresponding to the existence of the spin glass temperature at 38 K. The magnetic phase diagram of MnSi near T_N has also been established. The spinodal decomposition process of $Fe_{1-x}Cr_x$ alloys was studied for various compositions (x = 0.2, 0.3, 0.4 and 0.6) and the important contributions of thermal fluctuations and nonlinear effects are recognized. By the study of the semi-dilute polymer solutions around the compensation temperature, the binary cluster integral of polymer segments and the ternary cluster integral were separately obtained. The structure of nucleosome core from chicken erythrocytes were studied in a dilute solution with different Na^+ and an interesting ionic strength dependence of core sizes was found.

2.5 Time-of-Flight Spectrometer with Optical Polarizer (TOP)

After completion of the performance test of TOP it has been operated as the polarized neutron diffractometer with a polarization analyzer. Though polarization is not completely satisfied, the flipping efficiency and the reflectivity of the polarizer is 100 % and 90 % respectively, which is excellent.

Numbers of experiments have been carried out during a year, namely polarized neutron diffraction studies on the Fe-Pd, Fe-Sb and Fe-V artificial superlattice films. We could find unusual magnetic form factor due to the interfacial effects on the ferromagnetism of Fe layers. We also measured similar effects of the magnetic form factor of Ni ultra fine particles. Besides these studies, we have found novel feature of the dynamical depolarization of the transmitted neutrons through ferromagnetic alloys. We illustrate the typical examples in Fig. 7, where the depolarization is dependent of the velocity of neutrons when they pass through a quenched $Fe_{0.85}Cr_{0.15}$ alloy, whereas polarization is maintained completely in the case of the transmission through an anealed $Fe_{0.85}Cr_{0.15}$ alloy. It must be concluded that the comparable size of micro magnetic domains as the Larmor period are distributed in the quenched alloy which disappear by anealing.

3. NEW SPECTROMETERS AND INSTRUMENTAL DEVELOPMENTS

There have been a considerable progress in the instrumental development since last ICANS. Three spectrometers, FOX, CAT and DIX have been constructed and operated, and other two named PEN and RAT are now under construction. RAT and CAT are installed at the same beam hole H-7, and the combination is called RAC. CAT and DIX are the tentative machine for the instrumental development. A test machine for the PEN which is called Pre-PEN was constructed and operated. A prototype machine of RAT has also been constructed and the test experiments are in progress.

3.1 Four-circle Single Crystal Diffractometer (FOX)

FOX is a TOF type single crystal diffractometer, equipped with a large χ-circle (50 cm in diam.) and a conventional He-3 counter. The instrument has been installed at the H-1 beam hole. Single crystals of Si, $BaTiO_3$, V and pyrographite have been measured for the performance test with satisfactory results; the distinct Bragg reflections were observed for V, and higher order reflections were detected up to 0 0 26 for pyrographite. One dimensional Li-6 glass scintillation detector system will be ready at the end of this fiscal year.

3.2 Polarized Epithermal Neutron Spectrometer (PEN)

The Pre-PEN is a test machine of the PEN which was installed at the H-8 beam hole to produce a white polarized beam of epithermal neutrons by means of a dynamically polarized proton filter. Extensive tests have been carried out to improve the neutron polarization and to identify it. Neutron polarization of about 0.65 at 0.1 eV, 0.45 beyond 1 eV have already been attained with the proton polarization of 43 %. Details are given in a separate paper for this meeting[1]. PEN is under construction which will be completed at the end of FY 1982.

3.3 Cystal Analyzer TOF Spectrometer (CAT)

CAT is a inverted geometry type machine designed to measure the incoherent high energy excitation in the range 50 - 1,000 meV, with good resolution ($\Delta h\omega/h\omega = 0.02 \sim 0.03$), and with good efficiency. Since the two-dimensional focussing geometry is adopted in the scattered neutron path, larger planar sample can be used without sacrificing the resolution. In order to test the instrumental performance, local modes of hydrogens in the various metallic hydrides have been measured. It was found that the spectrometer can provide spectrum with extremely low background and with excellent resolution. For instance, in case of TiH_2, higher harmonics have been detected up to 5th order with respective fine structures. Details are given in a separate paper for this meeting[2)].

3.4 Resonance Detector Analyzer TOF Spectrometer (RAT)

RAT is a resonance detector spectrometer. The instrument of this type will make possible spectroscopy with scattered neutron energies in the range 1 - 10 eV, with resolution in the neighborhood of 50 meV. The system uses a resonantly-absorbing material, which captures scattered neutrons of fixed energy; a scintillation counter registeres the resulting gamma ray cascade. Time of flight disperses the energy spectrum as a function of incident neutron energy. We have constructed and operated a prototype machine to understand the principle of the instrument and to develop it, in collaboration with J. M. Carpenter from Argonne National Lab.

By extensive tests to identify sources of background and find corrective measures, we arrived at some general understandings which guided our development, and some spesific principles.

We have tested various scintillators for the gamma ray detection, and found bismuth germanate (BGO) scintillator is the best for this application. We have examined a fast and a slow electronics to handle the detector signal and found that the fast system workes well. We have tested and used three resonance absorbers, Ta-181, Sb-121 and Sm-149 both at room temperature and at reduced temperature. Figure 8(a) shows the time distribution of the measured detecting probability for a 12 μm thick Ta foil with a calculated curve.

We have measured and understood the inelastic scattering at large wave-vector change ($Q > 60\ A^{-1}$) from graphite, vanadium, lead and bismuth; we have measured and understood the scattering at smaller wave-vector change ($Q = 10\ A^{-1}$) from graphite and hydrogen gas. Figure 8(b) shows typical TOF spectra measured for bismuth at room temperature with Ta detector.

The resolution accomplished so far is only modest, around 100 meV, limited by the fact that absorbers have been subject to room-temperature Doppler broadening, as well as by the lack of a uranium-238 absorber (which has the narrowest resonance we are aware of). Counting rates have enabled measurements to be completed in about 1/2 day. Details of the measurements and the analysis will be given in separate article[3].

The construction of the RAT will be completed within FY 1983.

3.5 DIX

Another crystal spectrometer called DIX has been constructed and installed at the H-6 beam hole which views the polyethylene moderator at room temperature. The instrument has a large analyzer mirror which is similar to that of the LAM, but designed to measure the incoherent scattering in the range $\hbar\omega = 5 \sim 50$ meV with the resolution of about 0.5 meV. Test experiments are in progress.

3.6 UCN

The project for the ultra cold neutron production by means of excitations of HeII (UCN) is also in progress. A thin window (90 μm Aℓ)

He-3 counter was developed for detecting ultra cold neutrons. The He-3 cryostat producing UCN is being tested. First cooling will be started in the fall of 1982.

3.7 PSD

The position sensitive detectors (PSD) employing the Li-6 glass scintillator is also under development. The PSD (3 x 28 arrays) based on a fibre optic encoding method was constructed, and the performance was tested by using the Bragg reflections from a single crystal of KBr.

4. STATUS OF KENS-I' PROGRAM

KENS-I' program has been proposed[4)] which aimed to increase the neutron beam intensity about one order of magnitude by the improvements of the present accelerators and the target-moderator system.

A charge exchange injection system with H^- ion to increase the proton beam current is now under construction and the operation test is scheduled in next autumn. Energy up of the present 20 MeV proton linac is also being discussed in the accelerator group at KEK, but no decision has been made yet.

A grooved surface solid methane moderator has been proposed at KENS in order to increase the cold neutron beam intensity. A prototype cryogenic moderator chamber with a grooved surface has been constructed and extensive test experiments are now in progress, using the pulsed cold neutron facility at Hokkaido linac.

In Fig. 9 is demonstrated a measured spectrum obtained from the grooved solid methane at 20 K, compared with that from a flat one. A gain factor of about two has already been recognized at the cold neutron region. The results proves that the grooved surface is also very useful for the cold moderator as for the thermal neutron moderator. A first installation of a grooved solid methane moderator to the KENS target station will be completed at the end of this fiscal year. Details of the prototype experiment is given in a separate paper for this meeting[5].

The convension of the present tungsten target to a depleted uranium is one of the most important project in KENS-I' program. The rectangular target is necessary to keep the good coupling efficiency. We are hopping to realize this by the collaboration with Argonne National Lab. Some calculations and mock up tests are now in progress.

5. KENS-II PROGRAM

KENS-II program is a future project to construct a intense pulsed spallation neutron source at KEK. A tentative program has been presented at the meeting on future program of BSF last March. This was first formal presentation in KEK. Since the construction of a high intensity proton synchrotron is the most important part of the program, a design study has just started.

Design study of a proton synchrotron, which is the generator of the meson-intense and neutron-intense beam, Gemini, is in progress. This 800 MeV synchrotron is aimed to deliver an intense proton beam, e.g., 500 μA in time average. Such a beam intensity, for instance, will be achieved by accelerating 6×10^{13} protons per pulse with the repetition rate of 50 Hz. This machine also should play the role of the injector to the present KEK 12 GeV proton synchrotron on behalf of the 500 MeV booster synchrotron. The circumference of the machine, therefore, was determined to be a half of that in the 12 GeV synchrotron. The machine parameters are listed in Table 2. The accelerator will consist of an H^- ion source, preaccelerator including RFQ, 80 MeV Alvarez-type linac, and 800 MeV rapid-cycling synchrotron.

The requirements on the ion source are that 30 mA of H^- ion beam is injected into the synchrotron with the pulse width of at least 350 μsec to realize the beam intensity of 6×10^{13} protons per pulse. Since the beam loading on the linac is relatively small, a conventional Alvarez-type linac would be constructed. To simplify the RF power system, 400 MHz klystrons of 2 MW will be used, which drive five tank structures.

The rapid-cycling 800 MeV synchrotron of 54 m in diameter consists of 24 FBDO cell-structures. In order to attain high space-charge limit, the horizontal and vertical tunes are chosen to be relatively high, i.e., 6.8 and 7.3 respectively. Figure 10 shows the layout of the accelerator ring and the cell structure.

The emittance of H^- beam used for the injection at 80 MeV is small compared to the desired 97 x 84 (cm•mrad)^2 initial emittance for 6 x 10^{13} protons circulating in the synchrotron. To produce these emittances, the H^- beam must move both horizontally and vertically with respect to their orbits during injection. In the horizontal plane, especially, the beam emittance will be regulated by decaying the injection bump orbit, which is formed with a pair of bump magnets.

Beam extraction is basically the single-turn extraction, which makes possible the maximum use of the pulse structure of the beam in the neutron and muon physics. The emittance of the extracted beam is assumed to be twice of the expected one from the adiavatic damping of the initial emittance. For the extraction of such a beam with a total 2 % momentum spread, it is sufficient that each of two kicker magnets of 2.5 m in length deflects the beam by 15 mrad in cooperation with some bump magnets. The beam is extracted outwardly by angles of 110 and 380 mrad in two septum magnets, respectively. Since the bunch spacing at 800 MeV is about 160 nsec for the RF system with the harmonic number of 2, the rise time of the ferrite loaded kicker magnet has to be less than 150 nsec.

The accelerator ring is made of 24 bending magnets and 48 quadrupole magnets. The required semi-aperture of the good field region is 11.5 cm x 9.2 cm for the bending magnet and 13.5 cm x 11.0 cm for the quadrupole magnet. This defines the usable semi-size of the vacuum chamber. It is necessary to add 3 and 4 cm in horizontal aperture of the bending and quadrupole magnet respectively, to allow the room for the injection and extraction of the beam. The synchrotron ring magnet is excited by 50 Hz, dc-biased sine-wave current. All of the bending and quadrupole magnets are devided into eight or twelve groups. These are connected in series through resonant capacitors and forms a ring circuit. The dc bypass for the capacitors is provided by installing chokes in parallel to the capacitors and resonating the resultant tank circuits to 50 Hz. In order to reduce the RF accelerating voltage, the magnet system would be excited by a bi-resonant frequency system with the resonant frequencies of 33 and 100 Hz as proposed by M. Foss and W. Praeg at ANL. Even in this case, the max. voltage imposed on the exciting coil of the magnet will be kept within 10 kV to the earth. This is achieved by using hollow conductors of parallel current paths and by transposing those paths each other at the connection points between coil pancakes. This procedure will reduce eddy current loss as successfully applied at the KEK booster synchrotron magnet.

It should be guaranteed that a single bunched beam is always supplied to each of the neutron and meson experimental facility. This determines uniquely the harmonic number of RF acceleration system is 2. With the 80 MeV linac beam of 0.75 % full momentum spread, the emittance of such an injected beam is 0.84 eV•sec. If the RF bucket area has to be twice of this emittance, the required maximum RF voltage is 200 kV for the 50 Hz operation and 150 kV for the 33 Hz operation of the guide field magnet, respectively. Eight RF stations will provide with this accelerating voltage, each of which is installed in a 3 m long straight section. The reduction of RF bucket area due to space charge will require higher RF voltage. Therefore, the application of the bi-resonant frequency system to the excitation of the guide magnet is significant.

The design study of this machine is only on the start point. In addition to refining concept and hardware for each accelerator component, the problem remains to be solved on the radiation protection and handling. And also, some aspects of the designs may be changed in the process of the design work.

Table 2 Parameters of the proposed accelerator

Maximum kinetic energy	800 MeV
Maximum intensity	6 x 10^{13} p/p
Repetition rate	50 Hz (100/3 Hz & 100 Hz)
Average beam current	500 μA
Injection energy	80 MeV
Injection beam	30 mA H^-
Number of turns of injected beam	>240
Beam pulse width of injected beam	>350 μs
Magnet radius	7.00 m
Average radius	27.00 m
Number of period	24
Length of straight section	3.008 m
Structure	FBDO
Betatron frequency	
Horizontal	6.8
Vertical	7.3
Revolution frequency	0.687 - 1.489 MHz
Maximum beta-function	
Horizontal	12.4 m
Vertical	12.9 m
Momentum compaction factor	2.71 x 10^{-2}
Transistion energy/rest energy	6.07
Beam emittance	
800 MeV	0.26 x 0.23 $(mm\ rad)^2$
80 MeV	0.97 x 0.84 $(mm\ rad)^2$
Number of bending magnets	24
Length of bending magnets	1.833 m
Length of quadrupole magnets	
Focussing magnet	0.505 m
Defocussing magnet	0.547 m
Bending magnet field	
800 MeV	0.697 T
80 MeV	0.189 T
Quadrupole magnet peak field gradient	4.34 T/m
Peak energy gain per turn	94.9 keV (63.3 keV)
Harmonic number	2
RF frequency	1.374 - 2.978 MHz
Max. RF voltage	200 kV (150 kV)
RF bucket area	1.67 eV.sec
Number of RF stations	8
Incoherent space charge limit	7.7 x 10^{13} p

REFERENCES

1) M. Kohgi, et al., presented paper to this meeting (1982).

2) N. Watanabe, S. Ikeda and K. Kai, presented paper to this meeting (1982).

3) J. M. Carpenter, N. Watanabe, S. Ikeda, Y. Masuda and S. Sato, to be published.

4) N. Watanabe, H. Sasaki, Y. Ishikawa, Y. Endoh and K. Inoue, Proc. ICANS-V (Jülich, June 22 - 26, 1981) p. 21.

5) K. Inoue, et al., presented paper to this meeting (1982).

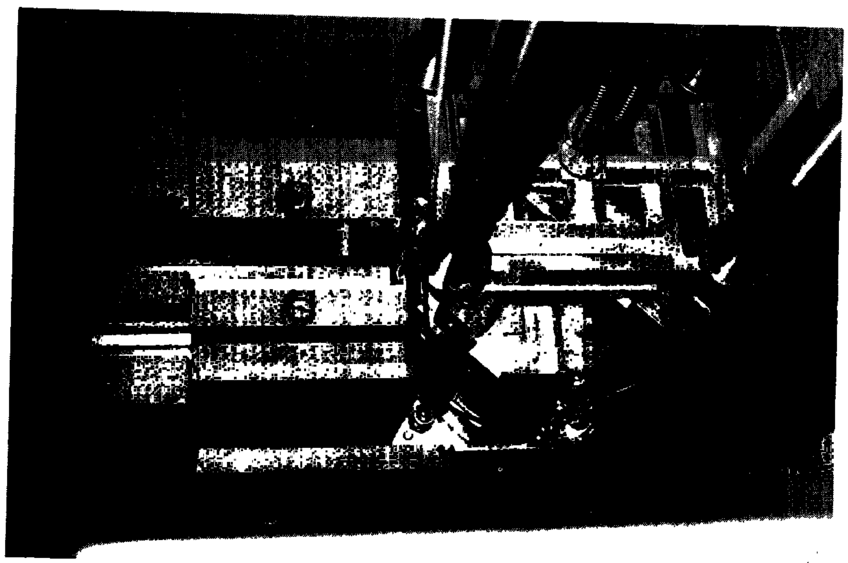


Fig. 1 Photograph of robot arm crane

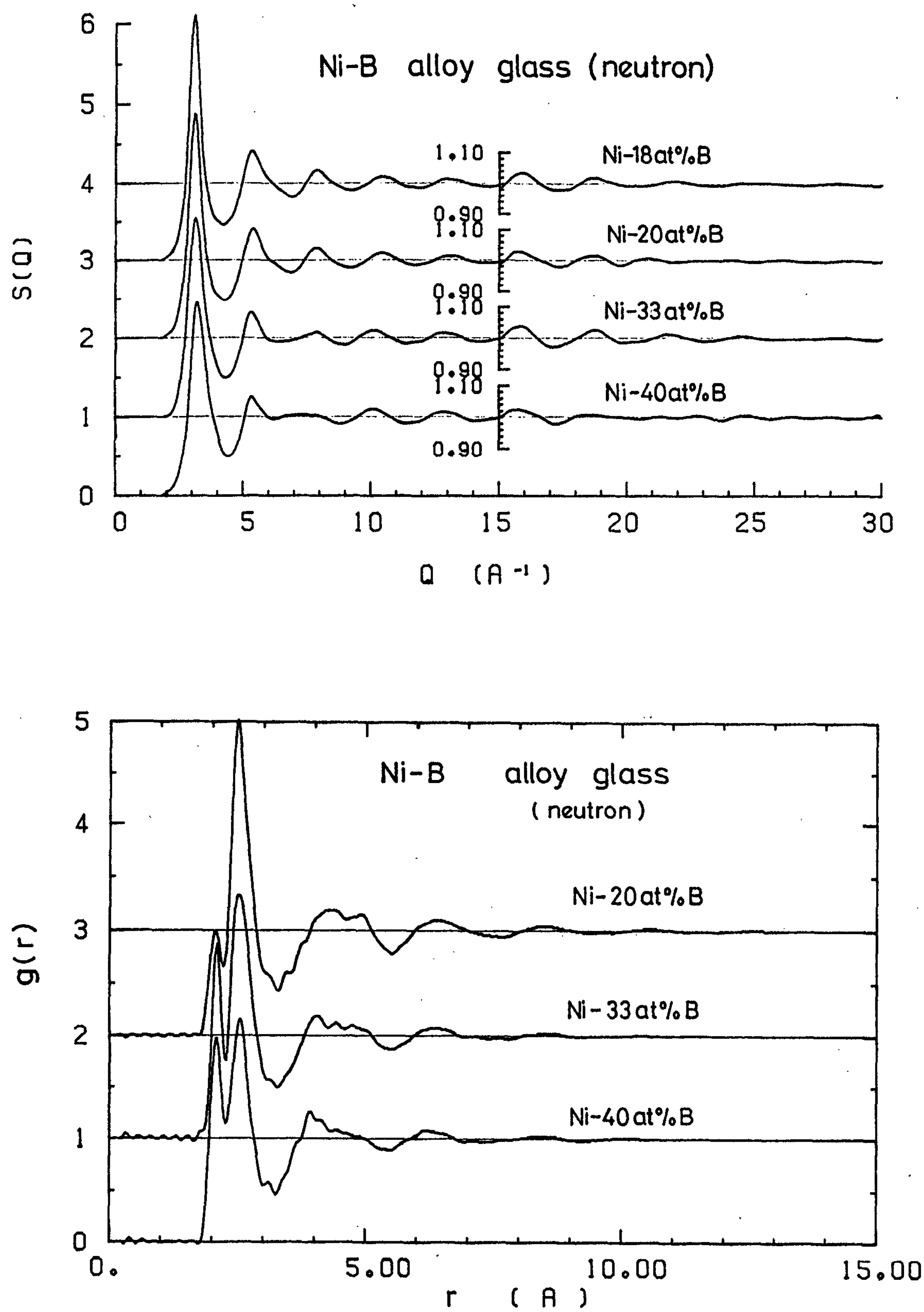


Fig. 2 S(Q)'s (a) and g(r)'s (b) of Ni-B alloy glass

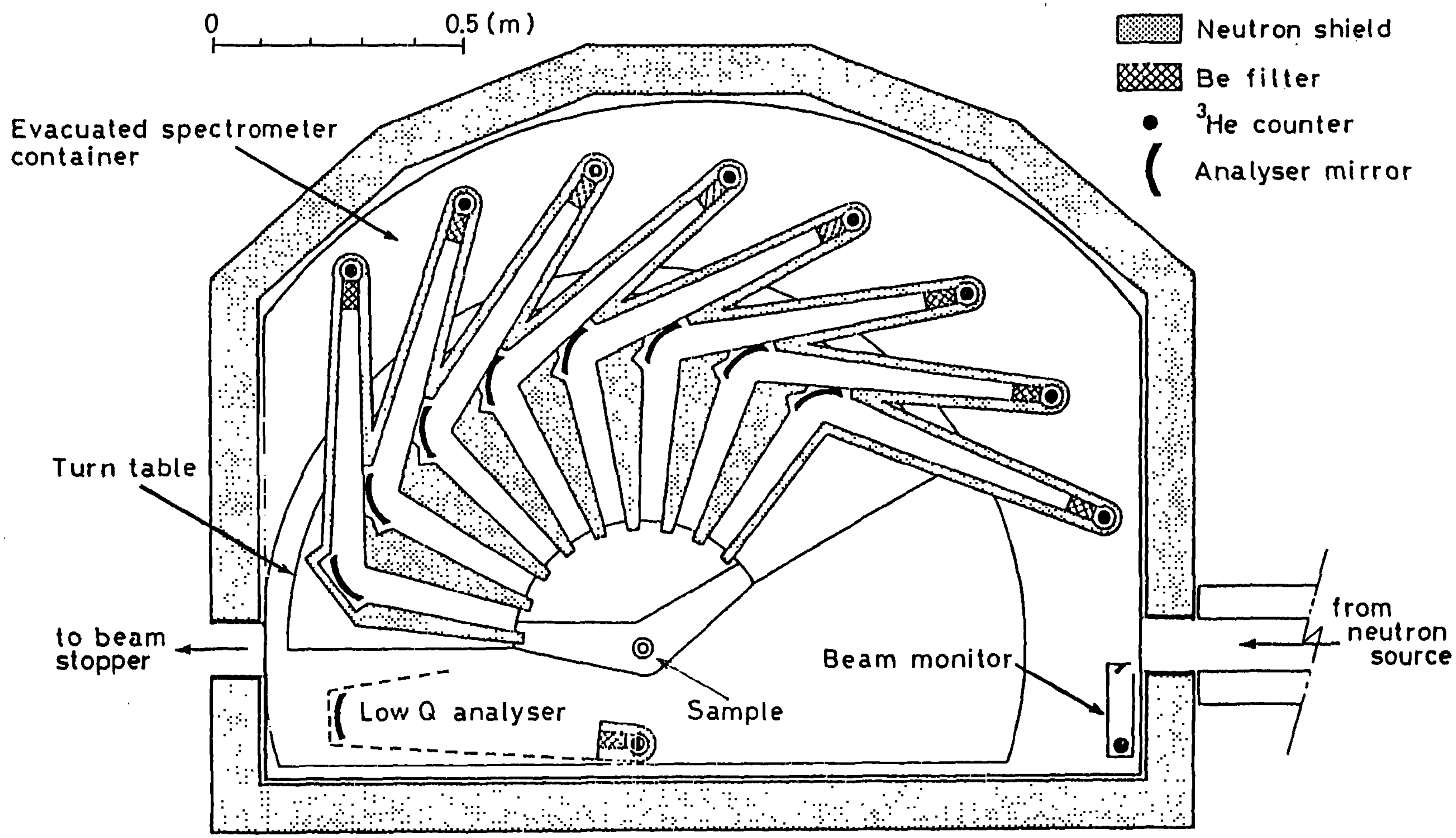
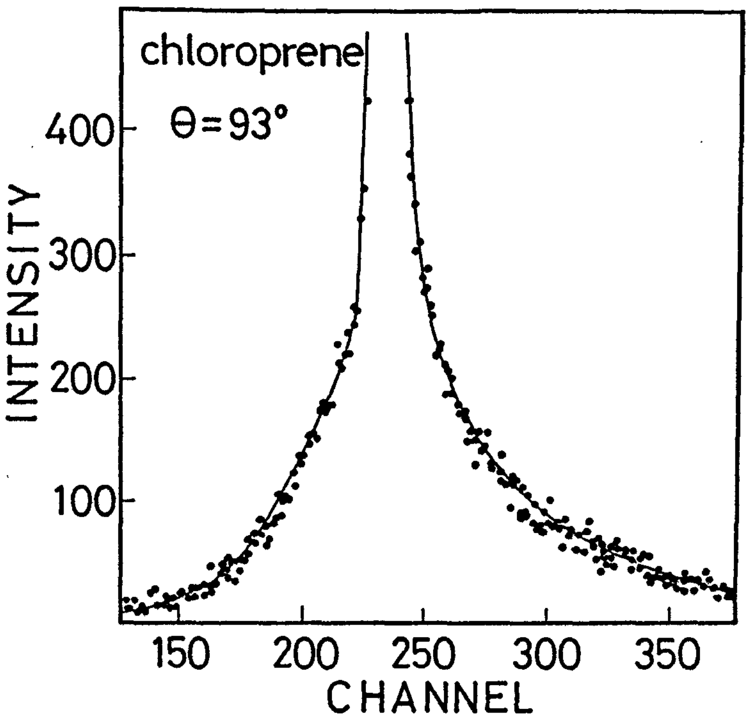
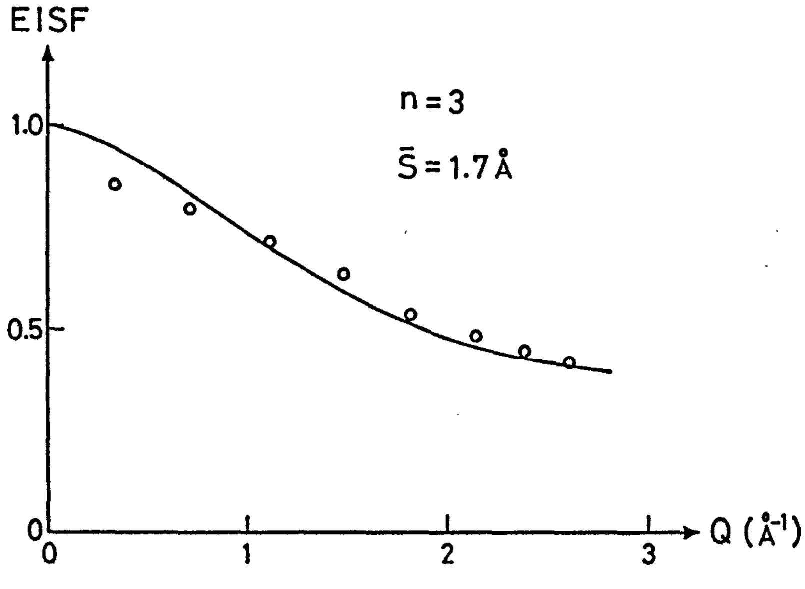


Fig. 3 Configuration of the improved LAM



(a)



(b)

Fig. 4 TOF spectrum (a) and calculated (solid curve) and measured (open circle) EISF (b) for chloroprene at room temperature

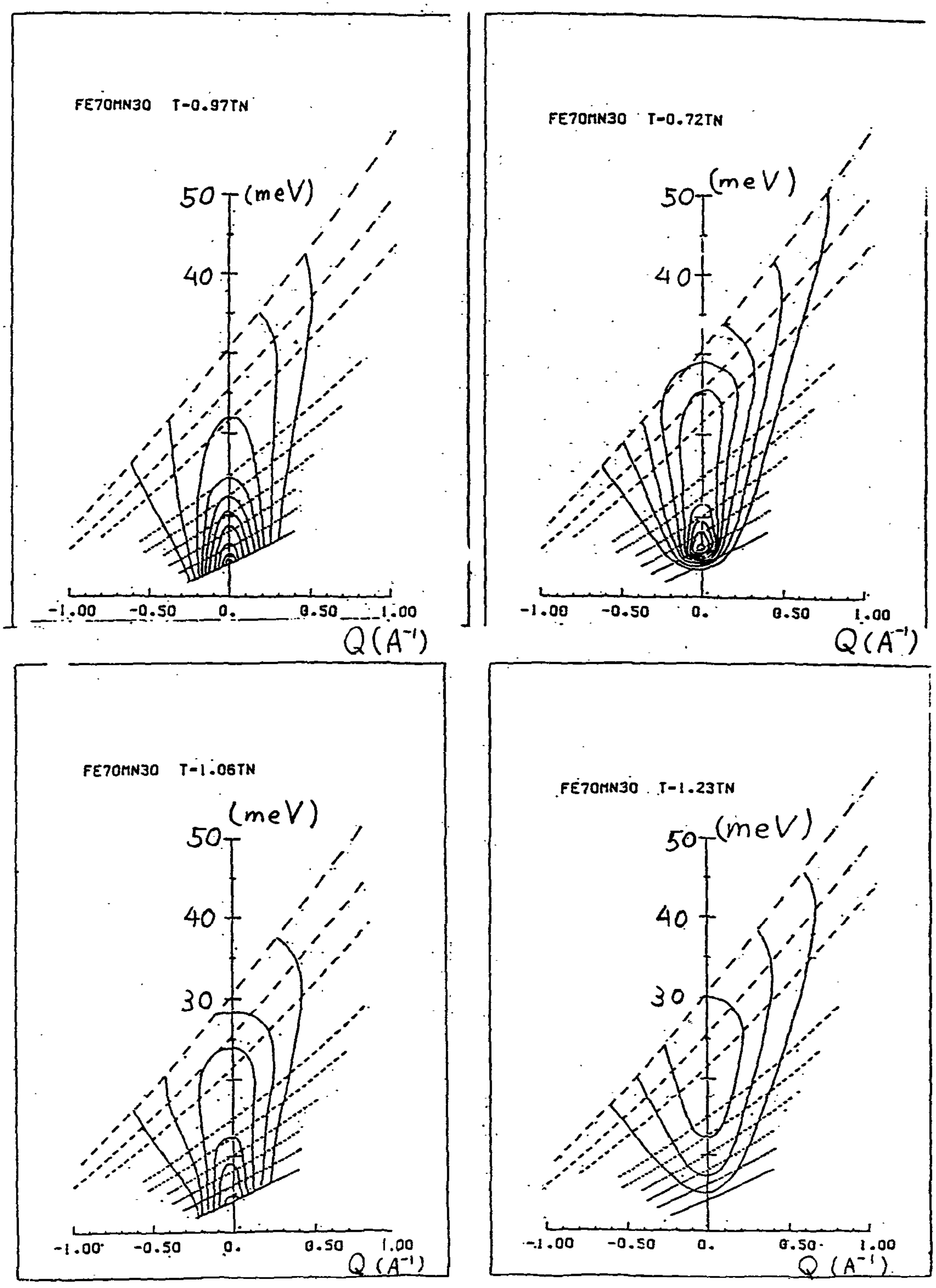


Fig. 5 Intensity mapping of the magnetic excitations in a $\gamma Fe_{0.7}Mn_{0.3}$ alloy at various temperature

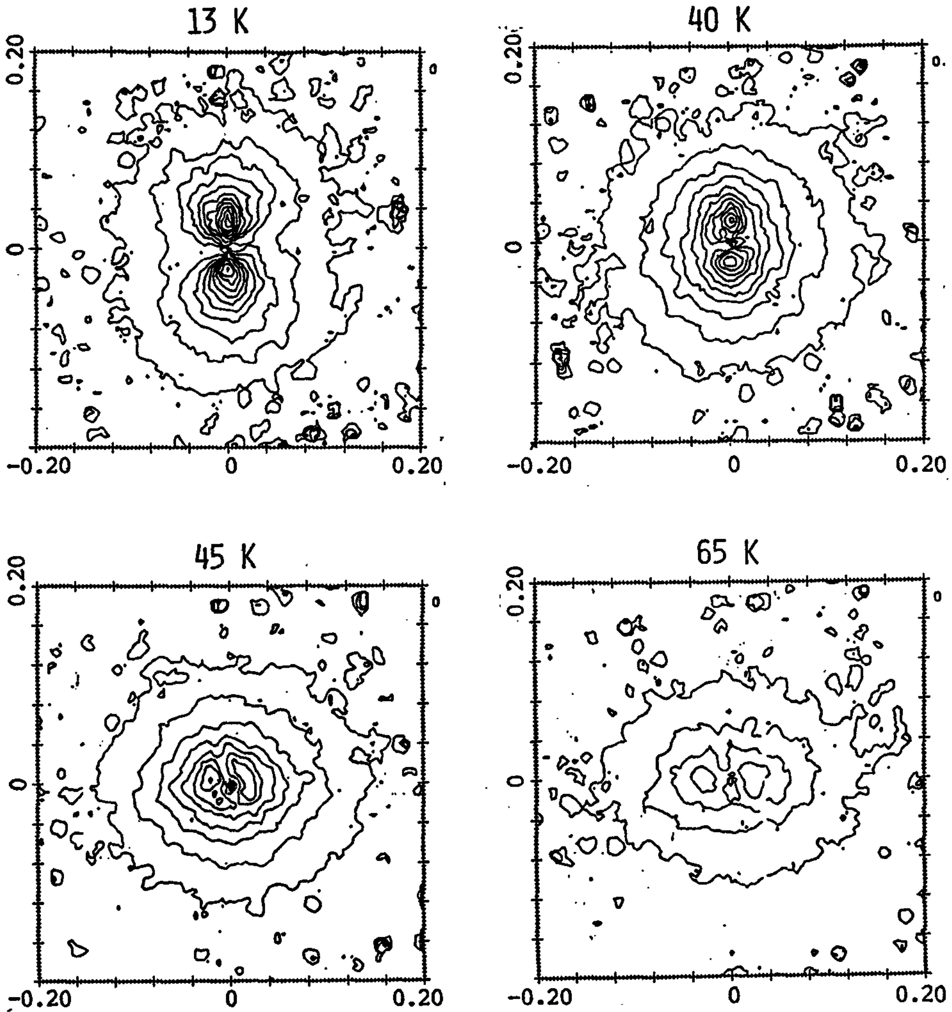
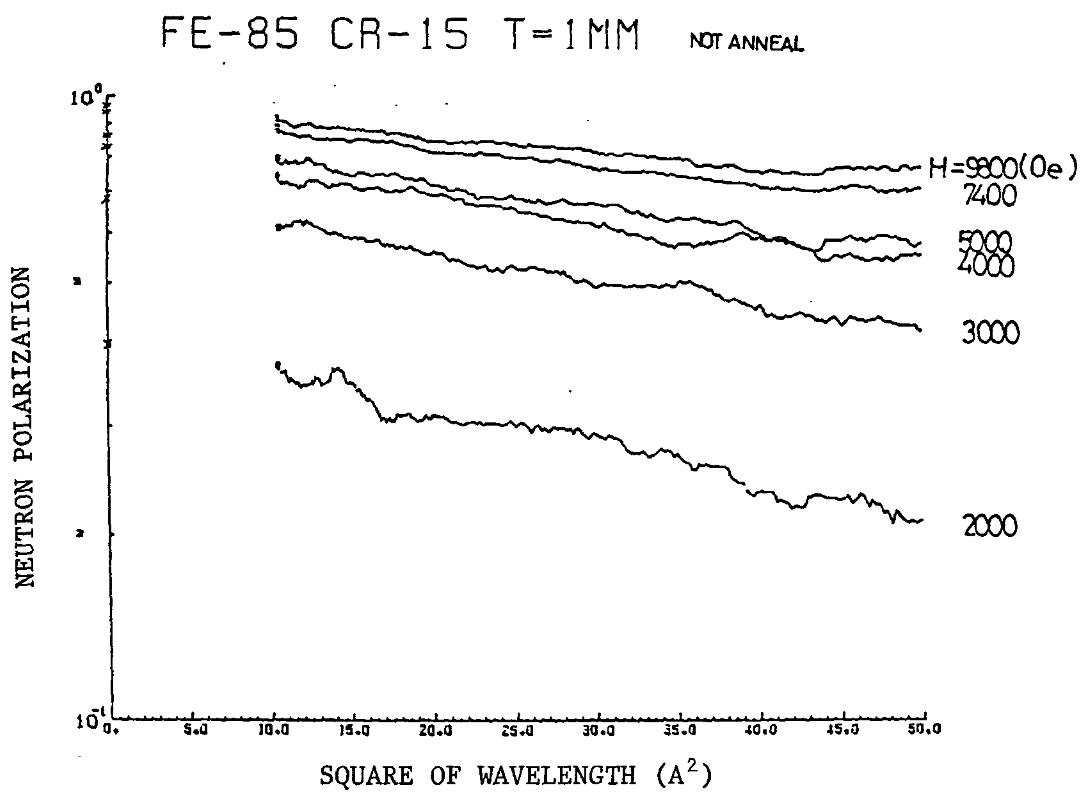
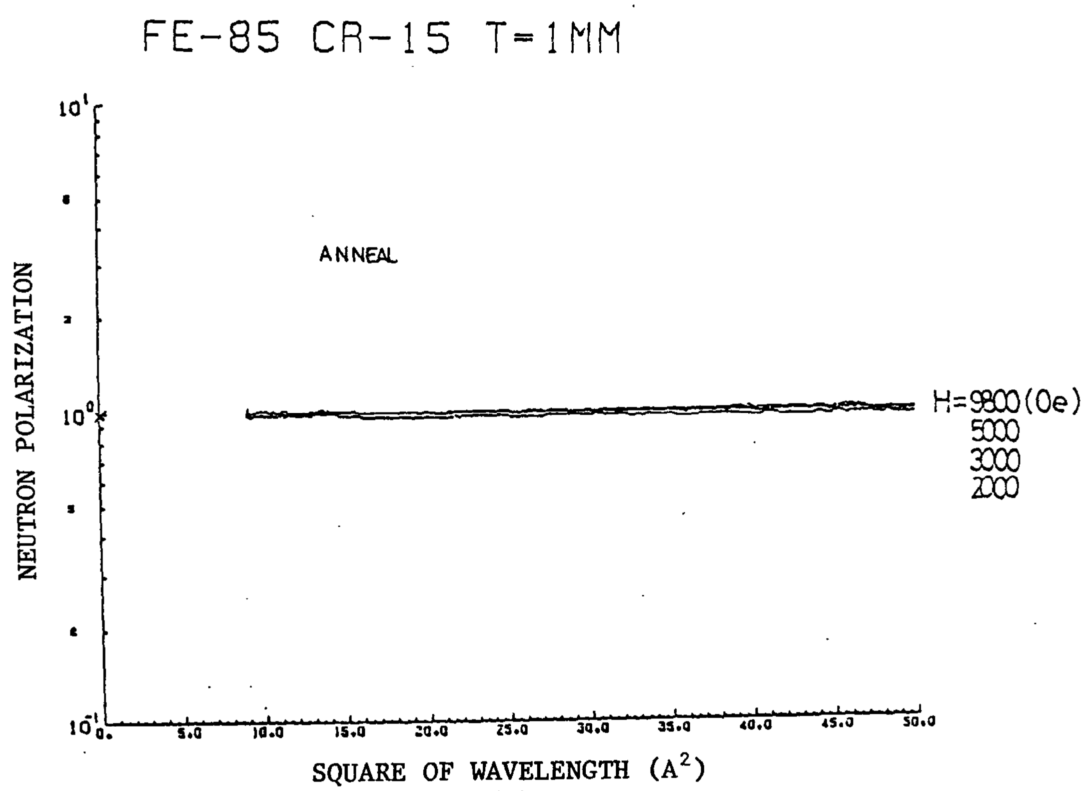


Fig. 6 Two dimensional display of magnetic correlation in $0.88FeTiO_3 - 0.12Fe_2O_3$

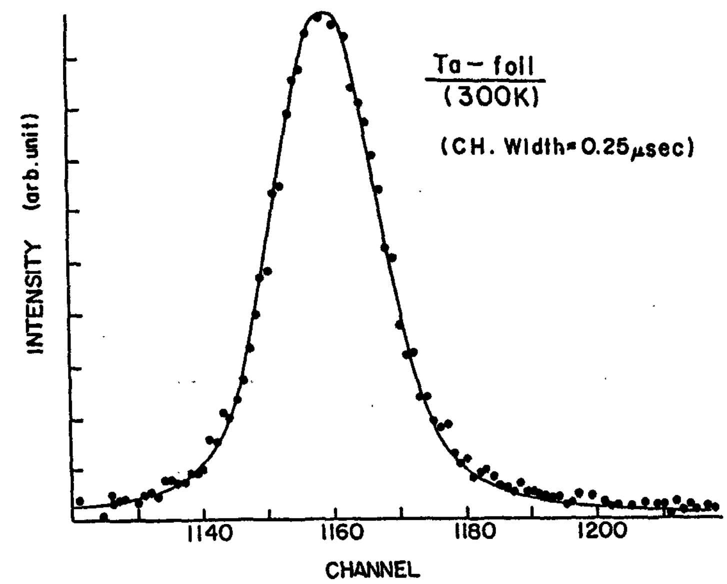


(a)

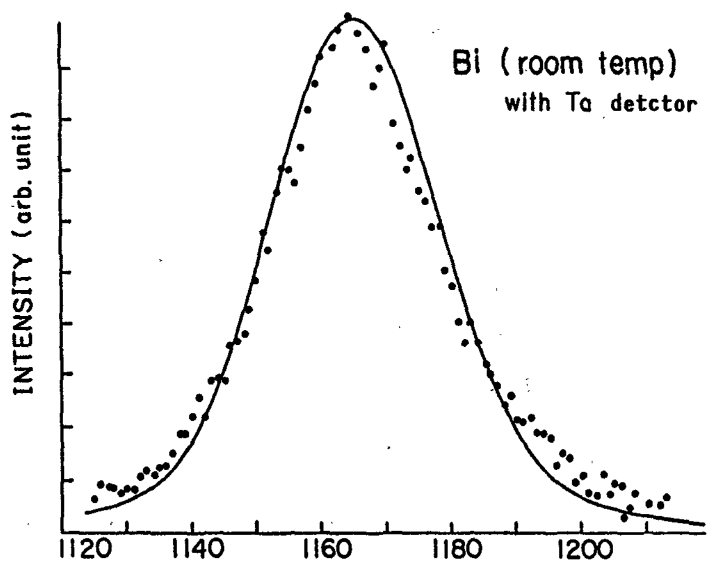


(b)

Fig. 7 Polarization of neutron beams after transmission through 1 mm thick $Fe_{0.85}Cr_{0.15}$ crystal, quenched from molten state (a), and after annealing (b)



(a)



(b)

Fig. 8 Measured (solid circles) and calculated (solid curves) time distributions of detecting probability for 12 μm thick Ta foil at room Temp. (a), and time spectra of scattered neutrons from Bi at room temp. measured by Ta detector (b)

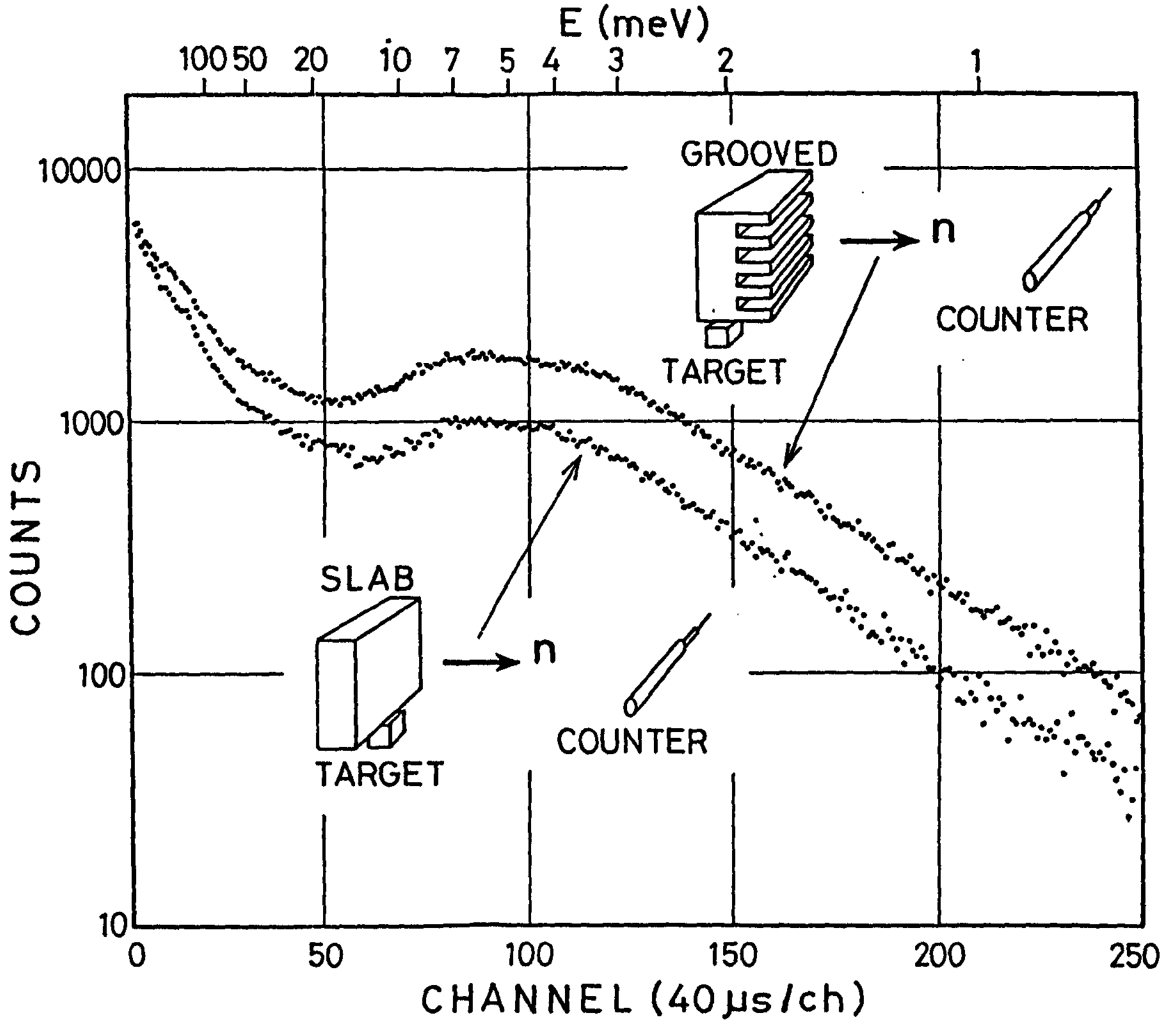


Fig. 9 TOF spectrum from a grooved solid methane moderator at 20 K compared with that from a slab one

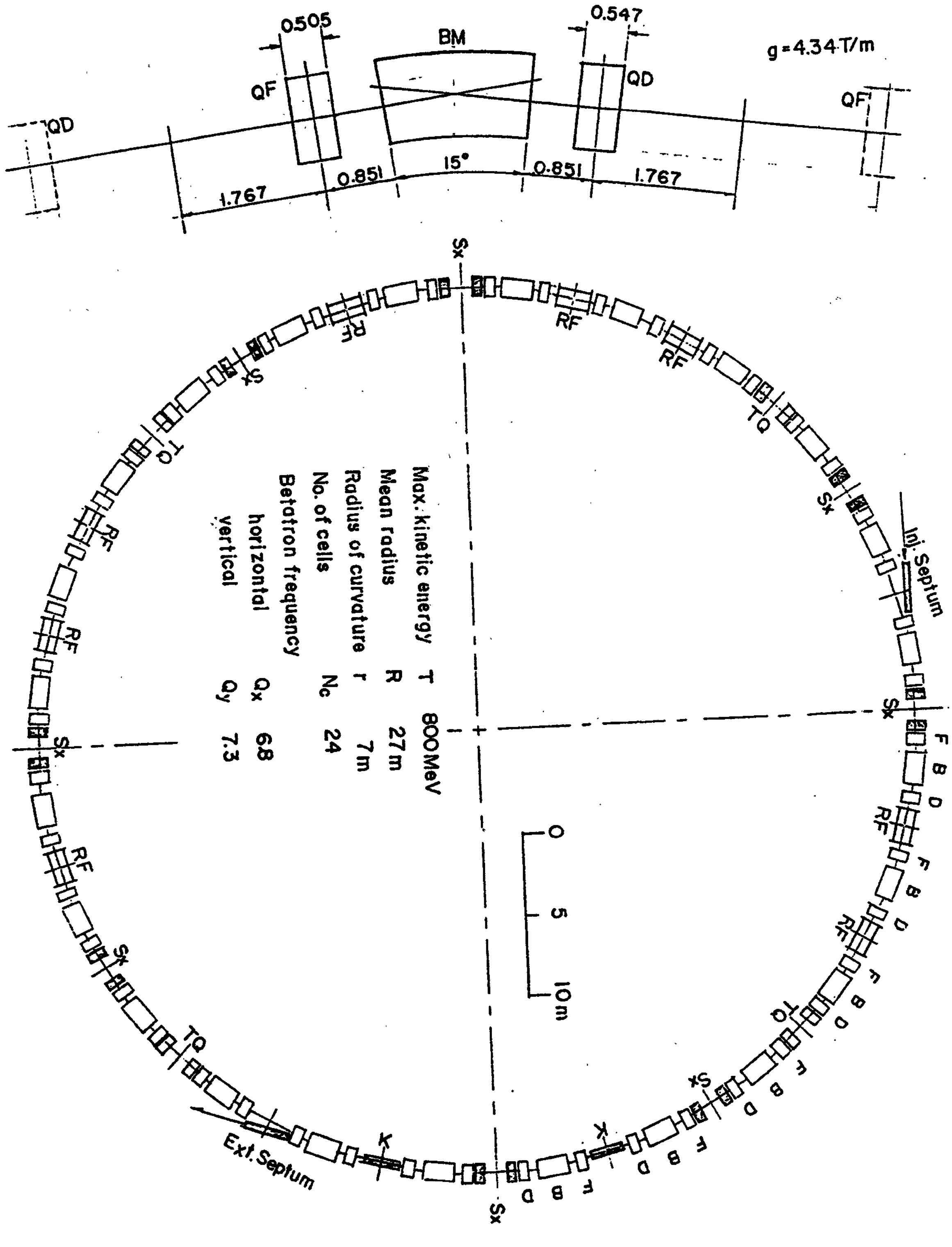


Fig. 10 Layout and lattice structure of the proposed accelerator

Russell	Q	Was the corrosion you mentioned outside the target canister?
N. Watanabe	A	Yes. For convenience we made the atmosphere outside the canister just air which produces ozone and oxides of irradiated nitrogen.
R. Kustom	Comment -	The 24 period synchrotron latice you showed doesn't seem to have enough room for extraction components.
N. Watanabe	A	Yes it's true that extraction will be very difficult!
D. A. Gray	A	Extraction is already hard with the SNS. For KENS-II the allowable beam loss would have to be < .3% on the same philosophy as the one adopted for SNS.
G. Lander	Q	For the quasi-elastic results on the cold source what was the resolution in energy transfer?
M. Kohgi	A	100 μeV.