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Status of KENS-I' and KENS-II

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ABSTRACT

Present status of the KENS facility (KENS-I') is reported here especially on the recent progress in instrumentation. Design concept of the KENS-II target station is briefly described with the results of recent R&D

I. KENS-I'

The present KENS Facility, KENS-I', has been successfully operated since the last ICANS meeting. The operation time of the 500 MeV Booster synchrotron in the past year was about 3500 hours, and the beam time allocated for neutron experiments was about 1500 hours. The average proton-beam intensity was 1.5×10^{12} protons per pulse (ppp) or less, which was lower than the maximum value of 2×10^{12} ppp achieved in 1988. This is due to various reasons including radiation safety problems. Since about 20% of proton-beam pulses were injected to the 12 GeV synchrotron, the average proton-beam current on the neutron target was about 4 μA. Thus, the integrated beam intensity over the past year was about 6000 μA or less which corresponds only to 3 days operation of ISIS. Nevertheless, we could perform various important experiments. We expect that the proton-beam intensity will reach 2×10^{12} ppp during routine operation. The beam transport line in the Booster Synchrotron Utilization Facility (BSF) has been improved to accept such intensity with tolerable beam loss.

The depleted uranium target has been operated trouble-free since the beginning of its operation in 1985. We experienced no serious problems with the cryogenic moderator (solid methane at 20 K) since the last ICANS meeting, because solid methane is renewed every two days before a "burp" can occur. A cold helium circulator had a problem and was repaired last year. The present cryostat which has been used for two years is still working.

During the last financial year, 76 experiments including 12 large proposals by groups responsible for the instruments were carried out. Scientists who visited the KENS facility spent about 4000 man-days. There are currently 16 instruments in the KENS facility as shown in Fig. 1. There was appreciable progress in the instrumentation since the last ICANS meeting. The construction of a new small/medium angle scattering instrument, WINK, started in 1989 and will be completed in 1991. The instrument was designed to realize a wider coverage in momentum transfer from 0.01 to 20 A^{-1} with much higher data rate, hopefully more than 10 times as high as that of the existing small angle instrument, SAN. Figure 2 shows the layout of WINK which will be equipped with more than 250 conventional He^{-3} proportional counters at a wider range of scattering angles from forward to backward. WINK was installed at the C4 beam line, sharing the beam with two existing instruments, LAM-40 (convential-resolution low-energy spectrometer) and HRP (high-resolution powder diffractometer) on the same neutron beam line as shown in Fig. 1. We were faced with various difficulties in sharing the same neutron beam by three different instruments, but now those are almost solved. Due to the relatively shorter flight path lengths for incident and scattered neutrons (9 m and 2.5 m, respectively), and to a lower repetition rate of the Booster synchrotron (20 Hz), the useful bandwidth of the incoming neutrons is quite wide, from 0.5 to 16 A, which enables the wider Q coverage mentioned above. In the last cycle, a preliminary measurement was performed on WINK with only one detector at each of 5 different angles. Figure 3 shows the result obtained with a measuring time of 2 hours. The result proved that the coverage in Q and the data rate are quite satisfactory as expected. After the full installation of detectors, measuring time of a few minutes would be adequate for a typical sample. The momentum resolution of WINK however is relaxed a bit at the lower Q range than that of SAN, because WINK employs natural beam collimation between source and sample, and the scattered neutron flight path length is limited to 2.5 m due to limited space. Details on this instrument and its performance will be presented by Furusaka1) at the Instrumentation Workshop "Total Performance".

There was remarkable progress on the high-resolution low-energy spectrometer, LAM-80. The LAM-type spectrometers2) are the inverted geometry instruments, developed by a famous Japanese neutron "Artist" Prof. Inoue, which have large analyzer mirrors composed of a large number of small analyzer crystals. LAM-80 has been improved twice. Firstly, all analyzer crystals of pyrolytic graphite were replaced by mica. This provided much better energy-resolution but with lower data rate (about one third). Then, the height of mirror was increased to realize a larger solid angle between sample and analyzer, and the number of mirrors was also increased from four to eight. As a consequence of these improvements, higher resolution with higher data rate were realized. The spectrometer is now called LAM-80ET. In order to confirm the performance of this machine, we performed a measurement on reorientational tunneling. As a standard sample, N-oxy-γ-picoline was measured at 5 K. Figure 4[3)] shows the result which demonstrates the superiority of LAM-80ET. In the present experiment, the 004 reflection of mica crystal was used to define the final energy (E_f) of the scattering process ($E_f \sim 0.82$ meV). The energy-resolution is about 5 μeV with a very wide energy window of more than 1 meV. Signal-to-background ratio is excellent. Note that the measuring time was only 8 hours with a proton-beam current of only 3 μA. We are convinced that LAM-80ET is one of the best spectrometer in the world in this energy range; it is well competitive with IRIS at ISIS operated at 100 μA and IN5 in ILL Grenoble.

The total scattering spectrometer for S(Q) measurements of liquids and glasses, HIT, has been one of the most productive instrument since the beginning of the KENS facility, but now it is the oldest instrument. It has been strongly requested to update this instrument. The construction of a new instrument, which is called HIT-II, was thus decided. HIT-II was designed to have much better momentum-resolution at smaller scattering angles with higher data rate, as in GLAD at IPNS and SANDALS at ISIS. The scattered flight path length, L_2, is shorter than in the latter two due to limited space in the experimental hall, consequently resulting in relaxed resolution. HIT-II will have a ring detector bank at forward angles between 10° and 20° in 2θ, which is composed of 72 normal He-3 proportional counters, and arrays with 80 counters at higher scattering angles. L_2 of the forward ring detector bank is about 1.2 m. The momentum resolution ($\Delta Q/Q$) of this detector is about 2.5%. HIT-II will be completed by the summer of 1992.

The high resolution powder diffractometer, HRP, is also one of the most productive and busiest instrument at KENS, although it is a prototype instrument equipped with only 12 normal He-3 proportional counters. The construction of a full-scale instrument is now indispensable. We decided to construct a new instrument, HRP-II, which is designed to realize much higher data rate with better resolution. The instrument will have large counter banks, at backward, 90° and lower angles, all being composed of 1D-PSD's as GLAD at IPNS. The data rate of the backward counter bank is expected to be about 5 times higher than that of the present instrument, with better resolution of about 0.2% in $\Delta d/d$ which shall be compared to 0.3% in the present instrument. The 90° counter bank will be composed of three arrays of 1D-PSD's at three different azimuthal angles in order to cover a wider range of azimuthal angle. This counter bank will be useful not only for industrial applications such as texture measurements and strain measurements, but also for diffraction under high pressure, etc. The maximum d-spacing covered by the backward counter is 5A with a total flight path length of 20 m and repetition rate of 20 Hz. The forward counter bank at 2θ=17°~40° can extend the d-spacing up to 30 A. HRP-II will be completed by the summer of 1993.

A reflectometer is one of the most useful instrument at pulsed spallation neutron facilities. As an option of TOP, the polarized cold neutron instrument at KENS, the development of a reflectometer using polarized cold neutrons is in progress. By using the second frame of the KENS period of 50 ms, a wavelength scan up tp 18 A becomes possible. Preliminary, but very promising, data are being obtained.

One highlight of the scattering experiments recently achieved was neutron diffraction under high magnetic field. Scattering under extreme conditions is one of the most promising fields of research using pulsed neutrons. However, we have never performed such an experiment. The maximum magnetic field so far used in neutron diffraction was below 10 T. As a first step of high field experiments, a Kobe University group developed a pulsed field instrument which can produce a high magnetic field up to 20 T every 2 sec with a pulse duration of about 1 ms. Neutron diffraction from a single crystal of metamagnetic $PrCo_2Si_2$ was measured under various high magnetic fields on the MRP diffractometer at KENS. The pulsed magnetic field was phased to the neutron pulse. When the neutrons of a specific velocity satisfying the Bragg condition arrive at the sample, the magnet is pulsed. $PrCo_2Si_2$ shows a complicated phase transition, a so-called successive magnetic phase transition, as shown in the magnetization curve (Fig. 5)4). The result proved that the proposed spin configurations (Fig. 6)4) are correct. Details on this topic will be presented by Motokawa5) at the Instrumentation Workshop "Sample Environments"·

II. KENS-II

KENS-II is a next generation pulsed-spallation-neutron-source in Japan for condensed matter research and partly for fundamental physics. KENS-II was first proposed as a part of the GEMINI (Le Génératour á Méson Intense et Neutron Intense) project and then combined with a Hadron project proposed by a nuclear physics group. The joint program is called the Japanese Hadron Project (JHP) which is aimed at exploring various research fields using various kinds of unstable secondary beams based on high intensity protons from a new accelerator complex. Neutron scattering is positioned as an important part of four major fields as shown in Fig. 76). After significant discussions and compromise between four research fields, we decided, as a first phase, to construct a 1GeV H^- linac and a compressor/stretcher ring (and a heavy-ion linac for exotic nuclear beams). The layout of JHP is shown in Fig. 8. The proposed site for JHP is located at the forest adjacent to the southern boundary of the present KEK site.

JHP was authorized by the Science Council of Japan almost three years ago, but is still under examination by Monbusho (The Ministry of Education, Science and Culture, Japan), and by University of Tokyo, because JHP is dependent on the conversion of the Institute of Nuclear Study, University of Tokyo, to a new national laboratory as KEK. We are expecting to have an answer at latest by next spring. The main parameters of the 1GeV linac and the compressor /stretcher ring are summarized in Table I6). There is remarkable progress in the R&D of the 1GeV linac, on which Kihara7) will give an invited talk. The compressor/stretcher ring delivers two bunches of proton beams-a 200 ns pulsed beam for the neutron scattering facility and 20 ns pulsed one for the meson science facility. Figure 9 shows the structure of circulating beam and a scheme of proton beam delivery.

We are aiming to realize the world's best pulsed-spallation-neutron-source with a proposed accelerator for JHP, which is comparable to those in the existing large scale facilities. The design goal of the proposed source is as follows:

(1) the world's brightest pulsed-cold-neutron-beams;
(2) bright and narrow pulsed thermal/epithermal neutron beams, at least comparable to those at existing intense pulsed-neutron-sources;
(3) wider range of neutron spectra;
(4) as many neutron beam lines as possible.

There are increasing demands for the use of neutron beams in various fields, but the total number of available neutron-beam-lines in an existing spallation neutron facility is much smaller than that in a high flux reactor. Another important problem which must be solved for extending the neutron beam technique to various research fields including industrial applications is that neutron beams from an intense source are very expensive. In order to solve this problem to some extent, we decided to adopt a vertical proton-beam-injection scheme rather than a horizontal one as used at present KENS, IPNS and ISIS. The total number of neutron-beam-lines is mainly limited by available opening angle around the target station. The removal of the proton-beam-line in the experimental hall with it's massive shielding will provide additional neutron-beam-lines as illustrated in Fig. 10. This scheme will bring about a considerable cost saving since proton-beam-line shielding in the experimental hall is very expensive. The amount saved can well compensate the additional cost for a large 90°-bending magnet in the primary proton-beam-line and extra overhead shielding of the target station.

In a vertical injection scheme, there is another important merit, in that we can take full advantage of the so-called "flux-trap type moderator"8). We carefully compared by computer simulation the slow-neutron beam intensity from a flux-trap moderator with that from a traditional wing-geometry type moderator and proved that the former can provide 1.3-1.4 times higher intensity of slow neutrons than the latter. This is a very important conclusion. Details on this topic will be presented by Kiyanagi[9] at the Target Station Workshop "Cold Neutron Sources and Moderators".

Now let us consider what kind of cold neutron source would be the most promising. It has long been believed that pulsed spallation neutron sources are not as advantageous as reactors for cold neutron experiments, especially for small-angle-scattering. This is mainly due to the fact that the time-averaged cold-neutron-beam-intensity from pulsed-spallation-neutron-sources are not adequate. The situation is gradually changing; for example, KENS has shown the usefulness of pulsed cold neutrons in various experiments even with its lower intensity, and LANSCE has proved that LQD (SANS instrument) can compete with D11 at ILL Grenoble within a certain range of Q. WINK at KENS is in the same situation. The lower time-averaged cold-neutron-beam intensity is natural because the duty cycle of a pulsed-cold-neutron-source is only $\sim 5\times 10^{-3}$, and the peak flux is to the utmost comparable to a high flux reactor. The problem which we want to point out is the lower conversion efficiency (from fast to cold neutrons) in the existing large scale pulsed-spallation-neutron facilities. This is also very natural because in those facilities decoupled liquid-hydrogen-moderators are used, which can provide narrow pulses of cold neutrons but lower time-averated flux. We studied what characteristics are important for a pulsed-cold-neutron-source in various scattering experiments. We concluded that the figure of merit (FOM) of a pulsed cold neutron source for small angle scattering is, to a first approximation, proportional to the time-integrated intensity per pulse and independent of the repetition rate and the pulse width in a realistic range, while for high resolution spectroscopy it is proportional to the pulse height and again independent of the repetition rate and the pulse width[10].

Based on this result, we looked for various candidates and finally found that a coupled liquid-hydrogen-moderator with an appropriate hydrogenous premoderator at room temperature is the most promising among various realistic moderators[11]. Our preliminary experiment was very encourging[12]. Thus, we continued further optimization experiments on this type of moderator and proved that a very large gain factor relative to a traditional decoupled liquid-hydrogen-moderator can be obtained with rather modest pulse-width broadening. Measured spacial (vertical) distribution of cold neutrons on the emission surface of the proposed moderator in a wing geometry is compared with two typical decoupled cold moderators in Fig. 11. The result demonstrates the superiority of the proposed moderator-two times higher flux than solid methane at 20 K, the best decoupled cold moderator. Details on this topic will be presented by Kiyanagi[13][14] at the Target Station Workshop "Cold Neutron Sources and Moderators".

The design concept of KENS-II is based on the flux-trap type moderator with a vertical proton-beam injection scheme and the coupled cold moderator mentioned above. In addition to these two, we proposed a new concept for the target station which has two separate target-moderator-reflector assemblies, as illustrated in Fig. 12, with a new scheme of proton-beam delivery. For every 5 pulses (100 ms), a pair of double pulses from the compressor/stretcher ring is delivered to Target-1 (dedicated to the cold neutron source), with the other 4 pulses of single pulse being fed to Target-2 (dedicated to the decoupled moderators for narrow pulses of thermal and epithermal neutrons)10). Both can be optimized independently. The new system with the proposed proton-beam delivery scheme can bring about several times better overall performance than a traditional single assembly of all decoupled moderators in wing geometry with a horizontal proton-beam injection scheme. Details on this idea will be presented by Watanabe15) at the Target Station Workshop "New Concept in Target-Reflector Moderator Systems".

REFERENCE

1 M. Furusaka, K. Suzuya, N. Watanabe, J. Suzuki and I. Fujikawa : Total performance of KENS small angle machines, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-675.
2 K. Inoue, Y. Ishikawa, N. Watanabe, K. Kaji, Y. Kiyanagi, H. Iwasa and M. Kohgi : Nucl. Instrum. Methods, A238 (1985) 401.
3 K. Inoue, T. Kanaya, Y. Kiyanagi, S. Ikeda, K. Shibata, H. Iwasa, T. Kamiyama and Y. Izumi : Total performance of LAM-80ET, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-682.
4 T. Shigeoka, H, Fujii, K. Yonenobu, K. Sugiyama and M. Date : J. Phys. Soc. Jpn. 58 (1989) 394.
5 M. Motokawa, H. Nojiri, M. Uchi, S. Watamura, H. Kawai and Y. Endoh : Neutron diffraction study in pulsed high magnetic field, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-977.
6 Pamphlet "Japanese Hadron Project -the first stage-", Institute for Nuclear Study, Univ. of Tokyo (1989)
7 M. Kihara : Progress of accelerator R&D for the Japanese Hadron Project, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-140.
8 G. J. Russell, H. Robinson, G. L. Legate, R. Woods, E. R. Whitaker, A. Bridge and K. J. Hughes : Proc. ICANS-IX (Villigen, Sept. 22-26, 1986) P-177.
9 Y. Kiyanagi and N. Watanabe : Some Neutronic Studies on Flux-Trap Type Moderator, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-408.
10 N. Watanabe, M. Furusaka and Y. Kiyanagi : A design concept for KENS-II cold neutron source, Proc. Int. Workshop on Cold Neutron Sources (Los Alamos, Mar. 5-8, 1990), in press.
11 N. Watanabe : Advanced Neutron Sources 1988 (Proc. ICANS-X), Institute of Physics Conference series Number 97, Institute of Physics, Bristol and New York, P-763.
12 N. Watanabe, Y. Kiyanagi, K. Inoue, M. Furusaka, S. Ikeda, M. Arai and H. Iwasa : Advanced Neutron Sources 1988 (Proc. ICANS-X), Institute of

Physics Conference Number 97, Institute of Physics, Bristol and New York, P-787.

13 Y. Kiyanagi, N. Watanabe, M. Furusaka, H. Iwasa and I. Fujikawa : Optimization studies on coupled liquid hydrogen moderator, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-388.

14 Y. Kiyanagi, N. Watanabe, M. Furusaka and H. Iwasa : Reflector optimization for coupled liquid hydrogen moderator, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-401.

15 N. Watanabe : A design concept of target-reflector-moderator assemblies for KENS-II, Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-471.

Table I Principal parameters of proton Accelerator for JHP

	Linac	Compewssor/stretcher
Energy	1Gev	1GeV
Average current	400μA	200μA
Repetition rate	50Hz	50Hz
Peak current	20mA	
Pulse width	400μs	200ns (for neutron exp.)
Size	500m long	54m in diam.

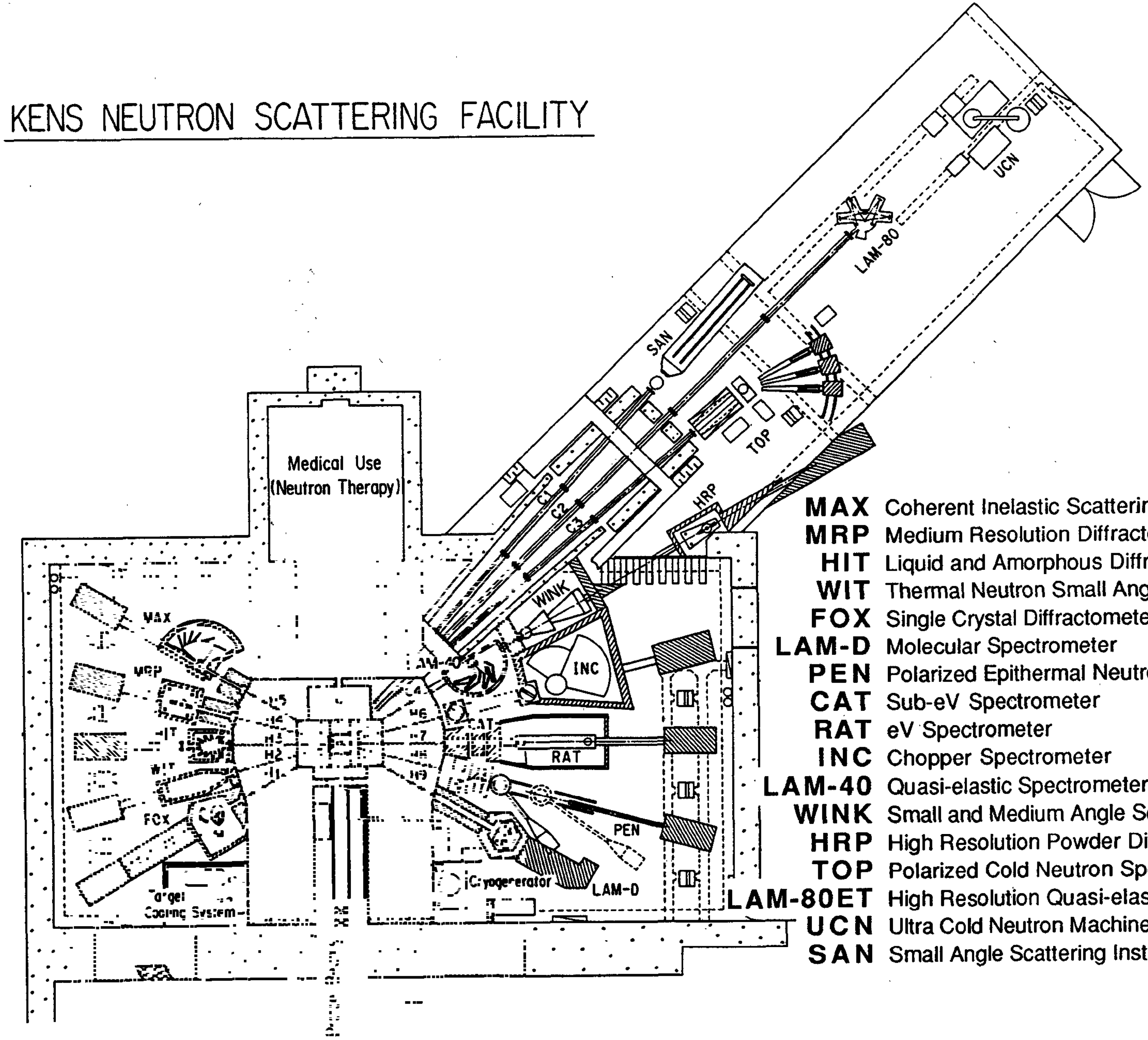
Q(G.J.Russell): Have you considered putting moderators upstream of the first target?

A(N.Watanabe): No, we have not.

Q(A.D.Taylor): On a green field site, with a solid target, would you still use vertical injection?

A(G.S.Bauer): Yes, I would. There is the advantage of a 2π region to be used for neutron beams. The cylindrical geometry is just very convenient and also the possibility of vertical target movement for exchange is a big advantage. Of course, design of the beam line needs thorough consideration.

Fig. 1. KENS NEUTRON SCATTERING FACILITY



MAX	Coherent Inelastic Scattering Spectrometer
MRP	Medium Resolution Diffractometer under Extreme Conditions
HIT	Liquid and Amorphous Diffractometer
WIT	Thermal Neutron Small Angle Scattering Instrument
FOX	Single Crystal Diffractometer
LAM-D	Molecular Spectrometer
PEN	Polarized Epithermal Neutron Spectrometer
CAT	Sub-eV Spectrometer
RAT	eV Spectrometer
INC	Chopper Spectrometer
LAM-40	Quasi-elastic Spectrometer
WINK	Small and Medium Angle Scattering Instrument
HRP	High Resolution Powder Diffractometer
TOP	Polarized Cold Neutron Spectrometer
LAM-80ET	High Resolution Quasi-elastic Spectrometer
UCN	Ultra Cold Neutron Machine
SAN	Small Angle Scattering Instrument

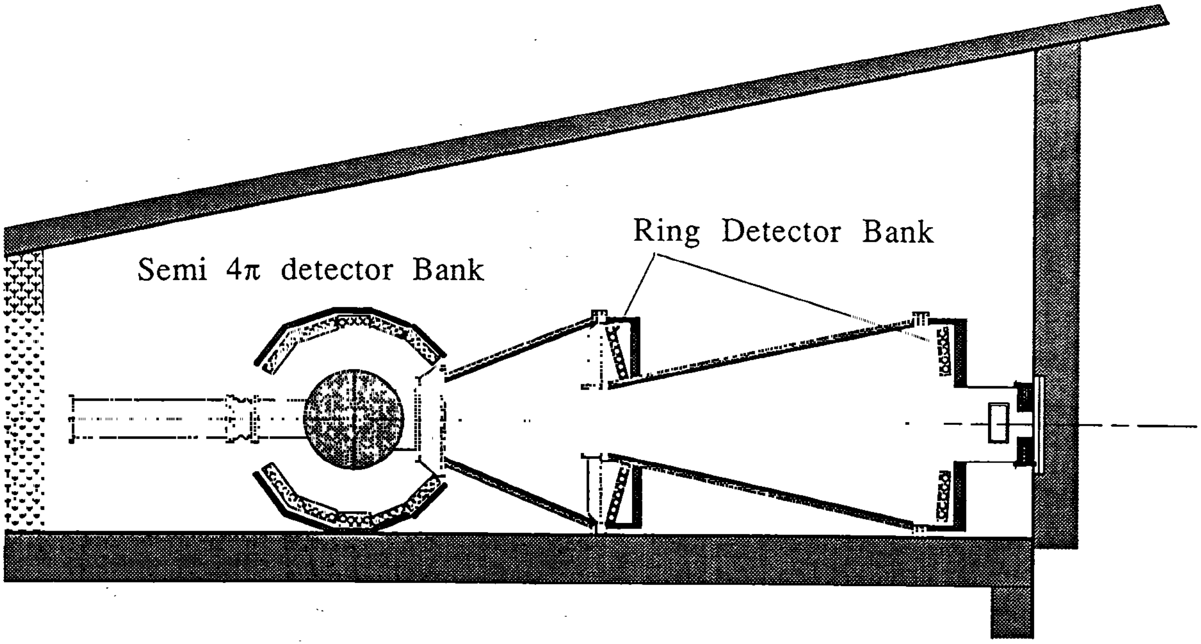


Fig. 2 Layout of WINK

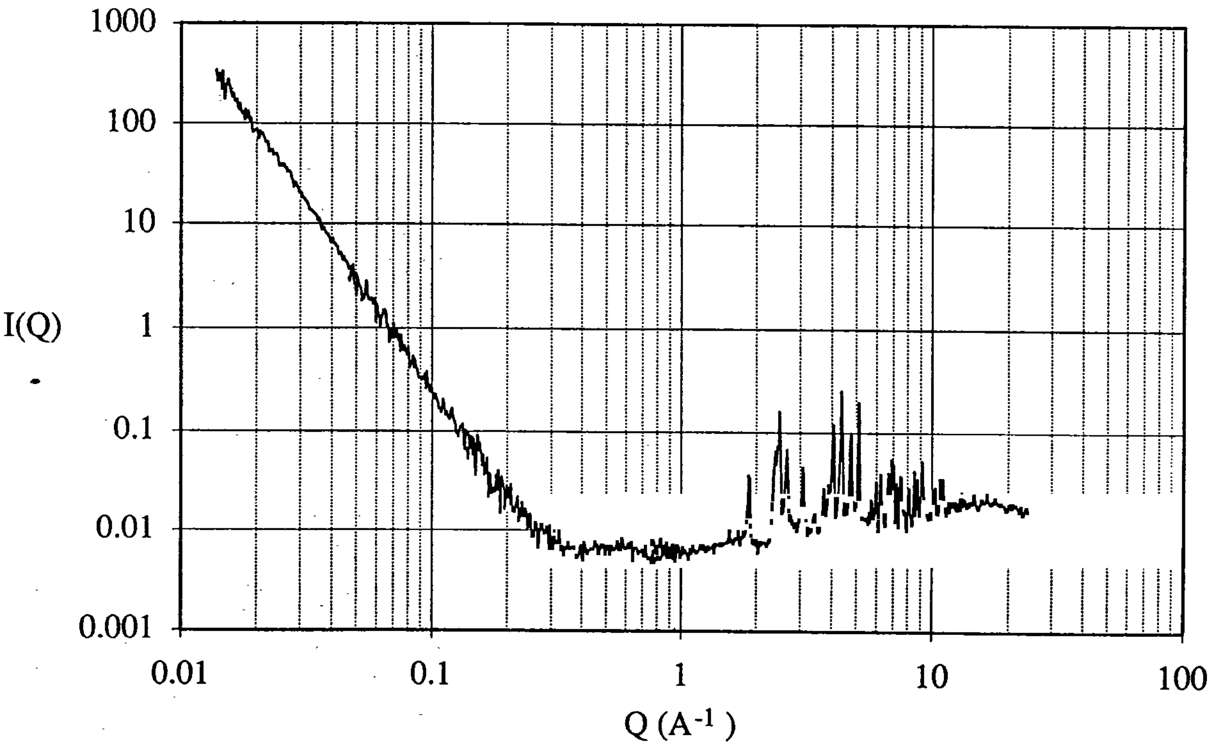


Fig. 3 Preliminary result of small angle scattering from SiC sample measured on WINK.

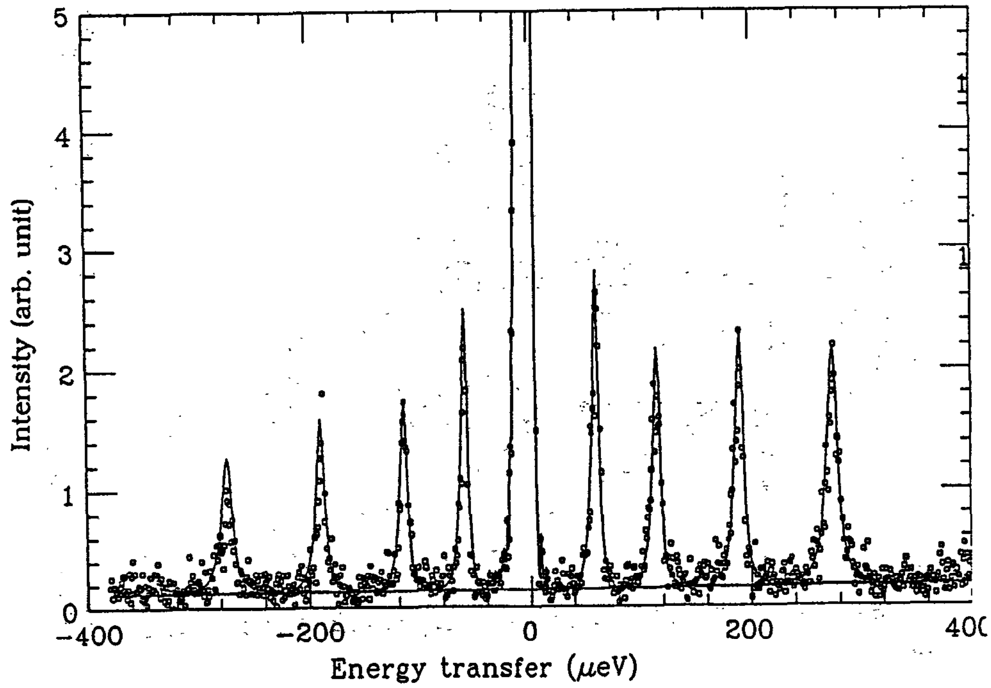
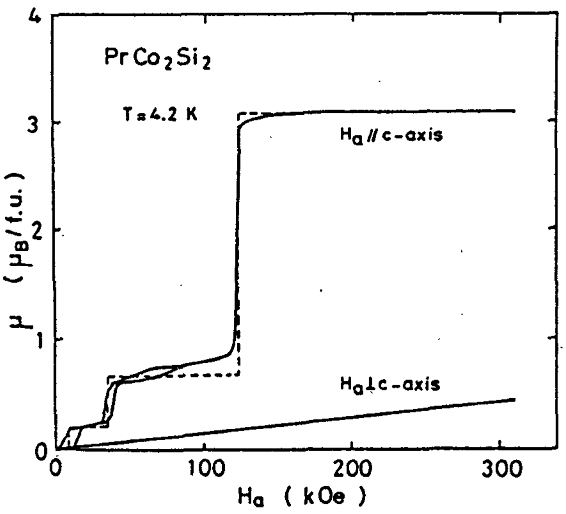


Fig. 4 Tunneling spectrum of N-Oxy γ picoline measured at 5K on LAM-80ET



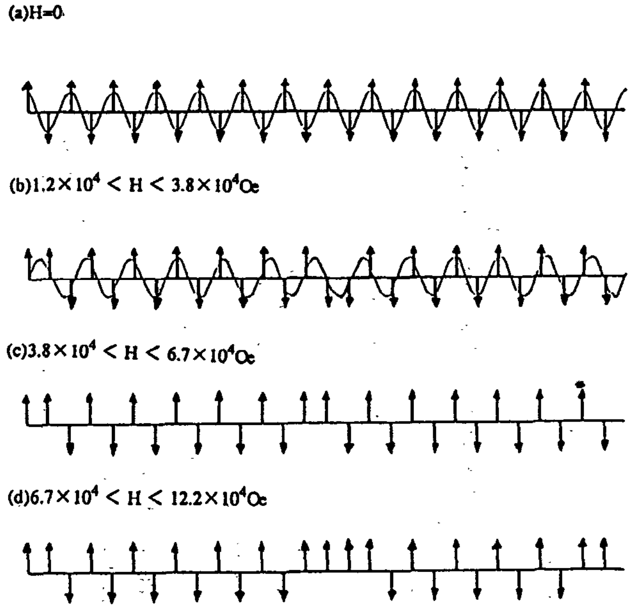
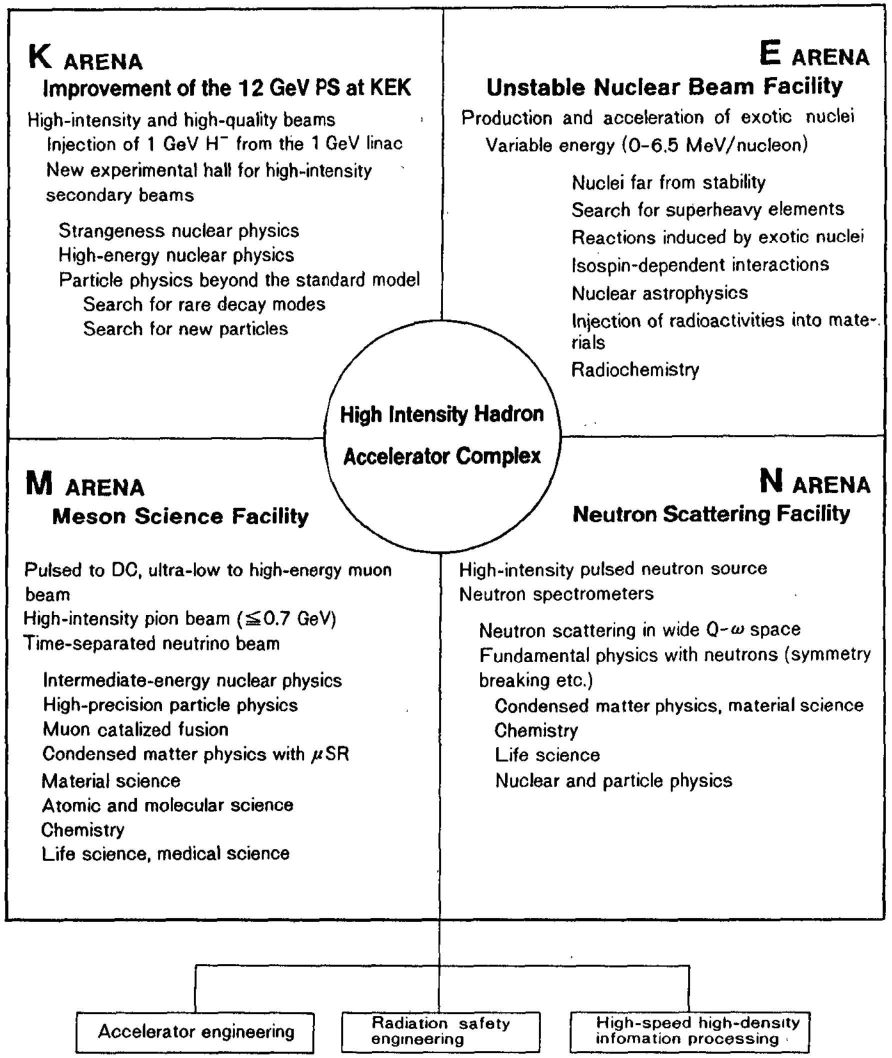


Fig. 5 High Field Magnetization curves along the a- and c-axes at 4.2K for $PrCo_2Si_2$ [after ref.4]

Fig. 6 A proposed spin configurations under various magnetic fields [after ref.4]



K ARENA
Improvement of the 12 GeV PS at KEK

High-intensity and high-quality beams
Injection of 1 GeV H$^-$ from the 1 GeV linac
New experimental hall for high-intensity secondary beams

- Strangeness nuclear physics
- High-energy nuclear physics
- Particle physics beyond the standard model
  - Search for rare decay modes
  - Search for new particles

E ARENA
Unstable Nuclear Beam Facility

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Variable energy (0-6.5 MeV/nucleon)

- Nuclei far from stability
- Search for superheavy elements
- Reactions induced by exotic nuclei
- Isospin-dependent interactions
- Nuclear astrophysics
- Injection of radioactivities into materials
- Radiochemistry

High Intensity Hadron Accelerator Complex

M ARENA
Meson Science Facility

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High-intensity pion beam (≦0.7 GeV)
Time-separated neutrino beam

- Intermediate-energy nuclear physics
- High-precision particle physics
- Muon catalized fusion
- Condensed matter physics with μSR
- Material science
- Atomic and molecular science
- Chemistry
- Life science, medical science

N ARENA
Neutron Scattering Facility

High-intensity pulsed neutron source
Neutron spectrometers

- Neutron scattering in wide Q-ω space
- Fundamental physics with neutrons (symmetry breaking etc.)
  - Condensed matter physics, material science
  - Chemistry
  - Life science
  - Nuclear and particle physics

Fig. 7 Research area of JHP

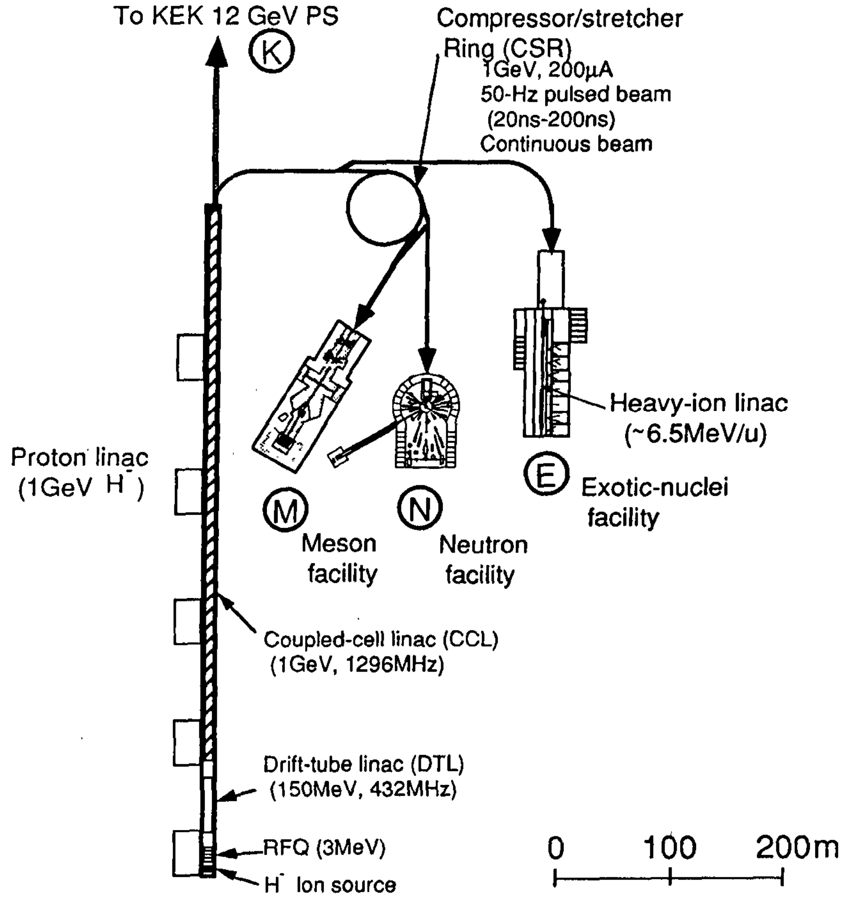

Fig. 8 Layout of JHP

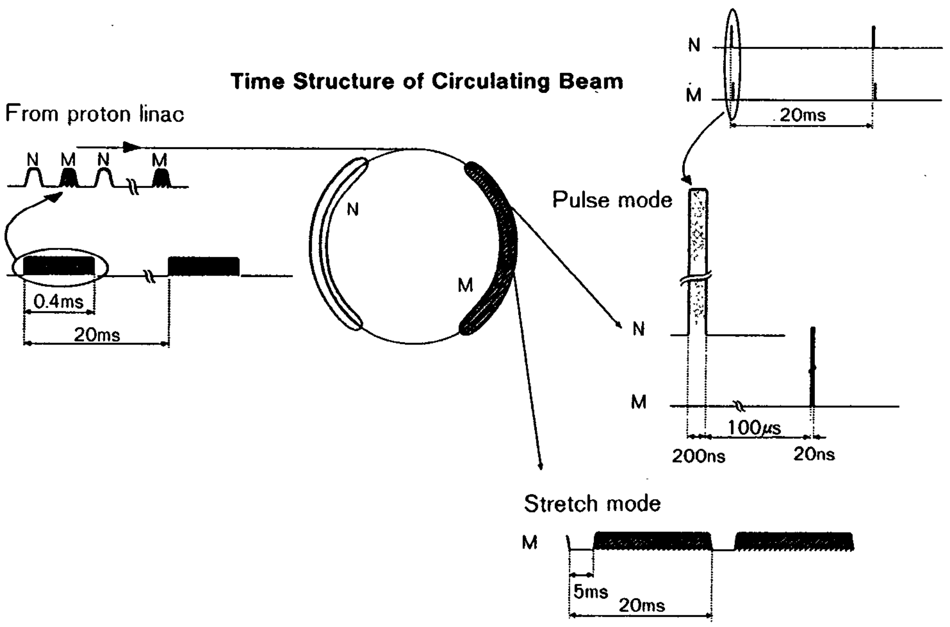

Fig. 9 Time structure of a circulating beam and a scheme of proton beam delivery

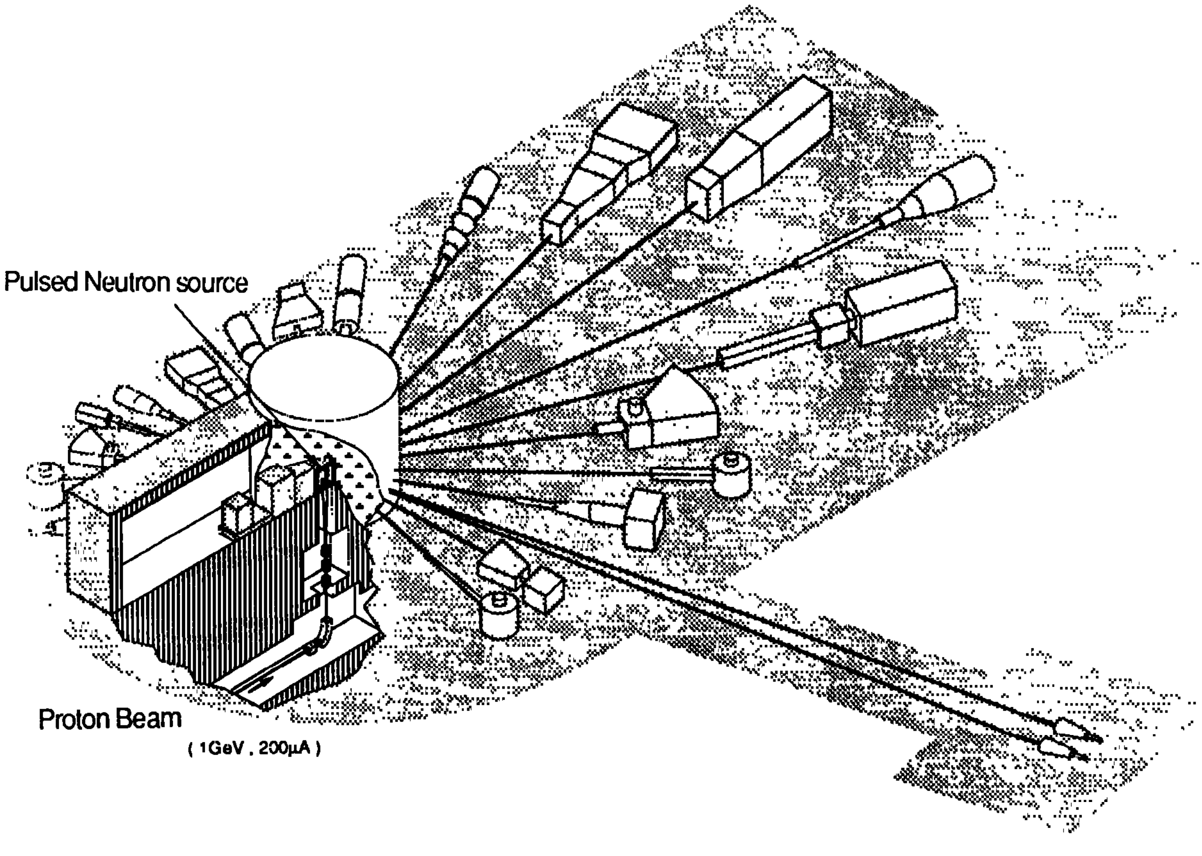

Fig. 10 Illustration of KENS-II (vertical proton-beam injection and layout of neutron instruments)

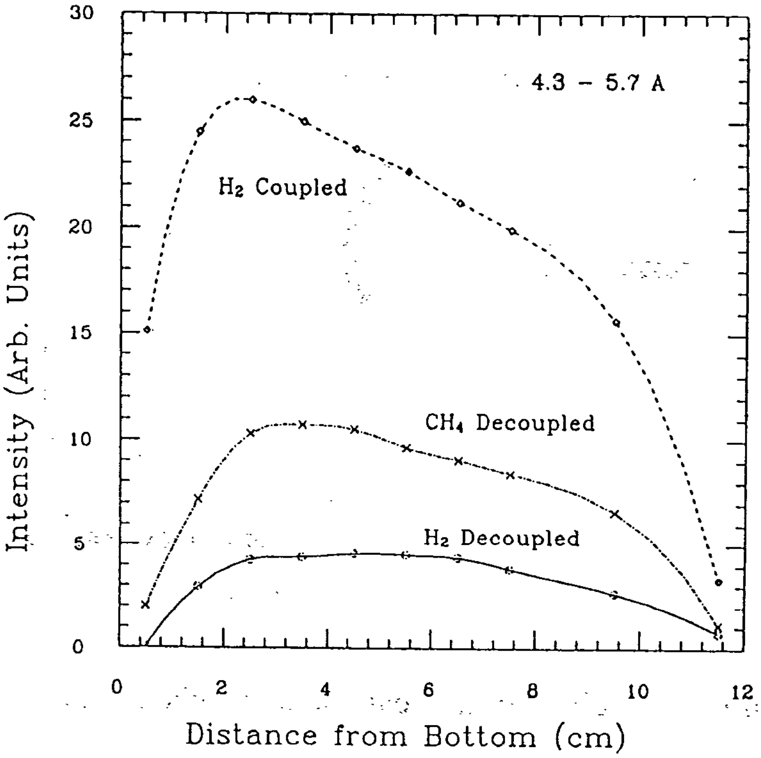

Fig. 11 Measured spatial distribution of cold neutron beam intensity along the vertical direction of the viewed surface of the coupled liquid hydrogen moderator.

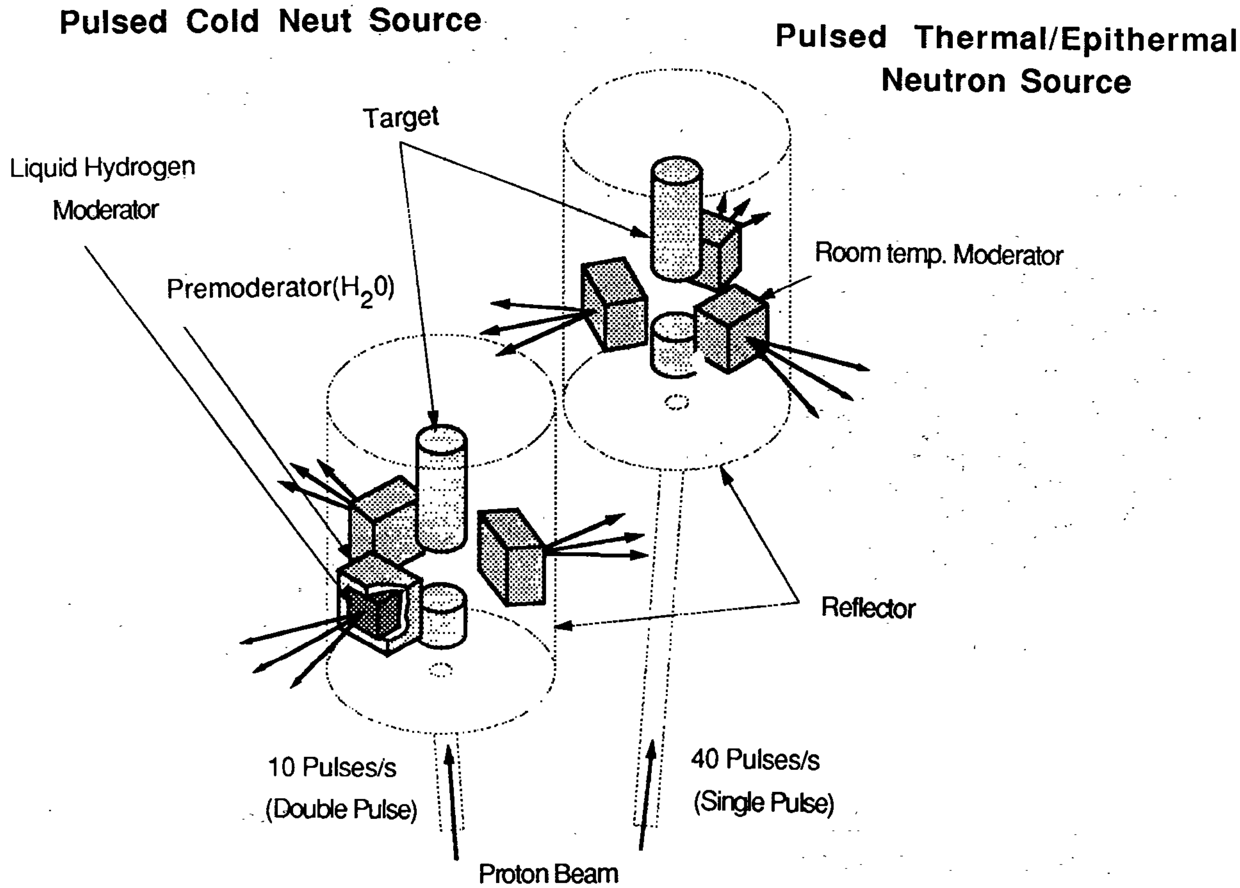

Fig. 12 Illustration of two target-reflector-moderator assemblies proposed for KENS-II