Materials Science Forum
ISSN: 1662-9752, Vol. 1024, pp 13-26
doi:10.4028/www.scientific.net/MSF.1024.13

Submitted: 2020-06-25
Revised: 2020-09-23
Accepted: 2020-09-24
Online: 2021-03-15

KENS-II, its History from Design to Removal

Masayoshi KAWAI [1,a*], Susumu IKEDA[1,b] and Takashi INO[1,c]

[1]High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan

[a]masayoshi.kawai@kek.jp, [b]susumu.ikeda@kek.jp, [c]takashi.ino@kek.jp

Keywords: Neutron, Proton, Target, Tungsten, Tantalum, HIP method, Moderator, Reflector, Neutron spectrum.

Abstract. KENS-II is the second generation of the spallation neutron source at KEK which was operated from 1st November 2000 to 22nd March 2006 supplying neutron beam to the neutron spectrometers for material science. The present paper reviews history of the KENS-II from its design to removal together with its performance for the neutron scattering experiments.

Introduction

KENS [1, 2] was the first pulsed neutron source for material science in the world, which was operated at the High Energy Accelerator Research Organization from 18th June 1980 to 22nd March 2006. It operated at 3 kW with a proton beam of 500 MeV in energy and 6 mA in beam-current. Proton pulses with 50 ns width bombarded the target at 20 Hz. Three kinds of targets were used before 2000: a tungsten target from January 1980 to November 1985, depleted uranium target from December 1985 to November 1996 and tantalum target from December 1996 to June 2000. **Fig. 1** shows main part of the target station composed of radiation shields and the 660 mm width x 610 mm TMRA (target, moderator and reflector assembly) components of KENS. Pulsed neutrons were generated by bombarding the target shown in **Fig. 2(1)** at the center of TMRA with high energy pulsed proton beam. **Fig.2(2)** shows thermal and cold moderators and their decouplers. Thermal neutron pulse was produced by thermal moderator and B_4C (boron carbide) decoupler. Initially, a polyethylene moderator was used but was replaced by a water moderator in 1988. The cold neutron pulse was also produced by a solid methane moderator and a Cd (cadmium) decoupler. The beryllium reflector reflected back neutron to the moderators and increased neutrons in the moderators.

In 1998, it was found that the cold neutron source intensity of KENS was decreased to about a third of the designed value because Cd liner decoupler at the cold neutron source deformed and obstructed the neutron beam line, TMRA was replaced in September 2000 by a new one with a tantalum-clad tungsten target and a Gd (gadolinium)-poisoned thermal moderator so that neutron

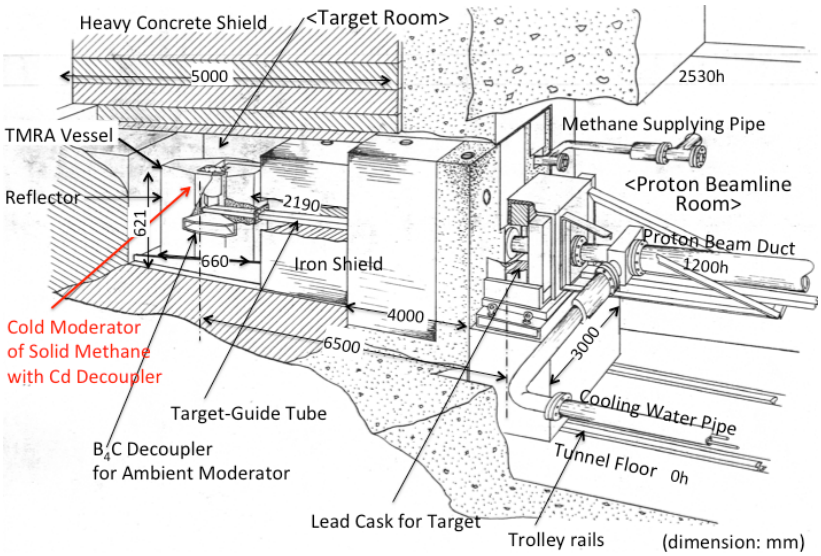
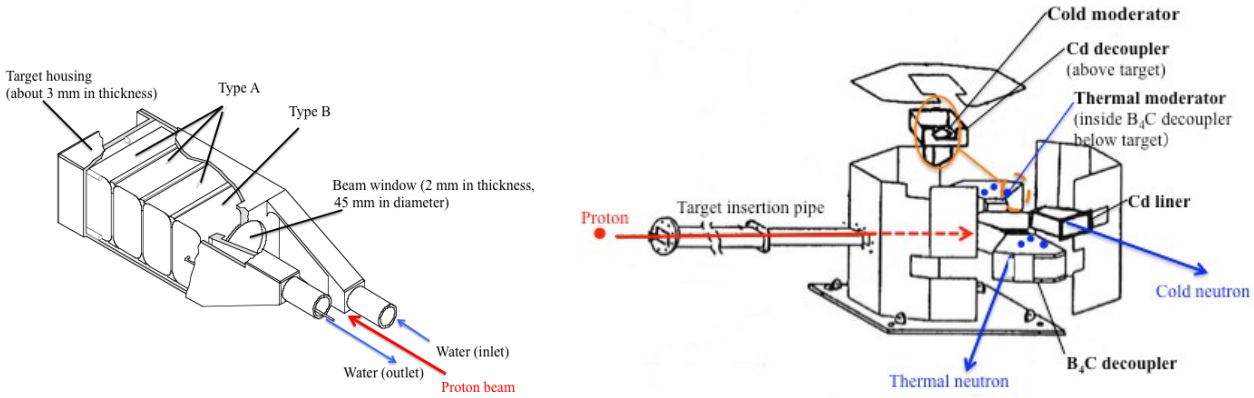
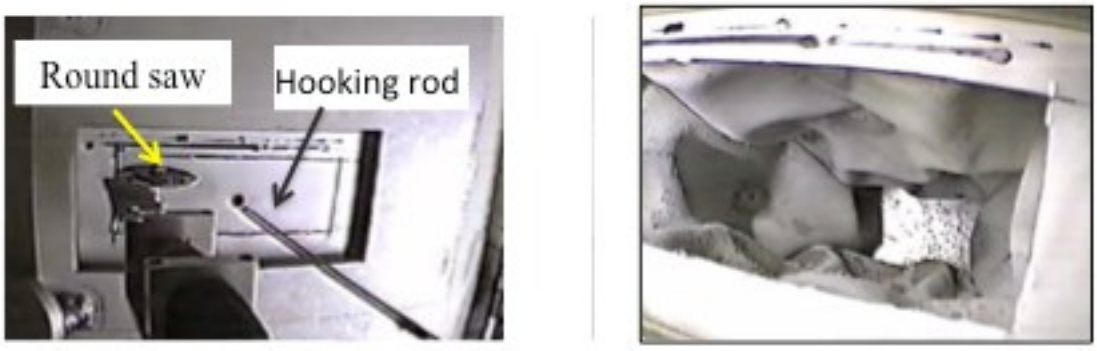


Fig. 1. Radiation shields, TMRA and auxiliary components of the KENS target station.



(1) Target (2) Moderator and decoupler

Fig. 2. TMRA components except for reflector.



(1) Photograph of opening the aluminum plates of TMRA and Cd liner window of cold moderator shown in **Fig. 2(2)**.

(2) Inside view of Cd liner of cold moderator. Cd plate is terribly waved and shades neutron beam line.

Fig. 3. Photo of the deformed cadmium Liner.

performance was improved together with recovering the cold neutron source intensity[3]. We called the KENS with the improved TMRA as KENS-II. It was operated up to March 2006 in order to extend to the J-PARC and dismantled in March 2010. This paper reviews its history.

Design and Fabrication of TMRA for KENS-II [4]

Absolute measurement of neutron fluxes with a gold foil activation method showed that the sub-cadmium neutron flux of the cold neutron moderator was about a third of the nominal value, while the epi-thermal neutron fluxes were nearly equal to the nominal value. The neutron spectrum measurement with time-of-flight method clarified that the measured neutron spectrum in the energy region below the cadmium cut-off energy was depressed from a single Maxwellian distribution with a 1/E-tail. Inspection of the Cd-liner clarified that its interior was uneven because of heavy waving and the color appeared more or less white, but dark yellowish parts were seen around rivets as shown in **Fig. 3(2)**. Accordingly, the renewal of the TMRA was decided.

The new TMRA was designed to improve neutronics performance, by means of neutronic calculations with the Monte Carlo method using the LAHET code system (LCS)[5]. The main items for developing the new improved TMRA system of KENS are as follows:

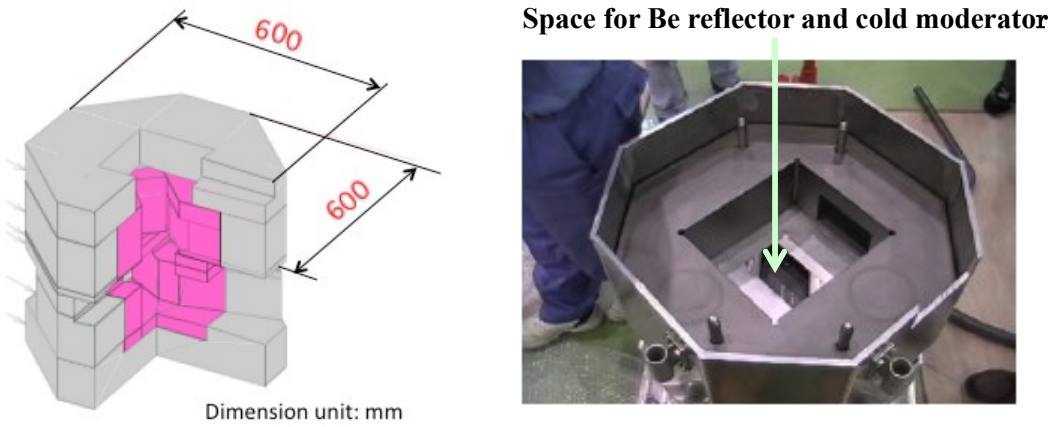
(1) Saving overall costs to fabrication and construction of the TMRA to maintain its performance was the first order of command under the condition of keeping the outer sizes of TMRA 660Wx660Dx610H (unit mm) and its components of the target, moderator, reflector and decouplers. Accordingly, various configuration of reflectors such as stainless steel that was effective to reduce slow neutron background and composite reflector of beryllium and graphite were analyzed with LCS. Stainless steel reflector was desirable to produce short pulse but abondoned because too heavy for the trolley carrying the TMRA. Since beryllium was the most

effective to increase themal and epithermal neutrons, sensitivity studies were performed by changing its amount around the TMRA by ascertaining neutron flux change at the important beam line at C4 and H9 behind target. Of course, H9 satisfied the value of the old TMRA in most cases. The quantities were determined so that cold neutrons at C9 became above 90% of that when whole beryllium reflector was used. The sensitivities were comparatively high around beam window where Cd liner was set up.

Thus, a composite reflector composed of a small amount of beryllium added to graphite was optimized by balancing the cold neutron source intensity while maintaining a low cost. Finally, the amount of beryllium was remarkably reduced from about 220 kg beryllium reflector of the old TMRA[2] to 35 kg in the new one. **Fig. 4** shows the typical cross sectional view of the reflector. The surface of the graphite reflector was processed using chemical vapor deposition in order to reduce the scattering of the graphite that occurs in the powder form.

(2) Chopper spectrometer (INC) required short pulse to measure precisely neutron spectrum scattered by a sample under low background. A 0.3 mm thick Gd poison in the thermal moderator of water was adopted to improve sharpness of the thermal neutron pulse below 0.1 eV, since the poison perfectly captured slower neutrons which was a main component of long tail in neutron pulse; **Fig. 5** shows the sharper decay and higher peak of neutron pulse in the new TMRA.

(3) Even with the addition of the composite reflector and Gd poison, thermal neutron intensities were further improved by substituting a tantalum target with a tungsten target which was clad by tantalum because tungsten is corrosive to hot water under radiation.



(1) Designed figure. (2) Fabricated graphite reflector.

Fig. 4. Cross sectional view and photo of the graphite reflector.

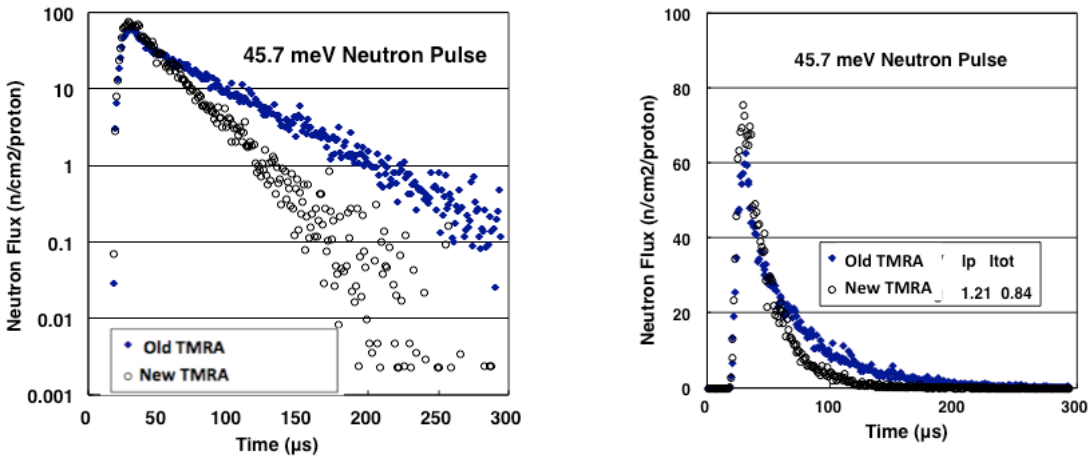


Fig. 5. Comparison of the pulse shape of thermal neutrons from water moderator at 45.7 meV. Ip and Itot are a ratio of peak and total intensities of new TMRA to the old one.

(4) KENS was a unique facility for material science because it had a high resolution resonance analysis TOF (time-of-flight) spectrometer (RAT) using a very sharp pulse of eV-neutrons. Such a pulse was obtained by high cut-off energy of the B_4C decoupler for thermal neutron to cut lower energy neutrons forming a tail of pulse. **Fig. 6** shows the thermal neutron moderator of light water and its B_4C decoupler for the new TMRA. **Fig. 7** compares calculated neutron pulse shape of thermal neutrons for a new TMRA with a various thickness of B_4C decouplers on the target side and the other sides of the decoupler with that of the old TMRA. The B_4C thickness is expressed by the decoupling energy. It was found that the combination of 100 eV and 70 eV produced nearly the same pulse shape as the old TMRA with the combination of 488 eV and 95 eV. Finally, combination of 100eV and 50 eV was selected by considering that it formed nearly equal main-pulse and high intensity of 1.31 times as much as that of the old TMRA.

(5) A local shield of 20 mm thick stainless steel was placed on the B_4C decoupler to decease the noises due to fast neutrons from the target at the new hoizontal reflectometer (ARISA). [6]

(6) Since Gd poison and small amount of beryllium brought a thermal neutron flux reduction, overall source intensity was increased by about 20%, by replacing the tantalum target with a tantalum clad tungsten one.

Fabrication of TMRA components had been performed from December 1999 to August 2000[4, 7]. Since tungsten was corrosive to hot water and especially its corrosion was accelerated by recrystallization due to radiation[8, 9], it was clad by tantalum with the HIP (hot isostatic press) process.[4,7] KENS target was composed of one target block having a hole for thermocouple insertion and three without hole as shown in **Fig. 2(1)**. Block size was 29.18 mm x 56.16 mm x 76.89 mm with fabrication tolerance of ±0.05 mm. The target block consisted of a tungsten block and tantalum clads composed of a side capsule, upper and lower lids and a sheath tube for thermocouple insertion as shown in **Fig. 8**. The tungsten block was made by discharge processing from rolled tungsten block with a density of 19.2 g/cm3 and a purity of 99.99%. The tantalum capsule was made by bending a rolled plate of tantalum 0.8 mm in thickness by fitting to a model of tungsten block and its ends were joined to each other with the TIG welding. The lids were made at first by cutting out material from the same plate with discharge processing and by fabricating edge with an endmills processing. The tantalum sheath was fabricated with three processes of central-drilling a cylindrical tantalum of diameter 14 mm diameter 150 mm long in 6.0 mm diameter, rolling to 4.0 mm diameter 1.0 mm thick and pulling out to 3.2 mm diameter plus tolerance with a mandrel. Then, target block was assembled with tungsten block and tantalum clad (capsules and lids) and sealed by an electron beam welding. Finally, the tantalum clads were tightly joined with the tungsten block with the HIP process.

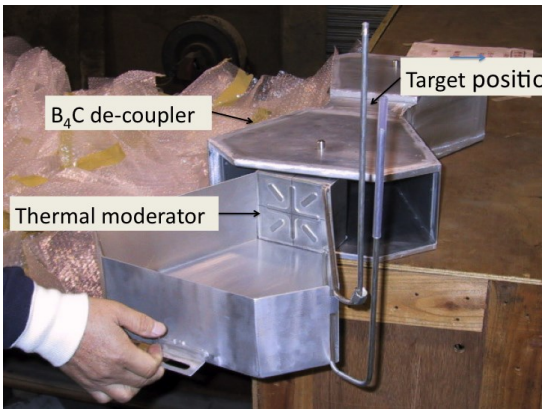


Fig. 6. Thermal moderator and its B_4C decoupler. The protrusion at the edge of the decoupler was made for fixing the stainless steel shield plate.

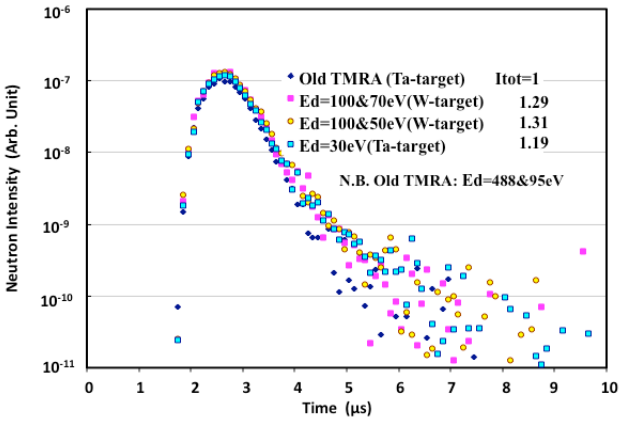
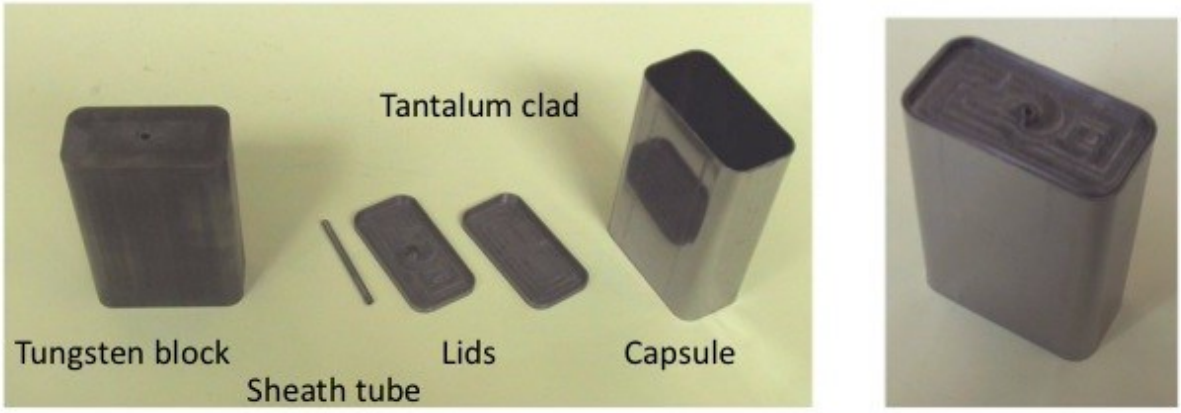


Fig. 7. Comparison of the pulse shape of thermal-neutrons at 4.57 eV among various combinations of decoupling energies of B_4C liner on the target side and the other sides, respectively.

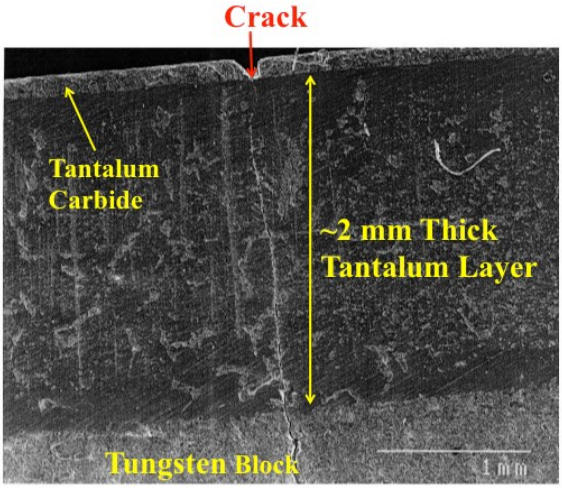
An optimum condition and method of the HIP process was investigated initially with small specimens preceding the fabrication of tungsten target block. There were two important failure experiences shown in **Fig. 9** to confirm the tantalum clad tungsten target fabrication method. To avoid second phase formation on tantalum, it was found that the control of the impurity gas in argon gas was very important to the tantalum clad[7]. Each target block was wrapped with zirconium foils and thin tantalum plates used for impurity getter materials. Quantities of getter materials were about 300 g/block. HIPing was made keeping the condition of 1,500℃ and 200 MPa for 180 minutes in 99.9999% purity argon gas with a molybdenum furnace. In the case of the block with a hole for thermocouple, it was found that the fabrication precision of a straight hole in tungsten influenced the results [9]. Accordingly, the hole was shaped in the tungsten block with five steps: electrical discharge machining (EDM), plunge EDM and reamer processings. After the HIPing, the portion of the lid was dropped by abrasive processing and tantalum surface was processed into a block of a predetermined clad thickness of 0.6 mm.

Fabricated individual components of TMRA were assembled and carefully checked if the geometrical sizes were within the tolreance, no defects and if they well fitted to each other and moved smoothly without any resistances, as shown in **Fig. 10** for an example of the target moving device and the lead-shield cask storing the target and assembling the moderator and TMRA vessel.

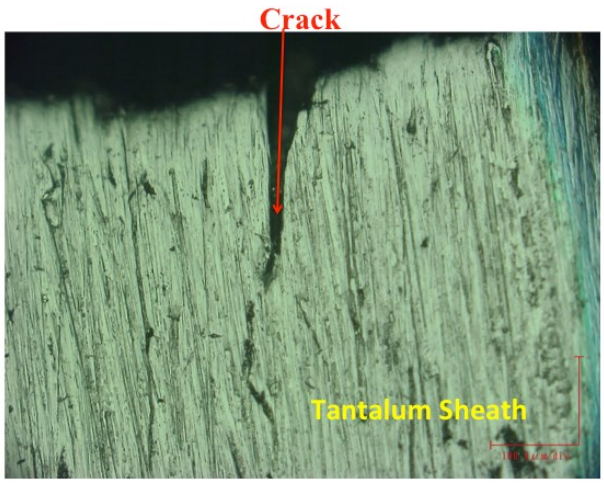


(1) Parts of target block: tungsten block and tantalum clads (2) Assembled block

Fig. 8. Target block with a hole for thermo couple.



(1)SEM picture shows crack penetrating to the tungsten layer which led to coarse re-crystallization because of carbonization of tantalum under the condition of 1,800℃ and 1,800 kgf/cm^2 in Ar gas[7].



(2) HIPing failure of the block due to a crack in tantalum sheath tube to put a thermo-couple because of rough drilling in tungsten[9].

Fig. 9. HIPping failure due to carbadization of tantalum and crack in a sheath tube.

(1) To check water pipes from the target moving device to the target in the lead cask.

(2) Inserting the target from the lead cask to TMRA through the target guide tube.

(3) Setting the cold moderator in the TMRA vessel.

Fig. 10. Combination test among the TMRA components and target movong device.

Work to exchang the TMRA

The exchanging work started with the removal of the rear shielding of the chopper spectrometer INC which was the nearest to the entrance of the neutron experimental room after the KENS operation was stopped on 30th June 2000. Next, we provided working space on the target station to exchange TMRA, by removing the auxiliary shields and the big condenser bank etc. around the apparatus of instruments for safety and vaccum at the center of the target station. The concrete blocks covering the proton beamline room were removed on 28th August. They were located at the places near the opened space for radiation protection of the workers. All components of the old TMRA on the trolley were removed. The lead cask containing the old tantalum target was kept in the iron box on the target station. The remainders were stored into the TMRA container which was constructed with flat iron boxes packed with grains (small ball) of lead for gamma-ray shielding (see **Fig. 11**). The TMRA container was carried to the radiowaste storage yard of KEK. Setup of the new TMRA with fabrication tolerance of ±0.2mm and its auxiliary equipment such as the pipes for cooling water and methane gas etc. was performed during 31st August to 11th September. **Fig. 12** shows photos carrying-out the old and -in the new TMRA components with the lifting tool. The most works were done remotely by operating the old simple tools to lift TMRA components with a video system using the CCD cameras and laser pointers to avoid radiation exposure to workers. Laser pointers installed at the legs of the lifting tool indicated the jointing plane of the TMRA components. The lifting tool was adjusted so as that laser point light matched the jointing position.

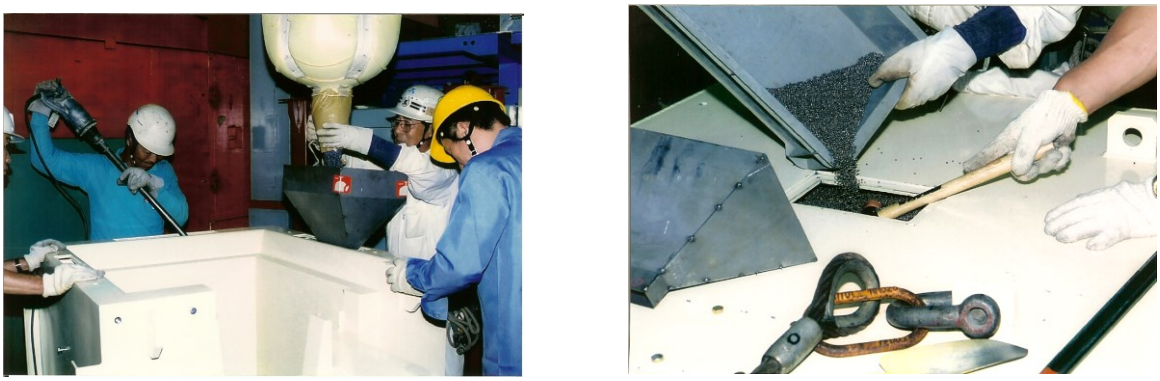
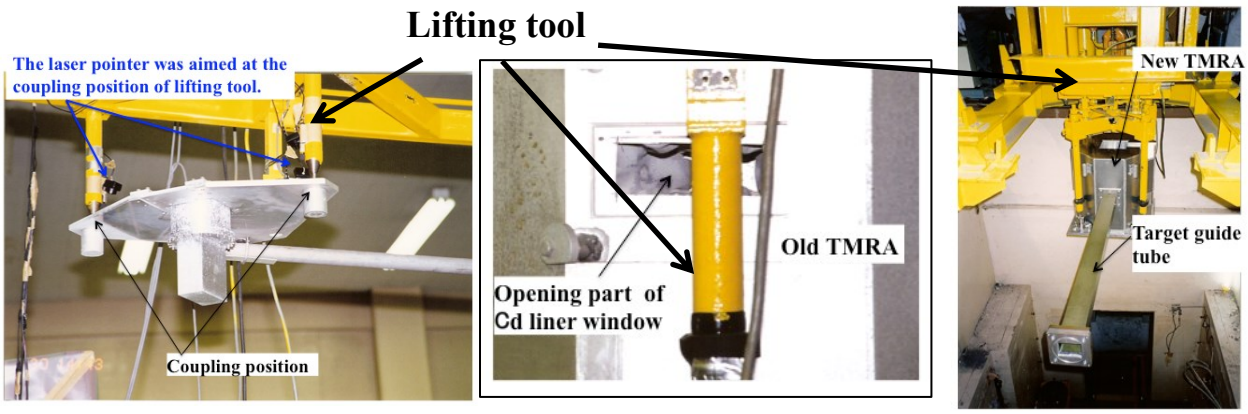


Fig. 11. Work packing lead grains into iron box of the old TMRA container.



(1) Old cold moderator

You can see small black flat laser beam pointers for setup installed to the tool. There is frost on the cold moderator.

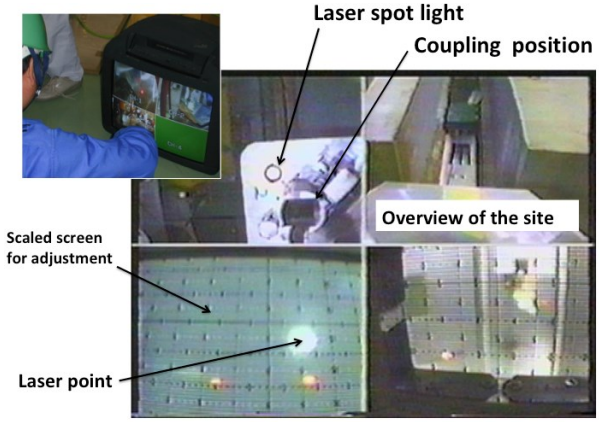
(2) Side view of old TMRA

Inside of the opened cold neutron window of TMRA, the deformed cadmium liner is observable.

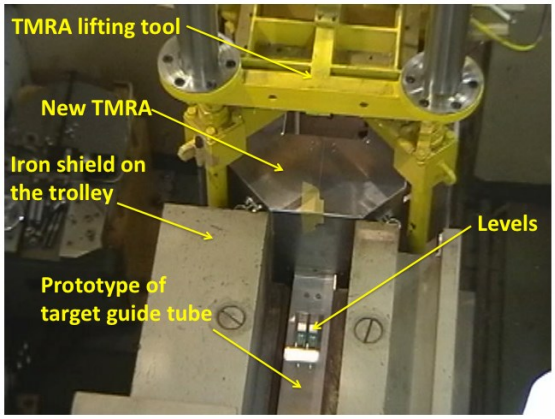
(3) New TMRA

New TMRA is hanged down to the trolley. Open space on the top of TMRA is for cold moderator.

Fig. 12. Photos carrying-out the old and -in the new TMRA components with the lifting tool. You can see the old simple lifting tools for each device.



(1) Remote control of setup of lifting tool to radioactive components by observing pictures of laser spot and overview of the site.



(2) Horizontal alignment of new TMRA using the levels attached on the prototype of target guide tube and the video system.

Fig. 13. Auxiliary tools for TMRA carring and alignment.

Fig. 13(1) shows the example of video pictures of laser point lights and siteviews. Scaled screen gave the operator information about moving width of the tool. TMRA alignment was completed with tolerance of ±0.5 mm by using the levels which were installed to a prototype of the target guide tube located above the new one as shown in **Fig. 13(2)**. Finally, the trolley was drawn back toward the target room and fixed at the predetermined place on 8th September and the proton beamline room was closed on 11th September.

Performance of TMRA of KENS-II

The first pulse was ejected from the new TMRA on 1st November, 2000. Neutron measurements were made[10,11] to characterize the following aspects of the thermal and cold sources: the absolute neutron intensities, energy spectra, and pulse shapes in the neutron beam-lines H9, C1 and C4. The absolute neutron intensities were measured using activation detectors of gold plate at the positions of various neutron spectrometers.

(1) Neutron energy spectrum and pulse shape

Neutron energy spectra were measured with ^{235}U fission counters. TOF (time-of-flight) counts were properly converted to energy spectra and pulse shapes at a certain energy with the ^{235}U fission cross-section. The typical results are shown in **Figs. 14** and **15**.

Neutron energy spectrum for the cold sources is shown in **Fig. 14** together with the LCS neutronic calculations. The figure clearly shows the recovery of the cold-neutron flux; the neutron intensity is tripled below 0.4eV, but there is no change above. The change in the energy spectrum confirms that the deteriorated Cd decoupler was shielding the neutron beam. The LCS calculation reasonably agreed with the measurement except in the low-energy regions below 10 meV, where the methane cross-section kernel was not adequately reliable.

Fig. 15 shows that the pulse shape of the thermal neutrons from the Gd poisoned light water moderator was obviously improved. It was also found that the energy spectra of the measurement and the LCS calculation were in good agreement.[10]

(2) Improvements in neutron spectrum measured on the new TMRA

Improvement in the neutron spectrum were investigated[11] at the other spectrometers in order to clarify the performance of the new TMRA. **Figs. 16** and **17** show the results for the spectrometers LAM40 (low-energy excitation) and LAM80ET (high-resolution, low-energy excitation) of the cold neutron beam line that the measured neutron fluxes of the new TMRA became about twice of the old ones in the energy region between 0.5 and 40 meV for LAM40 and between 0.7 and 2 meV for LAM80ET. **Fig. 18** shows the neutron spectra maseured at the HIT (liquid and amorphous diffractometer) and RAT (eV resonance spectrometer) in the energy range between meV and several hundred eV. Below about 50 meV, flux reduction of about 20% was found but remarkable increase was seen at the higher energies than 100 meV.

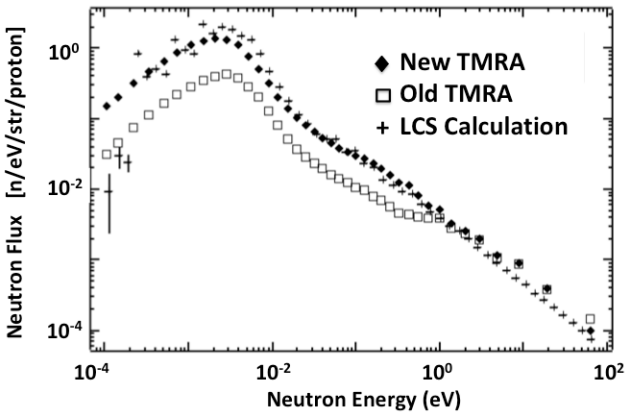


Fig. 14. Comparison of cold neutron spectra.

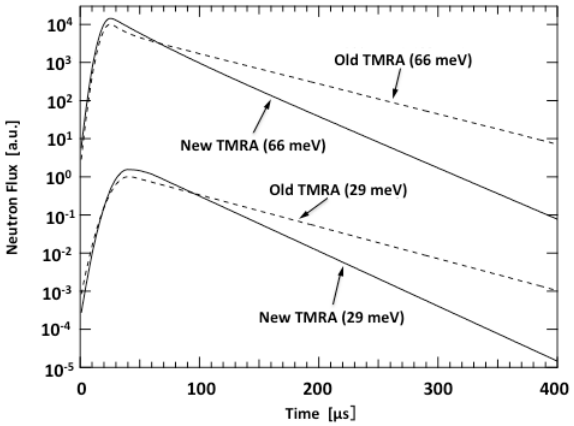
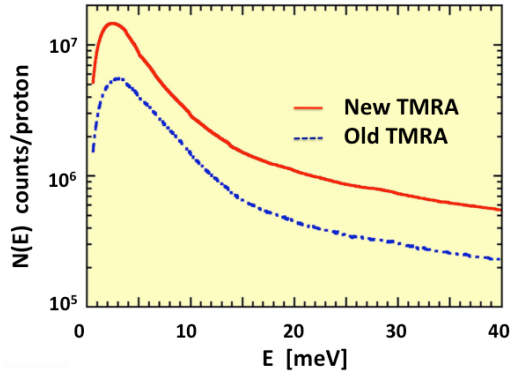
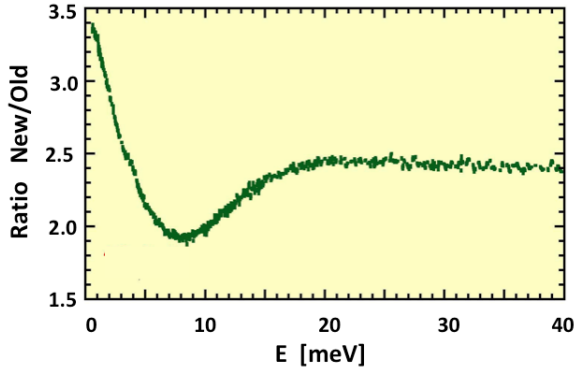


Fig. 15. Pulse shape of thermal neutrons.

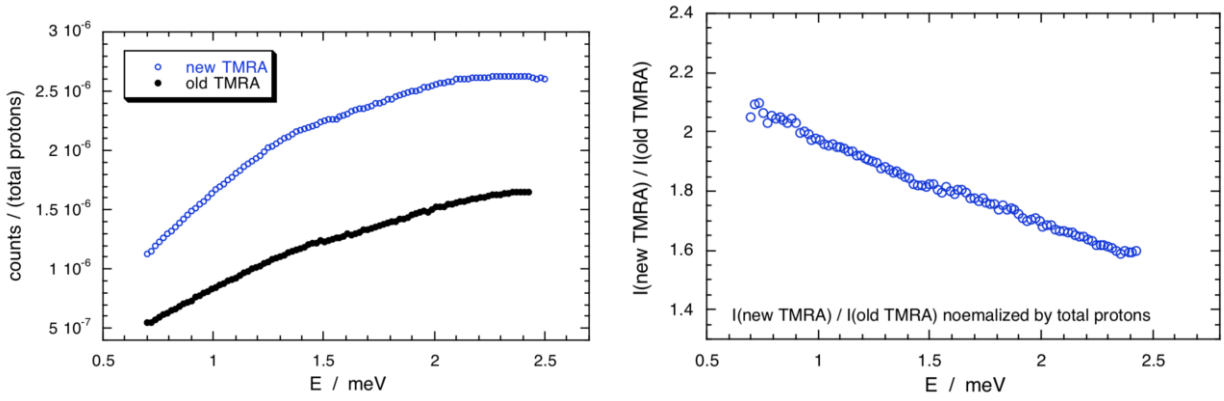


(1) Neutron spectrum



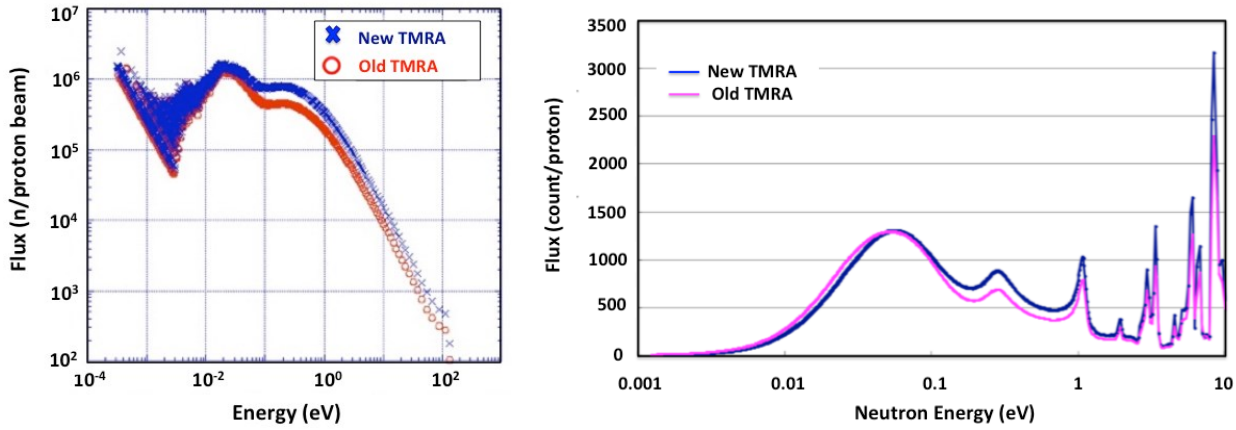
(2) Spectrum ratio of new to old

Fig. 16. Measured results of LAM40.



(1) Neutron spectrum (2) Spectrum ratio of new to old

Fig. 17. Measured results of LAM80ET.



(1) Neutron spectra at HIT (2) Neutron spectra at RAT

Fig. 18. Measured results at the thermal neutron beam line.

Table 1. Multiplicity of neutron intensity of the new TMRA to the old.

Spectrometer	Cold neutrons						Thermal neutrons		
	SWAN C1	PORE C1	LAM40 C4	LAM80ET C2	VEGA C4	SIRIUS C3	INC H6	HIT H3	RAT H7
Multiplicity	1.8	1-2	1.9 (2.3)	1.7 (1.6-2.1)	3 (3-4)	1.7	1.4	0.8-1.3 (1.4-8)	1.8

N.B. Upper value shows a value in the energy region used for the neutron scattering experiments and lower value in a parenthesis a value in the measurable energy region.

Table 1 summarizes multiplicity of neutron intensity at the spectrometers of the new TMRA to the old one. The renewal of TMRA produced the following three major improvements:

a) The cold-neutron intensity from the cold moderator was fully recovered for SWAN (small-angle instrument), PORE (reflectometer), LAM40, LAM80ET, VEGA (versatile powder diffractometer), and SIRIUS (high-resolution powder diffractometer).

b) The thermal neutron flux was also slightly improved at the instruments of INC and RAT. In case of HIT, **Fig 18(1)** shows that high energy neutron flux was increased by increase of the source intensity at the tantalum clad tungsten target and by less neutron capture of thinner B_4C decoupler, while low energy neutron fluxes were reduced by Gd poison. In the high energy region above 100 meV, the RAT spectrometer showed neutron flux increase as shown in **Fig. 18(2)**, and goodness of time spectrum was maintained as the energy dependent half widths of neutron pulses of the new TMRA showed nearly the same as the old one. This means that the decoupling energy of the B_4C decoupler was also optimized as well.

c) For the Gd poisoned thermal moderator of light water, the pulse shape of the thermal neutron was remarkably improved as shown in **Fig. 15**. In every instrument using the neutrons from the

thermal moderator, the results showed resolution improved and background reduced. With INC, the inelastic spectrum scattered from a one-dimensional $CsCrCl_3$ magnet became more symmetrical with the reduced tail[11, 12]. This might mean that possibilities as an inelastic neutron scattering spectrometer became wider. In the case of HIT, the radial distribution function obtained by a Fourier transform of S(Q) showed better resolution in position as well as a reduction of the spurious hump[11].

In summary, the following results are emphasized as characteristics of the new TMRA.

1) The new TMRA with the tantalum clad tungsten target was developed to increase the source intensity by about 20% compared to the former tantalum target.
2) The neutron performance was measured with several spectrometers. The cold-neutron intensity, which in the former TMRA had decreased to about 30% of its initial state, was recovered.
3) The epithermal neutron fluxes were increased as the neutronic design calculations indicated.
4) Along the thermal neutron beam line, time spectrum of slow neutrons below a few 100 meV was remarkably improved and low background was also realized and measuring accuracies were improved.
5) Even for low cutoff energydecoupler of B_4C, good time spectrum of epithermal neutron was obtained as like the old TMRA and was useful to resonance spectrometry.
6) The scattered-neutron profile at INC showed low background and became more symmetrical with the shorter tail. With the total-scattering spectrometer HIT, the radial distribution function shows better resolution in position.

KENS-II Shutdown and Removal of its Used TMRA

The PS (Proton Synchrotron) accelerator of KEK had to stop an operation in order to continue the activities at J-PARC at the Tokai campus of KEK. KENS-II was also shut down at 9:00 am on 22th March of 2006 by Y. Endo while many people including KEK directer, Yoji Totsuka were present at the KENS control room and the cold neutron experimetal room as shown in **Fig.19**. KENS supplied neutrons to users of material science as well as new users of radiation damage and shielding experiments since 18th June 1980. **Fig. 20** shows proton beam intensity supplied to the neutron target from the 500 MeV proton booster synchrotron. Total number of protons during 26 years was 3.83×10^{21} with high availability of 94.35% during beam on time of 39,082 hours. Total failure time caused by beam line trouble was only 0.6% and the others were mostly attributed to the proton accelerator adjustment.

Since the neutron source assembly TMRA of KENS-II highly activated by neutrons and high energy protons during 5 months and 5 years since 1st November 2000, its removal from the neutron experimental building to the radiowaste storage yard of radioactive materials in KEK was required from the Radiation Science Center of KEK. Removal objectives were the tantalum clad tungsten target, the thermal moderator of aluminium with poison gadolinium, the cold moderator of aluminium, their Cd and B_4C decouplers, the beryllium and graphite composite reflectors, the auxiliary devices of cooling-water circulation system of the target and the thermal moderator such as demineralizer and filter to purify water as well as the used tantalum target that was stored in the

(a) Shut down

(b) Meritorious awards

Fig. 19. Photos of KENS shutdown.

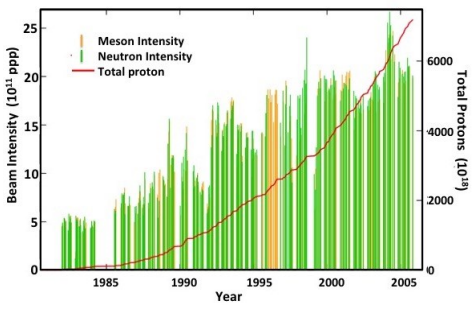


Fig. 20. Proton beam to KENS.

iron container located on the main shield of the target station. The accumulated tritium in water of target and thernal moderator must be separately removed from the water circulation systems.

Firstly, tritium contaminated water of 406 and 35 liters was taken during 16th through 22th January 2007 from the target and moderator systems to water tanks, respectively. Then, dry air was blown in the systems in order to dry up tritium water and the exhaust was released through water layer in small tank by checking the concentration of tritium. The drying-up work was continued for several months.

After about four years cooling of radioactivities, the removal work of the TMRA components in the neutron experimental room was set up in January 2010. Neutron staffs were busy in assembling and/or constructing their neutron spectprometers of J-PARC, and the authors discussed outsourced specification of the work on 25th December 2009. Preceding the TMRA removal work, a lot of remained neutron experimental apparatus were moved from the neutron experimental room to the cold neutron experimental room or J-PARC by contacting to the experimentalists within Feburuary. At that time, auxiliary neutron shields of boric acid and polyethylene mixture on the main shields were also transferred outside the room.

The actual work of TMRA removal was outsourced to four private companies according to the following four kinds of jobs such as major jobs of removal, fabrication of shielding container packed with grains (small balls) of lead to store main components of source except for target, removing and returning the main shield blocks over the proton beamline room and radiation monitoring. The substantial jobs began on 1st March and ended on 12th March as shown in **Table 2**.

Radiation dose was continuously measured during work with the support of the Radiation Science Center. While high dose rate was measured even for the short operation period of five years, the work was completed without any sounding an alarm meter to too high exposure. In addition, owing to an effect of blowing dry air during the water removal work in March 2007, accumulated exposure dose was negligibly small during works to remove demineralizer, filter and cooling water pipes etc.

Table 2. Schedule of the TMRA removal.

Date	Working Items	Radiation Exposure
1 (Mon)	Radiation training , preparation works.	-
2 (Tue)	Removing Pb cask with the used Ta target to the cold neutron experimental room afer separating cooling pipes etc. from the cask. Removing main shield blocks to open the proton beamline room.	1.4 mSv/hr on the cooling water pipe. 0.8 μSv/hr on cask surface.
3(Wed)	Removal of demineralizer and filter of water circulation system for target (See **Fig, 20(1)**) and thermal moderator.	-
4 (Thur)	Check of TMRA lifting tools, preparation of CCD camera.	-
5 (Fri)	Radiation monitoring of tunnel, removal of beam loss monitor and Al window etc., Storage of Ta-clad W target in the Pb cask.	Several tens mSv/hr on surface of cask and Al window. 50 mSv/h om Pb cask.
8(Mon)	Separating the moving device from Pb cask on the main shields(see **Fig 20(2)**) and storing it in the iron container (see **Fig.20(3)**), and additive shielding by Pb plates.	-
9(Tues)	Pulling out TMRA trolley and remove shield plug on TMRA. Removal of cold moderator from TMRA, Finishing new TMRA container by packing grains (small balls) of Pb.	-
10(Wed.)	Removal and storage of TMRA from trolley together with cold moderator into the new TMRA container, (See **Fig, 20(4)**) Return the empty trolley to original positions in proton beamline room. Adding Pb plates and Pb fibers on the target guide tube, cold moderator pipes stored in TMRA container for radiation shielding.	Surface dose on TMRA container was lower than10 μSv/hr near TMRA, 3 mSv/h near target guide tube and 0.6 mSv/h near cold moderator pipe, 200 μSv/hr near target guide tube.
11(Thur.)	Bringing TMRA container, two Pb casks containing Ta and W targets, demineralizers and filters of target and ,oderator cooling systems to the radiowaste storage yard. Smearing and clean up of working area in the neutron experimental room. Finally, returning bac the main shield blocks to close the proton beamline room.	-
12(Fri.)	Rearranging two Pb casks and addition of Pb plates in the radiowaste storage yard. Radiation monitoring and cleaning up the neutron experimental room.	-

(1) Removing demineralizer and filter. (2) Separating the target moving device from Pb cask. (3) Storing the target moving device into iron box. (4) Carrying down TMRA to container.

Fig. 21. Jobs of the TMRA removal from the neutron experimental room to the radiowaste storage yards.

Conclusion

The new TMRA improved neutron performance at each spectrometer by increasing the source intensity and supplying shorter pulses to thermal neutron spectrometers. Shorter pulse which brought lower time-background gave users a possibility to extend the ability of the spectrometers. It was also found that the local shields of stainless steel on the B_4C decoupler gave very low background at the horizontal reflectrometer ARISA. As a whole, it can be said that KENS-II had a very good ability to investigate material science except for the disadvantage of being small power. Now that KENS has stopped all activities, the authors look back on the contribution of KENS and its impact on the future.

In 1997, the international committee of KENS reviewed as follows [13]: Since the start of operation in 1980 as the world's first pulsed spallation neutron source used in neutron scattering research, the KENS has contributed greatly to the development of pulsed neutron scattering research and its technology, and has produced many high-level research results using pulsed neutron scattering in a wide range of research fields.

The characteristics of the neutron source of KENS were a good conversion efficiency from the proton beam to the low-speed neutron achieved by the development of an optimized target-moderator system. Since early on, solid methane moderators and guide tubes had been incorporated into the KENS neutron source, becoming a good example for the development of neutron facilities.

It was possible to measure in a wide range of energy and momentum space using a number of devices installed in KENS, observation of the dynamics of atoms and magnetism from the static structure of the material having a size of several Å ~ several μm could be performed. KENS neutron scattering devices, such as, MAX (multi-analyzer crystal spectrometer), CAT (crystal analyzer TOF spectrometer) and RAT were innovative designs while others made it as sophisticatedly designed as LAM-80ET and allowed the same measurement efficiency as it took to perform at the world's best facility ISIS in spite of small neutron source. Moreover, it created new frontier material science at KENS, by installing the super-mirror guide and improving detector systems.

The most successful achievement in solid structure research was the determination of the crystal structure of the world's first high-temperature superconductor material in 1987 and material research under extreme conditions such as ultra-high magnetic field, ultra-low temperature, and ultra-high pressure. Studies of various amorphous substances conducted at KENS and of magnetic structure in percolation limits have also received high praise.

After 1997, the techniques developed in the KENS renewal such as fabrication technique of tantalum-clad tungsten target have been inherited to the CSNS[14] together with the know-how of instruments. New spectrometers such as EXCED (new epithermal neutron diffractormeter) and ARISA were also developed. LAM-40 and RAT were unique and rich in ideas in early research of neutron physics. Towards MLF (material and life science facility) of J-PARC, high resolution and high intensity powder diffractometer, SIRIUS and VEGA grew Super HPRD (high resolution powder diffractometer), and SPICA (special environment neutron powder diffractometer), the chopper spectrometer INC upgraded HRC (high resolution chopper spectrometer), small and total scattering

instruments SWAN and HIT did NOVA (total scattering spectrometer), and ARISA grew up ARISA-II. The other spectrometers in KENS have also adopted in the scaled-up form in MLF. Solid target of tantalum clad tungsten will be likely adopted to the future SNS[15]. The KENS was also used in the experiments for radiation shielding[16, 17] and radiation damage of material[18].

As for the tantalum clad tungsten target fabricated with the HIP (Hot Isostatic Pressing) method, rapid cooling test has been performed to examine if the target will not be damaged in case of the loss of coolant accident [19, 20]. Tantalum pipes heated up to 800ºC were found to be oxidized above 600 ºC. Then, cooling down test was made by heating the target model up to 500ºC and quickly soaking it in water at a certain temperature in the range of 0ºC and 90ºC. The results showed no damage. Consequently, it can be said that tantalum-clad tungsten target processed with the HIP will be endurable to the ordinary loss-of-coolant accident below 500 ºC. The result shows future of the solid target for high energy accelerator.

Materials and life sciences are so diverse in their objectives, their structures, properties and functions depend on their raw materials, environment and generation conditions etc. So if you change your perspective, you will have new discovery. The authors hope you make your efforts to deeply cultivate these science fields, sow and bring up your novel ideas. Then you will find the wonderful progress of research and results.

Acknowledgement

The work on development of the tantalum-clad tungsten target has been performed under the support by 1999–2001 FY Grant-in-Aid for Science Research (A) by JSPS, Task No. 11358008 ‘‘Study on development of long-life target for spallation neutron source.” The neutronic calculation of the TMRA was completed with a great deal of cooperation with Prof. Yoshiaki Kiyanagi and his student Mr. Shin-ichiro Yasui of Hokkaido University. Much work has been also done with a lot of cooperation of many fellows and researchers in KEK, the JSPS Task team and surrounding universities and research institutes. In the TMRA renewal and removal works, much kind assistance and helpful advises were received from the staffs of Radiation Science Center of KEK. The authors would like to express their deep gratitude to these people.

References

[1] Y. Ishikawa: “Present Status of the KENS Facility,” in Proc. of the 4th Meet. of the International Collaboration on Advanced Neutron Sources (ICANS-IV), Tsukuba, October 20–24, 1980, pp. 89-101. (KEK, Tsukuba 1981)

[2] N. Watanabe, S. Ikeda and Y. Ishikawa: “KENS Target Station,” in Proc. of the 4th Meet. of the International Collaboration on Advanced Neutron Sources (ICANS-IV), Tsukuba, October 20–24, 1980, pp. 181-199. (KEK, Tsukuba 1981)

[3] M. Kawai, S. Yasui, M. Furusaka, T. Ino, N. Torikai and Y. Kiyanagi: “Renewal of KENS TMRA”, Proc. of ICANS- XV, Tsukuba, November 5–9, 2000, Vol. II, pp. 747- 757. (KEK, Tsukuba 2000)

[4] M. Kawai: “The birth of KENS-II with simple but powerful source, ” *The trajectory of proton accelerator – Neutron and Muon –,* pp. 30 - 36. (KEK, Tsukuba 2007) (in Japanese).

[5] R.E. Prael et al.: ‘‘User Guide to LCS: The LAHET Code System, ” LA-UR-89-3014 (1989).

[6] N. Torikai, M. Furusaka, H. Matsuoka et al.: Appl. Phys. A74 (2002) s264–s266.

[7] M. Kawai, K. Kikuchi, H. Kurishita, J.F. Li and M. Furusaka: J. Nuclear Materials, 296, (2001) 312-320.

[8] R.S. Lillard, D.L. Pile and D. Butt: J. Nuclear Materials, 278, (2000) 277-289.

[9] M. Kawai, M. Furusaka, K. Kikuchi, H. Kurishita, R. Watanabe, Jing-Feng Li. K. Sigimoto, T. Yamamura, Y. Hiraoka, K. Abe, A. Hasegawa, M. Yoshiie, H. Takenaka, K. Mishima, Y. Kiyanagi, T. Tanabe, N. Yoshida and T. Igarashi: J. Nuclear Materials, 318, (2003) 38-55.

[10] T. Ino, M. Ooi, M. Kawai, S. Yasui, M. Furusaka and Y. Kiyanagi: Measurements of neutronic characteristics of the KENS target-moderator-reflector assembly, Proc. of ICANS-XV, Tsukuba, November 5–9, 2000, Vol. II, pp. 758-765. (KEK, Tsukuba 2000)

[11] M. Kawai, T. Ino, S. Itoh, T. Kamiyama, M. Furusaka, Y. Kiyanagi, M. Ooi and T. Fukunaga: Applied Physics, A74-1 (2002) s43-s45.

[12] S. Itoh, M. Arai and M. Kawai: Applied Physics, A74-1 (2002) s198-s200

[13] The KENS International Review Committee: Review of the Neutron Science Laboratory KENS in the High Energy Accelerator Research Organization, KEK, (February 2008). Information from https://www2.kek.jp/proffice/archives/hyouka/pdf/kens_reviewreport_2008.pdf.

[14] S. Wei, R. Zhang, Q. Ji and X. Jia: "Developmemt of the CSNS target," presented at IWSMT-13, Oct. 30-Nov. 4, (2016) Chattanooga, Tennessee, USA: https://conference.sns.gov/event/20/images/2885-Development_of_the_CSNS_Target_Plug_-_Shaohong_Wei.pdf

[15] T. McManamy, M. Rennich, F. Gallmeier, P. Ferguson and J. Janney: J. of Nuclear Materials, 398 (2010) 35-42.

[16] H. Matsumura, K. Masumoto, N. Nakao, Q.B. Wang, A. Toyoda, M. Kawai, T. Aze, and M. Fujimura: Radiation Protection Dosimetry, 116 (2005) 1-5.

[17] N. Nakao, H. Yashima, M. Kawai, K. Oishi, H. Nakashima, K. Masumoto, H. Matsumura, S. Sasaki, M. Numajiri, T. Sanami, Q. Wang, A. Toyoda, K. Takahashi, K. Iijima, K. Eda, S. Ban, H. Hirayama, S. Muto, T. Nunomiya, S. Yonai, D.R.H. Rasolonjatovo, K. Terunuma, K. Yamauchi, P.K. Sarkar, E. Kim, T. Nakamura and A. Maruhashi: Radiation Protection Dosimetry, 116 (2005) 553-557.

[18] Y. Satoh, Y. Matsuda, T. Yoshiie, M. Kawai, H. Matsumura, H. Iwase, H. Abe, S.W. Kim and T. Matsunaga: J. of Nuclear Materials, 442 (2013) S768-S772.

[19] N. Takenaka, K. Kikuchi and M. Kawai, J.F. Li and T. Igashira: "Rapid cooling test HIPed tantalum-clad tungsten target, " *development of intense materials against radiation and beam impact,* report on the work supported by a Grant-in-Aid for Scientific Research from MEXT A-1 16206097 (2007) 213-233. (in Japanese).

[20] N. Takenaka, K. Kikuchi, Y. Kiyanagi, M. Kawai, J.F. Li and T. Igashira: "Progress in development of intense materials against radiation and beam impact, (5) Rapid cooling test of HIPed Ta-chad W target, " 2007 Fall meeting of Japan Atomic Energy Society at Kyushu Univ., (2007) G47. (in Japanese)