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Progress of the Materials & Life Science Facility of J-PARC

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Abstract. The facility has resumed since 17th February 2014 after reformation of operation safety system required from the new regulation because of the accident in the Hadron Facility occurred in May 2013. During eight-month shutdown period various hardware components have been improved; such as installation of additional RFQs in Linac to increase its energy to achieve higher power, repairing and replacement on the mercury(Hg) cooling loops of the neutron target, improvement on the cryogenic system for stable operation, etc. In order to mitigate the pitting damage on the Hg-target container we have been injecting helium micro bubbles in the target. The Laser Doppler vibrometory showed us that vibration amplitude on the proton bombardment has been drastically reduced by the injection.

Twenty one instruments have been already installed. Eighteen instruments are operated for user program and three instruments are under either commissioning or construction. Now the experimental hall is almost full with instruments, leaving only 2 ports available for the future use. Operational time for user program in JFY2014 was about 170 days, and we received more than 700 general experimental proposals from users.

World-class scientific outputs have been being created in various scientific fields, ranging from Li-battery science to bio-molecular science. Since J-PARC is internationally open for users, we have got experimental proposals from abroad more than 15% of the whole proposals. More than 10% of proposals have come from industries and a half of them are proprietary use. This fact has revealed a new horizon has come in the neutron scattering science in the 21 century.

1. Introduction

The J-PARC facility was funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and was jointly constructed by the High Energy Accelerator Research Organization and the Japan Atomic Energy Agency. J-PARC Materials & Life Science Experimental Facility (MLF) is a spallation pulsed neutron and muon facility, whose final power will be 1MW, operated at 25Hz. It ran at 300kW until before the summer shutdown since it resumed on 17 February 2014 from the shutdown due to the accident in the Hadron Facility occurred in May, 2013. MLF is a user facility for not only domestic but international users and even for industrial researchers. Unique user's number will be exceeded more than 1000 in JTY2014 with steady increase every year. Operation cycle is about 170days in a year and call for proposal is announced twice a year. We have received more than 700 general proposals in JFY2014.

2. Target Improvement for High Power

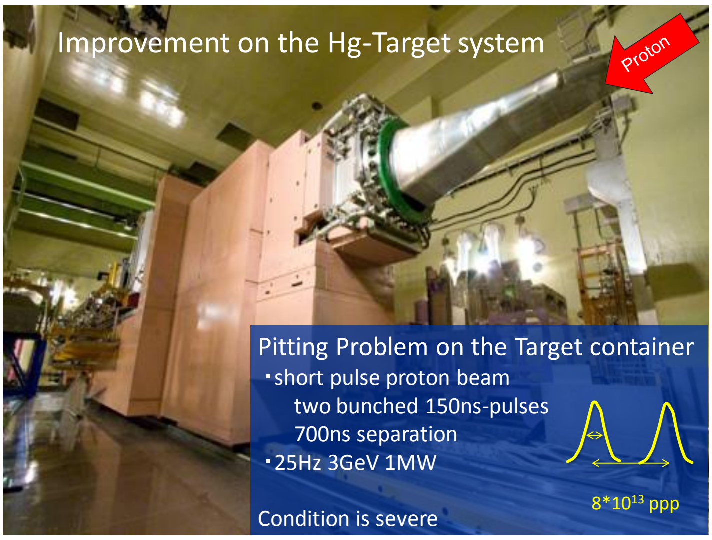

Fig.1 The Mercury target station of MLF.

2.1 Helium Bubble Injection

As it is a well known problem, "Pitting Problem", on the mercury target container is still a key issue to be settled down before ramping up the accelerator power. (Fig.1). High power proton bombardment creates cavitation in the mercury target followed by an instantaneous shock wave, which makes a serious damage on the internal surface of the target container, so called the pitting damage. In order to mitigate this problem, we have injected helium gas bubbles in the mercury flow [1]. The helium gas goes through a swirler making a mercury flow turbulence, which breaks the gas into small segments and makes micro bubbles, 100 μ in diameter. We have monitored the behavior of the container with a laser Doppler vibrometry method and found a drastic reduction of a vibration of the container on the proton bombardment. Figure 2 shows the observed vibration amplitude on the target container. There is a clear decrease for a higher gas density (charging speed).

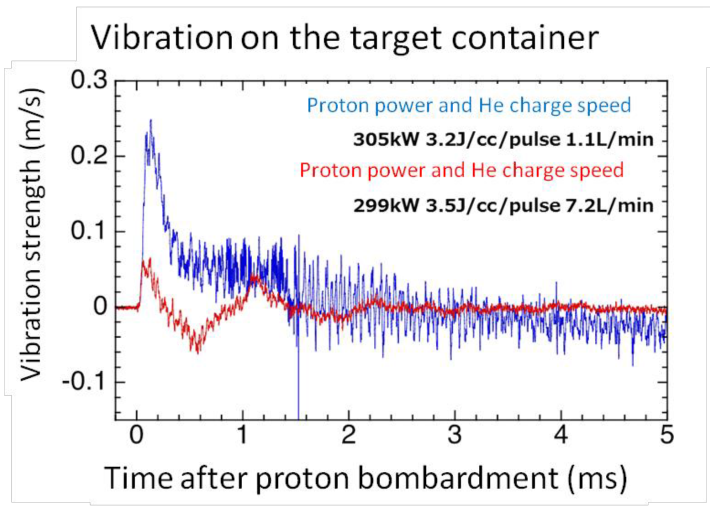

Fig.2 Vibration intensity at the target container with helium gas bubbling in a different charging speed.

Fig. 3 Octapole magnet installation for flattening the beam

In order to confirm the actual status of the pitting damage, we cut out the top portion of the target container during the summer shutdown, which experienced 2000MWh proton bombardment. We observed that the internal surface of the container does not have any obvious pitting damage although the exposed cumulated power is closing to the expected life time estimated from the radiation damage[2].

2.2 Installation of an Octupole Magnet

In order to reduce peak heat deposition in the target we have installed an octupole magnet which flattens the proton beam profile and can reduce the peak power as shown in Fig.3 [3]. Proton beam profile monitor has shown a flattened profile or a plateau shape profile modified from the original Gaussian profile by the magnet. We are now planning to estimate the effect from the flattened profile on the neutronics performance by a calculation code PHITS.

2.3 History of Beam Power at MLF

Figure 4 shows the history of the beam power at MLF since it started its operation in 2008. The beam power has been ramped up in step wise and reached at 300kW although there were two long shutdowns due to the disaster in 2011 and the accident in 2013. We have replaced the target two times to study the pitting damage during each long shutdown. We have started the gas injection since the end of 2012 when the power increased to 300 kW. We ran with 532 kW but for a very short period in 2012 to test an intrinsic ability of the accelerator, and it was successful.

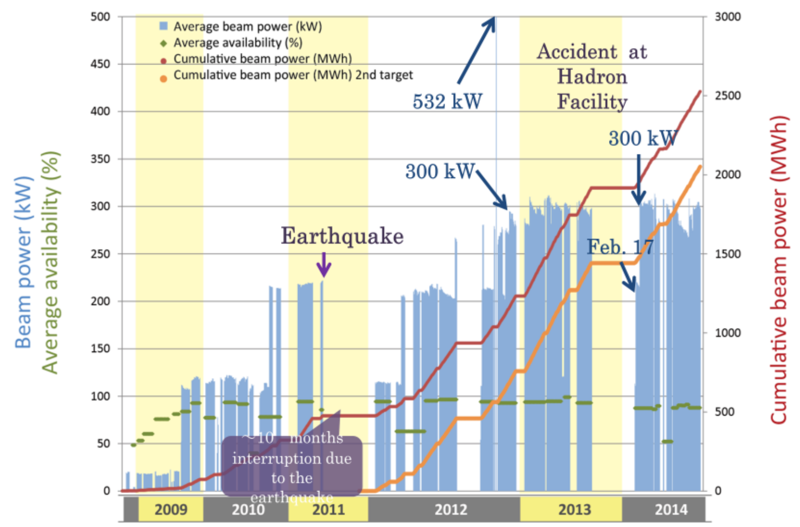

Fig.4 The history of the beam power at MLF.

3. Instrument Suite at MLF

3.1 Status of Instruments

MLF has 23 neutron beam ports and four muon ports [4]. Now 21 neutron instruments have been installed. 18 are in use for user program. Two instruments are under construction. Those are a spin echo instrument at BL06 and a polarized neutron instrument at BL23. One, an imaging instrument at BL22, is under commissioning. Two beam ports are empty and available for a future use, BL07 (poisoned decouple moderator), and BL13 (coupled moderator). Currently one muon beam port is in use for user program and three ports are under construction. Those are an ultra-slow muon channel, a surface muon channel and a high momentum muon channel.

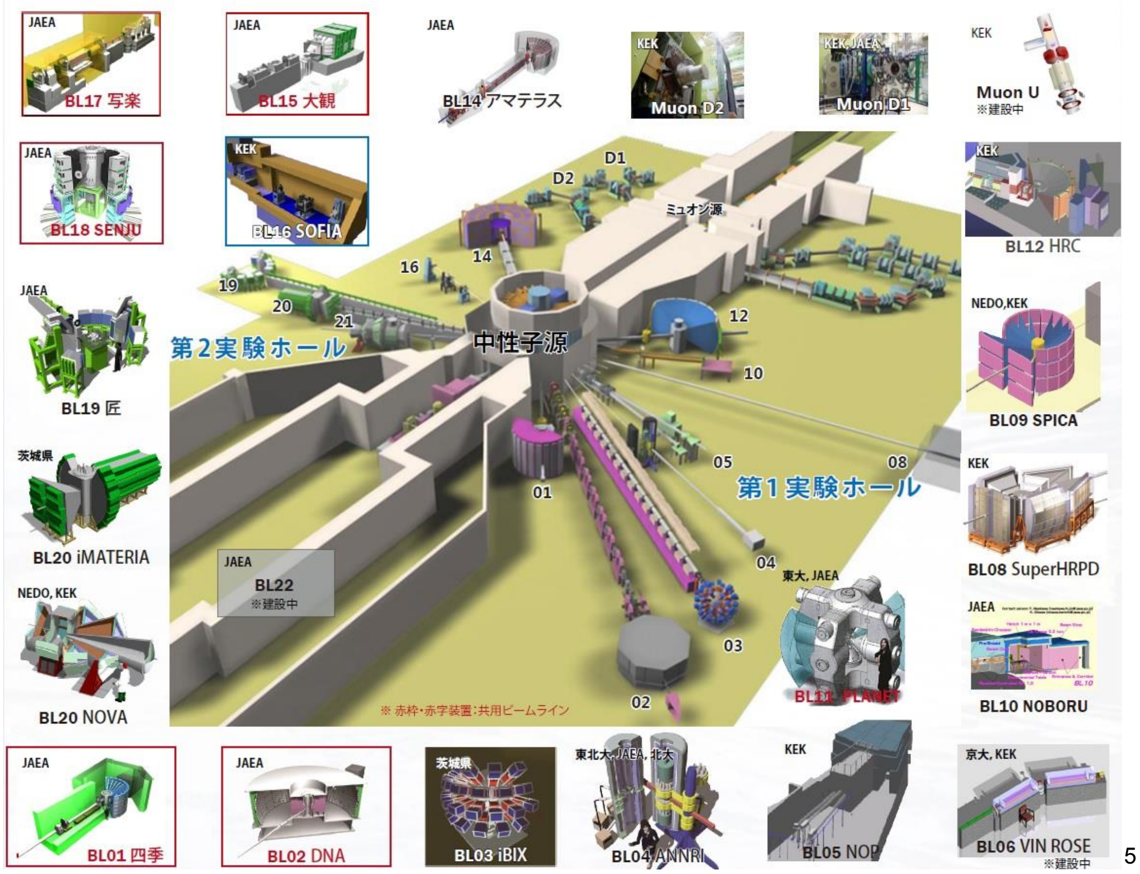

Fig. 5 Instrument arrangement in MLF

Figure 5 shows instrument arrangement in the facility. The instrument suite has been selected and constructed according to a requirement of the neutron community. All of the instrument were proposed and reviewed by the instrument selection panel. There are four organizations to operate those instruments. Those are KEK, JAEA and Ibaraki Pref., which is the local municipality, and CROSS. User program of the public beam lines are operated by a registered institution to the government (CROSS). The public beam line was built and owned by JAEA under the legislation for promoting user support/program of MLF, and its user support is done by the registered institution, CROSS. Ibaraki Prefecture owns two instruments, BL03 and BL20, to facilitate industrial use of neutrons. Two instruments, BL09 and BL20, were built by the Ministry of Economy, Trade and Industry to promote an intensive battery study and fuel cell study. Those are, however, opened for general users now. Table I summarizes the neutron instrument suit of MLF.

All of muon ports have been constructed by the KEK muon group and in use for inter-university program, and the general user program is operated as the MLF user program. This situation is the same as that of KEK owned neutron instruments. Currently only one port for decay muon channel is available for users. It is either D1(μ^+) or D2(μ^-) channel with an energy range of 30 MeV. Now Ultra-slow muon (μ^+) channel is under commissioning, which can provide very low energy muons in a rage from 50 eV to 60 keV to study surface magnetism. S-line is a new beam line under construction for the surface μ^+. H-line will be used for fundamental/nuclear physics experiment and under construction. Table II summarizes the muon channels of MLF [5].

Table I Neutron beam lines of MLF

BL no.	name		Owner	
BL01	4SEASONS	Fermi chopper instrument	JAEA	Public BL
BL02	DNA	Back scattering instrument	JAEA	Public BL
BL03	iBIX	Protein crystal diffractometer	Ibaraki Pref.	
BL04	ANNRI	Neutron cross section measurement instrument	JAEA	
BL05	NOP	Fundamental physics instrument	KEK	
BL06	VIN-ROSE	Spin echo instrument	KEK	
BL07	Empty			
BL08	SHRPD	High resolution powder diffractometer	KEK	
BL09	SPICA	Powder diffractometer dedicated for battery study	KEK	
BL10	NOBORU	Test port	JAEA	
BL11	PLANET	High pressure diffractometer	JAEA	Public BL
BL12	HRC	High resolution chopper instrument	KEK	
BL13	Empty			
BL14	AMATERAS	Cold disc chopper instrument	JAEA	
BL15	TAIKAN	Small and wide angle diffractomenter	JAEA	Public BL
BL16	SOPFIA	Horizontal surface reflectometer	KEK	
BL17	SHARAKU	Vertical surface polarized neutron reflectometer	JAEA	Public BL
BL18	SENJU	Single crystal diffractometer	JAEA	Public BL
BL19	TAKUMI	Engineering diffractometer	JAEA	
BL20	iMATERIA	High intensity powder diffractometer	Ibaraki Pref.	
BL21	NOVA	Liquid-amorphous diffractometer	KEK	
BL22	RADEN	Energy resolved imaging station	JAEA	Public BL
BL23	POLANO	Polarized neutron inelastic scattering instrument	KEK	

Table II Muon beam channels of MLF

Name		Owner
D1, D2 lines	Decay muon-channel	KEK
U-line	Ultra slow muon channel	KEK
S-line	Surface muon channel	KEK
H-line	High momentum muon channel	KEK

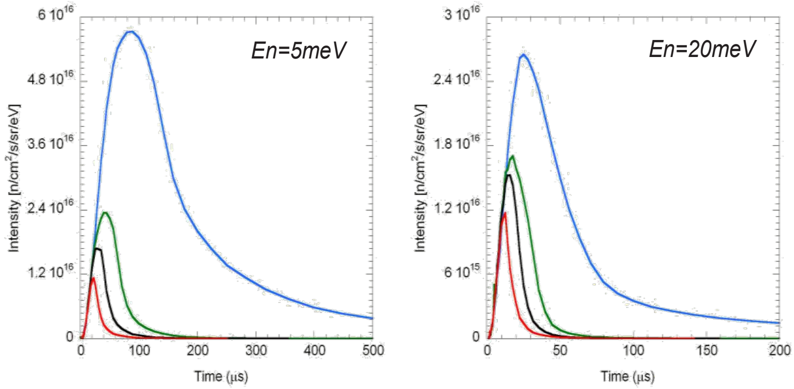

Fig. 6 Pulse peak structure at 5 and 20meV for Coupled moderator; blue, decoupled moderator; green, poisoned decoupled moderator; black and red (font and back surface)

3.2 Some Performance of Instruments [6]

The target station has three kinds of moderators as shown in Fig.6. The coupled moderator is very intensive, but has a broad peak structure. Decoupled one is good for high resolution instrument with sharp pulse structure but sacrificing intensity. Poisoned decoupled moderator has a sharper pulse structure and less intensity, and it is used for extremely high resolution instrument such as very high resolution powder diffractometer [7]. The energy of neutron is commonly analyzed by the time-of-flight of neutrons going through a flight path in a pulsed neutron source. Hence it is a natural consequence that a sharp pulse structure of neutron with a long flight path for instrument is necessary to realize a high resolution instrument. However, this traditional concept has been dramatically improved in the design work for instruments in MLF.

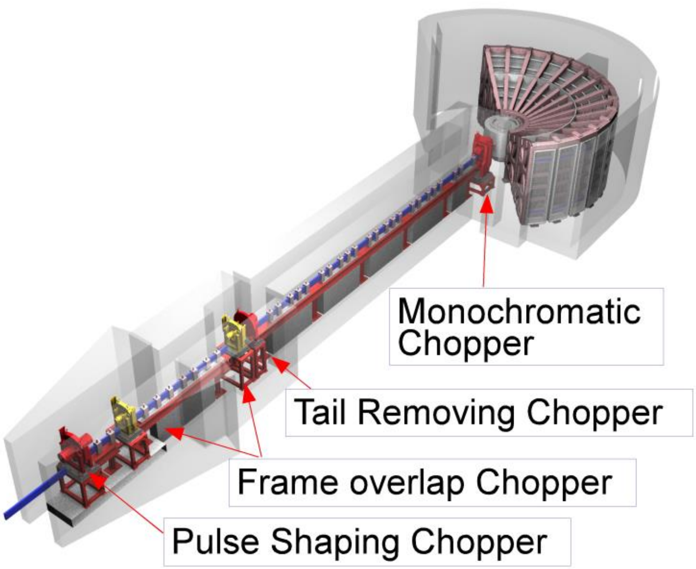

Fig. 7 Illustration of AMATERAS. Pulse shaping chopper cut out an intensive peak from a broad pulse of a coupled moderator.

One of good examples has been demonstrated in AMATERAS [8], in which a pulse shaping chopper has been implemented to cut out an intensive peak portion from the broad peak from the coupled moderator. This innovative concept has been firstly demonstrated by Feri Mezei group [9] and becomes a world trend for cold disk chopper instrument such as CNCS [10] at SNS and LET [11] in ISIS. Figure 7 shows an illustration of AMATERAS. A pulse shaping chopper makes a sharp and symmetrical shape pulse, and behaves as a virtual pulsed source instead of the actual moderator. A monochromatic chopper makes energy selection. Frame overlap choppers and a tail removing chopper suppress unwanted neutrons. Energy resolution can be tunable by choosing a pulse width at not only the monochromatic chopper but also the pulse shaping chopper, hence instrument becomes very much flexible on the resolution and intensity adjustable for various kind of measurements. A similar technique has been also adopted for the DNA instrument (Fig.8). DNA is a backscattering spectrometer and scattered neutron energy is analyzed by a crystal. An observed example is depicted in Fig. 9, in which tunneling spectrum obtained from γ-Picoline is depicted for two different conditions with or without pulse shaping chopper operation. It is clearly shown that the energy resolution can be also flexibly tunable in a measurement.

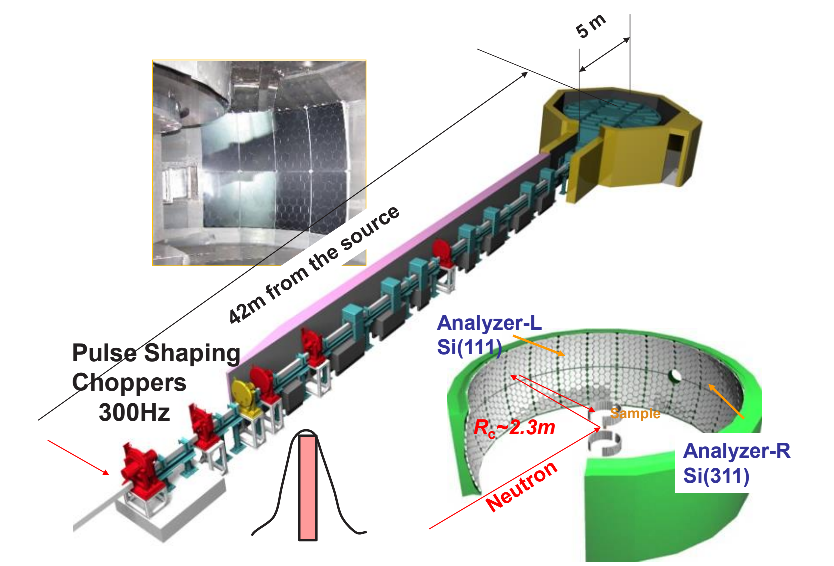

Fig. 8 DNA spectrometer. Pulse shaping chopper cut out a sharp peak band and the scattered neutron is analysed by a Si-crystal in the back-scattering geometry.

We have also developed so called multi-Ei method, in which multiple incident energies can be utilized in one time for a set-up for an inelastic scattering experiment. Therefore, spectrum observed with several different incident energies are automatically obtained. The method is very effective to make a survey in the different energy scales to find an unknown phenomena [12].

At pulsed neutron source we can utilize white beam and the neutron energy is analyzed by the time-of-flight method. Therefore, we do not need to scan scattered neutrons by moving detector angle. Instead detector can be fixed at angles. Therefore we can arrange detector banks at various scattering angle as much as we can afford as shown in Fig. 10 as an example for TAIKAN. With this detector arrangement TAIKAN can cover a very wide coverage in the momentum space from a small angle region to 20 $Å^{-1}$ in one measurement. An example on glassy carbon is depicted in Fig.11. The result shows from the small angle region to diffraction range with a very reasonable agreement with a result from APS in the absolute intensity [13].

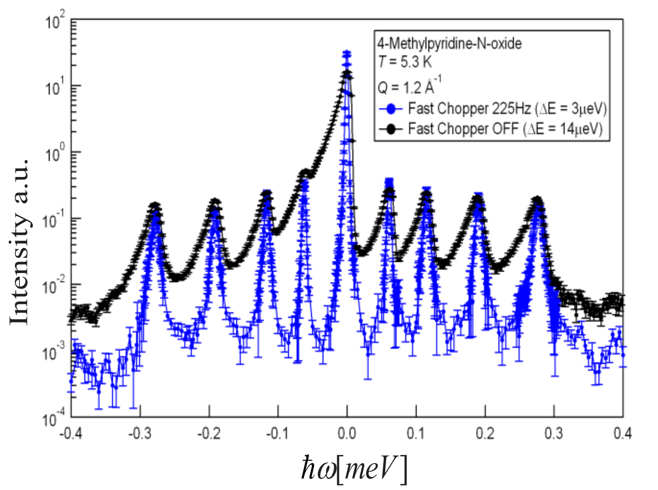

Fig. 9 Tunnelling spectrum form γ-Picoline with/without pulse shaping chopper. The resolution is about 3μeV/15μeV for each case.

NOVA also showed a very quick measurement on a SiO_2 glass sample. S(Q) ranging from 0.2 to 40 $Å^{-1}$ can be obtained in one second with a good statistics at 100kW in the accelerator power.

MLF has introduced an event recording data acquisition system as the standard system for the first time as a neutron facility [14]. In this system, neutron is counted/recorded with information when, where and

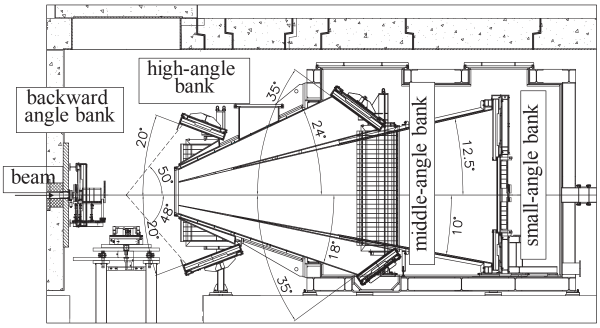

Fig.10 Detector arrangement of TAIKAN, small and wide angle diffractometer.

how the neutron was recorded one by one with relevant information such as temperature of sample, goniometer angle, even a rotation phase of a chopper system. Hence one event record contains many relevant information altogether. Once those information is recorded with neutron event, therefore, experiment can be done even with a continuous temperature scan, continuous goniometer rotation, etc. Data analysis can be done after experiment by choosing the data, which exist within required conditional limits such as sample temperature, goniometer angle, etc. As an extension, we can make a real time measurement of a transient phenomenon or an in-situ experiment as a routine experiment in any instrument in MLF.

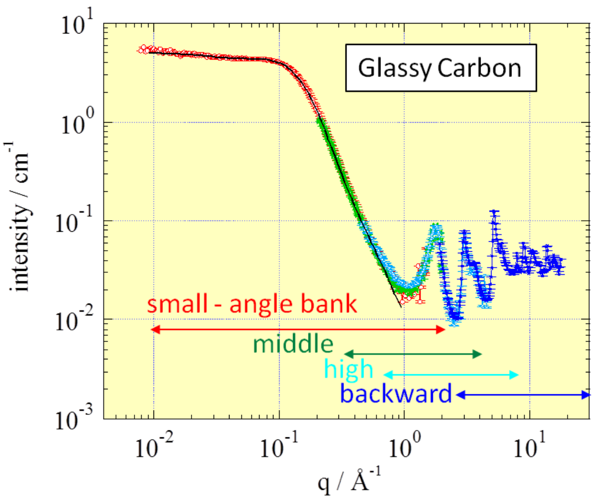

Fig. 11 Example of data of Glassy Carbon observed on TAIKAN. The data is comparable in the absolut scale with that obtained in APS.

4. Research and Development on Devices

4.1 Detector Development at MLF

We have been developing scintillation detectors since before starting the construction of the facility. One of the most intensively developed systems is a wave-length-shift-Fiber system (WLSF). This type of scintillation detector can have a two dimensional array of light guides, which shift the wave length of initially created scintillation light on the neutron absorber, and the shifted light can easily transmit along the fiber to photo-multiplier-tube (PMT) effectively. The spatial resolution can be mainly determined by the separation of the light guide so that the resolution can be easily tunable and can have good resolution less than 1mm [15, 16]. The event position is determined by using a direct encoding technique with multi-anode PMT's. Newly developed sintered ceramic scintillator material, $ZnS/^{10}B_2O_3$, improved detecting efficiency, gamma sensitivity and afterglow at the same time [17]

We are now implemented those detectors in iBIX(1.2mm resolution) [18], SENJU(4mm resolution) [19] and SHARAKU (4mm resolution) [20] as shown in Fig.12

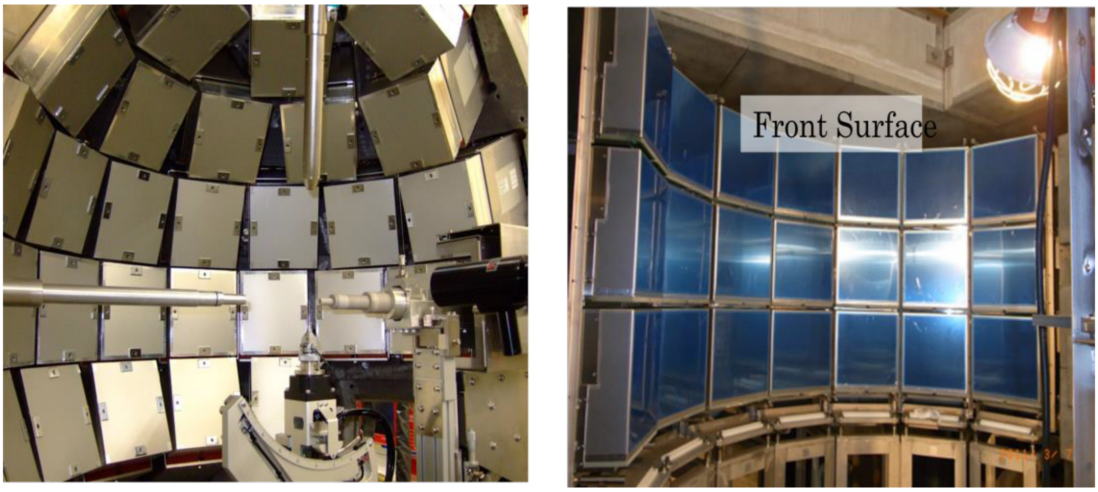

Fig.12 WLSF Detector system of iBIX V(1.2mm resolution) and SENJU (4mm resolution).

4.2 ^{3}He Spin Filter Development

We are developing a ^{3}He Spin Filter by utilizing the spin exchange optical pumping method (SEOP) [21]. Our development on the spin polarization was far behind from other facilities in the past, however, we have recently developed a very compact setup with a compact laser-optical system, and the ^{3}He polarization has exceeded more than 70%. Hence, the equipments are now good enough for a practical use in experiment. We have already tested them on TAIKAN and SHARAKU and obtained a very reasonable performance in the experiments.

5. Scientific outcomes

5.1 General Proposals to MLF

We call for general proposals twice a year. Since we had disaster and accident, we could operate the facility stably only in 2012. In Fig. 13 we show a statistics of proposals each half year. The number of the proposals is steadily increasing each year regardless the difficult situation in 2011 and 2013. Total number of proposals in 2014 is closing to 700. The trend of the increase of the proposal almost follows the increase in the accelerator power and we expect that proposal will be 1500 when we can have 1MW in the accelerator power with more than 2000 unique users number. Proposals from universities are about 45%, 16% from abroad, 10% from industries in 2014. The over subscription rate is about 1.7. This is a healthy competition rate, although a specific instrument has a very high rate more than 3.0.

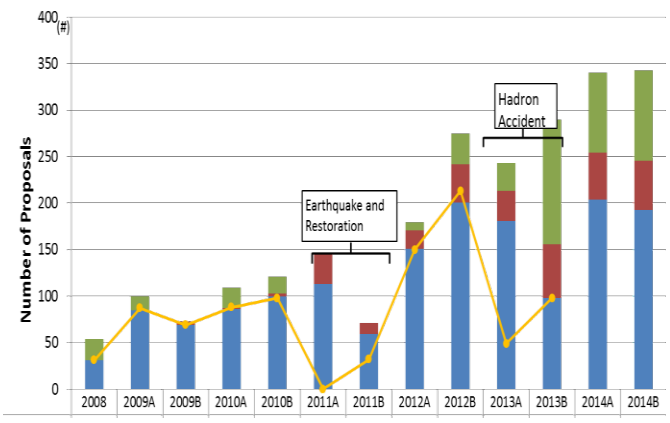

Fig.13 History of the general proposals to MLF. Blue; accepted, Brown; Reserved, Green; not accepted, Yellow; executed proposals.

The number of published papers for each instrument is depicted in Fig.14. The number is not high enough in

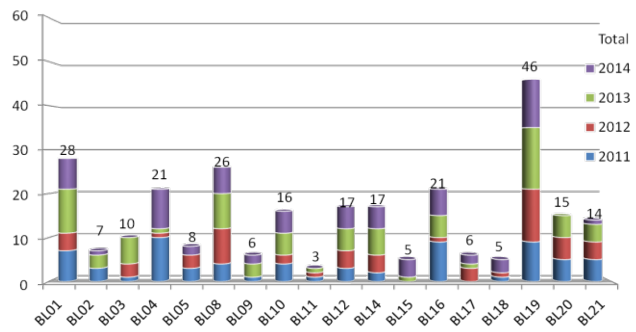

Fig.14 Number of publication for each instrument through year

comparison with a benchmark in the world class facilities yet, and further effort is necessary to catch up with them.

6. Conclusion

The MLF facility has been well developed regardless of the disaster and accident, and is well in use for a user program. The ability of the facility is steadily increasing in accordance with the improvement of the accelerator power. MLF has already reached in a world class level, although further efforts will be definitely necessary.

Acknowledgments

We acknowledge all of the MLF staffs to keep the facility operation stable and effective for the user program. This report is an extended version of a proceedings paper on J-PARC symposium held on July 2014, Tsukuba [22]

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