Report of the J-PARC Muon Advisory Committee (MAC)

MAC-2019

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The MAC-2019 meeting was held at J-PARC, Tokai (KEK Tokai Campus) between February 25th and February 26th 2020.

I Facility Overview

J-PARC Overview/Charge to MAC

J-PARC Director Professor N. Saito welcomed the panel and gave an overview of J-PARC status and activities. J-PARC research is focusing on the origin of matter and universe, and on exploring the diversity of matter and life. He highlighted the scientific output of MLF and the particle physics program, being in line with this mission. MAC acknowledges the continuation of combining academic research at J-PARC and MLF with industrial applications, which is considered important to develop the society for the future. The recently approved Hyper-Kamiokande experiment, including J-PARC upgrades, may have impact on the J-PARC operation due to its high priority on the upgrade of the MR. J-PARC established MR-FX operation at > 500 kW, and a new hadron target for a beam power > 80 kW in MR-SX mode has been installed. MLF continued the 500 kW operation in JFY 2019, again providing stable beam with > 90% availability. MLF operation at 1 MW has been demonstrated for ten hours, and preparations for routine operation at beam power > 500 kW are continuing, with the goal to reach stable 1 MW operation in JFY 2023. Within MUSE, the commissioning of the U-Line is continuing and the construction of the H-line is in progress. MAC was pleased to hear, that the Japanese Science Council JSC awarded the KEK part of J-PARC operation and the g_{μ}-2/μ_{edm} experiment as “Important Projects”. MAC welcomes the continuous efforts in forming new collaborations with industrial partners, and with other international facilities such as SNS, SCK-CEN, and ESS. Finally, Professor Saito gave a set of charges to MAC, presented in Appendix II, to evaluate the facility operation and to make suggestions for improvements.

MLF Overview

Professor T. Kanaya, the Director of the MLF, presented an overview of facility status and beam operation in FY2019. Stable operation at 500 kW beam power has been maintained. A successful 1 MW beam operation was achieved in July 2019 for ten hours. The planned beam power for JFY 2020 is 500 – 600 kW. Delay of resumption of the operation after the summer maintenance in autumn 2019 due to the treatment of tritium-containing gas was reported. The lost beam time of 32.5 days is planned to be compensated by increasing the time for user operation in cycles 2019B and 2020A. A second exhaust line was installed as a countermeasure for the tritium buildup. Plans with improved neutron targets with constraint-free structure with a gradual increase of the beam power up to 1 MW in a few years were revealed. Overall, the output of scientific publications from the MLF shows a continuous upward trend accompanied by an increase of the number of domestic and international users. MAC was pleased to hear that the J-PARC joint Neutron and Muon School for graduate students, postdoctoral fellows, and early career researchers, was held for the 4th time in October/November 2019. MAC fully supports the continuation of this school for the training of the next generation of users.

MUSE Facility Overview

Professor R. Kadono presented an overview of the MUSE facility. MAC acknowledges another year of successful user operation in the areas D1, D2, and S1, the progress in the commissioning of the U-line, and the preparations for the installation of the H-line. The damaged coaxial joint for the rotating muon target (target #1) found in FY2018 was fixed. However, the second coupling could not be replaced due to a too high radiation dose at the position of the second coupling. Therefore, the brand-new target #2 with improved rotary coupling replaced target #1. Necessary measures such as monitoring of target rotation and interlock for failure were properly introduced. The target system was tested with 1MW beam for ten hours, and saturation of temperature was confirmed for the whole system. A promising result of a μSR-LCR measurement at the S1 line with 1MW proton beam was presented, where, thanks to the high muon rate at 1MW, the level-crossing resonance could be swept within a few minutes. MAC was pleased to hear that the budget for the construction of the S2 line could be secured within the S1-type proposal "Precision measurements of the muon mass by 1s-2s laser spectroscopy of muonium", funded by a Kakenhi-grant. One concern is that there is no spare target in the case of another unexpected target failure. Detailed comments on the progress in each of the experimental areas will be given in subsequent sections of the report.

Inter-University Research Program

MAC greatly appreciates that the number of approved proposals shows a steady increase over the last two years: from 76 proposals (including 9 from overseas researchers and 3 for P-type) in 2018A/B to 108 proposals (20 international, 7 P-type) in 2019A/B. This is partly due to the stable operation of the S1 beamline and its increasing permeation into the community. MAC evaluates that the continual efforts of MUSE staff to expand the users' community paid off as an increase in the number of international users and P-type proposals. MAC recommends continuing a careful survey on the degree of satisfaction of users and various levels of outreach activities. MAC also evaluates that three S-type proposals (two S1-type and one S2-type) have proceeded to the 2nd stage approval in FY2019 and that their beam times have been allocated with due consideration to a balance with G-type proposals.

Scientific results from the Inter-University Research Program maintain a high standard of productivity. MAC was impressed to see that a variety of significant studies have recently been completed by the members of the program. This is highlighted, for example, by the observation of metallic spin-liquid-like behavior of a quantum spin system, coupled spin-charge-phonon fluctuation in an all-in/all-out spin-structure antiferromagnet, oxidation annealing effects on the spin-glass-like magnetism and superconductivity in T*-type high-T_c cuprates, and negative muon capture ratios for nitrogen oxide molecules. It is also highly appreciated that the joint research between IMSS and Toyota CRDL, Inc. has steadily been developing to establish the technique to detect non-destructively the spatial distribution of Li metal ions in battery structures using negative muons.

Although MAC positively evaluates the personnel actions (promotions, hires and changes) being activated in the past years for the ongoing alternation of generations, there is still a strong concern that the shortage of manpower may cause significant difficulties in keeping and developing the activities of MUSE in view of the planned expansion of the facility to the S2, H1, and H2 areas. MAC is also concerned about the situation that a large part of scientific and development activities of the MUSE facility have been carried out relying on non-permanent scientists and engineers. This is, however, an issue occurring not only in MLF but also in most other Japanese research institutes and universities nowadays. MAC strongly recommends increasing efforts to make tighter collaborations with universities and private companies, not only in Japan but also overseas. This will allow establishing a sharing human resource management system, such as by introducing cross-appointment positions, and organizing and providing attractive career-paths. MAC also encourages cultivating talent to take over leadership for the overall management of the MUSE facility.

II MUSE Facility Activity

Muon Source Facility: M1/M2 Area

The MUSE group has continued their responsible stewardship of the proton beamline around and including the muon production target. In particular, taking the activation issue seriously, they have focused on the fate of residual tritium (which is highly mobile and long-lived). The study of the muon production target as a potential source of tritium continued, and a new collaboration with external tritium experts is promising. The buffer tank system for controlling the ^3H exhaust from beamline vacuum pumps seems to be working well.

The responsibility for target and part of the proton beamline consumes significant manpower and resources in MUSE. Given the expertise and shortage of manpower of the MUSE group, J-PARC would be better served if this role were transferred to a site-wide J-PARC group, according to international standards, tasked with maintenance of high radiation beamlines and air activation risks. One engineer was moved from MUSE to COMET exacerbating manpower shortage in this area.

Muon Production Target

Activation of the first rotating target, being in operation from 2014 to 2019, prevented the replacement of its second internal (presumably weak) rotary coupler. The backup target, including stronger steel couplers, is installed and working well. However, now no further backup target exists. The entire muon program depends on this target, and this situation thus *presents a significant risk for the operation of the MUSE facility*. Several backup plans can be considered in the event of a failure of the current muon target. The previous one (with the weak coupler) might be re-installed, or an older design, nonrotating target might be used temporarily. Neither of these options is ideal.

The loss of technical experience complicates production of a new muon target, and the required budget has not yet been assigned. The preparation of a new target will need at least 3 years and should therefore be a high priority. When a new muon target is manufactured, it may be sensible to adopt a modular design so that the target could be disassembled by remote handling, some parts of the target assembly re-used and some spare parts pre-produced.

The exercise of target replacement was important to build up knowledge concerning the radiological risks and the required procedures for target exchange.

Continuous, real time monitoring of the muon production target temperature, in the form of an IR camera, has been implemented and is working. This will improve understanding of target operation, aging and potential release of residual activity, in particular tritium, and it will further enhance safe operation.

μSR Spectrometer and sample environment

On the S-line muon beamline, the S1 kicker is required to select the time structure (single vs double pulse) at the S1 end-station. There have been ongoing problems with the HV driver for the kicker, causing about 5 failures per year, with the risk of beam time loss for several hours. Some progress has been made, but the problem is not fully solved. This kicker will also be essential for the proposed S2 installation.

A second low temperature capability in the form of a ^{3}He fridge has been commissioned - an excellent extension of capabilities. While not as low in temperature as the dilution fridge, this cryostat should be substantially simpler to operate. It is essential to make its routine operation as easy as possible to minimize demands on facility staff.

The DAQ appears to work well at the highest muon rates achieved during 1MW operation, but longer high-rate operation will reveal the level of data distortion due to detector deadtime. This may take more effort to mitigate. The presented magnetic field scan across a muon-level-crossing-resonance in Cu, where each point took only 2 sec to measure, is very promising for future investigations of level-crossing-resonances in systems, where changes on a time scale of minutes are expected. This would open a new field of μSR applications.

Negative Muons at D1 and D2

A user program trend of increasing negative muon usage, including μ-SR experiments, was presented. A long-lived background component caused significant distortions in μ-SR measurements at late times. This background was significantly reduced by reducing slit widths to narrow the beam, and supposed to originate from the beam duct collimator at the beam exit.

Continuous commissioning work has been successful and enabled the increase of the number of negative muons for μ-SR experiments at the D1 line. Optimal beam parameters and profiles have been obtained with and without kicker operation. The upgrade plan to improve the detection efficiency in muonic X-ray experiments by increasing the number of germanium detectors was shown.

In order to improve the quality of science output with negative muons, MAC recommends to provide documentation of the D1 and D2 beamline characteristics (including beam transport simulations) for the users, asking user groups to assist. To help users in the preparation and analysis of the experiments at the D2 line, MAC recommends to provide more information about data acquisition (DAQ diagram), the analysis method for the use of the Germanium detector set, and instrument scientist in charge.

U-line/Ultra Slow Muons: Beam line

Commissioning of the USM beam line continued. The discrepancy between the measured beam spot size of about 10 mm FWHM and time resolution of about 10 ns, and the expected beam size of 1 mm FWHM and time resolution of 2 ns, has been identified to originate from the large source size and concomitant aberrations in the beam transport elements. Simulations of the beam transport are in progress to improve the beam size, including the use of a different extraction electrode (Pierce-type) for better beam injection, and pulsed beam extraction to improve the time resolution. The number of USM at the source has been established at about 500/s/MW. Although still about one order of magnitude too low for μSR facility operation, MAC acknowledges the steady increase achieved in the past three years, and MAC is looking forward to the impact of the expected increase of Lyman-α laser energy per pulse. MAC also acknowledges the attempt to use an aerogel target as a Mu source, since the room temperature of the target should yield an enhanced Mu ionization probability compared to the 2000-K-hot tungsten foil. Although the USM yield of the aerogel target is so far 80% of the tungsten foil, MAC encourages the team to continue optimizing the yield with the aerogel target. First tests of the muon microscope have been carried out, with a currently low rate of 0.033 events/s. MAC applauds the hiring of two additional persons, a postdoc and an assistant professor, and appreciates the continuous efforts and progress in the commissioning. MAC is pleased to see the presentation of task assignments, but it remained unclear who the responsible project manager is. MAC recommends to clarify this point and to develop a clear project and risk plan for the coming years.

The conversion efficiency of surface muons to USM is of fundamental importance. This is key information for understanding and optimization of the laser ionization process – which is, in addition crucial, for the planned g_{μ}-2 experiment and the Transmission Muon Microscope (TμM) at the H-line. MAC recommends to perform a beam characterization of the U-line to determine the muon rate, spin polarization, beam size and momentum spread. This study could be done in collaboration with external groups working on muon beam transport made purely with solenoids, which may also lead to stimulating future collaborations.

Laser System

In the course of continuous investigations of the final amplification stage at the primary wavelength of 1062.78 nm, it turned out that the Nd:YGAG bonded ceramic cannot be applied for high power amplification in the laser system due to random wave front distortions and low wavelength conversion efficiency. In contrast, the results obtained so far with the newly developed Nd:YSAG bonded ceramic look very promising to achieve the design value of 1 J/pulse at 1062.78 nm. MAC applauds this huge step towards the design energy of 100 μJ/pulse at Lyman-α wavelength. Rods with 6 mm and 9 mm diameter are available, where the 9-mm-rod already showed good gain properties. Optimizations of the laser system are in progress, and are anticipated to take about 6 months. MAC encourages the management of J-PARC and MUSE to support the activity, monitor the progress, and help mitigate the risks. MAC recommends to identify potential risks to complete the objective of routine operation at 1 J/pulse.

MAC is pleased to see the assignment of two persons for laser maintenance, currently being trained. The availability of additional manpower is essential for future routine facility operation of the laser system.

MAC acknowledges the establishment of an external advisory committee of international laser experts, as recommended last year, and is looking forward to their report.

H-line

The H-line is an essential part of the approved science program with DeeMe and MuSEUM in the H1 area, and with TμM and g_{μ}-2/μ_{EDM} in H2 in a future extension hall. The H-line is designed for very high rates of surface muons and cloud muons of both polarities. The performance simulations have been published already in 2018 (Kawamura et al.). Planning for the H2 area and extension hall is progressing. MAC acknowledges the installation of a J-PARC task force that has already endorsed the facility 'exterior design' needed for H2. The required resources for the realization of the extension hall and infrastructure have not been secured yet.

Construction of the H-line and the H1 area is ongoing and major milestones have already been met. Frontend devices (large aperture capture solenoid and dipole) have been installed and radiation shielding is in place. The first phase of the required new electrical substation is almost complete (expected to be finished in April 2020).

However, a lot of work still needs to be done to finish the H1 line. While all beamline magnets are available, the separator (Wien-filter), slit-systems and beam ducts have not yet been constructed. A schedule was presented for FY2020 to finish the cabling inside MLF from the new panel-boards to power supplies and magnets, to install the cooling water circuitry, and to implement the PPS safety system.

A minimal budget, not yet including separator and slits, of 55M JPY in order to be able to start a basic operation of the H-line was presented, of which only about half seems to be available in FY2020. MAC recommends that the missing resources be found in a prioritization effort to complete the construction as soon as possible, best during the course of this year. By that, timely commissioning of the H-line would be possible, using also external manpower provided by experimental collaborations. Beyond that, completion with separator and slits should remain among the highest priorities in order to enable timely production of physics results. As for the U-line, MAC recommends an evaluation of possible collaborations with other groups working on muon beam transport systems.

MLF Second Target

Working groups of J-PARC MLF divisions and of the Japanese Science societies for neutron and muon research continued their evaluation for a future target station 2 in MLF. This plan includes an upgrade of the proton beam power to 1.5 MW, a splitting of the proton beam in front of the existing MLF hall by a fast magnetic kicker, and the building of a new experimental hall with a combined muon/neutron spallation target. Improvements by a factor 20 of neutron intensities, and a factor 50 – 100 of muon intensities are expected, promising new kinds of applications of muon micro beams under extreme conditions (high pressure, high external magnetic field), bio science (small protein crystals), and industrial applications. A conceptual design report has been prepared, and a letter of intent was submitted in March 2019 to the Science Council of Japan (SCJ) for the Japanese Master Plan of Large Research Projects, which has not been approved by SCJ. A submission to the MEXT roadmap was planned for February 2020. The MLF second target is a project with a time horizon beyond 2030 and MAC welcomes this development of initial ideas for future large-scale muon projects at J-PARC. Considering the manpower constraints, MAC recommends to pursue this activity with lower priority.

III General Comments and Recommendations

MAC acknowledges the achievement of another year of stable operation at 500 kW beam power, and the outstanding work of the MUSE team. A ten hour test at 1 MW was successfully carried out, revealing no major problems thanks to the experience gained from operation in previous years. We are looking forward to stable long-term operation at 1 MW planned for 2023. MAC is very pleased to see the continuing interest from broad scientific communities in muon science at J-PARC, and that the user program is running smoothly. MAC appreciates the continuous efforts on ensuring safe operation of the facility.

The research reports presented to MAC demonstrate the rich field of muon applications, from fundamental particle physics to condensed matter physics, material science and industrial applications, elemental analysis, and ideas to use the muons as novel microscopy/tomography probes. This broad field of topical applications is a unique strength of MUSE.

The ongoing transition from construction to operational mode will naturally lead to an increase in user support requirements for MUSE staff. MAC strongly recommends to make available additional staff with part of their duties assigned to the ‘instrument scientist’ role that includes assisting new users in preparing proposals and training users to run their experiments. The development of a strong and stable muon user community depends on such support from the facility.

To provide more manpower for the muon science program, MAC recommends the transfer of the MUSE responsibility for the M1/M2 proton beam and muon production target to a single dedicated J-PARC-wide group, concentrating the expertise and capabilities to deal with beam transport, engineering and safety in a uniform site-wide manner, thus ensuring a J-PARC-wide safety concept. This would be in-line with international standards. MAC considers this as essential to the further success of MLF. Additionally, MAC encourages the J-PARC and MUSE management to establish joint appointments with universities and companies, to take up some of the tasks of user support. It will also be helpful to increase efforts to make tighter collaborations with universities, thus attracting more user groups to MUSE.

The laser for USM generation is of pivotal importance for the experimental program at MUSE. MAC reiterates their recommendation, as a medium-term measure, to establish a “laser development and maintenance team” under the responsibility of J-PARC to ensure long-term stable laser operation for the various experiments requesting USM. The laser for Lyman-α generation seems to make significant progress and, as a potential backup solution, a novel ionization scheme will be tested using the two-photon 1s-2s transition in muonium, which is strongly supported by MAC.

In view of the various projects and limited manpower, MAC recommends that the MUSE management clearly articulate their priorities in order to ensure an efficient completion of experiments and thus guaranteeing timely scientific output. This includes milestone control and risk management plans for the U-line/USM/H-line completion and commissioning, as well as the appointment of a responsible project manager of the U-line/USM. MAC strongly recommends to J-PARC and MUSE management to provide the missing budget of 55 M JPY for H-line completion, which could be accomplished by postponing budget of lower-priority projects. Considering the current situation of financial and personnel resources, the future plans for completion and operation of the S3 and S4 lines further call for an immediate creation of project and priority plans for MUSE.

MAC is highly concerned about the significant reduction of approximately 25% of the budget approved to MUSE in FY2020 from the previous fiscal year. MAC recommends to provide a financial plan for the completion and operation of the beam lines.

APPENDIX I

Members of MAC:

Hiroshi Amitsuka (Hokkaido University)

Andrew MacFarlane (University of British Columbia)

Klaus Kirch (ETH Zurich and Paul Scherrer Institute)

Kenya Kubo (International Christian University)

Martin Mansson (Royal Institute of Technology)

Takashi Nakano (Research Center for Nuclear Physics)

Thomas Prokscha (Paul Scherrer Institute) Chair

Tadayuki Takahashi (Institute for the Physics and Mathematics of the Universe)

Unable to attend: Martin Mansson (Royal Institute of Technology)

APPENDIX II

Charges given to MAC:

- Evaluate the appropriateness of the facility operation and its upgrades with respect to the following points :
  - safe, stable and efficient operation towards the production of science in a timely manner
  - timely construction of beam lines and their preparation to maintain the uniqueness of the facility, attracting not only domestic users, but also international users
  - operation and maintenance of proton beamline up- and downstream of the muon target
- Any suggestions for improvements are appreciated. Our particular concerns include, but are not limited to, the following:
  - Limited manpower to operate and maintain the beam lines
  - Urgency of commissioning of the U-line, preparation for H-line construction and the remaining S beam lines