Report of the KEK/J-PARC

Muon Advisory Committee (MAC)

MAC-2022

April 2023

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The Muon Advisory Committee (MAC) met on February 20th and February 21st, 2023, in the KEK Tokai Building, Room No. 116, and per zoom to review the progress and prospects since the last MAC zoom meeting in February 2022. All presentations were provided prior to the meeting, which proved very useful for MAC's efficient discussions in the Executive Sessions. The MAC thanks the MUSE staff for their considerable efforts put into the preparation of the material and the efficient running of the meeting.

I Facility Overview

J-PARC Overview

J-PARC Director Professor T. Kobayashi gave an overview of J-PARC showing the use of the various particle beams in a wide range of research fields at the Materials & Life Science Experimental Facility (MLF), Hadron Experimental Facility, Neutrino Experimental Facility, and the Transmutation Experimental Facility. MAC congratulates the positive evaluation of the MEXT review of the KEK side of J-PARC in 2022, allowing a 10-year continuation of J-PARC operation/developments for all the facilities.

Three highlights from MUSE leading to press releases were presented: Li diffusion in operando Li battery cells, elemental analysis using negative muons on material from asteroid Ryugu, and the Rabi-oscillation spectroscopy of muonium, awarded with the Nishikawa Prize. MAC applauds all involved for their great success.

In the KEK Project Implementation Plan (PIP), two out of five selected projects are located at J-PARC. One is the extension of the J-PARC Hadron Experimental Facility, and the second one is the Muon Transmission Microscope (TμM) at MUSE. MAC congratulates the MUSE team for their success with this strategic project.

Progress towards realizing a dedicated J-PARC road access is appreciated, allowing for an easier access of users to the facilities.

While the budget of JAEA and KEK remains nearly unchanged, the increasing costs for electricity are a matter of concern. MAC recognizes the efforts for additional budget to keep the user program running as long as possible in 2022B.

MLF Overview/Charges to MAC

Professor T. Otomo reported the status of the MLF facility. MAC highly evaluated the stable operation of the proton beam at 830 kW with the continuous increase of the beam power. Achieving the 1-MW goal is really coming close.

The skyrocketing electricity price has been preventing the full-cycle operation of J-PARC. The high price is out of the control of MLF and J-PARC. MAC recommends a full effort to obtain the budget to carry out the 2023B term beamtime and the following years.

MAC appreciates the hard work to extend the lifetime of the neutron production target to reduce the beam-off time due to the target replacement.

MAC acknowledges the large number of proposals submitted to MLF and the acceleration of publication output of MLF experiments.

Finally, a set of charges was given to MAC.

Present Status of Muon Science Laboratory

Professor K. Shimomura explained the status of personnel, facilities, and activities at MSL. The muon section has hired additional personnel: one permanent technical staff member, three concurrent staff members, one temporary staff member, and accepted one postdoc during the past year, bringing the total number of staff now to 47. MAC is pleased to note that staffing has been devised to effectively divide the workload between facility operations and experimental support for seven instruments on four beamlines to cover the retirements of experienced personnel that have occurred over the past few years. MAC acknowledges the tireless efforts of the Muon Science Division to reinforce its staff while promoting a smooth generational transition.

The number of beamtime proposals has remained roughly stable, albeit with fluctuations, during the covid-19 pandemic, and is expected to increase in the future as the number of foreign visitors recovers. MAC appreciates that the stable operation of the D and S lines has resulted in the publication and active press distribution of a wide range of advanced research utilizing positive and negative muons. The staff of the Muon Science Division also promotes outreach to the public through symposia in the arts and sciences, and activities to stimulate interest in muon science among people of all ages, from primary school to undergraduate and graduate students. MAC recommends conducting periodic follow-up surveys of participants to track the results of these steady efforts.

Facility (MUSE) Overview

Professor N. Kawamura reviewed the present status of the MUSE facility with some highlights covering the latest developments since the last MAC meeting.

The MUSE organization was explained. Professor N. Kawamura and Professor A. Koda have taken over the positions of the Muon General Manager and Sub-manager, respectively. MAC appreciates the alternation of generations and congratulates Professors Kawamura and Koda for their promotion.

The preparation of a new muon rotating target is ongoing following the advice from the previous MAC. The abnormal torque observed last year has been fixed by replacing the mechanical couplings connecting the upper and lower shafts with an Oldham coupling.

The quadrupole magnets for the D1 beam line have been replaced with the ones with higher focusing power achieving delivery of the muon beams with maximum momentum of 120 MeV/c. The muon cyclotron for the transmission muon microscope was installed in the experimental area U1B. MAC congratulates the steady progress of the facility.

While efforts are being made to introduce efficient operation, change internal organization, or outsource to other sections in J-PARC and universities, most of the instrumental groups at MUSE suffer severely from a lack of manpower for regular user operation as pointed out by the previous MAC.

II MUSE Facility Activity

Muon Source (Target and M1/M2)

MAC recognizes the outstanding work of the group to detect, identify and address the rotary coupling feedthrough problem on target No. 2. The importance of developing a workable strategy for maintenance of equipment in high radiation areas is also evident, as the same strategy was employed in dealing with the Kapton window failure at S1. One can expect as equipment ages and is exposed to the additional radiation load of 1 MW operations, that these kinds of problems may become more common. MAC appreciates the development of a strategy to carry out the work safely and limit the dose to workers.

The coupling problem also demonstrates how crucial it is to always have a spare target on hand. MAC is pleased to see that funding for the new target is secured and that it is in preparation.

While the expected lifetime of the target may be 10 years, this second instance of problems with the rotary coupling show that unanticipated problems with the entire chain of moving parts, and not the bearings themselves, could determine the practical lifetime.

This also clearly reveals the importance of the target health-monitoring that has been implemented, and MAC is pleased to see that investment is continuing in this direction with replacement of the IR camera.

Problems with the muon production target are also strong motivation to have a plan in place for decommissioning of end-of-life or failed targets, with capacity at the ready for unexpected target changes. MAC is pleased to see that the target storage vessel has been constructed and plans for long-term storage of spent targets are being developed. Clearly, the overall costs are highly dependent on the actual target lifetime. It may be useful to understand the radiological cooling time for a spent target, and to consider whether there is any obvious and simple change to the target design or materials that might reduce the amount of activity generated.

MAC is very pleased to see that the group has reached out to collaborate with groups within J-PARC and at PSI to benefit from the experience and aid from these other groups, and MAC strongly recommends that these efforts continue.

MAC appreciates that the group of MUSE people responsible for the M1/M2 proton beam line and muon production target has been strengthened by one person. MAC strongly recommends continuing these efforts.

D-line

The D-line is the first secondary muon line at MUSE and has already a long history of scientific productivity. MAC appreciates the efforts to broaden the range of muon energies that can be delivered to the D1 area, specifically by replacing the focusing triplet with a higher field version, to enable experiments requiring high momentum decay muons, in particular for μSR experiments at high applied pressure.

MAC appreciates the group's efforts to mitigate the radiation safety hazards presented by higher momentum operation of the D-line (which will apply to experiments at either D1 or D2 area).

As the facility continues to transition to full-scale user facility operation from the construction and development phase, it will be crucial to implement a user-support system that minimizes the load on MUSE staff. MAC appreciates the efforts in this direction in the form of remote operation and beam scheduling.

The group has also identified the urgent need for investment in analysis software for muonic X-ray data, motivated in part by the rapid growth in this application which involves many non-scientist users that lack the training to perform this analysis on their own. Unless the appropriate person to develop this software can be found locally, MAC recommends reaching out to the other muon facilities where muonic X-ray elemental analysis is under development (particularly ISIS, PSI, and TRIUMF), as software development as a consortium may be sensible both for the facility and for the new user community.

MAC also strongly supports the continuation of outreach activities that represent both an important investment in the future of the facility in terms of attracting students, and an important way to raise the profile of the lab with the public at large.

S-line

One of the long-term concerns at this beamline has been the crucial kicker and its power supplies that generated down-time due to multiple failures. The wise choice to relocate the power-supplies outside the concrete shield has drastically reduced the down-time to matter of hours. The team has also made efforts to implement preventive diagnostics. Unfortunately, a drastic increase in MARX board failures occurred during the most recent beam period. A strategy to replace the MARX boards with SiC FETs is proposed. The stable operation of the kicker is clearly essential for the operation of both S1 and S2 instruments and MAC strongly supports any efforts to resolve this issue as soon as possible.

A severe problem with the gate valve (SGV1) occurred in March 2022. It was found that it was caused by the shredding of a downstream Kapton foil that separates the primary (muon target) and secondary channel vacuum spaces. Even though it is not fully clear why this happened, the team has, through efficient actions and communications with other muon facilities, resolved the issue and found that one possible reason is the degradation of the Kapton due to the beam.

Finally, an issue with the high LF power supply of the Artemis spectrometer occurred. Through efficient planning and fast actions, the S1 team resolved the issue without affecting the inter-university experiments program.

The S-line is one of the busiest muon beamlines with many experiments conducted and continuous scientific output. In addition, here are proposed projects for obtaining external funding aiming to install a new spectrometer in the S2 area or the construction of the S3 area.

MAC congratulates the team for being so efficient, hard-working, and resilient.

D1/S1 Instrument (μSR)

D1:

The sample environment suite available for the instrument is impressive, including the full temperature range from dilution refrigerator all the way up to the furnace. In addition, both positive and negative muons are available, which makes the available range of science at D1 extremely comprehensive. Given such diverse capabilities, MAC has concerns regarding the rather low/decreasing scientific output (publications) during the last years.

The D-line with upgraded triplet allows for higher muon momenta. One of the clear purposes of such beamline upgrade is to use high-pressure sample environments. Even though beamline staff has made efforts for acquiring pressure cells, there is no official D1 project for a high-pressure program. MAC recommends the management to consider funding hardware as well as a dedicated high-pressure staff member and to harvest the new and important capabilities made available with higher momenta at D1. It would clearly be efficient to collaborate with already existing high-pressure expertise within the neutron groups at J-PARC.

Finally, MAC strongly supports the continuation of educational efforts with the involvement in the Neutron and Muon School as well as outreach activities. This is a very important task that will secure the expansion/regrowth of future generations of μSR scientists and users.

S1:

MAC is very pleased to see that the S1 instruments is generating publication output with several recent high-impact highlights in diverse research fields. MAC is also pleased to see the addition of one new staff member. The team has also made good progress with the efficient scheduling of cryostats to conduct the maximum number of experiments. Further steps are also being planned, e.g., a cryostat lifter, that will allow time efficient cryostat replacement without the need for a crane operator. There are still some concerns regarding possible understaffing of S1. MAC suggests that after current strategies for making the beamtime support more efficient are fully implemented (see above), the level of staffing contra workload should be properly evaluated.

The high-field magnet (CYCLOPS), that had reported problems in the previous MAC meeting, has now been repaired by the manufacturer and is ready for commissioning. The team has also taken action to establish a cooperative relationship with the sample environment team at the neutron facility. MAC strongly encourages that efforts for such collaboration is continued.

D2 Instrument (Muonic X-rays etc)

Additional Ge detectors for efficient muonic X-ray detection and a new spherical chamber for a variety of samples and measurements were installed. A new Ge calibration software was developed for quick energy calibration. Collaboration with industry users in the investigation of the occurrence of soft errors due to muon irradiation in SRAMs and metallic lithium precipitation in Li-ion batteries is highlighted. 2D and 3D elemental mapping with CdTe and Si detectors are in progress.

Users unfamiliar with radiation detection are coming in to use muons in cultural heritage studies. As a result, the load of user support on facility staff has become more demanding. Some researchers using muons express the need for easy-to-use data analysis software. Developments of hardware and software may be carried out in parallel.

S2 Instrument

The status of the development of the Muonium Laser Physics Apparatus as an S2 Instrument was presented. The S2 area is developed for muonium 1s-2s transition measurements. It is good news that the beam intensity required for the experiment was obtained simultaneously in both the S1 and S2 areas last year, and that the first observation of an 1s-2s resonance signal with a narrower linewidth at a high signal rate of $>5\times10^{-3}$/pulse was achieved. Although there were some difficulties, such as a missing Kapton foil in the beamline and kicker troubles, MAC appreciates that the first public use of the S2 area has finally begun.

U-line

MAC appreciates the formulation of project milestones as binding goals for the beamline commissioning over the coming years and is pleased to see the significant increase from 7 to 12 persons involved in the U/U1A/U1B team.

MAC is pleased to see the increased rate of ultra-slow muons (USM) at the F3 intermediate position by about 50% to 330/sec with a 1 ns time resolution due to replacing the hot tungsten foil by a room temperature silica aerogel target. A further increase to 1000/sec is expected due to the recent improvement of Lyman-α ionization laser pulse energy from 5 mJ to 13 mJ. MAC applauds the U/U1A team for this important advance.

Measurements of the surface muon flux by positron counting with a Si pixel detector are underway. This information is essential for determining the overall efficiency of USM generation, and MAC acknowledges that the team is following previous technical advice. Beam optics simulations are underway to optimize the USM transport to the μSR spectrometer.

MAC highly appreciates that the team is following their recommendation to begin a feasibility study using the cold moderator technique. MAC supports the R&D efforts on the U-line and recommends that the team continues the path they have taken.

U-line (LASER)

Important progress has been reported on several points:

- Output stabilizer of the Lyman-α laser is working well.
- New pumping geometry is implemented with shorter crystal length to reduce wavefront distortion.
- Improvement from 100 mJ to 160 mJ at fundamental wavelength 1062 nm.
- 13 mJ Lyman- α now available which should result in three times higher USM rate.
- The target pulse energy of 100 μJ can be now achieved with 500 mJ at 1062 nm.
- A new pulse scheme requires only 200 mJ at 1062 nm to reach the target pulse energy but needs an additional laser Ti:Saph 200 mJ@532nm. A commercial laser system would cost 60 M JPY.
- A Laser Development Group was formed, as requested by MAC.

MAC congratulates the team for their excellent achievements in increasing the Lyman-α pulse energy and showing new routes towards generation of higher Lyman-α pulse energies at achievable 200 mJ at 1062 nm.

MAC acknowledges the progress in the muonium laser ionization program for the generation of USM and recommends continuation of the proposed new upgrade plan.

After a stable rate of 1000/s USM has been established in U1A (allowing the USM μSR program to start), MAC recommends prioritizing efforts on the laser development in the H2 beamline for g-2.

Laser Review Summary

MAC greatly appreciates convening a J-PARC Laser Advisory Committee as a measure to improve the situation in USM production. Professor Katsuragawa presented the summary of the Committee meeting on January 6, 2023. The Committee assesses the current 5 μJ/pulse of Lyman-α, stable for 5 days, as a “praiseworthy achievement”, and future laser development prospects were presented. The report of the review was submitted to J-PARC Director and MLF Division Head. MAC requests the report to be sent as a basis for discussion at the next MAC meeting.

The external review reported by the J-PARC Laser Advisory Committee addresses key issues and covers the last year’s MAC comments. Especially important, the committee advises that the USM project at J-PARC should set an interim goal to generate 1000 USM/s. MAC recognizes that the U-Line team followed their technical advice. MAC appreciates the valuable report of the Laser Advisory Committee.

U1A Instrument (USM)

A first test experiment using ultraslow muons on a SiO_2/Pt multilayer thin film sample has been carried out at room temperature, showing the expected diamagnetic fraction of muons stopping in the Pt layer. As a next step, a thin-film sample (Ca,Sr)CuO_2 was prepared by T. Adachi's group from Sophia University. However, a water leak at the μSR spectrometer magnet – which is now fixed – halted operation for 3 months. Sample cooling tests and positron detector temperature control are in progress for the first μSR trial experiments.

A new spectrometer with 50% larger asymmetry and increased solid angle is being designed using Monte-Carlo simulations. MAC is pleased to see that the team followed their technical advice from last year.

MAC acknowledges the excellent work of the team and recommends providing opportunities for experiments to the community as soon as possible.

H-line

The H1 area came into user operation recently. The H2 area is under construction. Major progress with the commissioning of the H-Line has been made during the last year (FY2022). MAC is pleased to see a coordinated effort of two staff members with about 25 collaborators from the experiments to characterize the beam properties. Essentially, the beam behaves as expected, with measurements and simulations agreeing very well. Close to 10^8 surface muons/sec scaled to 1 MW proton beam power have been verified, where the remaining gap will be closed when the full current of the capture solenoid can be achieved.

Measurements of the beam spot were reported, as well as of the surface muon momentum bite with an RMS of 1.2 MeV/c at a beam momentum of 28 MeV/c. High negative muon rates were also measured, with the limited current in the capture solenoid being the main showstopper for the highest rates at higher momenta above 50 MeV/c.

MAC recommends repairing the power supply of the capture solenoid with high priority, since high-momentum operation is essential for the transport of the DeeMe signal-electrons.

MAC recommends the installation of the electrostatic separator with high priority, as the positron/electron contamination is presently still prohibitively large.

III Science Projects (S-type proposals)

U1B Instrument (Transmission Muon Microscope, TμM)

Various properties and requirements of the TμM project were presented:

- Muons can visualize electro-magnetic (EM) fields in objects by combining accelerator technology and electron microscopy.
- TEM can study sample thicknesses of up to 1 μm. By employing muons much thicker objects can be investigated (10 μm – cm).
- First results of a simple EM imaging the field around a permanent magnet in air were demonstrated.
- For the 5 MeV TμM in U1B, a very good energy resolution of $\Delta E/E \sim 10^{-5}$ is required.
- The cyclotron exists and is being commissioned, its RF amplifier is constructed, and efforts to acquire external funds ongoing.
- One needs 1000/s USM to start the feasibility study. The team needs to clarify how to share U1A/B.

Once funding is approved MAC strongly recommends the team to focus on the feasibility study.

MAC recommends defining the requirements based on scientific objectives from potential users from, e.g., device- and life- sciences.

The case of TμM would be strengthened if the proponents could clearly demonstrate the feasibility (muon rate after acceleration, demanding energy uncertainty, beam phase space etc.).

Element Strategy: Microscopic mechanism of hydrogen-sensitive properties in inorganic materials

This comprehensive S-type project combines a series of quantum beams (muons, neutrons, X-rays) to study the role of hydrogen within a group of materials relevant for technological developments (e.g., semiconductors, ferroelectrics, etc.). Here the power of muons/μ^+SR in simulating the electronic state of interstitial hydrogen is clearly essential. The project has continuously been very productive. However, no publications are presented for 2022 and so far, only one in 2023. Part of this could be explained by the kicker problems that occurred at the S1 beamline.

One very important fundamental outcome of this project is the “Ambipolar Model”, which is very interesting and beautiful in its simplicity. It should prove to be of high interest, especially within the μ^+SR community.

MAC acknowledges the success of this project and after this final report we congratulate the project leaders for the good progress and look forward to the additional publications that will appear during the following years.

Research on the integration of arts and sciences

MAC recognizes the importance of broadening the application of muon beams to the cultural heritage domain, where science, in the form of non-destructive muonic X-ray elemental analysis, is used to answer questions in the fields of archaeology and history.

MAC is pleased to see this direction is continuing to be fruitful with analysis of Okinawa gold coins revealing more about the history of surface finish treatments and the sutra cylinder composition. While this represents an important outreach activity of relevance to a completely different community, it is still important to try to assess the impact of this work more concretely. It would be useful to consult experts in these fields and ask them what the relevant measures of impact are.

Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams

Impressive progress in the use of high-resolution detectors in muonic X-rays experiments was reported. The project is of S1-type, consisting of a large collaboration of many researchers from different fields and research institutes. The topics presented include:

- new atomic/molecular physics, non-destructive elemental analysis, new detector development, and the generation of an ultra-low-energy μ^- beam.
- innovative spectroscopic techniques using a Transition Edge Sensor (TES) micro-calorimeter where a slight temperature rise by energy deposition is measured with high precision.
- very interesting recent results were published: the muonic Neon 5-4 transition (6 keV) as a QED test under large electric fields was measured with high precision (~eV), the investigation of muon atom formation process, and high precision muonic molecule X-ray spectroscopy (investigation of complex QM dynamics) of muon catalyzed fusion (μCF)
- very recent experiments on solid deuterium.

The long-term goal is to have a MUSE instrument with these advanced detectors. This would need additional manpower to offer it to the community. MAC notes, that this project causes a large workload on local staff in setting up and running these experiments.

DeeMe – Search for the muon-electron conversion utilizing pulsed proton beam from RCS

In 2022, the DeeMe collaboration was involved in H-line commissioning and could start commissioning of their spectrometer in the H1 area. A severe limitation for the effort was the insufficient field strength in the H-line’s capture magnet (see H-line). Nevertheless, the DeeMe system could be completely set up. In a first run, DeeMe measured Michel positrons at around

50 MeV/c and 20 μs after beam on target. The momentum was successfully reconstructed and some backgrounds in the preliminary study are presently under investigation. Two more tests were planned for momentum calibration. In the first one, positive pions of 40 MeV/c would be stopped at an intermediate position and 70 MeV/c positrons from pion decay detected. This turned out to be hampered by background, even persisting when switching off the HB1 dipole. It would be worthwhile to study the temporal development in detail.

After resolving the issues with background events and with full current in the capture coils, DeeMe could produce a first ever muon-to-electron conversion limit on carbon. With 700 kW beam power and more than 70 days of running with a C target, the collaboration estimates that they could improve over the existing best limit from SINDRUM-II.

MAC strongly encourages the DeeMe collaboration, J-PARC management, and funding organizations to consider an extension to allow for a reasonably long measurement campaign with a fully functioning beamline and apparatus in a timely manner.

MuHFS – Precision measurement of muonium and muonic helium hyperfine structure

The collaboration contributed to the important commissioning of the H-line. They are also pursuing their path to being ready for beamtime in H1 for the measurement of the muonium ground state hyperfine structure. Research on shimming the 2.9 T magnet continues. Simulations suggest that some further improvements, by almost a factor of 2, might be possible. Progress with field probes and field cameras continues with an impressive large prototype. Also, research on improved cavities is under way.

In a second effort the collaboration is pursuing the measurement of the zero-field hyperfine-splitting in the neutral muonic helium atom. An experimental campaign was successful in the D2 line. Two more pressure points in He+CH_4(2%) could be measured, and first results were presented. MAC congratulates the collaboration for the successful beamtime and is pleased to see the blinding scheme applied that was presented last year. Initial very promising results were shown on the repolarization of muonic helium using SEOP methods with spin polarized Rb vapor. Highly polarized muonic He was obtained which promises further improvements in this experiment.

Muon g-2/EDM

The importance of the new muon g-2/EDM experiment at J-PARC remains very high. New results from lattice calculations are in some tension with other theoretical calculations and estimates of hadronic effects based on dispersive methods. These potential discrepancies are presently opening more new questions than suggesting answers. The whole experimental and theoretical community has to work on clarifying the situation on all fronts.

The J-PARC muon g-2/EDM experiment has again made impressive progress. Construction of the facility started in 2022. A schedule and milestones were presented, placing the commissioning and start of data taking into 2028. The schedule is tight and the collaboration and supporting institutes must work hard to keep it. The experiment at this time will be very timely, because after the FNAL experiment stops data taking, no other efforts will come in before. Whether or not the theory debate is resolved, an independent determination of the muon g-2 value with completely different experimental systematics will be of great importance.

MAC continues to be impressed by the strength of the collaboration and its R&D efforts and results. It is important to maintain a good output on R&D results, in particular in view of the long-term nature of the effort.

Together J-PARC and KEK-IPNS have installed an effective review and organization structure to help the project move forward. This is important, in particular to mitigate risks for delays in the civil construction project ahead. The extension of the H-line and the construction of the H2 area are major successes along this direction (see H-line) and appear to be advancing very well.

Different scenarios are being pursued for slow muon generation, with different muonium production targets and different ionization schemes. MAC strongly supports a broad and open-minded approach to solve issues with providing high intensities of slow muons. While there might still be a factor of 20, the taken route offers alternative pathways to success. MAC acknowledges the great progress made with studies and hardware projects on the muon cooling and acceleration, injection and storage, and with the positron tracker. The collaboration provided extensive proof of advancements in essentially all subsystems. MAC congratulates the collaboration for their achievements and encourages the effort to work hard to stick to their schedule.

IV General Comments and Recommendations

MAC sees good progress in all areas of MUSE activities, from development, experimental results, organization of MUSE operation, educational and outreach activities to staffing policies including the transition to a younger generation of personnel. MAC reiterates that the impressive and important achievements of the MUSE facility are only possible thanks to the outstanding work of the MUSE team.

MAC applauds the increase of permanent MUSE members and of temporary members by new collaborations with other organizations, universities, and industry. Although still a concern and not sufficient, it is an important step towards a sustainable operation of the muon experiments at MUSE. To make available additional staff with part of their duties assigned to the ‘instrument scientist’ role, MAC reiterates its recommendation to manage – on a medium term – the safe delivery of proton beam by a J-PARC-wide group with the expertise and capabilities to deal with these issues in a uniform site-wide manner.

MAC applauds the progress in building and planning spare muon targets, providing a strategy for used target storage, and finding the required resources.

MAC recommends the continuation of the collaborations started with other international muon facilities and local J-PARC safety and neutron sample environment groups.

A key activity of MUSE is the development of intense beams of ultra-slow muons (USM) by laser ionization of muonium (USM-μSR, TμM, g-2). While progress on the generation of the required energy of Lyman-α pulses was slow in recent years, MAC applauds the team for a significant step forward this year in the three-fold increase of pulse energy due to a new pumping geometry, and the prospect to achieve the required 100 μJ by a new, feasible pumping scheme.

MAC greatly appreciates convening a Laser Advisory Committee on January 6, 2023, as a measure to improve the situation in USM production. MAC acknowledges the valuable report of the Laser Advisory Committee.

MAC acknowledges the progress in the muonium laser ionization program for the generation of USM and recommends continuation of the proposed new upgrade plan. After a stable rate of 1000/s USM has been established in U1A (allowing the USM μSR program to start), MAC recommends prioritizing efforts on the laser development in the H2 beamline to be able to generate a sufficiently high USM rate for the start of the g-2 commissioning.

MAC is pleased to see the progress in U1A. MAC recommends continuing the evaluation of the possibility of implementing a cryogenic moderator system while keeping the possibility to quickly switch to the laser ionization scheme. MAC supports the R&D efforts and recommends that the team continues the path they have taken.

MAC strongly recommends that the TμM team focuses on a feasibility study. MAC also recommends defining the requirements based on scientific objectives from potential users from, e.g., device and life sciences.

MAC recommends repairing the power supply of the capture solenoid of the H-line with high priority, since high-momentum operation is essential for the transport of the DeeMe signal-electrons. MAC also recommends the installation of the electrostatic separator of the H-line with high priority, as the positron/electron contamination is presently still prohibitively large for experiments using surface muons.

The negative muon program continues to show impressive results. The research is broad, comprising general proposals, industrial applications, joint projects of humanities and sciences, and educational experiments. The use of Transition Edge Sensors (TES) enables novel high-resolution muonic X-ray applications and MAC supports these new developments. However, MAC recognizes the additional workload on MUSE staff members and encourages MUSE management to review the organization of these important developments.

MAC appreciates the clearer articulation of responsibilities in their MUSE Organization, and the renewal of personnel. In view of the various projects and limited manpower, MAC reiterates its recommendation that the MUSE management clearly articulates the priorities of various projects to ensure their efficient completion and timely scientific output. We recommend drawing up a long-term vision/roadmap on the further development of the facility.

V Charges given to MAC and response of MAC

The following charges were given to MAC. Each charge is followed by the response of MAC.

1. Evaluate the J-PARC-wide collaboration of target development and maintenance.

   MAC is very pleased to see that the group has reached out to collaborate with groups within J-PARC to benefit from the experience and aid from these other groups, and MAC strongly recommends that these efforts continue.

2. Evaluate the response to last year's comments on the U-Line.

   MAC acknowledges that MUSE followed all recommendations from last year’s report. Our detailed evaluation can be found in Chapter IV and in the corresponding paragraphs of Chapter II.

3. Evaluate the support system for the inter-university research program at the D and S lines.

   The impression of MAC is that the user support works very well, and the users have an impressive sample environment suite available for their experiments. MAC strongly supports the continuation of educational efforts with the involvement in the Neutron and Muon School as well as outreach activities.

4. Evaluate the sequential-operation scheme of the inter-university research (S1-type) in the H1 area.

   MAC recommends that the DeeMe collaboration, J-PARC management, and funding organizations consider an extension to allow for a reasonably long measurement campaign with a fully functioning beamline and apparatus. At the same time, the MuHFS can be started in H1 with alternating beamtimes, giving each collaboration unique data sets as well as sufficient time for in-depth analyses.

5. Evaluate the strategy for the development of the transmission muon microscope.

   MAC strongly recommends that the TμM team focuses on the feasibility study. MAC also recommends defining the requirements based on scientific objectives from potential users from, e.g., device and life sciences.

APPENDIX I

Members of MAC:

Hiroshi Amitsuka (Hokkaido University)

Nori Aoi (Research Center for Nuclear Physics, Osaka)

Klaus Kirch (ETH Zurich and Paul Scherrer Institute, attended per zoom the morning session of Feb 20th)

Kenya Kubo (International Christian University)

Andrew MacFarlane (University of British Columbia)

Martin Mansson (KTH Royal Institute of Technology)

Thomas Prokscha (Paul Scherrer Institute) Chair

Tadayuki Takahashi (University of Tokyo)

APPENDIX II

Agenda for the MAC-2022 meeting of KEK/J-PARC in 2023

February 20th, 2023:

- 10:00 – 10:20 J-PARC Overview — T. Kobayashi
- 10:25 – 10:45 MLF Overview/Charge to MAC — T. Otomo
- 10:50 – 11:10 Present Status of MSL — K. Shimomura
- 11:15 – 11:35 Facility (MUSE) Overview — N. Kawamura
- 11:40 – 12:00 Executive Session
- 12:00 – 13:30 Lunch Break
- 13:30 – 13:50 Muon Source (Target+M1/M2) — S. Matoba
- 13:55 – 14:15 D-line — S. Takeshita/T. Yuasa
- 14:20 – 14:35 S-line — A. Koda
- 14:40 – 15:00 D1/S1 Instrument (μSR) — J. Nakamura/W. Higemoto
- 15:05 – 15:25 D2 Instrument (X-ray etc) — I. Umegaki/M. Tampo
- 15:30 – 16:00 Break
- 16:00 – 16:15 S2 Instrument — P. Strasser
- 16:20 – 16:40 U-line — Y. Ikedo/S. Kanda/N. Teshima
- 16:45 – 17:00 U-line (LASER) — Y. Oishi
- 17:05 – 17:20 Laser Review Summary — M. Katsuragawa
- 17:25 – 17:40 U1A Instrument (USM) — S. Kanda
- 17:45 – 18:30 Executive Session
- 19:00 – 21:00 Reception

February 21st, 2023:

- 09:00 – 09:15 U1B Instrument (TµM) Y. Nagatani
- 09:20 – 09:35 Element Strategy R. Kadono
- 09:40 – 09:55 Research on the Integration of Arts and Sciences Y. Miyake
- 10:00 – 10:15 Encounter and synergy of state-of-the-art astronomical detectors and exotic quantum beams O. Shinji
- 10:20 – 10:50 Break
- 10:50 – 11:05 H-line T. Yamazaki
- 11:10 – 11:25 DeeMe Y. Seiya
- 11:30 – 11:45 MuHFS S. Nishimura
- 11:50 – 12:05 g-2/EDM T. Mibe
- 12:10 – 12:30 Executive Session
- 12:30 – 13:30 Lunch Break
- 13:30 – 15:30 Executive Session
- 15:30 – 17:30 Facility Tour
- 17:30 – 18:00 Concluding Remarks T. Prokscha