Report from the 7th J-PARC Muon Science Advisory Committee Meeting Held March 6 - 7th 2009 at J-PARC, Tokai

Presented to J-PARC director by J.-M. Poutissou, Chair

April 16, 2009

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Executive summary:

MuSAC met at TOKAI on March 6 and 7th 2009 just as the first muon beam user period was ending successfully. The committee was very pleased that in demanding conditions the MUSE team was able to deliver beam to 7 proposals approved by the PAC in November and produces quality results worthy of publications with the refurbished beamline and the spectrometer from KEK, with some new addition from JAEA. The committee applauds this cooperation between the two parent institutions of J-PARC and congratulates the MUSE and the J-PARC team as a whole for an outstanding performance in completing the project on time and on budget.

A decent operational budget must allow for the construction of the high intensity channel and for improving the performance of the instruments at the end of the channel to capitalize on the foreseen beam intensities in the near term.

The committee was charged to review three new Letters of Intent focused on the exploitation of the unique Ultra Slow Muon beams potentially available at J-PARC. All three would provide ground breaking physics results and would place MUSE on the map of muon facilities in the world. MuSAC reiterates its strong support for this program and encourages the MUSE management to place the development of such a beam at the top of all priorities. The original concept for the full development of the muon beamlines is being revised to take into account the strong user demand for such beams and MuSAC agrees with this strategy. The difficulties in identifying funds for the high intensity muon beamline remain while users are exploring other funding avenues. Such may come with strings attached that will demand strong scientific leadership to maintain a proper course for the long term objectives of MUSE. However MuSAC believes that by placing science first, the whole MUSE program will benefit from the strong partnerships which are being considered. The committee recommends that a strong scientific leadership be maintained to carry MUSE forward. A strong commitment of both KEK and JAEA will be required, as well as support from the users and other Japanese research institutes like RIKEN, Universities and industrial partners.

The J-PARC project has come a long way and is about to deliver on its promise. In evolving into a user facility, science is coming to the forefront and the role of MuSAC may be reconsidered. This was discussed in the closing session. Although a strong PAC will be better suited for assessing the scientific program running on the commissioned facilities, MuSAC can play a role in helping shape the future facilities to optimize them to the user demands (expressed or anticipated).

MuSAC has been very fortunate to participate in this adventure and thank the parent organizations of J-PARC and the J-PARC management for allowing us the witness this great success.

Introduction:

The seventh meeting of the Muon Science Advisory Committee (MuSAC #7) was held at J-PARC, Tokai on March 6th and 7th 2009. This was held just as the first user beam cycle was completed successfully. The committee was presented with early physics results obtained during that period which showed promises of rapid publications coming from the MUSE facility. This represents a superb achievement by the group under trying conditions.

For this meeting of MuSAC, the charge was:

1) To comment on the need for a sufficient operation budget
2) To advise on the super Omega muon channel urgency
3) To review the new LOI's related with the ultra slow muon such as "*g*-2" and "Toyota" project and comment on a strategy for implementation
4) To reformulate the need for a shorter Pulse width of the 3 GeV proton beam
5) To consider the role of MuSAC in the future, its organization, mandate and membership

The agenda for the meeting is described in Appendix A and the composition of the committee in Appendix B.

Project Overview Session

Dr. S. Nagamiya presented a status report on J-PARC. The facilities are now into an operating mode with first user beam cycles delivered to both muon and neutron users. Up to 20 Kw of beam power from the 3 GeV Rapid Cycling Synchrotron (RCS) were routinely delivered to users over a two month period. Both the Muon and Neutron sources performed very well as planned. Seven day-one instruments and one muon beamline were taking data. Most notably a superb neutron pulse shape produced a 0.035% lattice distance resolution, a world first. A test of the 30 GeV main ring took place in January 09 which demonstrated acceleration and slow extraction to the hadron facility. The schedule calls for a test of the fast extraction towards the neutrino beamline in mid April 09. This will mark the end of the construction phase for the J-PARC project. Operational budgets have been secured to provide about 110 days of user program over the next fiscal year. Budgets have also been secured to upgrade the Linac to 400 MeV as a mean to increase the ultimate beam power for the complex.

The committee extends its congratulation to the J-PARC team for such an outstanding performance in bringing the J-PARC accelerator complex into operation on time and on budget.

Dr. M. Kinsho gave a status report on the accelerator performance so far. As mentioned above the accelerator chain is being commissioned with rapid progress. Main milestones are being reached and the performance of the accelerators so far doesn't indicate any show stopper. However as expected from such a complex system, it will take time to master all the performance factors to reach full beam power. Some weaknesses were encountered which need attention. Most serious is the instabilities which have developed in the RFQ accelerator. These require frequent conditioning (4 hours once a day) and currently limit routine beam delivery to 20 Kw. A special task force is studying the problem and a "spare" RFQ will be built to remedy these limitations. Beam spills are also larger than anticipated in some area where extra shielding has to be installed. Better understanding of the beam dynamics is required which will come from online beam development studies. A de-lamination problem of the RF core in the accelerating cavities of the RCS needs attention. A concerted effort by the accelerator team is still required to bring routine operation to high power levels. This is expected and doesn't diminish in our view the outstanding performance of the team so far.

Dr. Y. Ikeda presented a review of the neutron facilities and early results from the user run. Already 7 instruments were able to take advantage of the user beam cycle and of the high quality neutron beams generated. Most systems performed well within their specifications and initial intensity measurements show that this source will deliver when operated at 1 Mw, competitive pulse neutron intensities at the level of neutron reactor fluxes when time averaged.

Dr. Y. Miyake described the final stage of construction and the commissioning of the muon facility. He presented some of the early results obtained by experimenters which bode well for the potential of the facility. Even now under trying conditions publishable results are being obtained. The MuSAC committee was shown results from the Saitama-University /JAEA group which identified an anti-ferromagnetic state below 20 K in the $(BEDT\text{-}TTF)_2$ IBrCl compound, an organic superconductor material. Some results obtained on Iron-Oxypnictide Superconductors by the Kadono group (KEK) were combined with other data from TRIUMF to be submitted for publication and new results on lithium diffusion were collected by the team from Toyota Laboratories but the run was cut short by accelerator problems.

In both instances, an enormous amount of work was needed to achieve these milestones and MuSAC would like to congratulate the teams involved in the MLF for their splendid achievements.

To go beyond these initial experiments will require upgrades to the equipment existing at the end of the first decay channel (D1 and D2 position). The committee recommends that better spectrometers (larger acceptance) be constructed to maximize the use of the precious muons available in the early stages of commissioning of the accelerator. Major gains can be achieved (factor of ~4 from the 8% to 30% solid angle) in a more cost efficient way than by increasing the beam intensity by similar factors.

The longer range plan still calls for four channels looking at the current production target. Of those the highest priority must be to develop the high intensity surface muon beam using solenoidal injection and transport and the Dai-Omega axial focusing device. This will provide the highest intensity of surface muons which can be used as such or converted into Ultra Slow Polarized Muons for surface physics and many more applications.

The committee has repeatedly attached the utmost priority for this world unique muon source and that view is corroborated by the response of the muon community in Japan and around the world which indicates that the demand for such beams will explode in the future. To achieve such goals in a timely manner, the implementation of an experimental budget for MUSE is urgently needed.

Review of Letters of Intent

The committee was charged with reviewing three new letters of intent which all plan to use these Ultra Slow Muon (USM) beams.

Ultra-slow Muon Projects at MUSE D2 Area: N. Nishida (TIT)

A LOI was presented proposing advanced research of surfaces, interfaces and thin films in nanometer scale using the ultra-slow muon (USM) beam planed at MUSE. This proposal is supported by four large Japanese collaborations (38 scientists from 15 universities) seeking financial support from a KAKENHI "Grant-in Aid for Scientific Research on Innovative Areas".

The use of polarized ultra-slow μ^+ beams will allow a large number of novel material studies such as:

- scanning and tunneling microscopy of surfaces
- simulation of H dynamics and electronic states on the surface and in the sub-surface of materials, to investigate catalytic chemical reactions, fuel batteries, soft matter, hydrogen storage, etc
- superconductivity and magnetism ("spintronics") at material surfaces
- μSR in thin samples and small (single) crystals in the μg region

One project deals with the construction of this USM beam of highest intensity and luminosity. Two options are considered, option (1) installation on the existing D1 port of MUSE (expected intensity 4×10^4 μ^+/s at 1 MW primary beam power), option (2) installation at the U1 port after construction of the planned SuperOmega beamline, with an expected intensity of 1.3×10^6 μ^+/s.

Option (1) can only be considered as useful for the development and initial tests of the USM facility, since the projected μ^+ intensity is inadequate for efficient μSR use in the foreseeable future. It is therefore strongly recommended, that funding and construction of the SuperOmega beamline (U1 port) and the USM facility shall be pushed with highest priority. The MuSAC committee has been and continues to be advocating that this is the highest priority item for completing the MUSE facility.

"Industrial applications of μSR for Li-ion battery materials":

J. Sugiyama (Toyota Central R&D Laboratories)

The project is well-funded and includes collaborators from the leading centers of μSR-sciences (TRIUMF, PSI, ISIS) as well as well-known scientists from these centers. The main goal of this proposal is to study Li-ions diffusion in the battery materials and create a new generation of batteries. Such a goal cannot be achieved by using μSR alone, but μSR has a specific role to play for example in measuring the Li diffusion coefficient for each battery components (cathode, anode and electrolyte), in detecting subtle structural change s in the cathode material as a function of the cycling period etc. By combining surface muons (exploring the bulk properties of the material) and Ultra slow muons (exploring the surface or interface with the electrolyte) a better picture of suitable materials can emerge. In this LOI, no specific proposal was outlined and the proponents are encouraged to do so at the earliest opportunity to better specify their requirements more specifically in terms of fluxes and timing properties. MuSAC appreciates the importance of accommodating strategic programs such as proposed by the Toyota group at J-PARC. However the NEDO funding sought for this effort come with strings attached that must be negotiated carefully to maintain a generic user program at MUSE. A collaboration with other experienced groups (such as N. Nishida's at TIT), which have also planned similar experiments at J-PARC would be beneficial.

***g*-2 Project:** M. Saito (KEK)

The committee heard a presentation by Saito-san about the efforts by the KEK/RIKEN/Osaka U/U Tokyo/Kyoto U/USA group to develop a new proposal to measure the anomalous magnetic moment of the muon.

The physics motivation rests upon the 3.4 sigma discrepancy observed between the most recent measurement of the muon *g*-2 at the Brookhaven National Laboratory and the most up to date theoretical expectation from a pure Standard Model physics based calculation. It is important to continue to improve this test of a purely leptonic system for which very clean theoretical estimates can be made. An analysis of the experimental error budget indicates that the uncertainties related to the beam size and beam divergences in the BNL setup are a large contributor. The new *g*-2 team is proposing to use a different technique by doing the experiment at low energy with a very low divergence muon beam and very small phase space. This is very promising but a full detailed proposal is still being worked out. In any case the required beam characteristics would be very demanding to achieve.

One way to achieve such muon beam qualities is to capitalize on the development of ultra slow muon beams by the KEK/RIKEN-RAL team which is based upon laser ionization of muonium emitted from hot foils. This technique is particularly well suited for the pulsed beam available at J-PARC and offers the most promising prospect for an intense slow muon beam at J-PARC in the future.

Based upon the additional requirements of the potential *g*-2 experiment in Japan, the group has engaged the excellent laser expertise from the RIKEN group to develop high intensity lasers matched to the muonium ionization frequency. Because of the much larger intensity of USM needed for the *g*-2 experiment, there is a long way to go before the required beam would be demonstrated. However this development will also benefit many other groups seeking to use ultra slow muon beams for condensed matter research. This extra motivation for a particle physics experiment of high visibility would require that the MUSE facility be quite aggressive in developing the high intensity muon channel. The committee was impressed by the excellent work plan presented for achieving a major breakthrough in increasing the ionization efficiency currently obtained in the pioneering work at RIKEN-RAL. The MuSAC committee recommends that the pioneering work at RIKEN-RAL be extended to develop the laser ionization scheme and pulse laser technology, that the construction of the High flux muon channel be pursued actively in parallel and that a full proposal be developed in which all the systematic effects are demonstrated to be under control at the level of precision of the current result.

The Committee is of the opinion that pursuing this experiment should not be seen as conflicting with but rather enhancing the attractiveness of Ultra Slow Muon beams at J-PARC. Eventually should the *g*-2 proposal be approved by the PAC committee, a dedicated beamline should be established for it. The R/D should benefit all USM users.

MUSE Grand Design by the KEK/MSL Group: K. Nishiyama (KEK)

Professor Nishiyama presented a possible evolution of the facility development for MUSE. Working with the user community, the sequence of construction of the remaining three beamlines has changed.

The group is adapting its long term plan to the aspiration of the user community for a greater emphasis on Ultra Slow Muon beams as foreseen by MuSAC. The first step must be the development of the U beamline to generate high fluxes of surface muons. The front end solenoid is being installed now but considerable R/D remains for completing the solenoidal transport system and adapting the Dai-Omega focusing elements. The group is very resource limited and a strong coordination is necessary to exploit various potential sources of funding. The leadership of the KEK/MSL group must be able to deal with these opportunities which come however with severe constraints. Strong Scientific leadership must be maintained in that group to orchestrate this concert of talented players.

JAEA-ASRC Grand Design of the μSR Project: Y. Hatano/ W. Higemoto (JAEA)

The JAEA-ASRC project started four years ago, has produced interesting new results in the studies of *f*-electrons physics (These systems are quite interesting due to their strong spin orbit coupling) and was instrumental for the success of the several experiments during the first beam period at MUSE. The group has designed and implemented a beam slicer /focusing system which was fitted on to D1 port of the decay channel which benefited all other users. The committee heard about the results of the study of organic Anti-ferromagnets where an anti-ferromagnetic state was observed below 20 K which can lead to a publication. This is a significant accomplishment. A wide research program in solid state physics, atomic, molecular and nuclear physics, including muon pulse radiolysis is envisaged for Phase II of this program and is being developed. Again a significant contribution to better instruments is considered which would benefit all users.

Access to surface muon beams would be required for expanding the studies on *f*-electron systems (in particular for the promising studies of higher order multipole ordering in these systems) but also to negative muon beams. This group is well versed in other techniques complementary to the MuSR probe which brings a unique dimension to the ASRC group.

RIKEN-RAL Grand Design: M. Iwasaki (RIKEN)

Professor Iwasaki presented the plans developed at RIKEN for exploiting muon beams at RIKEN-RAL in as much as they are relevant for the J-PARC MUSE project. As reported above the RIKEN group has taken a strong interest in developing Ultra Slow Muon Beam and in particular in providing the enhanced ionization efficiency needed to obtain high intensities of USM. This is very complementary and well matched to the development plans for MUSE and for USM at J-PARC. A superb effort is being mounted on VUV laser development. Another effort on developing state of the art instrumentation for pulsed muon beams will be crucial for the J-PARC users in the long run. (High pressure cells, New DAQ, new spectrometers). The group is well positioned to commission these new facilities at RIKEN-RAL during the period of consolidation of MUSE and to provide these instruments in time for the exploitation of the new beamlines at J-PARC. This is seen by MuSAC as a win-win situation for muon users.

Role of MuSAC in the future:

Now that the MUSE project has moved from construction to partial operation, it was timely to debate the role of MuSAC in the future. The committee was presented with several different organizational scenarios in which MuSAC would be reporting either to the J-PARC IAC, the J-PARC management or the KEK-MSL laboratory. A Muon science proposal review committee (MSPRC) has been formed to approve beamtime for proposals on a per cycle basis and reports to the J-PARC management. MuSAC has a role to play in assessing the scientific potential of the global MUSE facility and in recommending a development path for the facilities in response to scientific opportunities and commitments from the user community as expressed in LOI's and in the global context of other muon facilities worldwide. While MuSAC has so far functioned as a subcommittee of the J-PARC IAC and reported directly to the J-PARC management, its advice could also benefit the head of the KEK IMSS division responsible for the user program at MUSE and the head of the JAEA-ASRC group responsible for the muon program at JAEA. In fact, MuSAC has both of them represented ex-officio on the committee. The very strong endorsement of the muon program as part of the MLF and the cooperation between KEK and JAEA to see it realized must be extended to the upcoming phase of operation and completion of the facilities. The most effective organization will be the one that communicates the advice most directly to the decision makers/ financial backers for the project.

Conclusions:

What a difference a year makes: The MUSE experimental program is started, the main facility is working well and the spirit of the team is very high. MuSAC has very high praise for what has been accomplished by a dedicated team of talented people under tough financial and personnel constraints. MuSAC is excited to have been witness to such a period and wishes well for MUSE's success.

The main overall recommendation is that Ultra Slow Muon beams is the future for this facility and the group should position itself to take advantage of new funding opportunities being pursued by users while maintaining a strong scientific vision. Strong scientific leadership will be needed to maintain the course but the future is extremely bright.

Appendices

Appendix A : Agenda

Fri March 6th , 2009

9:10- 9:30	Closed Session
9:30- 9:40	Opening Remarks..... O. Shimomura

Project Overview Session

9:40-10:10	MLF Project Overview .....Y. Ikeda
10:10-10:40	Status of Accelerator .....M. Kinsho
10:40-11:10	MLF MUSE Overview ..... Y. Miyake
11:10-11:40	MUSE Grand Design .....K. Nishiyama
12:00	Lunch
13:20-13:40	Status of J-PARC Project ..... S. Nagamiya

LOI Session

13:40-14:10	*g*-2 Project .....N. Saito
14:20-14:50	Ultra Slow Muon Project in D2 Area..... N. Nishida
15:00-15:30	Toyota Project ..... J. Sugiyama
15:40	Coffee Break

Muon Activity

16:00-16:30	Grand Design of JAEA Muon..... Y. Hatano / W. Higemoto
16:40-17:10	Grand Design of RIKEN-RAL .....M. Iwasaki
17:30	Adjournment
18:30	Reception

Saturday March 7th,2009

9:10- 9:30	Close Session
9:30-10:30	Future of MuSAC (task, Organization, Membership)
10:30-11:30	Discussion on the Grand Design and LOI
11:30	Report
12:00	Lunch
13:00	Site Tour
14:30	Summary

Appendix B :

MuSAC #7 Committee Membership

J. Akimitsu (Aoyama-Gakuin University)

Y. Hatano (JAEA-ASRC)

R. H. Heffner (JAEA-ASRC)

S. Ikeda (KEK-IMSS)

Y. Ikeda (JAEA- MLF)

M. Iwasaki (RIKEN)

Y. Miyake (KEK-MSL), MuSAC Secretary

N. Nishida (Tokyo Institute of Technology)

K. Nishiyama (KEK-MSL) Chair of Muon Users Group

J.-M. Poutissou (TRIUMF), MuSAC Chairman

C. Petitjean (PSI)

L. Ponomarev (Kurchatov Institute)

Y. Yamazaki (J-PARC, Vice Director)