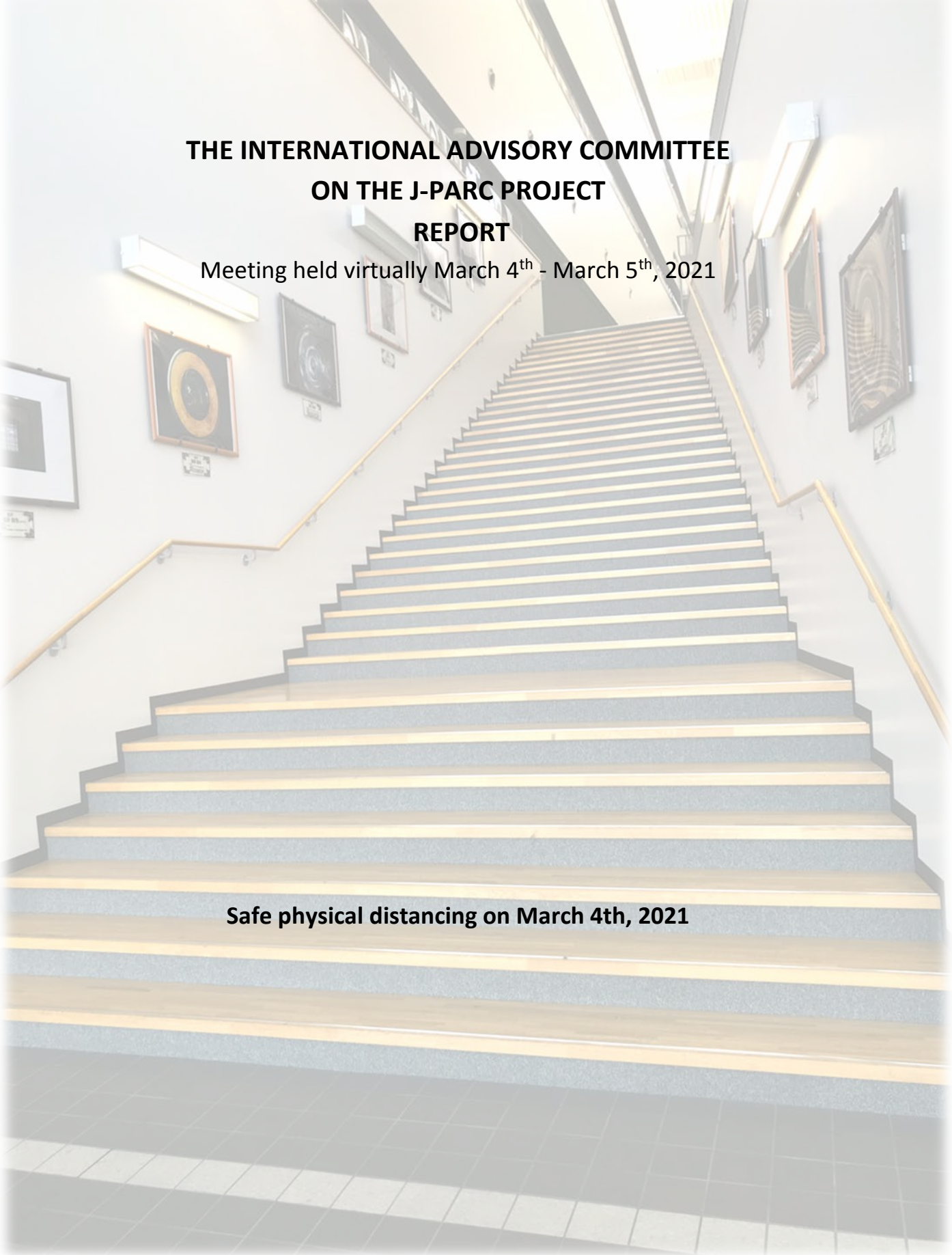
THE INTERNATIONAL ADVISORY COMMITTEE ON THE J-PARC PROJECT

REPORT

Meeting held virtually March 4th - March 5th, 2021



Safe physical distancing on March 4th, 2021

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EXECUTIVE SUMMARY:

The International Advisory Committee (IAC) on J-PARC met virtually on March 4th and 5th, 2021 to review the progress and prospects since the last in person meeting of March 2019. (The 2020 meeting was cancelled due to first wave of the COVID-19 pandemic.)

All the presentations were made available ahead of time, questions from IAC members were solicited and addressed in the 2 video calls. Overall, the committee was able to fulfill its mandate as set by the director (see Appendix III).

The committee was very pleased to see that J-PARC has continued to move forward towards the facility design goals while maintaining a sustainable user program, even faced with the restrictions due to the COVID-19 pandemic on travel and meetings. The beam delivery performances were outstanding with 95% of the beam allocation delivered to MLF users at 600 kW power and 90% to the main ring users with 60kW continuous beams in the hadron hall and 515 KW to the neutrino facility.

This produced some very exciting results, most notably the barocaloric effect in molecular crystals and the establishment of non-CP symmetry in the neutrino sector; these two results were published in Nature (the top scientific science journal) and attracted considerable attention. So did the evidence for doubly strange hyper-nuclei and new bound states of hadrons containing strange quarks. The IPNS plan is to complete two more high priority experiments in the hadron hall prior to the long shutdown. The first phase of the COMET rare decay experiment is moving ahead as the new extracted proton beamline is built.

At the same time the laboratory is implementing its decadal plan which will see the MLF facility operating continuously at 1 MW beam power, the main ring (MR) doubling its beam pulse rate with new magnet power supplies and RF improvements. These MR activities are now fully funded and the IAC is thanking MEXT for obtaining the extra support needed. Also, several J-PARC related projects were included on the MEXT road map and are seeking funding at a future date: increased operation funding for the MR operation, the approved muon g-2/EDM experiment, and future hadron hall extension, and COMET-phase II.

The MLF community is building up and will benefit from the JAEA research reactor III restart, providing a complementary source of DC neutrons. This also reinforces the case for providing a second pulsed neutron source as the demand for neutrons increases. The muon user community has access to three of the four planned beamlines (the innovative H line is in construction and will eventually support the muon g-2 program).

Constraints from the travel restrictions in 2020 led to the development of remote access protocols for users of J-PARC facilities which worked rather well and could provide a template for future user friendly support, in particular for neutron and muon users, with the consequences of increased workload on in-house support staff. This is less feasible for hadron and neutrino users with large international collaborations.

JAEA has focused its plans for ADS R&D development and is now providing accelerator improvements and irradiation facilities which will benefit both the international ADS community and the local J-PARC infrastructure, for example in improved beam stability and in experience in handling highly radioactive wastes.

The laboratory has been in very good hands and has been delivering exciting science under the direction of Dr. N. Saito, with the support of its parent institutions and of the Japanese government. The IAC congratulates the outgoing director for his leadership and vision which placed J-PARC on the world map of science facilities at the forefront of research and innovation.

The IAC welcomes the new director, Dr. T. Kobayashi, and wishes him all the success in continuing the magnificent journey of discovery set forth by his outstanding predecessors.

SUMMARY OF THE RECOMMENDATIONS BY SECTIONS IN THE REPORT

Management:

Recommendation:

- The IAC recommends the laboratory provide a presentation on waste management at J-PARC at its next meeting.

Safety:

Recommendations:

- The IAC recommends continuing to promote and strengthen direct communications links to top level management on matters of safety concerns.
- The IAC recommends continuing to implement systematic training and annual refresher sessions on all safety issues (not just radiation safety).

Accelerators:

Recommendations:

- Continue improving the Machine Protection System. For example, analyse the mechanism leading to recent failure of the Electrostatic Septum in the MR and implement means to avoid or at least minimise the consequences of such a failure in the future.
- Present at the next IAC meeting the plan for recruitment and succession of staff aimed at maintaining a proper level of skills and competencies.
- Secure a large enough inventory of spares (e.g., high power RF vacuum tubes, capacitors for the new power supplies …).
- Plan a solution for cooling the RCS and MR RF amplifiers.
- Plan renovation of aging electronics (e.g., LLRF).
- Schedule enough time when restarting the MR with new power supplies (> 1000 hours) for diagnosing potential weaknesses which might degrade medium/long term reliability.

Particle and Nuclear Physics

Recommendations:

- The primary issue for the science program with the main ring has been the limited funding for main ring operations, which has a strong negative impact on T2K, KOTO, COMET and the nuclear physics program. We urge the laboratory and the funding agencies to work to identify additional operating resources for these exciting science programs.
- Given the foreseen continued pressure on main ring beam time and the uncertainty in the fulfillment of the Hadron Experimental Facility extension, we urge the lab to follow through with workshops to determine, and then advance, the highest priority science program with the slow extracted beam.

Materials and Life Science Experimental Facilities:

Recommendations for MLF:

- The MLF should continue to prioritize stable operations and increasing neutron production hours to support growth in number of experiments and scientific productivity and continue the careful, systematic, stepwise power ramp-up.
- The MLF should always have at least one spare target on hand to minimize the risk does of an extended outage.
- J-PARC should take measures to increase the number of used targets that can be safely stored.
- Ensure that staff have time and are encouraged to engage in outreach and collaborations with top scientists and continue working with the academic and industrial research communities to strengthen research objectives and increase the number of high-quality proposals.
- While publications are generally increasing, the MLF should continue efforts to identify and reduce barriers to turning data into publications.

Recommendations for MUSE:

The IAC recommends making available additional staff with part of their duties assigned to the `instrument scientist' role. Developing a strong and stable muon users community relies on such support from the facility:

- The IAC recommends strengthening the group of MUSE people being responsible for the M1/M2 proton beam line/muon production target. On a medium-term, the IAC recommends that J-PARC manages the safe delivery of proton beam to the muon target by a J-PARC group.

- The IAC strongly recommends that MUSE management establishes new links of MUSE with other organizations to widely support the muon activities and community by increasing the number of staff to keep and enhance the current and future activities.

The IAC considers it urgent that a spare muon target should be constructed as soon as possible. MUSE should work on a spare target with highest priority, and the management should identify the required funding.

The IAC recommends a re-evaluation of the laser systems for USM generation within the next two years and reiterates its recommendation to set up a "laser development team" under the responsibility of J-PARC to ensure long-term stable laser operation for all experiments requesting USM.

MUSE management should clearly articulate the priorities of the various projects. It is also essential to develop a plan for the resources required to run MUSE as a user facility with all beam lines completed.

TEF (Transmutation Facilities):

Recommendations:

- J-PARC should continue to carry out targeted R&D on accelerator driven transmutation in association with the global R&D network on spent nuclear fuel management.

- The IAC supports the establishment of the irradiation facility at J-PARC which is an essential tool to develop the materials not only for the ADS development but also for the fusion and/or fission reactors. It recommends extending the communication with other societies to realize the irradiation facility in J-PARC and establishing a sort of consortium of stakeholders and users community to push the project.

- The IAC recommends getting involved in the OECD/NEA Task Force on Advanced Fuel Cycle and P&T.

INTRODUCTION:

GENERAL STATUS OF THE PROJECT:

The IAC congratulates J-PARC management and staff for the remarkable progress achieved in the very challenging conditions dictated by the COVID-19 pandemic. The complex has been operating most of the time under severe access restrictions yet was able to deliver high intensity beams (600 kW for neutron and muon users, 515 KW for neutrino users and 55.6 kW for hadron users) with superb availability (95.3% for MLF targets and 86.2% for the main ring). Several tests were conducted at the 1 MW level for the MLF and at 60 kW for the MR slow extracted beam with 99.5% extraction efficiency. With the approved funding and laboratory top priority for the MR upgrade (to double the fast extracted beam pulse frequency), everything is in place to meet the design performance in the first few years of the decadal plan as shown by the director.

Users were able to make use of the beams available with a combination of remote access improvements, strong support for in-house staff, sample delivery procedures, etc. and no exposures to the COVID-19 virus were recorded.

The IAC notes with pleasure the recent awards to Professor Ichikawa-san and Nakazawa-san for two high visibility publications on CP violation in neutrino interactions and on evidence for doubly strange hyper-nuclei respectively. Also, the number of press releases continues to increase, promoting the good science emerging from J-PARC.

The decadal plan was discussed: a workshop was held to anticipate what science program will be making full use of the 1 MW power of the MLF and to defend the need for a potential second target station. For the hadron hall, the recent completion of the extracted proton beamline opens up new opportunities in meson studies while allowing the rare decay program to start its first phase with the COMET setup. The longer-term plan is to extend the hadron hall and provide a second production target which should allow for more beamlines to operate concurrently hence improving beam availability.

The fast extraction from the main ring will be dedicated to supporting the running T2K experiment and the approved Hyper-Kamiokande (HK) program scheduled to start around 2027. J-PARC and KEK have placed top priority for the upgrade of the MR power supplies to increase the beam pulses frequency and hence double the proton beam intensity on the neutrino production target. The funding allocation and procurement schedule will allow completion of the upgrade during the scheduled long shutdown of the MR in 2021-22.

The IAC welcomes the MEXT supplementary budget associated with HK project and the improvement to the MR.

Several J-PARC projects have also been included in the MEXT road map and are awaiting future funding:

Muon g-2/EDM, HEF and COMET-II and future 9cycles operation.

The IAC was made aware of the potential long term bottleneck in disposing of the spent mercury targets at the MLF and would recommend that this issue be reviewed further at subsequent IAC meetings, together with presentations of the more global context of radioactive waste disposal policies and procedures at J-PARC.

The impact of the COVID-19 pandemic was presented and the IAC noted the superb effort made by the local staff members to accommodate external users, most notably MLF users. Many improvements to neutron and muon beam access protocols were developed. These will also be beneficial in the long term.

A dedicated group was formed to specifically target research that could be supporting pandemic related topics, like virus, enzyme structure and dynamics, personnel protection material properties, etc. The IAC supports these initiatives and compliments the laboratory for undertaking such a timely effort.

For large international collaborations, travel restrictions are limiting foreigners' on-site access and new modes of operating are being considered. But for example, this may impact the installation schedule for the near detector upgrade of the neutrino on-site complex.

The laboratory has extended the program of communication with the potential user communities, with overseas collaborators and with the general public increasing the visibility of its science portfolio and further opportunities.

A conservative approach to beam delivery has been very successful in providing reliable beams to MLF users. Significant science output has been ramping up. But budget constraints are still severely limiting beam availability for MR users. This has been the case for many years and was compounded with a few unplanned interruptions.

The IAC was briefed on the concerns regarding long term disposal of the MLF target assemblies after operation. This is raising the more comprehensive issue of the general laboratory policy on waste management, more specifically radioactive waste management. The IAC would recommend having a session on this matter at the next meeting of the IAC as part of its mandate for overseeing safety and operation.

Recommendation:

- The IAC recommends the laboratory provide a presentation on waste management at J-PARC at its next meeting.

SAFETY:

The IAC was very pleased to see the number of reported incidents declining. This is the result of considerable effort by management to implement a comprehensive safety culture and systematic safety training for staff, users and contractors. Management has made excellent progress implementing the elements of the safety policy: accident and near miss reporting, training refreshers, work manager training, lesson learned, external contractors mentoring etc.

Each Project must now include a work manager position responsible for safety related matters.

Radiation exposures have been kept low even as beam power delivery was increased substantially while the new protocol implemented for operation during the COVID-19 pandemic has resulted in no lab exposures so far. The laboratory is to be complimented for providing a safe environment for staff and users.

An annual safety day and safety promotion throughout the year contributed to more buy-in from everyone.

Recommendations:

- The IAC recommends continuing to promote and strengthen direct communications links to top level management on matters of safety concerns.
- The IAC recommends continuing to implement systematic training and annual refresher sessions on all safety issues (not just radiation safety).

STATUS OF THE ACCELERATOR SYSTEMS:

Highlights and Observations

Operational performance of the J-PARC accelerators has continued progressing since the IAC meeting in 2019, with new record beam power from RCS and MR (both for slow and fast extraction) and high availability, namely:

- the RCS beam power was brought up to 600 kW in regular operation for MLF with 95% availability,
- beyond 55 kW was delivered with Slow Extraction (SX) by the MR with 86% availability, and an extraction efficiency of 99.5%,
- 515 kW was obtained with Fast Extraction (FX) from the MR, with a total beam loss reduced to 0.8 kW.

The accelerator team is commended for these achievements which result from its continued efforts invested in improving hardware performance and machine tuning in all accelerators. In the context of the COVID-19 pandemic experienced in 2020, this is especially remarkable.

Promising results have also been achieved during test periods, demonstrating convincing progress towards the planned future performance for all users:

- the RCS operated continuously with 94% availability during 38 hours at a beam power of 1 MW. Limitations due to the cooling system of the RF amplifiers were identified.
- the new bending magnets power supplies of the MR were successfully tested with a repetition period of 1.3 s during 50 hours. Current ripple at low frequencies is one tenth of what is observed today and input power variations will be half of today's (30 MVA instead of 60 MVA).

To continue progressing as outlined in the decadal plan, and especially to be capable of maintaining high reliability at increasing power levels during a larger fraction of the year (as will be required when the Hyper-K experiment is on-line), identified weaknesses must be addressed, equipment must be consolidated, and spares inventory must be adequate.

The construction and operation of the J-PARC accelerators were performed with a relatively small, but very skilled group of accelerator scientists and engineers. The availability of such skills and competencies will be crucial in the future as well, when many present members will have retired or moved to other positions. Provided the above conditions are met, and if the upgrades are pursued at the foreseen pace, one can be optimistic in reaching the foreseen performance after a setting-up period.

Recommendations:

- Continue improving the Machine Protection System. For example, analyse the mechanism leading to recent failure of the Electrostatic Septum in the MR and implement means to avoid or at least minimise the consequences of such a failure in the future.
- Present at the next IAC meeting the plan for recruitment and succession of staff aimed at maintaining a proper level of skills and competencies.
- Secure a large enough inventory of spares (e.g., high power RF vacuum tubes, capacitors for the new power supplies …).
- Plan a solution for cooling the RCS and MR RF amplifiers.
- Plan renovation of aging electronics (e.g., LLRF).
- Schedule enough time when restarting the MR with new power supplies (> 1000 hours) for diagnosing potential weaknesses which might degrade medium/long term reliability.

SCIENTIFIC PROGRAMS:

Particle and Nuclear Physics:

Particle Physics:

The J-PARC particle physics program includes the neutrino program, the kaon decay physics programs in the hadron hall and the muon physics program consisting of the COMET experiment under construction in the hadron hall and the new muon g-2 experiment in the muon beam of the MLF facility.

During JFY2020 the main ring (MR) has delivered slow extracted beams with a maximum of 60 kW beam power and an availability of 86% for the hadron program. In this fiscal year, the MR had delivered 1534 kW days to the hadron program by the time of the review. There have been a few incidents that have caused unexpected delays to the MR program. During the unexpected 2019-2020 shutdown, the production target for the hadron experiments was replaced. This new target will enable beam intensities operations above 90 kW.

The laboratory will complete upgrading the MR power supplies by summer 2022. Since the installation will require a long shutdown of the MR program, the laboratory has made a decision to extend current operations for a few more months in order to complete two nuclear physics experiments. They will reserve one cycle of beam operations before the shutdown for the operation of T2K with the Gd-doped Super-Kamiokande.

The new MR power supplies will be essential for the physics program of the planned Hyper-Kamiokande experiment and is a step along the path for the facility to reach its ultimate intensity goals of 1.3 MW in 2028. The MR will be shut down for 10 months until summer 2022. The IAC continues to support these upgrade plans but is concerned by the impact on the ongoing program. At the previous IAC in 2019, we recommended a return to a 6 or 9 months running schedule to fully exploit the planned upgrades.

Neutrino program:

The contribution of J-PARC to understanding neutrino oscillations via the T2K experiment continues to be world leading. T2K had a major publication last year that was cited in the top 10 discoveries of the year by Nature. Many upgrades are planned for the neutrino facility for the upcoming long shutdown period. In addition, the upgrade of the MR power supplies will enable the program to remain competitive throughout the next decade. T2K Near Detector (ND280) upgrades are on-going and are scheduled to be completed in 2022. These include a new SuperFGD and a new TPC. This T2K upgrade was approved by the J-PARC PAC in July 2020.

The upcoming T2K run will be a test of SK-Gadolinium operations at Super-Kamiokande (SK). Gd loading is used to capture thermal neutrons and to tag $\bar{\nu}$e.

T2K published 7 papers in 2020 including an important result that put a "Constraint on the matter–antimatter symmetry-violating phase in neutrino oscillations". (Nature 580 (2020) 7803, 339-344; Nature 583 (2020) 7814, E16 (erratum)). The measurement of long-baseline neutrino and antineutrino oscillations by T2K shows a large increase in the neutrino oscillation probability and is the first indication of CP violation in leptons. T2K sensitivity for δCP will continue to improve following the planned upgrades assuming sufficient running time.

The neutrino program remains a highlight of the J-PARC physics program. KEK proposes to support four months of T2K beam operations per year until the start of HK if possible. The committee again notes that the experiments will need reliable high-power operations with maximal user time and availability for this program to remain world leading.

The Hyper-Kamiokande (HK) has been approved and construction began in 2020. Preparation of the cavern excavation and production of PMTs has started. The 190kt-FV detector is expected to begin operation in 2027 and relies on the upgrade of J-PARC to 1.3 MW. As noted above, these J-PARC upgrades are already on-going.

The KOTO experiment:

The KOTO collaboration recently completed the analysis of the 2016-2018 dataset. With this dataset, KOTO's single event sensitivity (S.E.S) was 7.2×10^{-10}. They observed three candidate events when 1.22 ± 0.6 background events are expected from contamination from $K^{\pm}$ and scattered K_L decays. Their recently submitted publication sets an upper limit of 4.9×10^{-9} for the branching fraction of $K^0_L \rightarrow \pi^0 \nu\bar{\nu}$ at the 90% confidence level (C.L.).

Results from more recent running should have reduced levels of background. Several important upgrades were installed before 2019 data-taking and after the flux of K^+s was measured in May-June 2020 a new charged-particle veto counter was installed in the beam at the upstream edge in February 2021. They are considering new cuts to the 2019-2021 data to extract the incident angle of the photons in order to suppress the background from beam-halo $K_L \rightarrow 2\gamma$.

Sustained stable running with reduced backgrounds could bring KOTO to a result below 10^{-10}. However, significant and stable running with ideal background conditions and 50-100 kW beam power is required for KOTO to approach SM sensitivity (3.0×10^{-11}).

A proposed longer-term upgrade to the experiment (KOTO-II) will require a new K_L beam line and the completion of proposed extension to the hadron hall. The Hadron Hall Extension is in the MEXT roadmap, but funding has not yet been allocated. KOTO-II is estimated to have 100 times better sensitivity than KOTO. They estimate they will be able to observe 60 SM event in 3 years with a 100 kW beam and S/N ratio of ~1. This proposal should be attractive to the international community. The schedule for a completion of the Hadron Hall Extension and the beam line is listed as FY2029 which would set the timeline for the start of any KOTO-II run.

Muon Physics:

COMET:

The COMET experiment will search for coherent neutrino-less conversion of a muon to an electron. The proton beam line construction is in progress and is scheduled to be completed in JFY2021. The construction of the first phase of the experiment with the beam line, the Pion Capture Solenoid and the first part of the Muon Transport Solenoid (COMET-I) is scheduled to be completed in JFY2022. COMET-I will have a target sensitivity less than 10^{-14}. An engineering run is scheduled for FY2022 with a physics run in FY2023. There is competition from the Mu2e experiment at Fermilab which will have greater sensitivity but is currently scheduled to start collecting physics data in 2024.

COMET-II with a target sensitivity of 10^{-16} will require an extension of the muon transport solenoid to handle the higher beam power. The detector will also have a straw-tube tracker and LYSO calorimeter. The R&D for the target needed for operations with higher beam power is under way.

Muon g-2:

The muon g-2 experiment at the MUSE facility in the MLF has made good progress and is ready to receive construction funds when they are available. The collaboration has received a new Grant-in-Aids for 6 years (2020-2025). KEK will request funding for infrastructure and base elements. Although there is competition for the measurement of muon anomalous magnetic moment from the FNAL muon g-2 experiment which will announce their first results soon, this experiment will use an entirely different experimental approach and will have different systematic uncertainties.

Nuclear Physics Program

The physics objectives of the nuclear physics program at J-PARC focus on understanding non-perturbative aspects of Quantum Chromodynamics, the theory of the strong interactions, especially in exploring the strangeness degree of freedom in hadrons and nuclei with the intense kaon beams and the properties of hadrons in the nuclear medium. One significant example of this science that was published in 2020-21 was the identification of a $\overline{K}NN$ bound state through the $K^-+{}^3He$ to Λpn reaction. The quality of the data obtained at J-PARC was sufficiently higher than previous data to have attracted world-wide attention. A second example is the observation of a Ξ^-- ^{14}N Coulomb assisted bound state.

This scientific progress has been accompanied by significant technical progress. Robust production targets able to deal with higher power for the slow extracted beam have been produced and operated at 60 kW beam power. There is increasing confidence that after the long shut down, the slow extraction beam power can be increased to 90 kW approaching the design goal of 100 kW for slow extracted beam. A new high energy beam line is now available to deliver up to 30 GeV proton beams to experiments. The first experiment with this beam line, E16, to measure vector meson properties in nuclei has taken commissioning data.

The laboratory and the user community have been seeking an extension to the Hadron Experimental Facility to add important new capabilities for particle and nuclear physics beams. While this has been included in the Science Council of Japan's master plan for some time it has still not received funding. Over the past two years, the laboratory and the community have re-examined these plans, and identified significant possible cost reductions while retaining important features such as a high-intensity high-resolution dispersion matched beam line (HIHR) and an expanded KOTO2 experiment. The extension would also allow more slow extracted beam experiments to run simultaneously. The lab and the community continue to work to deepen the physics case for the new facility through international workshops. Working groups focusing on the technical designs (HIHR+K1.1 / high-p+K10 / KOTO2) were formed under the user community Hadron Hall User Association.

Funding for main ring operations continues to be the major issue for both the particle and nuclear physics programs in the hadron hall. Interference between fast extraction neutrino physics, slow extraction nuclear and particle physics, and future dedicated COMET muon-electron conversion runs put a priority on efficient use of resources. The IAC support the lab's priorities for the MR upgrade. We appreciate that, following the IAC advice, the lab has brought a number of experiments to completion, and support the 2021 plan to finish two slow extraction experiments (E03 and E42) before the long MR shutdown.

Nuclear and Particle Physics Recommendations

- The primary issue for the science program with the main ring has been the limited funding for main ring operations, which has a strong negative impact on T2K, KOTO, COMET and the nuclear physics program. We urge the laboratory and the funding agencies to work to identify additional operating resources for these exciting science programs.
- Given the foreseen continued pressure on main ring beam time and the uncertainty in the fulfillment of the Hadron Experimental Facility extension, we urge the lab to follow through with workshops to determine, and then advance the highest priority science program with the slow extracted beam.

Materials and Life Science Experimental Facility (MLF):

MLF - Neutrons

The Materials and Life Science Facility (MLF) has the potential to be a world leading research institute. The combination of the proton power on the target, the 25 Hz frame rate, the exceptional design of the moderators, and 20 developing instruments provide the scientific community in Japan and around the world an outstanding resource for neutron-based research. In the past, issues with the mercury target including unanticipated failures have limited the productivity of the MLF. Thus, the IAC was pleased to hear that the operation has been stable at 0.6 MW during the current run year. Target #10 has performed very well allowing the MLF to achieve an impressive availability of 95%. This type of performance is

essential for maximizing the scientific return on the considerable investment Japan has made in neutrons at J-PARC. The IAC applauds this remarkable achievement.

While the new target design is performing admirably, unexpected failures can still occur. To avoid extended unplanned shutdowns, it is important that the MLF always have a spare target on hand and ready for installation. The IAC also notes that space for storing used targets is limited. Thus, it is essential that J-PARC develops the ability to safely store more used targets so as not to limit MLF operations due to the inability to store used targets.

Targets remain a single point-of-failure that could cause an extended outage of the MLF. Thus, the IAC recommends that the MLF continue a conservative approach that prioritizes reliability over power. We note that the excellent design of the target-moderator assembly along with 25 Hz operation already delivers substantially more cold neutrons per pulse at 0.6 MW than the SNS delivers at a power of 1.4 MW.

Recommendations

- The MLF should continue to prioritize stable operations and increasing neutron production hours to support growth in number of experiments and scientific productivity and continue the careful, systematic, stepwise power ramp-up.
- The MLF should always have at least one spare target on hand so minimize the risk of an extended outage
- J-PARC should take measures to increase the number of used targets that can be safely stored.

The IAC again congratulates J-PARC on developing an exceptional suite of neutron instruments that the MLF has made available to the scientific community. It is also notable that more than 1000 scientists used the MLF in each of the past three years. An excellent source which operates reliably, great instruments, and a strong user base are elements necessary for scientific success. It is encouraging that over the last three years, the MLF has produced an average of 200 publications per year. While this is on the low end of the range that one expects for a facility of the quality of the MLF, we expect that it will continue to gradually increase. We also note that the large industrial engagement (25%) will significantly reduce the number of publications (maybe by 50).

MLF and J-PARC leadership have taken steps to promote the scientific utilization of the excellent facility they have developed. The IAC applauds these initiatives. We also note that “solutions” that don’t directly address real problems are likely to distract staff from actions that might improve the situation. Moreover, beginning further initiatives to promote science are likely to be distractions. And although the long-term plan for the MLF must include a second target station, the immediate priority should be on realizing the potential of the considerable investment already made in the MLF.

While the number of publications may currently be on the low end of expectations, the quality of the publications remains good. Of particular note is a recent paper (Nature **567**, 506 (2019)) which

demonstrates a large barocaloric effect in molecular crystals near an orientational order-disorder transition. This work highlights the potential of these "plastic crystals" as refrigerants.

Recommendations

- Ensure that staff have time and are encouraged to engage in outreach and collaborations with top scientists and continue working with the academic and industrial research communities to strengthen research objectives and increase the number of high-quality proposals.
- While publications are generally increasing, the MLF should continue efforts to identify and reduce barriers to turning data into publications.
- While planning for the future of neutrons at J-PARC is important, the MLF should focus most of its attention on exploiting the world-leading capabilities provided by its instrument suite and intense neutron source.

The IAC notes that one issue limiting the number of papers is likely lack of user support after experiments have been completed. We note that the staffing of instruments at the MLF has varied considerably based on instrument ownership. The IAC continues to believe that users should have a similar experience at the MLF and receive similar "aftercare" regardless of the MLF instrument their science requires.

Recommendation

- The IAC strongly believes that all users should have a similar scientific experience at the MLF regardless of the instrument "owner".

The IAC is pleased with the recent restart of the JRR-3 reactor which will provide expanded capacity for neutron scattering in Japan. The proximity of JRR-3 to the MLF may provide a wide range of opportunities to better serve the Japanese neutron community. These might include shared resources such as a common proposal system and/or some common user training, a few shared sample environments, a common instrument development team, etc.

Recommendation

- The IAC encourages the MLF and J-PARC to seek potential synergies with activities at the recently restarted JRR-3 reactor.

COVID-19 has disrupted scientific operations at facilities world-wide. The IAC applauds the MLF for limiting the loss of operating days and pivoting to a complex but seemingly effective combination of in-person and mail-in user experiments. This is resulting in an entirely new way of working which is expected to evolve to a "new normal" as the threat from COVID-19 wanes. This has undoubtedly placed new demands on MLF staff that should be carefully monitored to ensure users receive appropriate assistance regardless of the access model. Staffing levels will need to be adjusted accordingly. Moreover, new processes that will inevitably arise from a modified operational model should be optimized so that staff and users can efficiently and effectively produce science.

Recommendation

- Continue to evaluate the impact of remote access and mail-in measurements on staff workload, scientific productivity, and user engagement as MLF seeks a “new normal of user program”, increasing staffing levels as appropriate.

Materials and Life Science (MUSE Facility):
MUSE Facility:

The IAC is pleased to see the continuing outstanding work of the MUSE team in all fields of its responsibilities, and the increase of permanent staff by two people. The MUSE team overcame the challenges of the COVID-19 pandemic by quickly reorganizing the beam schedule and enabling a mail-in-service and remote control of experiments. This allowed minimizing the loss of beam days, while putting additional load on MUSE staff. IAC acknowledges the very safe and stable operation of the facility at 600 kW proton beam power at an outstanding availability of 95.3%. Another test at 1 MW during a period of 36 h demonstrated that the facility and instruments are well prepared for higher beam power operation.

The IAC highly appreciates the continuing interest from broad scientific communities in muon science at J-PARC, which we attribute to the well-balanced program of MUSE between fundamental physics, materials science, and developing new research directions. These include the muon microscope, new mSR techniques to measure changes of sample properties on a minutes time scale (“transient mSR”), and the negative muon program. The negative muon program is making significant progress, including industrial applications and joint projects of humanities and sciences in non-destructive elemental analysis, and the combination of latest x-ray detector technologies for observations in space with negative muons to develop high-resolution spectroscopy of muonic atoms and “m- 3D non-destructive imaging”.

In the ongoing transition from the construction phase to operational mode, the IAC appreciates the impressive progress in instrumentation for user operation in the D1/D2 and S1 areas, and the first successful test of the new high field (5 Tesla) mSR spectrometer “CYCLOPS” in S1. The IAC is pleased to see the efforts and progress in constructing the S2- and H-lines. These are important steps to start the long-awaited particle physics program in S2 (Mu 1s-2s two-photon spectroscopy) and the MuSEUM and DeeMe experiments in H1 in 2021, and to prepare for the extension of the H-line to start the gm-2 experiment in 2025. Commissioning of the U-line for the generation of ultra-sow muons (USM) is continuing, with detailed studies to improve the transmission of USM. The USM-mSR spectrometer has been commissioned, and the users program at the U-line is expected to start within the next three years.

The Lyman-a laser for generation of USM by laser ionization is making progress, and the energy per pulse has been increased by a factor of two in 2020. The improved laser will be used for USM generation in 2021. Since the generation of USM is of pivotal importance for the muon program at MUSE (USM-mSR, muon microscope, gm-2), IAC is looking forward with great interest to the results of the improved system.

Instead of the Lyman-a laser, the Mu 1s-2s two photon transition could be a promising backup scheme for the generation of USM. The laser for the Mu 1s-2s experiment in the S2 area is currently being developed and will be tested at the end of 2021 in the S2 area.

At the moment, no backup muon target is available after replacing the first rotation target in 2019, which was five years in operation. Unanticipated problems at 1 MW operation may cause a reduction of target lifetime. Failure of the present target risks the entire muon program.

Insufficient manpower for user operation and the laser for USM generation are the most important concerns about the operation and further development of the facility. These pose a risk for the full exploitation of the extraordinarily rich scientific opportunities of muon applications from fundamental to applied/materials science.

Recommendations:

The IAC recommends making available additional staff with part of their duties assigned to the 'instrument scientist' role. Developing a strong and stable muon users community relies on such support from the facility:

- IAC recommends strengthening the group of MUSE people being responsible for the M1/M2 proton beam line/muon production target. On a medium-term, the IAC recommends that J-PARC manages the safe delivery of proton beam to the muon production target by a J-PARC group.
- IAC strongly recommends that MUSE management establishes new links of MUSE with other organizations to widely support the muon activities and community by increasing the number of staff to keep and enhance the current and future activities.

The IAC considers it urgent that a spare muon target should be constructed as soon as possible. MUSE should work on a spare target with highest priority, and the management should guarantee the required funding.

The IAC recommends a re-evaluation of the laser systems for USM generation within the next two years and reiterates its recommendation to set up a "laser development team" under the responsibility of J-PARC to ensure long-term stable laser operation for all experiments requesting USM.

MUSE management should clearly articulate the priorities of the various projects. It is also essential to develop a plan for the resources required to run MUSE as a user facility with all beam lines completed.

Nuclear Transmutation:

The IAC congratulates the team for the progress accomplished despite the constraints due to COVID-19 and notes that the project team has considered the recommendations from the T-TAC & IAC.

The ADS Team is congratulated for the recent start of the OLLOCHI (heavy liquid metal (Pb-Bi) loop experimental) installation and encourages positioning it in the international community for performing complementary material research programs for ADS & HLM community.

The IAC recognizes the collaborative efforts already deployed by J-PARC for the Japanese ADS program with other organizations on the national and international (SCK CEN, KIT, PSI, …) level and further encourages growth in it.

The developed automatic oxygen control system and its validation by dedicated experiments in OLLOCHI loop since the beginning is a good achievement, so is the improvement of the ultra-sonic flow meter performances.

Regarding the work on the LINAC for ADS, the IAC supports the work done to identify a solution for making it possible to shorten the total length of the accelerator and acknowledges the R&D of the single spoke resonator that showed encouraging results

The work on the accelerator reliability, for example implementing the automatic restart procedure in order to reduce the trip duration following a RFQ trip, is quite promising and of value for J-PARC current operation whereas it is a necessity for ADS application.

Under the limited budget situation, the international and domestic collaborations become more important to implement the R&D on ADS. The IAC notes that the R&D on the target and accelerator technologies in J-PARC are world class.

Recommendations:

- J-PARC should continue to carry out targeted R&D on accelerator driven transmutation in association with the global R&D network on spent nuclear fuel management.
- The IAC supports the establishment of the irradiation facility at J-PARC which is an essential tool to develop the materials not only for the ADS development but also for the fusion and/or fission reactors. It recommends extending the communication with other societies to realize the irradiation facility in J-PARC and establishing a sort of consortium of stakeholders and users community to push the project.
- The IAC recommends getting involved in the OECD/NEA Task Force on Advanced Fuel Cycle and P&T.

Institutional Support:

MEXT view of J-PARC:

The IAC was very pleased to hear that MEXT had secured the funding for the main ring power supplies upgrade in the supplementary budget for FY 2020-21. This guaranties that this highest priority project will be completed in the next long shutdown of the main ring. Together with the approval of the Hyper-Kamiokande project, this will position J-PARC to keep a leadership role in neutrino science.

Also, several of the key future projects at J-PARC (muon g-2/EDM, Hadron Hall Extension and COMET-II) identified in its decadal plan have been included in the new 2020 MEXT road map o but will require further funding.

JAEA's view of J-PARC:

The IAC was given an overview of the JAEA program and how J-PARC fits in its overall mandate. The IAC is pleased to see continued support for the J-PARC related activities at a constant level. This allows for adequate planning and for users support which in these difficult circumstances has been crucial in maintaining the community's activities. Moreover, the restart of the JRR-3 reactor offers a complementary DC neutron source for neutron scattering users. The work related to the transmutation program is now better integrated in world activities. This benefits the J-PARC accelerator R&D and offers some needed tools to deal with high level radioactive components (neutron mercury target vessel disposal, for example).

KEK's view of J-PARC:

KEK has a large and diverse users program with activities on the Tsukuba and Tokaimura campuses as well as activities related to the Japanese community participation in international projects like CERN-LHC, CERN-ATLAS, ILC R&D and accelerator R&D. SuperKEK-B and BELLE are now in full data-taking mode supporting a growing international user community.

All KEK institutes (IPNS, IMMS, Accelerator, ARL) are contributing to J-PARC but KEK has struggled to find enough resources to fund substantial beam time delivery to users of the main ring (MR) and to support the condensed matter and particle physics research at MUSE. The MR program's reach potential is limited by beam time. Yet KEK has been quite successful in obtaining the necessary funds for upgrading the MR power supplies and increase its beam power to meet the initial specifications. KEK has given top priority to this program. With the approval of Hyper-Kamiokande which will require the full capability of the MR fast extracted beams, and with COMET operating as a single user of an 8 GeV proton beam, the issue of beam delivery will not go away and must be addressed in the near term.

Conclusions:

After a two year gap and a virtual meeting, the International Review Committee is finding a J-PARC laboratory which has surmounted the difficult period of the COVID-19 pandemic remarkably well and has made considerable progress towards meeting the original design performance and delivering a world class scientific portfolio of publications in a wide range of subjects. This is due to the continuing support from the Japanese government through MEXT, the support of the two main partners (KEK and JAEA) which bring considerable and complementary expertise, a dedicated staff and a strong and diverse user community. Recognizing that an orchestra needs a good conductor, the IAC is congratulating Dr. N. Saito for having led J-PARC via strong leadership, vision, a strong collaborative spirit and drive. The IAC is honored to have been associated with his team.

We welcome Dr. T. Kobayashi as the next director of J-PARC and wish him success in taking over the direction of the laboratory and in getting down to the business of going after gold medals.

Appendix I

Agenda for the International Advisory Committee Meeting of J-PARC in 2021

IAC2021

Thursday 04 March 2021

Connecting to Zoom (20:45-21:00)

Charge to the Committee / Report from the Director (21:00-21:15)

time	title	presenter
21:00	Charge to the Committee / Report from the Director	SAITO, Naohito

Views from Funding Agency and Host Institutes (21:15-21:45)

time	title	presenter
21:15	View from MEXT	HIGUCHI, Shin-ichi
21:25	KEK and J-PARC	HABA, Junji
21:35	JAEA and J-PARC	MIURA, Yukitoshi

Safety (21:45-21:55)

time	title	presenter
21:45	Safety at J-PARC	ISHI, Tetsuro

Accelerator (21:55-22:15)

time	title	presenter
21:55	Progress and Prospects	KINSHO, Michikazu
22:05	A-TAC View of Accelerator Activities	WEI, Jie

Material and Life Science I (22:15-22:35)

time	title	presenter
22:15	Overview of Neutron Facility	OTOMO, Toshiya
22:25	NAC Review	MCGREEVY, Robert

Break (22:35-22:45)

Material and Life Science II (22:45-23:05)

time	title	presenter
22:45	Status of MUSE	SHIMOMURA, Koichiro
22:55	MAC Review	PROKSCHA, Thomas

Particle and Nuclear Physics (23:05-23:25)

time	title	presenter
23:05	Overview of Particle and Nuclear Physics	TOKUSHUKU, Katsuo

23:15	PAC Report	YOSHIDA, Rikutaro

Accelerator Driven Transmutation Research (23:25-23:35)

time	title	presenter
23:25	ADS Project	MAEKAWA, Fujio

Executive Session (closed) (23:35-23:59)

time	title	presenter
23:35	Review and Discussion	

Friday 05 March 2021

Connecting to Zoom (20:45-21:00)

Executive Session (closed) (21:00-23:30)

time	title	presenter
21:00	Review and Discussion, Drafting Recommendations	

Close out (23:30-23:59)

time	title	presenter
23:30	Recommendations	POUTISSOU, Jean-Michel

Appendix II

IAC Committee members for 2021

Jean-Michel Poutissou (TRIUMF) - chair
Thomas Prokscha (PSI)
Jun Sugiyama (CROSS)
Jie Wei (Michigan State University)
Roland Garoby (ESS)
Eckhard Elsen (CERN)
Patricia McBride (Fermilab)
Robert Tribble (BNL)
Donald F. Geesaman (ANL)
Paolo Giubellino (GSI)
Hamid Aït Abderrahim (SCK CEN)
Akira Hasegawa (Tohoku University)
Paul Langan (SNS/ORNL)
Hidetoshi Fukuyama (Tokyo Science U)
Dan Alan Neumann (NIST)
Andrew Dawson Taylor (STFC)
Helmut Schober (ILL)

Appendix III

Charges to IAC2021 from J-PARC by N. Saito, director

- **Evaluate overall performance of J-PARC Center**
  - **Promotion of science with safety**
- **Each facility should have a good balance of user program and facility improvements**
- **Future vision of the facility – J-PARC Decadal Plan**
  - **Actions on pandemic of COVID-19**
- **Review safety activities at J-PARC**
  - **Safety culture is well penetrated through staff and users?**
- **Any suggestions to improve the total performance are welcome. Our concerns include but are not limited to**
  - **Open access for users**
  - **More uniform operation combining KEK, JAEA, and CROSS efforts is critical to further success of MLF**