J-PARC Materials and Life Science Facility Technical Advisory Committee (N-TAC)

Report on the Second Meeting
Held at KEK High Energy Accelerator Research Organisation, Tsukuba Sept. 24 – 26, 2003

Executive Summary and Main Recommendations

Since the first N-TAC meeting the overall design for the target station and supporting facilities has addressed all the major issues. The Committee notes with satisfaction that its recommendations had been taken very seriously and have been dealt with in great detail.

The Committee notes that the Project Team has successfully re-evaluated the replacement and handling procedures and as a consequence has identified options for substantial cost savings by reducing the volume of newly provided storage space for activated or contaminated components. *It is now of prime importance to get approval for the long term use of the substitute space identified*.

The present level of detail in general is appropriate for this stage of the project and has been developed adequately to support procurement of components and systems. While no significant issues have been identified during the present review which would require major redesign, several systems and activities deserve further attention and refinement.

Despite substantial progress in understanding the pitting issue, to which in particular the work of the JAERI members of the International Collaboration made a significant contribution, there still remains considerable uncertainty about the target life. *Apart from recommending that the pressure wave effects mitigation research should continue to be supported, the Committee also feels that the possibility of minor changes to the target design should be investigated, which would avoid the need of dealing with open mercury spills in the case of a failure of the inner target container.*

Some more scrutiny is also recommended regarding remote handling and installation issues, yet this mostly relates to medium or small size components still under development.

While generally pleased with the progress made, the Committee is concerned that the schedule slippage incurred so far mainly due to funding profile issues may not be recoverable, in contrast to the Project's hopes.

A matter of major concern is the reduction of the Linac energy from 400 MeV to 180 MeV as proposed to alleviate budget problems. In the Committee's assessment this will reduce the performance of the MLF by some 60 to 70 %. ***The Committee, therefore, strongly endorses the statement made by the JPARK-SAC that every effort should be made to reverse this decision at the earliest possible point in time.***

1. Introductory remarks

The N-TAC Committee, comprising the members

Dr. Günter S. BAUER (Chair)	Forschungszentrum Juelich GmbH, Germany
Dr. Timothy A. BROOME*	ISIS, Rutherford Appleton Laboratory, UK
Dr. John M. CARPENTER	Argonne National Laboratory, USA
Mr. Hajo HEYCK	Paul Scherrer Institute, CH
Prof. Hiroaki KURISHITA	Tohoku University, Japan
Dr. Thomas J. MCMANAMY	SNS Project Oak Ridge, USA

was invited to hold its second meeting on September 24 to 26, 2003 at KEK, the High Energy Accelerator Research Organisation in Tsukuba, Ibaraki Prefecture.

As before, the Committee felt very well received and preparations by the Project Team were excellent. We wish to express our sincere gratitude to the Project Management and its supporting organizing team for a smooth and effective meeting and for the confidence put in us as an Advisory Team. The presentations on the technical status given were complemented by an informative visit to the construction site at JAERI, Tokai-mura, which demonstrated in an impressive way the rapid progress the Project is making.

The second meeting of N-TAC was called at a point in time, when the Project was already well into the procurement phase. Numerous orders had already been placed in an attempt to keep up with the extremely tight project schedule. As a result the Committee feels that there is little scope left for recommendations of revolutionary significance. We therefore chose to give our general findings primarily in the form of comments and observations and leave it to the Project to draw the right conclusions and decide on possible actions.

We are, on the other hand, extremely pleased to note that the comments and recommendations of the first N-TAC meeting have been studied very thoroughly by the Project Team and, where deemed appropriate, they have been adopted and new designs presented. **The design team is to be congratulated for developing a mature design in a relatively short time from the start of the project and for staying abreast with the overall progress by appropriately prioritising their decisions or leaving enough flexibility for future adoptions where feasible**.

* Dr. T. Broome was unable to attend the meeting; the present documents contains some of the findings, however, which he reported after a one week's visit to JAERI in July 2003.

2. General Comments

The following are general comments the Committee wishes to make regarding the overall facility or progress of the Project without deriving direct recommendations at this stage. **The Project is nevertheless encouraged to draw its own conclusions and react accordingly.** More detailed comments and recommendations are given below.

1. While a clear schedule end date for the project has been set, the Committee was under the impression that acceptance criteria on neutron beam spectral intensity and pulse widths have not yet been defined.

2. Likewise, there will be several items that need to be procured after the end of the Project, funded from operations money. The Committee was unable to judge the implications of this decision, because no operations budget seems to have been formulated as yet.

3. Although the Project is generally very conscious about safety issues, no Preliminary Safety Analysis Report (PSAR) seems to be in place at present to demonstrate in writing that a consistent philosophy has been developed on this issue and is being followed throughout. With the Project well into the procurement phase this is a risky situation by any standard because experience from other project shows consistently that safety issues can have profound effects on the design or, vice versa, safety issues can be eased significantly by appropriate changes in the design. Sometimes consequences of safety measures in one part can have rather far reaching consequences in others. This is why a comprehensive and widely accessible safety report is of great value. Apart from being essential in identifying equipment and design requirements, a PSAR is usually also crucial for getting permission to proceed with the project.

4. Along the same line, the Committee was also alerted by the obvious lack of a unique nomenclature or a unambiguous component identification system, as clearly demonstrated by different speakers using different designations for the same components (at least in their English language presentations). Such a component identification system is not only extremely helpful for the planning team itself, it is almost indispensable in interactions with manufacturers and vendors and, if properly conceived, can be an important tool in the planning of operations and maintenance.

5. Another important tool would be a carefully designed and well maintained parameter list – which seems to be missing. Such a list is of great value in unambiguous communication and interface control and should be easily accessible for everyone on the Project, while the authority to change the list should be very limited.

6. Due to difficulties in the funding profile the schedule has slipped by 1 year, about half of which the Project hopes to recover by clever payment provisions with vendors. The Committee has serious doubts as to whether this will be successful. Also, the early placement of contracts during the design phase

carries a high risk because specifications must usually leave many details open which, once fixed, may cause the vendors to revise their cost estimates.

7. The most worrisome news was the decision to reduce the LINAC energy to 180 MeV from 400 MeV. The Committee cannot verify the Project's estimate of a maximum of 50 % reduction in resulting beam current injected into the synchrotron. In our view this will be more like 60 or 70 %. *Such a reduction in research power is highly deplorable and will have a significant effect on the competitiveness of the neutron source relative to other facilities world wide.* ***The Committee, therefore, strongly endorses the statement made by the J-PARC-SAC that every effort should be made to reverse this decision at the earliest possible point in time.***

3. Observations Concerning the Overall ML-Facility

- The reconfiguration of the target servicing and storage area was the result of careful planning and the reduction of storage space resulted in significant cost savings. ***Getting approval for the use of the proposed alternatives over the required time period is, however, essential***. So far, there seem to be several open questions. A few open questions also remain about the *adequacy* of the storage capability and space for maintenance retained in the MLF building. In particular *TAC would like to draw attention to a risk of underestimating the amount of space required to store and manipulate (maintain) ancillary equipment.* With the new concept it would be helpful to generate a video, accurately scaled in time, to portray and refine the target exchange plan including removal of components from the hot cell and transporting them to their intermediate-term storage positions.

- The Committee feels there is a need to provide an interface between the personnel protection safety system and other systems, such as fire, seismic events, experiments involving materials that are chemically toxic, radiological, biohazardous, explosive or combustible, etc..

- The decision to use AIC for decoupler material had a profound effect on the shielding requirements for the moderator exchange due to the hardness of its emitted gamma-radiation. Although the moderator unit is rather compact, the large size of the reflector plug (already on order) that must be handled with it results in very heavy loads that need to be lifted by the crane in the high bay area. The need to go as high as 130 t in crane capacity is likely to have a cost-driving effect on the whole building. The Committee considers this as one example, where early placement of contracts had a negative overall effect. Otherwise it might have been possible to change the moderator piping in the reflector plug in such a way that only a smaller, inner part of the reflector needs to be handled for moderator exchange (an operation occurring once in six years), making a much lighter shielding cask and hence a less powerful crane possible.

<u>4. Observations and Recommendations Concerning the Cold Moderator Systems</u>

The basic concepts for the moderator/reflector system remain as at the last review, and are well established. These reflect the general aim to emphasize cold neutron applications in the MLF, while JRR-3M carries the burden to provide facilities for thermal- and higher-energy-neutron beam research. Efforts to refine the design of the moderator vessels have succeeded in reducing wall thicknesses and slightly increasing neutron beam intensities. Inclusion of superinsulation in the piping has reduced heat loads on the system; this and other modifications have provided a desirable margin of extra cooling capacity.

While the concept for the nested hydrogen piping lines is attractive, the Committee has concerns about how these will be constructed. The method of fabrication needs to be determined in order to establish feasibility, the final design, and ultimately the cost.

The coupled moderator may be a vapour trap. This makes no difference if the moderator is supercritical hydrogen. If there is any chance that there may be a significant gas phase present, consider reversing the flow direction in the moderator.

Concerning cladding of decoupler and poison plates and the difficulty found so far in obtaining complete bonds, we observe that *HIP bonding is sensitive to surface cleanliness*. Experience indicates that special attention is required on this point.

The refined design of the hydrogen circulating system and revised assumptions as to ortho conversion in the moderator are welcome developments. However, the system still needs further improvement, *in particular, we recommend comparing the o/p converter design with that of ISIS. We recommend as well giving further attention to the estimate of the ortho fraction.*

The effort to refine the method for disconnecting (and reconnecting) water and hydrogen lines at the shield-plug top is commendable, but the current plan seems more complicated than it needs to be. The presence of 7-Be dominates the dose picture, and would be much diminished if the facility included an effective beryllium getter. Experience at SINQ (PSI) in this respect is positive and should be taken advantage of. Given the fact that this operation is planned for 6-year intervals, a more relaxed scheduling may be possible, e.g. allow more time for the operation, simplify the dry-out operation (tritium removal), use a rinsing procedure and simplify the entire plan.

The hydrogen pipe connecting system as it presently stands is a very ingenious design, but is very heavy and difficult to operate under conditions of space restrictions and increased radiation levels. While the Team is aware of the need for simplification, the Committee would, again, like to recommend that the corresponding, proven systems at SINQ and ISIS should be studied carefully.

5. Observations and Recommendations Concerning the Target Systems

5.1 Conceptual and Technical Issues

The new, flat beam profile results in significant load reductions on the target container window, but *feasibility and reliability needs to be reconfirmed with the accelerator team*. The direct heating of the inner flow guide plates is not necessarily a problem, if sufficient flow along the plates can be secured for appropriate cooling. Diagnostic and fast beam trip systems will be required to protect the target and window if it is possible for the accelerators to deliver a sharp gaussian beam profile. The stresses in the target window from a gaussian profile were shown to be very high and the lifetime of the target in these conditions requires study.

While excellent progress was made by the JAERI team in assessing the effects of the pressure waves on the integrity of the target shell and in finding surface treatments that reduce cavitation erosion (see below), it is still not possible to predict in a reliable fashion what the anticipated service life would be under the conditions that will prevail in the MLF-Target. ***Given this fact the Committee is of the opinion that it would be wise to modify the target design in a way that would make failure of the beam window of the primary mercury container an incident without further consequences and covered by the design***. In the Committee's opinion this can be achieved by introducing a containment wall that connects the primary mercury container and the inner shell of the surrounding water cooled shroud at a position some 50 to 60 cm back from the window. This would create an almost fully enclosed space (apart from a helium inlet and outlet to control and monitor the atmosphere in it) which would prevent mercury spills on the target connection apparatus in the event of a window failure. The target could then be removed with the mercury in the interspace (heavy) or could be drained by opening a valve, if a suitable drain pipe is provided – perhaps even using the helium outlet.

The diagnostics proposed to detect a leak of mercury into the interspace between the target vessel and safety hull are a resistance wire and measurement of radioactivity in the helium gas. Detection of radioactivity in the helium is an unambiguous indication of a leak in the target vessel. However, it would be useful to identify which isotopes will give greatest sensitivity. It is possible that the resistance wire detector could fail without a leak so it is *recommended that several (at least three) are installed and a leak is defined by requiring at least two giving positive readings.*

In allowing for the later addition of provision for pressure wave reduction (i.e. injection of gas bubbles) it should be borne in mind that there may be a need to generate the bubbles right next to the beam interaction zone. *Any piping provision made to allow later installation of such a system should, therefore, allow transport of the gas into the target module rather than to the mercury injection pipe only, as in the present design.*

Measurements on the JAERI mercury loop have shown that the rate of erosion of the container, resulting from flowing mercury is small and will not be a life limiting effect for the target. However, these measurements also gave data which predicts the amount of mercury left on the target container after draining. This will lead to high residual dose rates (~1 mSv/h) around the mercury circuit which may have significant implications for the remote handling strategy and waste disposal.

5.2 Effect of Pressure Waves on the Target Container

Since N-TAC1, the JAERI-group has contributed significant progress to the International Collaboration regarding the understanding of cavitation erosion and possible ways of surface protection.

- Extension of the incubation period by various surface hardening treatments: Among 15 surface hardening treatments examined, plasma nitriding seems to be most effective in extending the incubation period.
- Effect of power on pitting damage: It was shown that there exists a threshold of power density against pitting damage for 316SS, which corresponds to about 0.5 MW beam power for the MLF-target.
- Bubble dynamics and effect of frequency on pitting damage: Less pitting is observed at higher pulse repetition rate, which is attributed to the survival of bubbles from one pulse to the next. The effect is more significant for pulses at 60 Hz and 100 Hz than at 25 Hz at which the MLF target will be running. Bubble dynamics simulation to estimate the bubble lifetime under the repeated pulse injection suggest that bubbles expand to 10^4 times their original size and collapse around 14 ms after pulse injection, producing microimpact due to jet emission at collapse. Residual bubbles may act as dampers against the imposed pulses.
- Dependence of incubation period on power, frequency and materials: A semi-empirical equation was derived to estimate the number of pulse cycles in the incubation period that precedes rapid increase of mean depth of erosion (MDE) with pulse number. Together with the 4^{th} power law found for MDE after the end of the incubation period this resulted in a pitting-damage evaluation diagram that relates power density, pulse number and MDE. The concept of a "damage potential" was proposed. A remaining open question is the residual strength of the material after surface erosion has arisen, because micro-cracks were observed at the bottom of several of the larger pits. A meaningful measure of the "residual strength" needs to be defined.

Based on these findings, further work is being prepared:

- Fatigue tests in 4-point bending for hardening-treated 316SS with pitting damage, which is essential to evaluate the lifetime of target vessel. A specially designed fatigue machine that enables fatigue tests to be performed up to 1 kHz in Hg has been installed and testing is now going on.
- Investigation of the effects of irradiation by triple ion beam (Ni^{3+}, H^+, He^+; 200°C) on hardness and microstructural evolutions for Kolsterised and plasma nitriding treated 316SS. Distinct differences in radiation hardening and radiation-induced microstructures between the hardening-treated layer and 316SS with 20 or 50%CW were observed.
- Testing and examination of the effect of imposed stress on pit formation is in preparation by using MIMTM.
- Cavitation intensity monitoring with Laser Doppler vibrometer: Acoustic vibrations are induced by impact forces with high energy density due to bubble collapse, which may allow damage evaluation by measuring acoustic

vibration. This may make the fraction of eroded area or MDE predictable by using the damage potential defined by high-frequency components of acoustic vibrations resulting from localized impacts induced by bubble collapse, regardless of power and frequency.

Recommendations:

The Committee recommends continued support for this research and the International Collaboration it is embedded in. In particular, the JAERI team is encouraged to

- *Conduct microstructural examinations including XRD and TEM to understand the mechanism of the beneficial effects of the plasma nitriding treatments.*
- *Find optimum thickness of the plasma nitriding treated surface layer for SUS316, since extension of the incubation period may depend on the thickness of hardening-treated surface layer. The curve of MDE vs. number of cycles changes slope from hard layer to substrate at steady states of damage formation for 316SS.*
- *Examine the growth behaviour of cracks as a function of the number of pulses to determine where and how main cracks are produced.*
- *Examine whether or not the occurrence of such main cracks is related to surface hardening treatments and the degree of cold working in substrate 316SS*
- *Try to establish the applicability of the damage potential concept to steady states with mass loss.*
- *Try to refine the concept of "Residual Strength" (RS). While it is important to understand whether MDE simply reduces the effective engineering thickness of the wall or has other, further-reaching effects, there is, to date no clue on what the residual engineering strength of a wall with eroded surface would be. It is, therefore, of prime importance to find a method of how to evaluate RS. Perhaps using other, less tedious methods of creating similar surface damage might be an option.*

6. Operational and Remote Handling Issues

The design team has identified the major remote handling tasks and developed maintenance procedures which appear to be realistic and well developed. Full scale mock up tests of the key mercury vessel sealing method have been performed and shown to meet design requirements. Mock up testing of the seal between the target module and the helium vessel have also been performed and shown to meet design requirements. A few comments on details are given below.

The general design concept for replacement and maintenance appears acceptable. Some detailed comments and recommendations are also given below.

The policy regarding entry of personnel into the hot cell requires clarification. The dose rates in the cell could be very high if any mercury is spilt (1 ml mercury gives ~

10 mGy/h at 1 m). In the discussions it was evident that some groups still anticipate that entry into the cell may be possible and some do not assume this.

No design information was presented for the core vessel inserts or the remote handling procedures. These have required a significant effort in the SNS design. Several mock up tests and specialized tooling have been developed. Some of the initial concepts required major changes after the first tests. Water cooling is needed for the inserts and this complicated the design of the system and required special tooling for replacement. The space needed for the tooling affected the layout of the vessel port, studs, and shielding around the ports. The design for theses systems should be well developed and mock up testing performed in time to incorporate hardware changes if they are needed.

The conceived shutter gate insert installation procedure seems to lack some desired features for example, how to align the included guide. There is not yet a lot of energy invested in the shutter insert procedure, so it should be helpful to try it out and go forward on the basis of what is learned.

The Committee was also concerned about the choice of aluminium as material for the 2-m-long shutter insert shell. Fabrication with the necessary precision appears to be difficult and in a tight fit as required to minimize neutron streaming along the path it may also be difficult to slide it into the shutters.

The design analysis for the proton beam window presented showed a lifetime for the aluminium window of over 10 years. The replacement frequency of the proton beam window assembly was at 2 years based on preliminary estimates of the lifetime of the beam diagnostics.

Comments and Recommendations

<u>General</u>

- *It is strongly recommended that the systems be designed so that cell entry is never required. If it turns out that entry is possible even after extended operation this can be considered as a bonus, however, if the opposite was true, it would be a disaster if entry had been assumed to be possible.*

<u>Target Replacement</u>

- *The mock up testing of the mercury seals should continue and include multiple cycles with complete removal and reinsertion of the "target" parts to demonstrate that the sealing surfaces do not become damaged.*
- *Remote adjustment of the linkage to accommodate different target module fabrication tolerances should be demonstrated.*
- *Evaluate methods to reduce the number of bolts needed to attach the Safety Hull since access to them may be difficult on the bottom.*
- *Evaluate removing the drive from the cart used to install the target module. It may be possible to accurately locate the cart with the 20 ton crane with fixed alignment features on the floor of the hot cell and use the target trolley drive to bring the two components together.*

- *The replacement scheme should be developed so that a mercury leak into the helium space can be accommodated within a normal target change out period and does not result in significant contamination of the hot cell or equipment (see above).*
- *The details of the remote handling operations during target replacement for the water lines and other utilities should be developed and included in mock up testing and possibly in video simulations.*
- *The evaluation of off normal events should systematically consider failures of remote handling equipment including the crane and develop recovery methods.*
- *The target replacement time should be evaluated including the time required for configuring other systems, such as the hydrogen system and vessel systems. One week appears optimistic.*

<u>Reflector and Moderator</u>

- *Evaluate allowing a drying period prior to removing the water piping. This may be more efficient and economical overall.*
- *Devise and exercise mockups of all critical work to be done hands on. This should be done early enough so that if changes are needed they can be incorporated.*
- *Evaluate adding features to the reflector plugs to eliminate the need for installing a separate grapple tool.*
- *Ensure that handling in the hot cell can be performed without mercury contamination of the tooling for aluminium assemblies that are to be reused.*

<u>Core Vessel Inserts and Shutter Inserts</u>

- *The precision requirements to the core vessel and shutter inserts need to be defined in a binding document and the manufacturing and the procedures for reproducible alignment should receive more attention and refinement.*
- *Mock up testing of the installation and alignment procedure seems highly desirable.*

<u>Proton beam window</u>

- *Considering the large difference in lifetime estimates for the proton beam window and the diagnostic equipment attached to it we recommend evaluating if there are ways to replace the diagnostics separately or run without them or replace them with simpler, more rugged devices after initial calibrations of other upstream diagnostics. This could reduce the waste storage requirements.*

7. Concluding Remarks

The fast progress made by the Project team in designing and ordering components for the ML-Facility is breathtaking. This, however, required several decisions at an early stage which could not be substantiated by parameter and case studies to the extent that would have been desirable. While most of the educated guesses taken turned out to be valid, there are cases like the late decision to use AlC as decoupler material, whose consequences (in this case the need for an excessively heavy reflector plug shielding and a correspondingly large crane in the high bay area) could have been minimized in a more relaxed schedule situation. The Committee feels a little uneasy about having been informed about this pending decision at its first meeting without realizing immediately what the indirect consequences would be. On the other hand, the long intervals between TAC meetings in such a fast moving project always bear the risk that not all aspects can be assessed in detail. We nevertheless hope that our work will continue to have a positive impact on the Project and would like to thank the Project Management and Team for their openness and confidence.

Jülich, Nov.11, 2003

For the review team

Günter Bauer, chairman