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

Report on the first Meeting held at JAERI-Tokai site on Oct. 28-30, 2002

Final version Dec.17, 2002

Executive Summary and Main Recommendations

The N-TAC Committee, comprising the members

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was asked to hold is first meeting on October 28 to 30 at the Tokai site of JAERI. The Committee was impressed by the amount and quality of work done by the Project Team since Phase 1 of the (now) J-PARC project was approved and by the well thought through overall concept of this endeavour of highest scientific importance. The presentations given to the Committee were of high quality and coherency and covered in great detail the work done by the Team.

The Materials and Life Science facility, which was the subject of the Committee's deliberations is well planned, with a clear vision of the importance of slow neutrons to these rapidly growing fields. The team and its leaders are demonstrating foresight and are fully in line with the other high power spallation source projects world wide adopting a flowing liquid mercury target as their reference concept. They have contributed greatly to the understanding of the problem of pressure wave induced cavitation erosion (pitting) first discovered at JAERI in the present context. The progress made so far towards developing a target container that has promise for satisfactory life time, in particular in the early operating phases of the facility, strengthens confidence that this research will be successful. The work is carried out in a highly effective international collaboration in which the Japanese team has played an important role and will hopefully continue to do so.

The Project Team also is to be commended for the design of their cold moderators, where they decided to take advantage of the superior transmission of para-hydrogen for very cold neutrons. While a similar, non-optimized system has been in use at ISIS for several years, the J-PARC team has, for the first time, embarked on a comprehensive optimization study. Their design holds a promise of combining good slowing down properties (narrow pulse width) with high cold neutron intensity. The suite of three moderators, coupled, decoupled and decoupled and poisoned pays tribute to the fact that, together with JRR-3, the new facility will have to cater to the needs of all neutron users in Japan and beyond.

The design of the facility was well advanced in almost all aspects and much thought had already been given to engineering details at the time of the review. While this made this first review by the present Committee a fascinating and exciting exercise, it also made it difficult to do justice to all aspects presented. Of the comments and recommendations on many details contained the main body of the report, the most important ones are listed below:

Continue active participation in the International Collaboration on High Power Target Development with the goal to find a method to mitigate pressure wave build-up in liquid metal targets under pulsed operating conditions.

Carefully reassess the benefits of a cross flow configuration with a permanently fixed outer shroud for the mercury target system in terms of

- *technical and manufacturing complexity*
- *overall cost and handling*
- *flexibility to incorporate a pressure pulse mitigation system.*

Reassess the required size of the ortho-para hydrogen converter by confirming the anticipated conversion rate in the moderators.

Re-examine the purpose and specifications of the proton beam dump to ensure efficient accelerator commissioning and development without relying too heavily on the mercury target being in service.

Consider making available at least limited funds for instrument planning at the present point in time to fund a few full time scientists for this task. This is important to guarantee that instrumentation needs get sufficient attention in the planning process and the needs of the instruments are fully taken into account in the design of the target station.

Develop procedures and make suitable provisions for recovery from abnormal operating conditions and equipment failure and for post mortem and after service examination of components in order to improve continuously the system performance and availability. All documentation should take this into account.

1. Introductory remarks

The first review of the Materials and Life Sciences Facility (spallation neutron source) of the Joint KEK-JAERI Project now named J-PARC was called for October 28 to 30, 2002 at the Tokai site of JAERI. At this point in time the Project was already well advanced and the Committee was presented with comprehensive documentation on almost all aspects of the design. In many instances considerable engineering detail had already been worked out, which provided clear evidence that the Team is abreast with developments elsewhere and is generating own ideas and concepts at the same time. Despite well prepared documentation the amount of material presented made it sometimes difficult for the Review Team to capture and question all aspects of the Project, in particular since the Team had been working so hard on their presentations that advance information came only as a last minute action, making it almost impossible to work through it ahead of time. Nevertheless the Committee made every effort to comment on as many details of the design as possible. We apologize if something of importance should have escaped our attention and look forward to more in depth reviews of selected items as the Project progresses.

While the Committee was working as a team with everyone paying attention to everything, the structure of the report broadly follows the mandates given to individual committee members: overall issues,- moderator system aspects, - Target system aspects, both with associated materials questions - and finally remote handling and operational issues. We have refrained from distinguishing between findings, comments and recommendations at the present time, because this is largely a matter of personal preferences, but have used italics to highlight points to which we attribute particular weight. This does not mean that the remainder of the comments given should be discarded.

It was a pleasure for all of us to enjoy the hospitality and confidence and openness of the Project Team and Leadership and we wish to express our sincere gratitude for the honour of having been selected to work on this Committee.

2. General Comments

The N-TAC committee congratulates the JSNS team on their rapid progress and excellent results in bringing the Project to its present stage. The Committee is especially impressed that this has been accomplished by a relatively small group ? evidence of hard work, dedication, inspired vision and high technical competence. It is gratifying to observe a motivated team including many young people working together in a wonderful spirit under the competent guidance of experienced leaders as well as evidence of a high level of communication among the presenters. The material presented and the handouts distributed were of very high quality and coherency. The Committee was particularly pleased to observe that KEK and JAERI teams seem to be good complements to one another at working level and have found a way of collaborative task sharing.

The wealth and detail of information presented was so overwhelming that it was difficult for the Committee to follow through all of it with the attention to detail required to track down potential weaknesses.

The Committee noted in particular:

- The design presented for the (now) JPARC 1MW Spallation Source is generally well developed with good technical solutions for all major target station requirements and appears technically feasible.
- Neutronic, structural and thermal analysis were applied to give a solid basis of design for the major components.
- In accordance with a world wide trend towards a growing importance of long wavelength neutrons for the investigation of large structures in materials research and life sciences emphasis has been placed on cold neutron performance. Along these lines innovative features for moderator design have been developed which hold a promise for significant improvements in performance for long wavelength neutrons.
- Well developed neutronic shielding analysis has led to cost optimisation by reducing the amount of machined steel shielding required in the monolith.
- Calculations of induced activity have covered all crucial areas. Some information on validation of the code system used would be helpful and important.
- The design presentations focused on normal operations with little discussion of the design requirements for off-normal events or the level of quality assurance required for the equivalent of safety significant or safety class systems.
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In general, the review material presented did not permit an evaluation of design features for off-normal events or accidents. This may have far reaching consequences as experience shows that the design is often significantly influenced by the requirements for containing and recovering from such events. This should be a prominent subject in future reviews.

3. Observations Concerning the Overall Facility

3.1 Technical Concept

The facility parameters adopted are an excellent and consistent choice and the way that they were arrived at, taking into account the capabilities of the nearby JRR-3M reactor installation, are further tribute to the enlightenment of the project leaders.

The overall configuration of the JPARC facility is a good solution to the problem of reconciling the scientific needs of very diverse user communities with the limitations imposed by the available real estate and cost considerations. Placement of the Materials and Life Science (MLS)-facility inside the 50 GeV ring makes good use of available land, leaving space for additions to the overall facility in Phase 2 of the Project without posing undue restrictions to the length of neutron flight paths. The resulting long 3 GeV p-beam transport line is a cost factor but is technically not beyond existing experience elsewhere. Careful shielding of the 50 GeV PS and associated experimental area will be required though, to make sure that there is no unacceptable effect on the neutron background in the scattering instruments. Particular attention should be given to issues of sky shine. This also applies to the region around the muon target.

Having a muon target and a neutron target in tandem configuration optimizes the use of the p-beam, but makes both targets part of one system. The design should, therefore, advance in parallel. In this sense the Committee is somewhat concerned that the μ-Target design seems to be lagging behind. The operational feasibility of the envisaged concept (edge cooled stationary Graphite target) is not proven and insufficient detail was given to judge its feasibility. Transients associated with scheduled (injection into the 50 GeV-ring) and unscheduled beam interruptions should be studied very carefully. Also, the region between the two targets will be a very high radiation area with significant activation. Comprehensive studies are undertaken to ensure that there is enough shielding to eliminate any risk of background to the neutron instruments from this region, which the Committee supports very strongly. The sky shine considerations for the site boundary may lead to acceptable values there, but this does not automatically guarantee that the background in the neutron scattering experiments is sufficiently low to allow low intensity data taking under undisturbed conditions.

The proton beam dump is being designed for a heat load of 4 kW. This means that high power tuning requires that the spallation target be operational. This may limit the amount of time available for accelerator studies and tuning and so lengthen the time taken to commission the accelerator to full power. *The committee recommends that this decision be discussed thoroughly among all groups involved and that the Project should examine whether some provisions can be made to allow the heat load capability of the beam dump to be increased significantly in the future should that turn out to be necessary.*

With respect to overall issues on the Materials and Life Science Facility the Committee noted the following:

- The proton energy of 3 GeV chosen for the MLS facility allows a moderate beam current and adequate concentration of the neutron production under the moderators. The peak power deposition is moved away from container wall, further reducing the load on this sensitive structure.
- The 25 Hz repetition rate is a good compromise. It gives a sufficiently long frame for long wavelength high resolution work and is well matched to the pulse width from coupled moderators for highest intensity spectrometers. It also allows advanced techniques such as frame multiplication to be applied in reasonable limits.
- The 13 cm wide footprint of the beam on target is almost ideal for a 14 cm Ø para-H2 moderator, ensuring good target-to-moderator neutronic coupling. Yet it still leaves an option for enlarging the beam in case the pitting issue would call for lower power density.
- The design team opted for a large number of neutron beam lines, which results in very close angular spacing between some of the lines. This requires careful instrument planning from the very beginning. It will limit the lateral shield dimensions and may well mean that instrument installation can only be done with beam off.
- In this context the Committee was concerned to learn that currently there is no funding for instruments or instrument planning. Although there seems to be a dedicated team of “volunteers” devoting part of their time to instrument planning, this may not be enough, given the close interdependencies between instrumentation and source layout at pulsed neutron facilities. Facility designers have been instrumental in setting many of the basic specifications

of the facility that will affect the instruments and users, in response to initial ideas of the users. This is excellent and should continue like this. We understand that within about two years, all the details will need to be settled. *This makes continuing close interaction essential, which would be significantly facilitated if a few full time scientists could be funded. The committee was concerned that otherwise this might prevent features of the instruments which affect the target station design from being elaborated, for example the need for choppers in the bulk shield which is not allowed for at present.*

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Special points which caught the Committee's attention are:

- The width of the shutters foreseen is about the same as in use at ISIS, albeit at 6 times lower power. It might be worth while re-checking the dose limits set for the sample positions with the shutters closed (200 µSv/h, which seems high) or, alternatively, verify the efficiency of the shutters for the spectrum to be closed off. Providing supplementary shutters to reduce the dose rates may prove more complex and costly than choosing a more effective main shutter design (i.e. a different material in the section which blocks the beam).
- The lifetime of the mechanical shutter drive system should be evaluated carefully since this may require relatively frequent maintenance for 23 shutters. If it is not acceptable consider a hydraulic system.
- The design of the cranes for work on the target station and experimental areas leaves 'dead' regions near the bulk shield as cranes do not overlap. This may be a problem for chopper handling and beam line installation.
- The water cooled shielding which is between the outer plug and the vessel is currently non-replaceable. The Project should consider developing a concept to allow replacement or ensure sufficient redundancy in the cooling to cope with possible leaking.
- Helium vessel flanges for inserts should be designed to allow remote replacement of the four bolts used for attaching the inserts.
- Forced dry air cooling is foreseen for the target shield. The Committee had some doubts whether this is really necessary. For example SINQ, which operates at comparable power level, does not have such a system. It introduces significant complexity and cost, which might be avoided.
- Proton Beam Window remote handling operations should be demonstrated in a validation test.

3.2 Schedule and integration

The schedule for the whole project is extremely ambitious. It is the understanding of the Committee that this is dictated in part by a funding profile which is beyond the Project's control. This affects the procurement sequence and requires difficult decisions to be made at a very early point, making sure that there remains enough flexibility to adjust to arising needs. Project Management seem to have been able to cope with this difficult management job well so far. However, the Committee anticipates problems to arise if deliveries come in at times when the site is not ready for the installation of the components. Significant amounts of space must be provided for receiving, acceptance testing and storage of parts and components. Simultaneous construction activities on all project units in a rather limited space will require special measures and tight organisation. It is particularly important to ensure adequate testing time and provisions to demonstrate remote handling systems.

3.3 Cost

Although reviewing the cost estimates was not within the Committee's mandate, it is obvious that there are several potential cost drivers which can be identified. Among them are

- The long beam transport line
- The high radiation section between µ- and n-targets
- Remote handling facilities
- Size and foundations of MLS-building
- Required precision of large amounts of steel
- HVAC requirements

Those items need careful analysis and planning and strict management. In particular the sizes of the two instrument halls will be an important issue since this will be a trade-off between cost for the building proper and cost for beam lines extending beyond them.
Attention should also be paid to the cost involved with the present choice of the target design and operating parameters, since they involve a large mass flow and low temperature rise, which is likely to result in high cost.
The TAC-team was not in a position to verify any cost estimates in any detail.

4. Observations and Recommendations Concerning the Cold Moderator Systems

4.1 Conceptual and Technical Issues

The Committee observes that the moderator system design is already highly evolved and well optimized. It displays the broad experience, bright insights, and the extensive computer and experimental efforts of the team and its leaders.

While the system, based on nearly pure para H_2, may not be optimal for all purposes, it certainly serves long wavelength neutron applications well and simplifies operation and control. Moreover, this choice facilitates the moderator design process by exempting the ortho/para ratio from optimization. Furthermore, having provided space for moderator vessels large enough for p-hydrogen operation, the o/p ratio may be subject to refinement at a later time. The three-moderator system as chosen serves the purposes of the facility well and provides highly competitive performance.

The Team carried out a very extensive optimisation study for the moderator-reflector geometry, varying even seemingly less important parameters such as the shape of the moderator top wall facing the target and the side coverage of the cylindrical moderator by reflector material. In this way, by taking advantage of every few percent gain without allowing adverse effects to affect the overall performance they arrived at a set of design parameters which are very likely the absolute optimum under the criteria they adopted (emphasis on long wavelength neutrons and use of established technology).

In this context the Committee notes that a concave shape of the high resolution moderators was found to be superior (advantage not quantified) to the "canteen shaped" one as selected. Depending on the possible gains it may well be worth while to consider coping with some added design and manufacturing difficulties for the concave version. Of course, there should be no sharp edges as shown in the sketches presented.

The hydrogen inventory in the system as presently planned is extremely high and may pose a significant safety problem for a worst case accident. Ways of reducing the inventory should be sought. For example, there is a 5% para-ortho conversion rate in the moderators postulated by the design team, which corresponds to a latent heat of about 1.73kW transported to and released in the converter (ca. half of the total nuclear heat load). This looks like a very high number and the basis for the above postulate should be checked carefully. If this number is high, as it is likely to be, it might be possible to reduce the size of the converter and the hydrogen inventory in the system, which would be a big advantage. *The Committee recommends that the necessary size of the converter be verified by tests and experience at ISIS be accounted for, which indicates that, in their case, a few cm^3 of iron oxide balls is sufficient to make the measured neutron spectrum agree well with the one calculated for 100 % para-hydrogen.*

In this context we also note that the design team uses a very low value for the allowable stress in Al6061-T6, which leads to relatively thick walls. We suspect that this value allows for the weld regions and recommend that the team should evaluate if higher allowable stress can be used for the vessel if the welds are located in intrinsically low stress regions. Here both thermal and pressure-induced stresses in moderator vessels as well as potential requirements for accident scenarios must be accounted for to optimize wall thickness variation in order to minimize neutron attenuation and nuclear heating.

Despite some concerns about activation of this material (see below) it is a good idea to have borrowed for use as a decoupler the AIC material already qualified in reactor experience. The Project should carefully examine the effects of the AIC decoupler on spectra and pulse width as a function of wavelength – the gap in the attenuation between about 0.5 and 1.0 eV may broaden the pulses and introduce anomalies in the pulse width function compared to what is familiar with "1/v" absorbers. This is not to call for a change in the design choice, but rather to point out that these effects should be known to the users and instrument designers.

A supercritical H_2 system as presently favoured is a safe choice in terms of heat removal and operational stability. It may not be necessary, however at the heat loads in question. It requires high operating pressure leading to thick moderator vessels, which are a disadvantage in terms of heat load and neutron performance. While safety considerations for a liquid hydrogen system, may also require extra wall thickness, the Committee was not able to verify that the supercritical hydrogen solution is the optimum one. *The team is encouraged to re-examine this choice in the light of system control requirements and overall complexity.*

Consider the overall moderator flow installation as a control system. Facility designers should set performance requirements and design philosophy (e.g., "dump to atmosphere only at operator's option," vs. "let the system vent when it will"). Have a control system engineer to work with cryogenic system engineer to work out and prove the means to stabilize the defined operating parameters.

Only one circulator is proposed for the hydrogen loop. This gives no redundancy should the circulator fail. It might be wise to make provisions for adding a second one at a later stage.

There appears to be very little margin in the cryogenic cooling system i.e. calculated heat load (5521 W) and output of cooling system (5600 W) are almost the same. On the other hand, the heat leak in the transfer lines, 1 kW, looks very high.

4.2 Materials Choice and Radiation Effects

The moderator vessels will be fabricated from Al base material for neutronic reasons and are estimated to experience irradiation up to 3 to 3.5 dpa before replacement. The main concerns are significant radiation embrittlement with A5053 and a significant decrease in strength due to welding or high temperature heating like HIP with A6061-T6 . In general, radiation embrittlement is very difficult to control, whereas the strength decrease in A6061-T6 can be made less significant by suitable heat treatment (aging), e.g., at 170 – 180°C, which will cause some recovery in strength. In addition, in view of the use of the moderator vessel at very low temperature around 20K and the occurrence of radiation hardening due to radiation induced defects, there will be an appreciable strength increase at such low temperatures. It has been reported for A6061-T6 that irradiation effects on room temperature strength are much more significant in weldments than in the base-metal. It has also been reported that for the weldments of A6061-T6 a ductility increase occurs in the unirradiated conditions, indicating that the amount of allowable DBTT shift by irradiation increases. *At present, therefore, it is reasonable to say that A6061-T6 is a better choice than A5083. The Committee concurs with this choice made by the Project.*

As a decoupler material AIC has been selected, which is used for reactor control absorbers and consists of Ag-15%In (0.5 mm thick) and Ag-35%Cd (2.5 mm thick). AIC is canned with Al alloy to protect it from water corrosion and for support. To remove a high decay heat of AIC, strong bonding between AIC and the Al alloy is required. For the bonding, HIP was applied and a good result was obtained under the condition of 500°C, 100MPa and 60 min for three kinds of heat-treated Al alloys, A5083, A6061 and A7N01. For the latter two Al alloys, a significant decrease in hardness was observed.

As discussed above, A6061-T6 appears to be more suitable than A5083. To suppress the observed strength decrease in A6061-T6 and also expected thermal residual stresses between AIC and Al alloy, *it would be recommended to conduct HIPing at lower temperatures, higher pressures and longer holding time, e.g, 400-450°C, 200MPa and 180 min*. *Atmosphere control during HIPing may be necessary in order to avoid embrittlement.*

In view of the high residual radioactivity of AIC efforts should continue to develop a decoupler material without Ag or with reduced Ag contents.

5. Observations and Recommendations Concerning the Target Systems

5.1 Conceptual and Technical Issues

The Project has opted for a flowing mercury spallation target as first adopted as reference design by the ESS team and subsequently also chosen for the SNS project at ORNL. However, JSNS decided to use a cross flow configuration rather than the flow reversal configuration selected by the other two projects. Some components of the system are already well under way and the designs of the conventional facilities adapting to that concept, are well advanced.

Excellent progress has been made on all aspects of R&D for the target. In particular the committee would highlight the following:

- The finite element and thermal hydraulics design tools have been validated
- The mercury flow distribution was optimised
- Thermal hydraulics of the system have been thoroughly analysed
- Operational safety issues have been identified and addressed
- The target trolley design has been established
- A remote handling concept has been established
- Considerable progress has been made on measurements to quantify and understand the phenomenon of cavitation induced erosion of the target container.

The work on cavitation induced erosion deserves particular attention. The split Hopkinson Pressure Bar experiments at JAERI provided the first indication that cavitation induced by the high pulsed power deposition in the mercury could cause damage (pitting) in the surfaces of the mercury container. This was a crucial observation and resulted in the rapid formation of an international collaboration to investigate the scale of this phenomenon and its importance to the viability of the mercury target concept for high power pulsed spallation sources. The work of this collaboration, in which the JAERI team has been a leading contributor has made significant progress in the last six months including prototypic tests at the WNR facility at Los Alamos (at a low number of pulses) and offline tests at ORNL and JAERI. The JAERI tests have now been extended to 2 x 10^7 pulses using the MIMTM apparatus.

The results of screening tests with the MIMTM apparatus show that the pitting damage formation in SS316-CW is divided into three phases. Homogeneous erosion with significant mass loss occurred in phase 3, the onset of which very likely depends strongly on the load level.

The conclusion from the studies so far is that one material, Kolsterised (a proprietary, commercial surface hardening process) cold worked SS316LN has significantly (up to two orders of magnitude) less damage than other materials tested and that electropolishing of surfaces may also delay the onset of cavitation erosion. It may be assumed that surface hardening treatment is efficient to reduce pitting damage mainly by increasing the threshold cycles for the occurrence of significant erosion: for Kolesterizing treatment, obvious pitting damage was observed only at cycles above 1 million, however, there is indication of significant increase in mean depth of erosion (MDE) and weight loss around 10 million cycles. In all tests evaluated it appears that the MDE increases with the number of cycles to the 1.27th power While it is encouraging to see progress in reducing pitting damage, more work needs to be done before the operational viability of the mercury target can be fully established. This relates to questions such as:

- How representative are out-of-beam tests?
- Does crack formation occur regularly in addition to MDE?. Since the deepest and crack-like eroded area may determine the lifetime of the target vessel, more emphasis should be given to the depth distribution of the eroded area.
- Does the volume in which the pressure build-up occurs have an effect?
- How does any surface treatment stand up to irradiation?
- Can irradiation hardening have a beneficial effect in the bulk material?
- What would be the influence of weld-affected zones?
- What is the effect of additional stress in the walls (from thermal gradients and static pressure)?
- What will be the influence of flow and a less confined system?
- etc.

The Committee therefore recommends that future near term research should focus on the following issues

- *The relationships between proof tests and service conditions must be more accurately established.*
- *The extension of low cycle data to the high cycle regime needs to be verified–tests so far have run in only one instance up to 2 x 10^7 cycles, while 10^8 - 10^9 cycles are necessary for a viable lifetime.*
- *The variation of damage rate with delivered proton pulse energy density (i.e. as a function of pulse pressure) is far from clear and needs to be worked out. So far, a fourth-power-law seems to be the most probable. (This is important because the power deposited by a JSNS proton pulse is two times higher than that for an SNS pulse at 1 MW average power).*
- *The influence of the volume and distance from the walls in which the pressure builds up must be established.*
- *Geometry in general is likely to have a serious effect on the pitting/erosion problem. While we heard only a little about this during the present review, this aspect of the problem should receive both analytical and experimental attention*.
- *In order to improve the resistance of the inside wall of the target vessel to high pressure responsible for pitting formation, it might be useful to fabricate specimens having a multi-layer structure or a thick surface layer consisting of several different layers by coating or cladding technologies and subject them to the MIMTM test up to around 2*10^8 cycles. Please note that beneficial effects were observed for both the cellophane taped area and the hardened surface layer*

The committee would, therefore, like to emphasise that it is crucial that the work of the international collaboration continues. It recommends that the JSNS team continue to play a leading role. ***The ultimate goal of this work should be to***

***develop mitigation techniques for the pressure pulse itself in order to avoid having to protect against its consequences**. Such efforts are pursued in particular by the ESS team and the Committee recommends that the J-PARC team should be actively involved..*

Although there remains limited lead time in which to solve the pitting problem, about five years until proton beam operation followed by a start-up period at low power, *the committee is convinced that the choice of a mercury target remains the correct one of the JSNS.*

The committee has the following comments to make about the current design.

- Mitigation of the pressure pulse build-up may require additional installations, such as a bubble injection and gas recycling system as presently under study. The design team should make allowance for this to the largest possible extent in order to be able to benefit from the result of the work, if successful.
- The cross flow configuration chosen is a relatively simple way of ensuring adequate cooling of the target front face that is directly heated by the proton beam. While the team managed to keep the asymmetries in pressure and temperature distribution in reasonable limits by an elaborate design of flow guides, the required high mass flow (41 m^3/h) results in a very modest temperature increase of only 21K, which, together with the low inlet temperature of 50°C calls for a large and expensive heat exchanger and piping system.
- Attention should be paid to possible erosion problems at the front edges of the flow guides, in particular on the return flow side. Integrity of these blades is crucial for the proper functioning of the system and there is no way to check it during operation.
- The solid beam dump downstream of the Hg-volume was not treated in any detail with respect to internal stress distribution and potential fatigue effects. Attention should be paid to these issues, too.
- Furthermore, the cross flow configuration results in a large and heavy target with wide, flat top and bottom faces. It is not clear that, with the present flow concept there is scope for reducing the target size. However, given that there is a possibility of a variation of up to 20 mm in the centre of the proton beam position the extended lateral size of the target may turn out to be an advantage. Similar considerations hold for an eventual need to increase the beam footprint, if this would turn out to be a way of reducing pressure pulse effects. Nevertheless, the risk of deformation of the target container under the load, in particular of the pressure waves requires special attention to protect against. It is important to make sure that there are no intolerable stress concentrations at the welds joining the vertical flow guides to the top and bottom walls which might lead to fatigue failure. The Project team tried to address some of these issues by providing for a bolt-and-weld connection between the safety hull and the target. This, however generates other difficulties related to target handling, as discussed below.
- *The Committee would also like to recommend reconsidering the use of D_2O for the safety hull cooling. The Committee feel that this creates unnecessary complication and cost for little benefit.*

5.2 Materials for the Target Container and Proton Beam Window

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JPCA-SA and 316F-SA, which are candidate materials for the target vessel, were irradiated in spallation spectra at 80 ~ 400°C to 3.5 – 11.6 dpa and then static tensile tested at RT and 250°C. The test results show that both materials exhibit appreciable ductility at the two test temperatures; approximately 10 and 5 % in STN (strain-to-necking) at RT and 250°C, respectively.

Comparison of tensile data on JPCA-SA and 316F-SA irradiated in SINQ with 316L/304L in LANCE at T_{irr} < 250°C shows that radiation embrittlement depends strongly on test temperature and may be most significant at around 150°C. In addition, comparison of STN after spallation and fission irradiation at T_{irr} < 250°C shows that ductility (STN) loss at around 150°C is appreciably larger in spallation than in fission irradiations. *Since the maximum temperatures to which the target vessel will be exposed are estimated to be under 200°C, it would be recommended to try to obtain tensile data at 100 - 200°C and at spallation relevant He contents.*

For the proton beam window (PBW) material, Inconel-718 has been selected by the Project because of its higher strength than SUS316. An analysis of the maximum stress values accounting for an H_2O pressure of 1 MPa and the thermal stress resulting from energy deposition in the window yielded about 110 MPa and a temperature of approximately 110°C, for 0.5 mm thick IN-718, While these values are acceptable, difficult manufacturing techniques for IN-718 may not allow to produce a 0.5 mm thick PBW with a curved surface. The Project therefore decided to use 1.5 mm thick IN718 for the beam window.

From the point of view of strength requirements, 1.5 mm thick IN-718 appears to be oversized. *Since the PBW should be as thin as possible (have as low a linear mass as possible), to minimize beam scattering, it is recommended*

- *to re-check whether the poorer fabricability of IN-718 indeed does not allow to produce a thinner PBW with curved surface in regard of recent progress of fabrication technologies.*
- *to reconsider the question of using an aluminium alloy for which good experience exists elsewhere and a thickness of 2 mm would probably be sufficient.*
- *to consider a hemispherical shape of the window, which is known as most accommodating to stress.*

In this context the Committee notes that a double walled and water cooled hemispherical proton beam window separating the accelerator vacuum from the target coolant (heavy water) has been in use for many years at SINQ. The peak current density is about 20 µA/cm^2 ,which is more than what has been specified for and the JSNS (10 µA/cm^2 at the target; the value at the PBW is not exactly known, but may be slightly higher). This window is made of AlMg3 alloy and the latest one has been exposed to a total of 10 Ah over a period of two years. While post irradiation examination is still in progress, the fact that no failure occurred is strong proof for the wisdom behind this choice. Using a light aluminium base alloy rather than a much heavier steel has several advantages:

- less heat generation and hence better coolability
- better heat conductivity and hence much smaller thermal stress

- less beam scattering and hence less activation of the environment
- less radioactivity and hence easier handling
- little or no manufacturing problems

Most of these advantages will persist even if the thickness of the window has to be chosen higher than in the case of steel, and the fact that practical experience exists is a strong argument.
The Committee therefore recommends that the Project team should seriously consider to take advantage of this experience and should obtain pertinent information from the SINQ operating team before deciding definitively on their PBW material.

Comparing experience with radiation embrittlement in AlMg3 and IN718, the following may be said: Post irradiation examination of two beam windows that were in use at Los Alamos (IN718) and at SINQ (AlMg3) showed that

- The beam window of IN718 used at Los Alamos had zero ductility after having been exposed to roughly $5*10^{25}$ p/m^2 with 4% ductility left after $2.5*10^{25}$p/m^2.
- The beam window of AlMg3 used at SINQ Target 3 still had 7% ductility after $3x10^{25}$ p/m^2 . The one used in Target 4 survived $4.5*10^{25}$ p/m^2 but has not yet been examined.

This shows that from a radiation damage point of view IN718 is certainly not superior to AlMg3, while AlMg3 can be designed to produce less proton beam scattering and is much easier to manufacture.

5.3 Comments relating to the Alternative of a Solid Water Cooled Target

An outline design of a solid water cooled target had been performed. Given that the viability of the mercury target concept has not yet been fully confirmed the committee supports this effort with the following comments:

- Tantalum is not a practical target material due to the high afterheat and consequent complexity required in the cooling system design necessary to provide a safe system in the event of a loss of coolant accident.
- Tungsten plate target has good neutronic performance, the afterheat may be just acceptable but there is a need to clad the tungsten to prevent corrosion by the cooling water.
- With the present goal of 1 MW proton beam power delivered in short pulses at 25 Hz, a D_2O-cooled, clad tungsten plate target might perhaps serve as well as a mercury target.
- The concept appears viable if required but considerable R&D would be needed to produce a fully practical design.
- Going for a solid target, even as a commissioning target, has far reaching consequences and it will be difficult, costly and time consuming to revert from this decision at a later stage.
- The waste stream the Project has to gear up for is completely different from that for a liquid target. This concerns the target itself as well as filters and ion exchangers in the cooling water loop.

- Proton beam powers much above 1 MW present a considerable challenge for the design of a solid, water cooled target and so use of a solid target may well limit future upgrades in proton power.

Thus, *a liquid metal target is the "Target concept of the future" a characterisation given at the review, which the committee endorses*.

6. Operational and Remote Handling Issues

6.1 Remote handling for the mercury target systems

The concept for changing the target has been thought out in some detail. The Committee is concerned that some of the crucial operations have to be carried out with almost no view of the tool operation. The most notable and serious example is undoing the nuts to release the target. The space for this operation is very limited with no direct sight possible and if there are difficulties then it will be almost impossible to diagnose the problem. This is, in part, a direct consequence of the permanent fixtures between the target hull and the outer shroud. The latter cannot be removed independently to facilitate access to the target flange. Furthermore, the flange is not accessible for leak testing, an operation that is difficult to carry out remotely to begin with. Since the flange connection is not made through direct tightening of bolts, but by means of a link system working in a similar way as some mechanical car jacks, the only control over the tightness of the system is through the stiffness of a compressible body (bellows) between the two flanges. While such a system may be all right for vacuum connections where the outer pressure will work to tighten the seal, the Committee has doubts whether adequate tightness can be guaranteed under internal pressure and with very limited alignment control possible in the given situation.

The Committee notes that the Project team is in the process of manufacturing functional models for the flange connections involved to verify their viability in early mock-up test. *It recommends that these tests be carried out under the most realistic conditions possible (i.e. with remote handling and representative load and pressure levels) and assembled as a unit. The time frame for these tests should be such that it is still possible to reconsider the design and handling procedure for the target module, if serious difficulties are encountered.*

Another consequence of this permanent fixture between the target hull and the outer shroud is the need for bellows in the Hg-piping on the target side of the flange to compensate for thermal expansion. Apart from being a weak point in the loop this is a likely source of mercury spills and spreading of contamination, because there will always be mercury trapped in these bellows when the system must be opened.

As a general thought, it might be worth while to have a section of the mercury piping which can be cooled below the freezing point of mercury and then valved off. This might act as a cold trap before the mercury loop is opened and might help to greatly reduce the risk of mercury release to the atmosphere,

The Committee also has concerns about the sealing between the atmosphere surrounding the Target-Moderator-Reflector (TMR) module and the hot cell. This seal is at a location of only 1.8 m from the target and is tightened by correct positioning of the trolley, whose positioning accuracy is given as ±1 mm and whose length will vary due to thermal expansion and contraction. The Committee feels that, in order for this seal to be tight and to remain so also in the event of an overpressure in the TMR atmosphere active pushing with sustained force of the target trolley against the fixed flange is necessary, but it could not find out how this would be accomplished.

It might be a good idea for the Project to consider developing a system with precise self aligning features for fine alignment of the target to the vessel port. Having a feedback system to verify correct positioning might also be very helpful.

An important topic which was not covered in the presentations or supporting materials was the plan for servicing the components of the mercury cooling loop. This must be considered carefully since it may have far reaching design implications.

Limited personnel access to the Remote Handling Cell (RHC) for replacement and repair of equipment is highly desirable. This depends on the dose levels in the cell during shutdown, which result from direct radiation from the loop components and from activation of the surroundings by delayed neutrons and nuclear photo effect. *Shielding of the mercury loop should therefore be considered to reduce dose rates both during normal operation and during target change or maintenance procedures*.

With the present concept several operations require equipment to be placed in front of the target cart. Failure of equipment in this position does complicate recovery action as it prevents the target cart from being moved.

Some vulnerable operations are listed below. This list is meant to be illustrative not exhaustive.

- Movement of cask transportation truck - it is inaccessible under the target should the drive fail and a failure will block target cart.
- Crane failure when rotating target storage cask.
- Failure of power manipulator positioning controls when attached to target pipe flange bolt.

Other possible problems that need attention are:

- Recovery from damaged threads
- Failure of target storage cask lid lock
- Damage to instrumentation connectors
- Distortion of mercury flow pipes
- Leak testing.

These are examples of why the committee recommends a detailed study of possible equipment failures and recovery procedures.

The Committee also is of the opinion that it is important to carry out post mortem analysis of failed components and to examine certain parts, in particular the target module, after their rated service time in order to improve continuously the performance and availability of the facility. Concepts and procedures for such examinations may affect the design of the parts as well as the need for tooling and should be worked out early on.

6.2 Remote Handling of Reflector and Moderators

Most general comments given about the target change also apply to moderator changes. The scheme presented did not include details of other pipework such as water and instrumentation lines. Their presence is a considerable complication which needs careful study.

The dose rate above the reflector plug is predicted to be < 100 µSv/h where connections are expected to be made hands on. To provide contingency these connectors should be designed to allow remote work just in case dose rates turn out to be high. A portable manipulator system could then be employed at a later date if necessary.

As with the target change some vulnerable operations were identified.

- Failure of rotating mechanism supporting the reflector module.
- Failure to attach the gripper to the module in the RHC.
- Failure to disengage the gripper when assembly is being replaced.
- Failure of winch during removal or replacement of reflector plug.

As with the comments on the target change this is not a complete list but illustrates the need for careful analysis.

6.3 Remote Handling, General

Most of the remote handling procedures described rely on accurate alignment of large equipment and robots. This leaves little flexibility to deal with difficulties. It requires high accuracy in the manufacture of replacement assemblies together with sophisticated mock up and checking equipment.

The committee is concerned to ensure that the consequences of failure of the remote handling equipment receive sufficient priority. It is the experience in other facilities that the possibility of failure of such equipment and the required recovery procedures is a driving force in the design process.

The circumstances in which personnel entry into the RHC is envisaged need to be established together with the procedures and conditions for entry. Entry may not be possible in certain circumstances and this could have a large influence on practical procedures to recover from an equipment failure as, in this case, the recovery would have to be done entirely remotely.

All remote handling described will take place in the integrated hot cells. The Committee is of the opinion that the target handling cell can only be used when the proton beam is off. Ideally the reflector handling room should be available when beam is on. Otherwise the work to refurbish components limits the amount of operating time available for the user programme. The use of other hot cells at JAERI should be considered for certain manipulations. We have, for example, not heard about repair of defective beam line components. Also, it may be unwise to carry out certain sample removal operations in the RHC.

Good access through the RHC roof should be assured. At present only one hatch is foreseen in a position that would not allow to access equipment at the front of the retracted target trolley with the High Bay crane in case of a failure.

Mercury spillage is likely to occur to some degree. This will contaminate the tooling and is also very likely to contaminate the outside of the target storage cask and cask transportation cart. Given the use of aluminium components in the moderator - reflector assembly it is very important to keep mercury out of the reflector handling cell. Procedures for control of contamination are required. The committee is concerned that without rigorous procedures in place contamination will spread throughout the hot cells and the irradiated components storage facility. This would lead to high dose rates to operating staff and a significant risk of transferring contamination outside the Target Station areas.
It might be a good idea to consider adding a glovebox for maintenance on mercury contaminated through-the-wall manipulators.

Thus the committee recommends that:

Detailed procedures be written and a full risk analysis performed so that:

- *The consequences of all equipment failures are defined.*
- *The probability of all failures is estimated.*
- *Recovery procedures from all failures are defined.*

Concepts be developed for:

- *Leak testing of all joints on the target and cart,*
- *Retrieving irradiation samples from the target,*
- *Maintenance of contaminated manipulator arms and other RHC equipment,*
- *Confining potential mercury contamination to the target remote handling cell,*
- *Easy replacement of basic RHC equipment such as lights and cameras,*
- *Conditioning old targets or moderators for disposal.*

For each major system the Project should have documentation of the design requirements to include safety functions and off normal operations.