Dear Dr. Hurd and members of the NPDG LH2 safety committee:

This is our first response to the report of the 2nd NPDG LH2 target safety review.
Our collaboration is very satisfied to the professionalism, dedication, and commitment of the Committee. The NPDG collaboration is determined to construct and operate an absolutely safe LH2 target at the Lujan Center. Our determination to have the most optimal and safe LH2 target is demonstrated by the steps that the collaboration has already taken; we have had two separate independent engineering analysis of the target cryostat design – conceptual and final - we have gone through already two target safety reviews. The first review was for the conceptual safety of the target and the 2nd review focused to the final design of the target cryostat. There will be the 3rd review that will deal with facility interface and target operational safety issues.

Below please find our first response to the report of the 2nd NPDG LH2 review. We have chosen to respond first in general terms, with a more detailed response to follow.
We have included the full text of the committee report and responded to each issue as it is raised in the report. Our responses are in **boldface.**

Mike Snow
Hermann Nann
Bill Lozowski
Mike Gericke
Igor Kuznetsov
Seppo Penttila

AGENDA AND DESCRIPTION OF SYSTEM

The committee met at the Indiana University Cyclotron Facility (IUCF), Bloomington, Indiana, on December 4-5, 2001. The charge to the committee was given by the LANSCE-12 Group Leader, Alan Hurd:

The Committee is asked to report to the LANSCE-12 group leader, Alan Hurd.
The Committee is asked to;

- Provide an independent review of the hydrogen safety aspects of the Liquid Hydrogen Target System of the np->dγ experiment on flight path 12 at LANSCE with priorities of protecting people (highest), protecting equipment and providing reliable operation.
- Provide an overall assessment of and recommendations for improvement of proposed hardware, procedures and facilities, including such aspects as design, controls, instrumentation, interlocks, safety systems, ease of operation and reliability.
- Review a list of possible failures and comment whether each is adequately represented and consequences correctly assessed, if the proposed mitigation method is adequate, if there is a better mitigation method, and if any failures have been overlooked.
- Comment on whether all physical phenomena or physical behaviors with significant safety or operational consequences had been adequately considered.

- Comment on any other safety or operational issues observed.

The committee members were:

- James Knudson, LANL LANSCE-7, Chair
- James Kilmer, Fermi National Laboratory
- Trevor Lucas, Oak Ridge National Laboratory
- Mike Seely, Jefferson National Laboratory
- William Schneider, retired, formerly with Brookhaven and Jefferson National Laboratories

Indiana University faculty, staff and students present:

- Mike Snow, IU Physics Department faculty
- Hermann Nann, IU Physics Department faculty
- Igor Kusnetsov, IUCF postdoctoral fellow
- Bill Lozowski, IUCF staff, target expert
- Mike Gericke, IU Physics Department graduate student

Los Alamos facility staff present:

- Dan Seely, LANL LANSCE-FM, TA-53 Facility Manager
- Roger Klaffky, LANL LANSCE-12, Lujan Facility Experimental Area Manager
- Seppo Penttilä, LANL P-23, NPDGamma Project Manager
- Jeff Schinkel, LANL P-23, Group Safety Officer
- Jan Novak, retired from LANL, Laboratory consultant for cryogenics

The meeting began with welcoming remarks by IUCF director John Cameron, who discussed the changes occurring to that facility as a result of the conversion of IUCF from an NSF facility to a state-supported medical treatment facility. This change has opened other opportunities and facilitated experiments at other facilities in user mode; hence the participation of the IU team in NPDGamma.

The review began with presentations of the present status of the $\vec{n}p \rightarrow d\gamma$ experiment, NPDGamma, the requirements and limitations placed on the target by the needs of the experiment, facility requirements, target safety and design, and details of the design of several safety-related components of the target.

Seppo Penttilä, the Project Manager for NPDGamma, described the present status of the experiment. The collaboration was scheduled beam time during Fall 2001 to develop beam monitoring equipment, the neutron spin flipper, and the CsI detector. This work has been progressing satisfactorily. The collaboration expects to begin work on building the shielding enclosure beginning January 2002, with target fabrication beginning at about the same time. The plan for commissioning the target in Los Alamos calls for this to happen in May 2003. At the request of the DOE, the collaboration is implementing full project management for the construction and operation of the experiment.

The design goals for the target were given by Mike Snow of IUCF. In order to meet the physics goals of the experiment, the target must:

- Capture >50% of the incident neutrons while shielding the gamma detectors (this implies a low-Z target)
- Maintain the neutron spin
- Introduce no systematic effects from polarized-neutron capture on other materials present
- Introduce no noise effects above $\sqrt{N_\gamma}$ from fluctuations in target pressure, temperature or density (implies that bubbles must be suppressed)
- Minimize the magnetic interactions between the target and the polarized neutrons that could affect the overall level of polarization
- Be safe and reliable to operate

SUMMARY OF REVIEW FINDINGS

The sense of the committee is that the basic target design concept is sound and that the target would work as proposed by the collaboration and would likely meet the criteria required of the experiment. A number of details are still to be worked out, and the committee should be consulted when all of the final decisions have been made. With the basic design under control, the committee was able to put a significant emphasis on operational considerations for this target; where it was generally felt that the most likely source of difficulty that will arise from the operation of this target will be from operator error. No other significant failure modes were identified by the committee.

First and foremost, the committee agrees that a quality assurance (QA) plan should be established as required by the management plan being implemented. The QA program will need to meet the requirements of the relevant DOE orders while ensuring that the resulting system also meets the intent of the electrical and fire codes, and ANSI B31.3 for the system piping. The committee requests that the designers provide a statement describing how the various vessels will meet the intent of the ASME pressure vessel Code standards along with LANL requirements.

Response: the QA issue is very important part of our planning and covers a broad range of issues starting from the facility authorization basis down to detailed planning of the target testing. The QA Plan is in preparation. We have made significant progress in assembling documentation for this QA plan through the construction of our NPDG LH2 Target Engineering Document (TED), where the full QA Plan will be presented. The TED contains all design information and technical documentation for the target.

The vessels will meet the intent of the ASME pressure vessel code by designing all vessels to ASME requirements, by constructing the target using approved welders, by radiographing welds and certifying all materials used, and by pressure testing at IUCF. In the TED we will have at the end of every section that deals with different target vessels, a summary chapter that explains how the ASME code is met and if there is any exceptions to the Code. When the we have the QA Plan it will be sent to the Committee for approval.

RECOMMENDATIONS FOR THE TARGET DESIGN

1. Operational considerations:

A number of issues arose regarding target operations that the committee felt the need to comment about:

- The committee was concerned that the presence of the 10 kW heater called for in the present design is a potential source of trouble. It is intended to assist in the rapid venting of hydrogen in the event of an abnormal situation, but the (conservative) calculations of the design team indicate that there is little benefit to be gained in turning on this heater over such other solutions as spoiling the insulating vacuum or simply turning off the cryo-coolers. The committee viewed the consequences of an unplanned or inadvertent activation of this heater while the target flask is empty, causing severe damage to the vessels, to outweigh the small benefit gained in the venting scenario. The committee recommends that the design team investigate alternative methods of initiating the rapid vent.

Response: We are not going to install the 10kW heater. Instead we plan to implement rapid venting of the target by turning off the refrigerators and introducing a controlled amount of dry nitrogen gas into the main vacuum chamber. The nitrogen will transfer heat efficiently from the target to the outside environment through both the thermal conduction of the gas and also the latent heat of the nitrogen liquid-gas phase transition. We are performing an estimate of the expected time for target venting. The venting method will be thoroughly tested and results recoded. The design and test results will be sent to the Committee for approval.

- While some members of the committee have successfully operated sub-atmospheric cryogenic systems, no one was aware of a hydrogen target being operated in this fashion. To the best of the committee's understanding the sub-atmospheric operating principle presented did not appear to work. It was the committee's conclusion that operating at less than one atmosphere invites a host of difficulties should leaks develop, despite the large size of the proposed vent lines. The committee recommends that the target philosophy be modified so that the target operates at greater than 1.25 bar rather than at sub-atmospheric pressures, and that the collaboration give a clear explanation of the operating principles involved. If the return line from the target is returned to the main manifold at a point below the gas feed/vent connection, the liquid will subcool and a small heater can be used to control its operating temperature. With subcooling of about 4K, boiling in the target is unlikely and the outer refrigerated radiation shield should no longer be required.

Response: We plan to implement this recommendation by simply filling the target and the entrance and exit lines until the liquid-gas phase boundary is located in an area where the vapor pressure is 1.25 bar. This can be done with minimal changes in the design of the target piping.

On the question of whether or not the radiation shield/second refrigerator is still needed: we are performing new heat flux estimates for this changed configuration to make sure that we can still cool the target with the increase in the heat leak due to the higher liquid level in the fill and vent tubes. The second refrigerator may still be required for this reason.

The final design and test results will be sent to the Committee for approval.

- Considerable discussion revolved around the possibility of using a storage tank to contain the charge of hydrogen, rather than relying on a manifold and rack of up to six hydrogen bottles. Given the expected 48-hour cooldown time to fill this target, it was felt that a storage tank would be advantageous in that bottle changes at all hours would be eliminated, and, given a clean tank, that overall cleanliness of the charge could be better maintained. Recognizing that some serious logistical details would need to be worked out, the committee recommends that the use of a storage tank large enough to contain the entire hydrogen inventory be investigated. The inclusion of such a tank would have consequences on other parts of the system, and perhaps also other parts of the Lujan facility, that would have to be thought through. Additionally, the committee suggests that a warm buffer or ballast tank would ease the cooldown process by smoothing out the fast pressure transients that would likely occur during cooldown.

Response: We have looked into the possibility of using a storage tank at LANL. We have such a tank at IUCF that has been cleaned internally. The problem is that the size of the target (20 liquid liters) means that the volume of gas at room temperature is very large compared to the size of high pressure gas bottles, and any compressor that is added to make the use of a smaller container possible will add another possible failure point in the system. Furthermore, any such system has to be located outside the ER-2 area 40-50 yards away from the target , and therefore the use of either gas bottles or a dump tank will require long lines - the dump tank requires also a six inch diameter line - from outside the building to the experimental area. We are still evaluating this concept. The issue has been also introduced to the Facility Management and to the fire marshal.

The final design and conclusions will be sent to the Committee for approval.

After the safety meeting, we have become aware of the existence of commercially-available hydrogen gas generators which produce hydrogen gas at the pressures, flow rates, and purities required for filling the target. These gas generators produce hydrogen by electrolysis from deionized water and are compact, automatic devices which incorporate a palladium leak purifier which we had proposed to include on the gas handling system. The use of such a system would simplify both the gas handling system design and the connection between hydrogen source and experiment location, which could be shortened substantially thereby reducing the risks associated with a long high-pressure hydrogen gas line in ER2. We are therefore redesigning the gas handling system to incorporate this element into the design. If the hydrogen generator will be our solution for the target hydrogen supply, we will initiate a change process as defined in this report.

2. Relief setpoints:

The committee and the design team spent a significant amount of time discussing the choice of set points for the relief valves on the both the hydrogen flask and the helium jacket. These settings appear to be far above the operating pressure, be it either less than or greater than one atmosphere, and are greater than the crush pressure of the vacuum jacket. Recognizing that the final settings could be affected by whether or not a storage tank is chosen, the committee wishes to see a thorough description of the philosophy and rationale behind the eventual relief valve settings. The committee recommends that relief valve pressure settings be included with the piping schematics so that values will be unambiguous.

Response: This will be done. A detailed gas handling schematic along with the operating pressures and set points will be provided to the committee.

3. Vent line sizing:

The size of the hydrogen vent line was one topic revisited by the committee in its concluding discussions. This discussion is also a consequence of the lack of understanding on the committee's part concerning the basic principles of operation proposed. It was not immediately clear that venting hydrogen would warm sufficiently to be buoyant when it reaches the end of the vent stack. Clearly the design team needs to perform new calculations of the vent line conductance once the vent line design is finalized. The committee recommends that the design team review the size of the vent line considering the following points concerning the cold gas in the line;

- The ortho-hydrogen to para-hydrogen ratio of recondensing gas may be sufficiently changed from the target liquid as to make maintaining the desired ortho/para ratio difficult. However, operating the system with sub-cooled liquid, as suggested, would improve control of the ortho/para ratio since the constant body of fluid is not required to condense and re-condense.

- The heat leak back into the target flask needs to be of manageable proportions.

Response: We are looking into how to ensure that the gas close to the end of the vent stack continues to exit instead of sinking back down the pipe. This may involve the use of heaters in the upper areas of the vent pipe.

The final design will be provided to the Committee for approval.

We estimate that, in the absence of a strong catalyst for that portion of the recondensing hydrogen located in regions whose temperature is larger than 17K, there will be negligible back-conversion of para to ortho. The ortho-para catalyst will be held at a temperature of 17K and so the o-p ratio will eventually equilibrate to a value appropriate for this temperature. Once the hydrogen has been converted to para in the catalyst, the rate of back-conversion in the absence of a catalysy is very low.

We are reestimating the heat leak of the exit tube on the target for the proposed 1.25 bar operating conditions.

5. Pressure vessels:

Significant work remains to be done on the design of the hydrogen pressure vessel. The committee is satisfied that the present plan of bolting the upstream/downstream dome to the aluminum body of the vessel will work, and is also satisfied with the progress made at correcting the deficiencies with the entrance head pointed out by the analysis performed by ARES Corporation. The design team is encouraged to review the stiffening around the penetrations into the vessel for the fill and vent lines. The committee would like to see more analysis of the entire vessel, including the interactions between the vessel and its supports, the flange designs and of the outer vessels as well. The committee agrees with the design team that the transfer of the target to Los Alamos should be done with the target disassembled and properly packed. The design team is encouraged to perform a vibration analysis of the components during shipping to preclude damage.

Response: The ARES analysis not only pointed out stress concentrations in the first vessel design but also specified a design and an assembly procedure that would remove these stress concentrations and allow the vessel to meet the safety requirements. We therefore propose to construct the vessel following exactly the ARES recommendations and then proceed to testing.
The final design of the vessels and the final analysis results will be provided to the Committee for approval.

The target will rest on low thermal conductivity plastic inserts in such a way that it is free to move relative to the radiation shields and the main vacuum vessel. Furthermore the fill and vent lines of the target will include a section with flexible tubing to eliminate stresses due to differential thermal contraction.

Stiffening rings will be added to the outer vessel using the Code-approved calculational procedure.

The final design of the target support and couplings will be provided to the Committee for approval.

The target will certainly be shipped in separate pieces for assembly at LANL.

6. Testing:

The committee was concerned that the testing plan for the target is not complete. It does, however support the present idea that testing with inert liquid be done at IUCF in order to debug the gas handling system before everything is shipped to Los Alamos for final testing with hydrogen. The committee requests the opportunity to review the testing plan prior to implementation.

Response: We will certainly present the details of the testing procedure for review by the committee.

7. Gas handling system:

The committee was concerned that the conceptual design for the gas handling system is too vulnerable to operator error and disruption of target operations, especially during cooldown. The committee specifically identified the residual gas analyzer (RGA) as a potential source of trouble in that a valve line-up error or even leaky valves could cause either hydrogen or helium to enter the isolation vacuum. The committee recommends that the design team investigate alternative methods of installing or operating the RGA to prevent the former scenario. This should eliminate the cross-connect and move the RGA from one part of the system to the other. Two RGAs could be used to avoid the cross connection, or a dedicated pumping system designed for RGA to pump continuously. The proposed design also showed a palladium leak downstream of the cold trap; some concern was raised by the committee that the palladium would catalyze hydrogen and residual oxygen into water that would then plug the system. The committee recommends that the final design have the palladium filter upstream of the cold trap. The design presented to the committee was incomplete, with some potentially trapped volumes lacking pressure relief. Therefore, the committee requests that a new gas handling design that addresses these issues be developed, and a detailed full piping diagram be created to full engineering standards. Finally, the committee suggests that the eventual operating procedures that will be written include straightforward checks of system integrity such as rate-of-rise tests.

Response: Our plan is to use two RGA sensor heads, one on the main vacuum and one on the hydrogen fill line, to address this concern. We will also implement the palladium leak before the cold trap as requested. Indeed if the hydrogen generator is used the gas it produces at the exit has already passed through a palladium leak.

Operating procedures for the gas handling system will certainly be written and submitted to the safety committee for approval.

Redesign of the gas handling system to respond to these recommendations is in progress.

The final design of the gas handling system will be provided to the Committee for approval.

8. Code compliance:

Fire and electrical code issues are serious hurdles for operators of liquid hydrogen targets to overcome, as these codes do not address the special circumstances of these systems. The project must obtain the agreement of the appropriate authorities at Los Alamos before operating this target. The committee agrees that the construction of a tent to enclose the portion of the gas handling system located above the shielding cave is the best solution for isolating the hydrogen system from sparking electrical equipment. The committee felt that the potential for the ER-2 overhead crane to cause difficulties with the gas handling system can be minimized through the use of appropriate administrative controls on crane operations. The design team is encouraged to pursue this approach with the Los Alamos fire protection authorities. The suggested construction method of using Herculite (a self-extinguishing coated fabric) over a Unistrut framework with a vented fan drawing air through the enclosure has been used successfully by most of the committee members at their home institutions. Since final acceptance of this system will be made by LANL, the committee does not need to be involved in any further review of this subject beyond being assured that a tent is implemented.

Response: We will implement the tent over the gas handling system. An approach for the safety of the gas handling system is discussed with the Facility people and fire marshal. The final solution will be sent to the Committee.

9. Facility interface issues:

A discussion of facility interface issues covered areas that will require extensive interaction between the project and the relevant authorities at LANL. The potential exists for impacting the requirements of the authorization bases of actinide experiments and of the 1L Target Facility. It is clearly in the best interests of the experiment that any such negative interactions between the experiment and its neighbors in ER-2 be eliminated.

The committee is of the opinion that the best way to achieve this goal is to develop the safest, most reliable target possible consistent with meeting the physics goals of the experiment. It will be up to the collaboration to convince the appropriate LANL and DOE authorities that the target design does indeed pose no threat to other experiments and to the facility. The failure table prepared for the engineering document that describes this target will be a key component of these discussions.

Response: We will continue to elaborate our failure table and address any questions raised at LANL with respect to interaction with other experiments. The committee was absolutely correct in raising the issue of the facility interface. The 2nd target safety review was planned to focus to the target vessel design issues and leave the facility issues to the 3rd review that will be done by the different combination of reviewers since we need more LANL experts for this committee.

The advanced Engineering Document of the target will be provided to the Committee. This will also include the updated failure analysis table.

10. Change control:

Change control is part of the larger issue of quality assurance (QA) that must be addressed by the project. The basis for all QA will be the Engineering Document, once finalized, being prepared by the project, and the assembly drawings. Any deviations from this basis, for whatever reasons, will be subject to the change control process. While the full details of this will be part of the project management plan, the committee recommends the following broad details be included in the change control process:

1. When a change is identified, the Target Work Package Leader sends a written change request to the Project Leader. The change request will include sufficient detail to describe the change and full justification for the request.

2. A Target Change Control Board (TCCB) consisting of J.D. Bowman (Experiment Spokesman), J. Knudson (Review Committee Chair), S. Penttilä (Project Manager), and J. Schinkel (P-23 Group Safety Officer) will review the change.

3. The TCCB will either approve the change or recommend that it be forwarded to an appropriate level for further review and approval. The hierarchy of levels might be: TCCB, LANSCE Facility, LANL LH_2 Safety Committee, LANL management, DOE.

The TCCB will function mostly as a screening committee.

The committee requests that a final readiness review of the target be completed prior to the start of operations.

Response: We will follow these procedures for change control.

11. Approval to proceed with target fabrication:

Given the fact that a multi-institution collaboration is interacting with a DOE facility in this effort, the committee recommends that the following steps be undertaken before proceeding with fabrication of the target:

- A detailed response to this report is prepared and accepted by Alan Hurd, LANL LANSCE-12 Group Leader.
- A complete set of assembly drawings for the target and its support structure is prepared, signed off by IUCF authorities, and approved by the appropriate LANL authorities.
- That the Committee reviews the drawings and concurs with the detailed response to this report.