RESPONSE OF THE NPDGAMMA LH2 TARGET WORK PACKAGE TO THE VENT STACK REVIEW REPORT

An internal Laboratory review committee met at the Lujan Center auditorium on December 3, 2004 to review the 10% designs for the vent and ventilation lines of the liquid hydrogen target being built by the NPDGamma collaboration. Below is a response of the NPDGamma LH2 target work package to the findings and recommendations of the review committee. Our response is highlighted in italic.

RECOMMENDATIONS

The committee was very interested in the results of the testing of Conflat flanges done at Indiana, and concurs that this is the proper route for validating the use of these items in the target assembly. The Indiana tests did not subject the flanges to pressures much beyond the MAWP of the target system and so the committee is concerned that there is a risk that the tests stopped just short of inducing failure in the flanges. Testing to failure would be extremely useful information if the Indiana team can do so safely with an appropriate set up. Otherwise, testing to at least twice the system MAWP would suffice to establish a comfortable safety factor.

A further point to follow up on is to repeat the cold tests of the Conflats, this time watching for leaks the entire time while the flanges warm from liquid nitrogen temperature to room temperature. Experience at the 1L Target Facility showed that Conflats would leak badly when undergoing a temperature gradient, yet would be tight when cold or warm.

Recent LANL experience with Conflats shows that regularly checking of the tightness of the fasteners should be part of a preventive maintenance program. Using Belleville washers, rather than lock washers, has shown to be a useful method of helping to keep the fasteners tight.
Additionally, the committee repeats earlier recommendations that welding be the preferred method for connecting components of the both the vent lines and the gas handling system, and that use of connectors such as Conflat flanges or VCR fittings be minimized. VCR fittings remain the connectors of choice where non-welded joints are unavoidable.

Response:

Indiana has performed a thorough test of Conflat flanged joints and VCR joints at low temperatures. Results can be found in the NPDGAMM LIQUID HYDROGEN TARGET ENGINEERING DOCUMENT which is available in the web site www.iucf.indiana.edu/U/lh2target/export-files/. Properly made Conflat flanged joints are reliable even at low temperatures under internal pressure.

The committee recommends that the fill line from the hydrogen supply bottles to the target be armored, and that the vent line from the cryostat also be armored.

Response:
The design of the fill line from the hydrogen supply bottles to the gas handling system and vent line from the cryostat to the ER1/ER2 wall are still in their conceptual design stages. The requested armor has been considered, and found to be a good idea, and will be designed to protect these two lines.

The committee was impressed with the results of the first-principle calculations by Jankowski. We request that the following related questions be investigated:

- The calculations of Jankowski should be extended to see how long it takes to vent the entire hydrogen charge.

- What is the effect on vent times and flow rates of the first rupture disk opening only partially?

- What is the effect on vent times and flow rates of the failure of the first rupture disk to open?

- What is the appropriate K factor for the rupture disk?

Response:
Attached to this document is Jankowski's report LA-UR-04-9020 Transient Analysis of Hydrogen Discharge from the NPDGamma Target Vessels. Some of the committee's questions are addressed in his report. He will perform more calculations to answer un-answered questions but this will take some time.

The committee expects to see a formal, documented review of the stack drawings at the 70 – 80 % level. This can be done as part of the regular meetings that the local stakeholders have been having.

Response:
The detailed drawings have been done and the date for this review have been set to be Jan-04-2005.

The committee will also want to see the as-built details of the ventilation systems at the time of the experiment readiness review.

Response:
The plan is to have the committee to see the as-built ventilation system at the time of the readiness review.

The committee strongly suggests that the microswitches installed on the gas handling panel in MPF-35 be rendered safe (non-sparking) by cutting their cables if they are not removed.

Response:
The LH2 work package considers that the miroswitch issue is not exactly in the scope of this review but appreciates committee's effort to increase the safety of the target system. We promise to the committee that the switches will be removed before the hydrogen operation starts.

The committee recognizes the progress made on establishing change control for the target system and encourages the collaboration to keep up this effort. One important aspect of change control is the use and availability of materials certification. Making scans of these documents available on the collaboration's web site would be worthwhile.

Response:
The team will continue the established change control procedures of the target system.
At least, the certificates of the materials of the most important and critical components will be posted at the web site. The rest of the certificates are available by request. This way we can avoid a large volume and time consuming scanning job and use the saved time for safety improvements in the target system.

The committee will welcome the opportunity to look over the target operation procedures as they are developed beyond the rough draft stage.

Response:
We will provide to the committee the operating procedures as soon as they will be ready for review. Most of the operating procedures have been initiated.

The committee would like the collaboration to investigate further the following issues:

- Is 10 SLM really the worst-case scenario for dumping hydrogen into the target cave?

Response:

A clarification; There will be no hydrogen dumping into the cave. If there is a failure in the gas handling system (GHS) the leaked hydrogen will be confined by the enclosure around the gas handling system. Only way that hydrogen gas can get into the cave is a rupture of the target vessel followed by rupture of the vacuum chamber, the probability for this sequence of events is zero.
Note, that in the gas handling system before the Pd membrane filter, the supply pressure is 200 psia and limited to 250 psia by a pressure relief valve RV106 in the supply manifold. After the membrane filter the pressure of the hydrogen gas is limited to 15 psid by two pressure relief valves RV102 and RV103 in GHS. The probability for a component failure is larger in the high-pressure side of GHS than at the low pressure side. If we have a failure in the supply line before GHS, the 10 SLM is still the maximum flow rate and the gas will be conducted outside ER2 by the armor tube around the H2 supply line.

- Work with the 1L Target Team to determine if the installation of the ER2 vent stacks creates an Unresolved Safety Question for the 1L Target Facility.

Response:
We have started to work with the 1L Target Team to identify Unresolved Safety Questions and work out satisfactory solutions.

- Conduct a Failure Modes and Effects Criticality analysis on the helium system used to purge the joints and welds.

Response:
This is a good issue. The LH2 Target work package is updating the existing Failure Analysis of the full target system.
The following is the analysis for the helium system used to purge the helium channels. The purpose of the helium purge is to have a buffer between the isolation vacuum and air. If there is a failure of the joint or weld between air and the isolation vacuum, there will be helium leak to the vacuum which will be detected by RGA. This will lead to the forced discharge of the liquid hydrogen in the target vessel. The all helium channels are in series and at the input and output of the channel system are two flow meters.
The use of the helium channels is based on the fact that if there is a failure if a joint or weld there is a helium leak to the isolation vacuum which will cause a signal in RGA.

Failure modes and effects criticality analysis:

1. *RGA malfunction*
   Effect: RGA not sensitive to helium-4.
   Controls: procedure to mitigate the probability, in PLC has the RGA signal has to be inside the preset upper and lower limits.
2. *PLC not functioning*
   Effect: Helium content in the vacuum not known.
   Controls: Have to have a backup system to see the mass spectra of the vacuum – a portable PC.
3. *Valve V307 or V207 closed.*
   Effect: RGA not measuring helium-4 in the isolation vacuum.
   Controls: procedure to control valves, , in PLC has the RGA signal has to be inside the preset upper and lower limits.

4. One of the flow meters indicates zero flow rate
Effect: No flow in the channel or meter has lost calibration or supply bottle is empty.
Controls: regular calibration of flow meters, alarm if no signal from a flow meter, procedure for the following gas pressure in the supply bottle.
5. Rupture in connecting tubing between channels.
Effect: loss of flow and alarm
Control: the tubing between channels has been well constructed and tested. Regular checking.
6. Rupture of a joint or weld in the vacuum chamber.
Effect: helium into the vacuum and alarm and fast discharge of the liquid hydrogen from the vessel.

- Investigate the use of pressurized helium to force out the hydrogen charge as opposed to the proposed argon dump in the event of an emergency vent.

Response:
This suggestion has to be considered very carefully because it effects on the overall designed safety of the target system:
How does the helium flow forces the liquid hydrogen out from the vessel? The helium gas will not push the liquid hydrogen out of the vessel. When it is flowing through the liquid hydrogen it will create a turbulent behavior in the liquid.
If the incoming helium gas is warm, it may boil off the liquid hydrogen faster than using argon spoiling of the vacuum. Let's look at the numbers roughly to get an order of magnitude of the effect;
To vaporize 21 liters of the liquid hydrogen requires about $6x10^5$*J. If we want the liquid out from the vessel in 20 min, this means that we have to bring heat in with the rate of 500W which requires a room temperature helium mass flow rate of about 0.38 g/s corresponding to about 2 liters/s in STP.*

Our safety goal has to be to increase the overall safety of the target system, we are not sure that the proposed forced and thus uncontrolled removal of the liquid hydrogen will improve the safety of the target.
The cornerstone of the safety of the target system has been the strength and reliability of the target vessel. The target vessel has been carefully designed to be mechanically as strong as it can be and still meet physics requirements. The target vessel and its vent line have been designed to handle any emergencies that can happen. The other safety aspects are considered as redundancies for this basic safety approach. A very careful and thorough finite element analysis was performed to find out the most optimum material thicknesses, shapes of the windows, how to couple the two input ports to the vessel and so on. This design formed the base for the rest of the design of the target.
Any additional piping to the target or to the vessel has to keep the overall safety level as it has been.
It is therefore important to understand:
Requirement for a fast discharge – what does drive this requirement and what is considered to be fast enough.
This requirement, in our opinion, will not increase the overall safety of the target system.

- Conduct an oxygen deficiency/depletion hazard analysis for the helium bottles used in MPF-35.

Response:
The LH2 target work package concludes that this finding has little to do with the vent stack review that was a subject of the review. We however appreciate the committee's dedication to the target safety and we will take a serious action to solve the issue. This is a part of a bigger issue that we are working with

namely, usage of cryogenics in bldg 35 and related issues. We are working with a LANSCE industrial hygienist with this matter.

- Investigate the consequences of the heat load from a fire directly under the cryostat to be certain that the loss of the cryostat' will not exacerbate the effects of the fire. The committee recognizes that the target need not be designed to survive such an extreme event.

Response:
In the cave is no combustible material! The cryostat is surrounded by a one-metric ton of 48 CsI crystals which are packed into a Al foil. The crystals are hold in place by a heavy Al frame on an Al table. In order words, there is no space under or near, the cryostat to have any combustible material and thus fire is impossible event under and near the cryostat.

Of course, a question can be asked what are consequences if there is a fire under the cryostat.
For an analysis of the situation we have to make an assumption regarding the fire. From the data given us by our fire marshall, Jane Lataille, we have created the following model.
Combustible material under the cryostat is white poly HDPE that often is used in neutron experiments. HDPE has a high heat content, burns very quickly, and melts into a flammable liquid that can spread the fire. The heat release rate of the poly is 1.125 MW/m^2. A reasonable time-temperature curve for the fire is that the fire burns 1 cm deep of one m^2 of HDPE surface which has a surface density of 10^{4}g/m^2 with a rate of 26g/m^{2}s. This gives a burning time of 385s = 6.4 min. Handbooks of fire protection engineering and fire models differentiate fires as slow medium, fast very fast and ultra fast. Fires in plastics like HDPE have been shown in tests to be fast. CFAST (and other sources) define fast fire as reaching the flat heat release rate in 150 seconds.
Our model is that we have a step function – the heat release rate from the beginning of the fire is 1 MW and stays on with a constant rate.

This is again only an order of magnitude estimate.
The area of the cryostat seen by fire is 0.5 m^2. The weight of the cryostat is 250 kg. The fire has not been noticed by experimenters, no effort to extinguish it. Indium and Viton O-rings will be lost at about 150 C. It will take about a minute to elevate the cryostat temperature to 150 C. Before that we have lost the helium flow in the helium channels because of melt down of the connecting tubes, let us assume that there is no alarm. Next, we loose the vacuum, air is getting into the vacuum, we start to boil off the liquid hydrogen with increasing rate. There will be a large heat flow from the hot outer jacket to the cold LH2 vessel. A moment later, 2-3 min after failure of the vacuum, the outer Al jacket around the target vessel will start to melt, this will happen at about 600 C. Now heat can directly reach the target vessel. Let's assume that at the first for a few seconds, the heat rate seen by the target vessel is about 0.1 MW. This heat will boil of liquid hydrogen with the rate of 230 g/s. If in the vessel is left of liquid hydrogen 75%, to empty the vessel will take 5s with this heat rate. In his report Transient Analysis of Hydrogen Discharge from the NPDGamma Target Vessel Jankowski shows that most of the hydrogen charge is out in a few second.

As a summary, we can say that even in the case of a CFAST fire from HDPE, the designed safety of the target system will prevent a catastrophe, hydrogen gas contact with air in the cave, to take place.