Design Criteria for the NPDGamma Liquid Hydrogen Target Vent Stack on Bldg MPF-30, in Flight Path 12 at ER2

Location: TA-53, building MPF-33, flight path 12 at ER2
Organization: P-23
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Purpose of document

A purpose of this document is to identify design criteria for the hydrogen relief line of the NPDGamma liquid hydrogen target so that the design will be in accordance with requirements.

System Description

The NPDGamma Collaboration has built a 21-liter Liquid Hydrogen (LH2) Target System for the n+p->d+γ experiment that is planned to run in flight path 12 at the Lujan Center in 2005. The LH2 target system was built and preliminary tested in the Indiana University and then moved to Los Alamos where it was reassembled for testing in the bldg MPF-35 at TA-53. To date, we have tested without cryogenics the cryostat, gas handling system, and instrumentation. Before moving the target to the experiment in flight path 12, it has to go a thorough testing in MPF-35 including hydrogen operation. The description of the LH2 target system and its safety can be found in the NPDGamma Liquid Hydrogen Target Engineering Document [1] that is available at web site www.iucf.indiana.edu/U/lh2target/expoert-files/.

The LH2 target system requires a vent stack for normal operational and emergency discharges of hydrogen safely outside the building MPF-30, ER2. The main purpose of the relief line is to conduct safely hydrogen gas (total volume 17000 liters in STP) from target to outside of ER2 in every possible operational mode.

The LH2 target vessel relief line consists of a 1.5" id stainless steel pipe from the LH2 vessel outside the cryostat to a relief chamber where it is connected to a relief device formed by a relief valve parallel with a rupture disk. The main isolation vacuum chamber of the cryostat is connected through a 4" id pipe to the relief chamber; a relief valve and two parallel rupture disks. The relief chamber is followed by a check valve. The relief chamber up to the check valve is filled with helium gas to 2 psig to prevent air to have an access to the hydrogen volume or to the vacuum chamber in a case of a leak. From the check valve a 6" id stainless steel pipe - vent stack - conducts discharged hydrogen gas safely outside of ER2.

This document gives design criteria for the design of the vent stack. The vent stack starts from the check valve CKV101, see Attachment A, and it is about 100 ft long and it has several 90-degree bends, see Attachment B. Attachment C summarizes results of the sizing and other design issues.

The total conductance of the vent stack, the relief chamber, and the check valve has to be large enough to prevent pressure build up in the target vessel during an emergency venting caused by a loss of the isolation vacuum or a rupture of the LH2 vessel. These two extreme failure modes have been used to design a safe relief system for the target as discussed in the Engineering Document [1]. MAWPs of the LH2 vessel and for the main vacuum chamber of the cryostat are 60 psid. In the Engineering Document are presented the details of the sizing calculations of the vent stack and the results are summarized in Attachment C.
The design of the vent stack should meet requirements given by CGA G-5.5-2004 "Hydrogen Vent Systems" [2]. The design criteria document addresses also requirements of NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites* [3] although strict compliance is not achieved due to operational requirements and space constraints.

Path of the relief line piping

The relief line starts from the top of FP12 experimental cave where the pipe from the LH2 target cryostat penetrates the roof. From the cave top the pipe goes to West along the guide tunnel of the FP12 beam line to the ER1/ER2 wall with a positive slop. On the wall the pipe will climb to North and then penetrate the wall outside of ER2 where it will extend up some 50 ft to the same level as the exit of the 1L target moderator vent stack. See Attachment B.

Hazard Analysis

The primary hazard of concern in design of the vent stack is the flammability of hydrogen and fire in the stack. The following are the failure scenarios that have been considered. Those of very low probability are not addressed by this document:

1. Hazard: Hydrogen burning inside pipe.
   Mitigation: Pipe is designed and tested for 150 psig or higher.

2. Hazard: If there is a fast hydrogen burning inside the pipe, a pressure shock will damage the LH2 target vessel and cause a rupture of the vessel.
   Mitigation: The check valve CKV101 will prevent the shock wave entering the LH2 target vessel.

3. Hazard: During a fast venting of hydrogen gas the pipe will become cold and thermal contraction of the pipe will cause physical damage to the pipe causing a hydrogen leak.
   Mitigation: Thermal stresses on the pipe have to be properly taken care in design.

4. Hazard: The vent stack pipe will cause a loading to the LH2 target vessel.
   Mitigation: The mechanical design anchors the pipe so that there will not be any forces to the target system – there is a bellow between the relief chamber and the target cryostat.

5. Hazard: Under internal pressure of 150 psig and at low temperatures the 8" Conflat flange joints can leak.
   Mitigation: We have tested CF joints up to 200 psid at low temperatures without any observation of leaks.

6. Hazard: Failure of the stack caused by static mechanical loading like ice, wind and seismic loading.
   Mitigation: Proper engineering of the structural support to handle static loading like the weight of the pipe.

Design Requirements

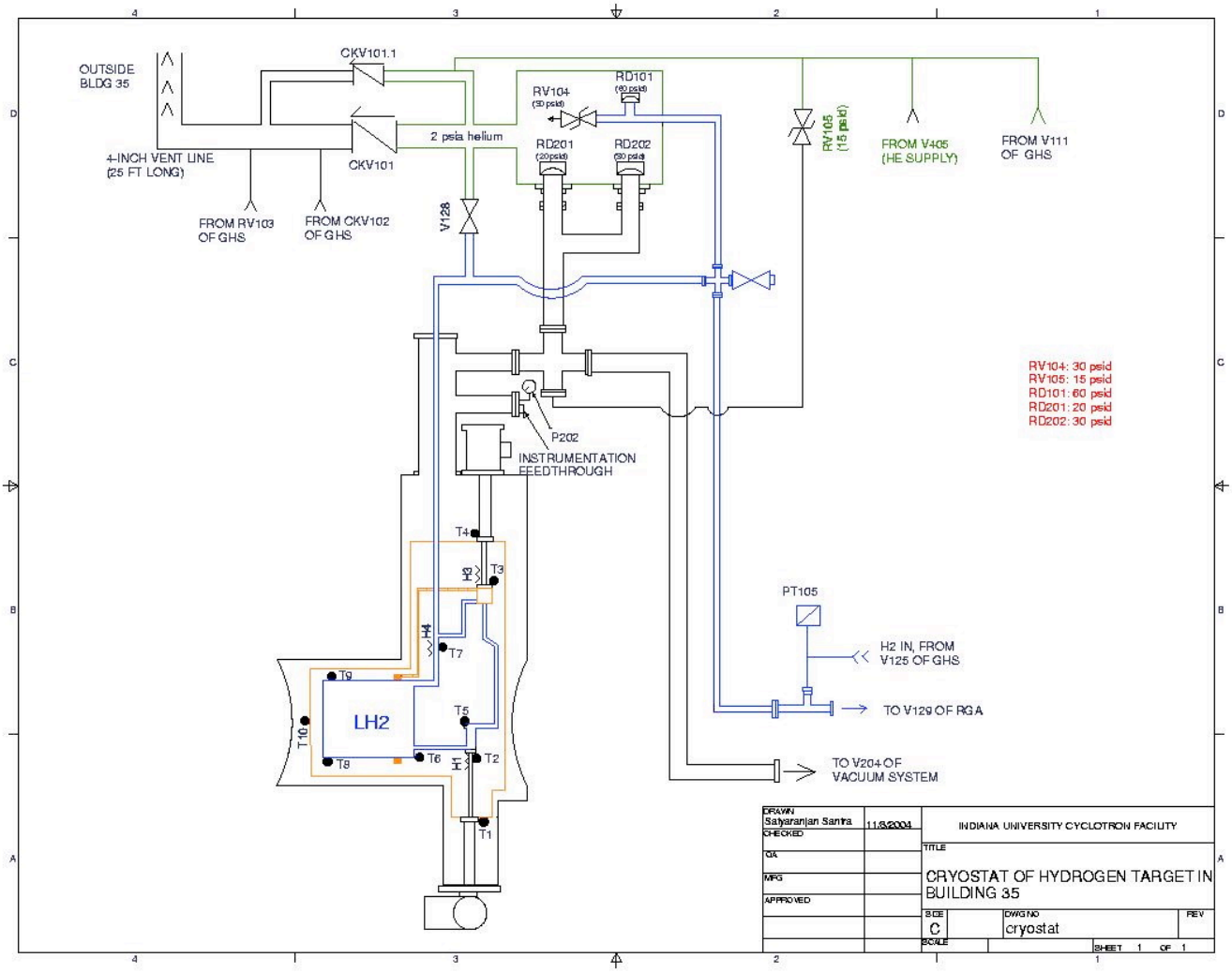
1. Vent stack piping will be ASME 31.3 compliant, vacuum tight to 10^{-7} atm cc/s helium, pressure rated to 150 psig or higher and compatible for use with hydrogen.
2. The piping shall be constructed using 304L stainless steel pipe with welded 8" Conflat flange joints. CF flange joints meet the Compressed Gas Association guideline for Hydrogen Vent Systems, section 5.5 [2].
3. The exit of the vent stack shall be at the same level as the exit of the 1L target vent stack.
4. Vent exits shall be cut at a miter angles.
5. The vent pipe shall be sloped upward and shall not contain traps so that hydrogen will not concentrate within it.
6. Grounding of the vent stack shall be ensured by routing a lighting conductor the by bonding each component of the system to the building's existing lighting conductors.
7. The vent structure shall be designed to withstand static loading from weight, ice, wind, and seismic events as prescribed in the local building code.
8. Thermal contraction of the piping shall be accounted in the design.
9. A drain shall be designed to low point of the vent stack to allow removal of moisture.
10. The design of all other aspects of this system such as structural support and lighting protection shall comply with the LANL *Facility Engineering Design Manual*.

References

[1] NPDGamma Liquid Hydrogen Target Engineering Document, V1.0, November 29, 2004.
[2] CGA G-5.5 –2004, Hydrogen Vent Systems, 2nd ed.
[3] NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*

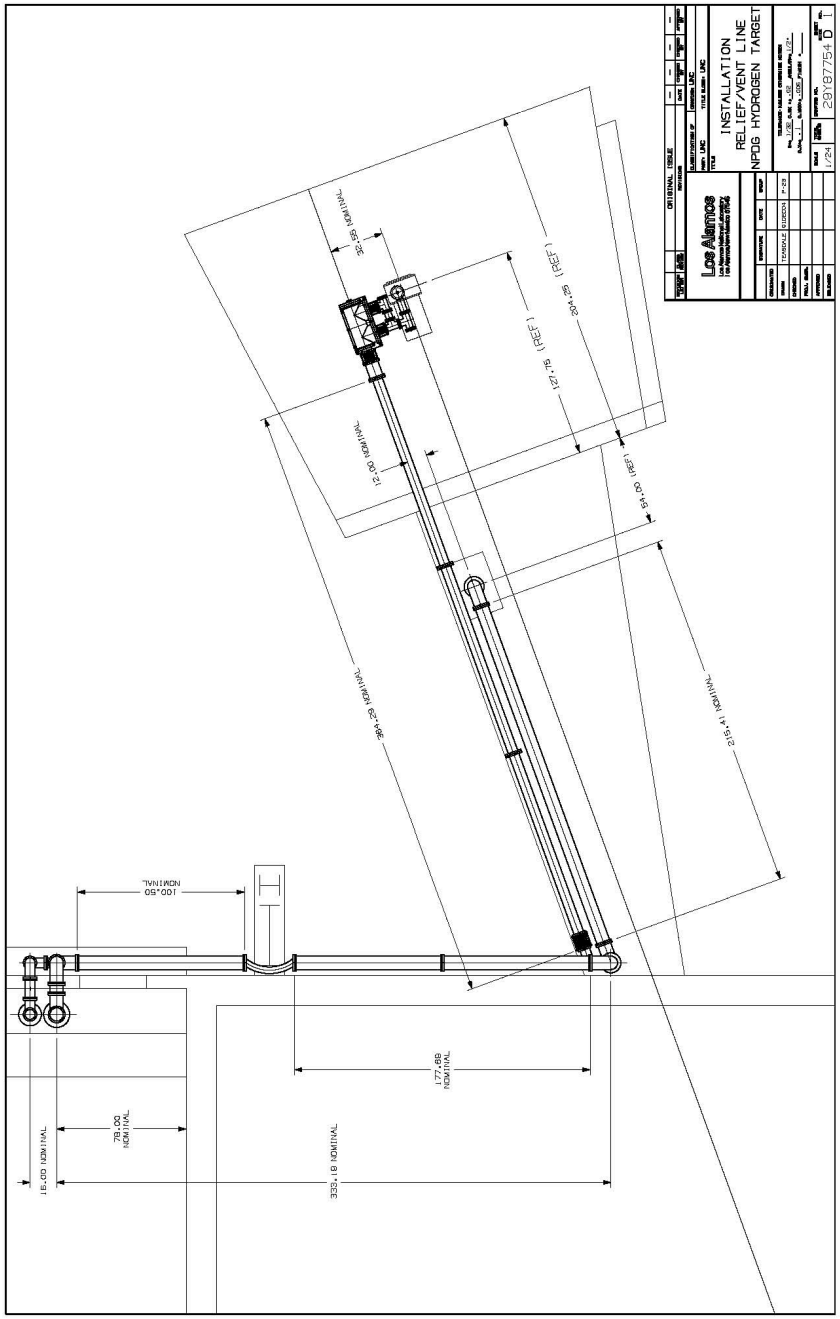
ATTACHEMENT A

TARGET SYSTEM SCHEMATIC



ATTACHMENT B

LH2 TARGET VENT STACK ASSEMBLY AT ER2



Side views will be available later.

ATTACHMENT C

Summary of Sizing of the ER2 Vent Stack Pipe

The 1.5" id pipe from the LH_2 target vessel is connected to the relief chamber and the main isolation vacuum chamber is connected to the same relief chamber using the 4" id pipe. The relief chamber, in turn, is connected to a 6" inner diameter vent stack pipe which conducts hydrogen gas through a check valve outside of building MPF-30, ER2, in normal operation or in case of an accident or emergency discharge. The vent stack has to handle the flow from all discharges and thus has to have a capacity, which is sufficient to avoid over-pressurizing the LH_2 vessel or main vacuum chamber of the cryostat. A check valve, CKV101, is provided in the relief pipe to limit backflow of air. The pipe section up to the check valve is filled with helium gas to 2 pisg.
Calculations based on the Bates Internal Report #90-02 [1] and the Crane Technical Paper No. 410 [2] show that the 6-inch inner diameter and 100 ft long vent stack pipe with four 90-degree bends, one check valve, one pipe entrance, and one pipe exit which gives the total resistance coefficient K=7.8 (in calculations were used K=10 (15)), can safely handle a mass flow rate up to 0.5 lb/s with a pressure build-up of 60 (67) psia.

Table 1 contains a list of the various parts of the relief system along with their performance specifications. Each component from the individual enclosures possesses a primary relief system consisting of a spring-loaded pressure relief valve and a secondary relief system consisting of rupture disks in parallel with the relief valve. All pressure relief systems are connected to a 6" id relief line which is filled with helium gas to 2 psig pressure up to the check valve. After the check valve 6" id vent stack conducts the hydrogen gas outside of ER2 building.

Table 1. Specifications of relief devices and relief lines.

Relief lines	Mechanical and conductance properties of relief lines/blow-offs			Max. pressure in worst-case failure
	Dimensions	Material	Mass flow capacity	
LH_2 target fill/vent line	1.5 "diameter resistance coefficient K = 10	304L	0.20 lb/sec	47 psia
Main vacuum chamber vent line	2.5" diameter resistance coefficient K = 10	304 L	0.50 lb/sec	43 psia
Main vent stack line	6" diameter K=15	304L	0.5 lb/sec	24 psia

Values of resistance coefficients for 6” id steel pipe and components:

1.	1 ft long pipe:		$K = 0.03$
2.	standard 90° elbow		$K = 0.45$
3.	standard 45° elbow		$K = 0.24$
4.	standard tee:	flow thru run	$K = 0.30$
		flow thru branch	$K = 0.60$
5.	pressure relief valve		$K = 3.00$

Table 2. Maximum pressure rise at the entrance to the vent stack for various tubing sizes and values of the resistance coefficients K, assuming a mass flow rate of 0.5 lb/s. The exit pressure is 14.7 psia at LANL.

	Pipe id =2.5” inlet pressure (psia)	Pipe id=4.0” inlet pressure (psia)	Pipe id=6.0” inlet pressure (psia)
p_{max} ($K = 6$)	35.1	18.6	
p_{max} ($K = 8$)	39.0	19.8	
p_{max} ($K = 10$)	42.4	20.8	17.0
p_{max} ($K = 15$)	50.1	23.3	23.8

References

[1] W. Schmidt and C. F. Williamson, Bates Internal Report #90-02 (1990).

[2] Flow of Fluids Through Valves, Fittings, and Pipe, Crane Technical Paper No. 410, Crane Co., New York, 1991.

ATTACHMENT D

Temperature Distribution in the Vent Stack Pipe

To eliminate in the design stresses caused by the thermal contraction of the vent stack pipe, we have estimated temperature distribution in the pipe during the maximum cold hydrogen mass flow.

The heat which will warm up the cold H_2 gas (GH2) in the vent pipe comes from two sources: the heat capacity of the stainless steel pipe and the heat from the surrounding air conducted through the pipe wall.

Details of the this calculation can be find in the NPDGamma Liquid Hydrogen Target Engineering Document, V1.0, November 29, 2004, in section 6.4.4. www.iucf.indiana.edu/U/lh2target/expoert-files/.

Summary of the temperature distribution during the maximum mass flow is;

Initial temperature:		Temperature increase per ft:	
$T_{initial}$ (K)=	23	ΔT (K/ft) =	4.1
	31		5.5
	42		7.1
	56		9.0
	74		10.9
	96		12.8
	122		14.0
	150		14.4
	179		13.8
	207		12.0
	231		9.7
	250		7.2
	264		5.2