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Title: LAPD Preliminary ODH Assessment

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Key Words: LAPD, ODH

Abstract Summary:

This is the preliminary ODH assessment for the LAPD argon tank and associated equipment.

Applicable Codes:

1. *Fermilab Oxygen Deficiency Hazards (ODH), FESHM Chapter 5064, May 7, 2009*

FERMI NATIONAL ACCELERATOR LABORATORY

LAPD PRELIMINARY ODH ASSESSMENT

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January 14, 2010

I. INTRODUCTION

This ODH Risk Assessment is for the Liquid Argon Purification Demonstration (LAPD) facility located in PC4. A Fatality Rate is computed to determine the ODH Classification.

The LAPD project has an Argon storage tank and Argon purification system in PC4 to produce ultrapure Argon. A pumped circulation and filtration system is used to reduce impurities in the Argon. Liquid Nitrogen is used as a coolant to remove heat absorbed by the Argon system by condensing Argon gas.

II. SIZES AND VOLUMES

The PC4 building space is comprised of a central enclosure and a beam enclosure. For the purposes of this analysis only the central enclosure is being counted. Only the people space of floor to 6 foot is being counted since heavier than air gases are involved. The resulting volume for analysis is 37,570 cubic feet. Room dimensions[1] and calculation details are in the appendix.

Liquid argon will be stored in PC4, in the LAPD tank. This tank will hold 6,000 gallons (663,000 SCF) of liquid argon, when full. Liquid argon to fill the tank will be supplied from an argon trailer, located outside. Argon will be used as purge gas. The argon for purging will be supplied from argon dewars, located outside.

Liquid nitrogen will provide cooling for the LAPD tank. The liquid nitrogen will be supplied from a liquid nitrogen trailer, located outside. The trailer assigned to LAPD is trailer #22 which can hold 4,000 gallons (364,800 SCF) of liquid nitrogen.

Filter regeneration will use combination gases, argon/hydrogen gas and nitrogen gas. The combination gases and argon/ hydrogen gas will be supplied from gas bottles stored outside. The nitrogen gas will be supplied from the same outside, liquid nitrogen trailer supplying the LAPD cooling. The liquid nitrogen will pass through a vaporizer, located outside, before entering PC4.

III. VENTILATION SYSTEMS

PC4 has existing basic ventilation. All the existing ventilation intakes and exhausts are located near the ceiling and will have little effect on risks from heavier than air gases. For this reason, the existing ventilation is not counted in this ODH analysis.

[1] Drawing 8-4-4-PS-2, REV A/B, Jan 4, 1974, Titled: Proton Laboratory Phase G

IV. ODH DETECTORS

There will be two ODH detectors in PC4. The detectors will be located at ground level near the LAPD tank. These detectors are expected to detect an Argon or Nitrogen leak from the LAPD system.

V. LAPD ODH EXHAUST SYSTEM

When an ODH condition is signaled by any of the ODH detectors the following automated responses occur:

A. Activation of ODH alarm horns and lights

B. Activation of the ODH exhaust blower

The large exhaust blower will be located at floor level in PC4. This blower will draw a minimum of 3,000 CFM of heavier than air gases from floor level in the vicinity of the LAPD system and exhaust the gases outside. Fresh air is drawn in through existing louvers near the ceiling on the East and West wall. The ODH exhaust blower will be tested before LAPD work starts. Based on the initial blower tests, a determination will be made as whether additional fresh air intakes are needed.

VI. SIGNIFICANT SOURCES OF CRYOGENS

The following are the significant sources of cryogens and gases which could produce ODH conditions in PC4 during LAPD work. These are the sources considered in the analysis of component failures or ruptures. The potential leak rates for argon and nitrogen are based on available pressure and leak size. The details can be found in the appendix.

NITROGEN SUPPLY HEADER

The nitrogen supply header brings liquid nitrogen from the outside trailer. This header is part of the LAPD system and holds a finite nitrogen supply of 4,000 gallons (364,800 SCF).

Trailer Tank Normal Operating Range: 30-40 psig

Trailer Maximum Allowable Working Pressure: 50 psig

ARGON SUPPLY HEADER

The argon supply header brings liquid argon from an outside liquid argon trailer during LAPD tank filling. This trailer holds a maximum argon supply of 4,000 gallons (442,000 SCF).

Liquid argon dewars, located outside, will be supplying continuous argon for purge gas after LAPD tank filling is complete. There will be xxx connections available for hooking up liquid argon dewars.

ARGON/HELIUM HEADER

A header brings a 95% argon/5% hydrogen gas mixture from an outside trailer. This trailer has a finite capacity of 40,000 standard cubic feet of the argon/helium gas mixture.

LAPD TANK

The LAPD has a volume of 6,500 gallons. Once filled, the LAPD tank would be kept full for the LAPD work. The liquid argon is pumped from the tank through filtration steps and then back to the tank.

VII. FAILURES CONTRIBUTING TO ODH

A. Pressure Vessel – Leak and Failure

All of the small vessels, used in the LAPD tank cooling system and in the argon filtration loop are pressure vessels. A conservative catastrophic failure rate[2] of 1.09×10^{-8} per hour is being used. More likely is that a pressure vessel develops a leak. The risk of leak is an order of magnitude greater than the vessel catastrophic failure risk so a rate of 1.09×10^{-7} per hour is being used for the leak risk[3]. The details for these numbers are in the appendix.

[2] Ref. 2

[3] Leak risk based on a combination of ref. 2 and ref. 3 data. See appendix for details.

B. LAPD Tank – Leak and Failure

The LAPD tank is manufactured to API 620, appendix Q standards and has 100% radiography. This reduces its leak and catastrophic failure risks to a level comparable to pressure vessels. The pressure vessel leak and catastrophic failure rates will be used.

C. Piping – Leak and Failure

Piping can fail by leaking and by breaking. The leak failure can be further broken down into a small leak and a large leak. A small leak is an opening of 10 mm^2 or less. A large leak is an opening of 10mm^2 to 1000 mm^2. For this analysis, an average of 500 mm^2 is be used to represent large leaks. The small leak risk rate[4] is 3.05×10^{-10} per foot per hour and the large leak risk rate[4] is 3.05×10^{-11} per foot per hour. The pipe break risk[4] is 9.14×10^{-12} per foot per hour. The use of these factors provided additional clarity over the basic per section risk factor listed in FESHM 5064.

D. Relief Valve - Leak and Release

All the LAPD relief valves are either located outside or are vented to the outside. The vent piping is handled as piping with a leak and failure risks as noted previously.

E. Human Error – Opening Valve

The argon pump loop has several piping connections points for servicing the filters. One of these connection points could be uncapped and operated in error without proper positioning of block valves. A failure rate of 1.25×10^{-5} per hour was estimated for this possibility. Details are contained in the appendix.

[4] Ref. 2

VIII. ODH CALCULATIONS

Oxygen concentrations are calculated using FESHM, 5064, equation 4 at time equal to infinity.

$$C = 0.21 \cdot \left(1 - \frac{R}{Q}\right)$$

Q is the rate the ventilation is drawing out the contaminated atmosphere, R is the spill rate of the air displacing gas and C is the concentration of oxygen assuming perfect mixing.

Oxygen concentration of 0% is used for the all cases of ODH blower failure.

The fatality factor is per the graph in figure 1, FESHM 5064. An equation was used to represent the graph in the ODH analysis, detailed in Table 1.

Failure rates for the LAPD tank, piping and human error valve operation are detailed in the appendix.

IX. References

1. ***FESHM 5064, May 7, 2009***
2. ***Guidelines for Process Equipment Reliability Data, CCPS, 989***
3. ***Risk Analysis for Process Plant, Pipelines and Transport, 1st ed, 1994***

X. Recommendations

The total of the fatality risk rate without an ODH exhaust blower is 1.48×10^{-6} per hour which is ODH Class 1. Addition of a 3000 CFM ODH exhaust blower further reduced the fatality risk rate down to 8.41×10^{-7} per hour. Addition of the ODH exhaust blower reduces the fatality risk rate by over 40%.

LAPD should have a 3000 CFM ODH exhaust blower and follow ODH Class 1 control measures, detailed in FESHM 5064.

TABLE 1: LAPD Oxygen Deficiency Hazard Analysis

1/14/2010

LAPD SPACE (building PC4): 37,570 cu. ft.
ODH Exhaust: 3000 cu. ft./min
Ventilation Failure Rate: 1.12E-04 /hr (Includes ODH monitoring system failure, see failure rate calculation in appendix)

	Failure Type	# of	Individual Failure Rate (/hr)	SOURCE	Total Failure Rate for Item	Leak rate, in PC4 (CFM)	C(O2) at infinity	Fatality Factor	Fatality Rate	ODH CLASS	Notes
EQUIPMENT											
LAPD Tank w/ vent.											
TANK	leak	1	1.09E-07	D	1.09E-07	2415	4.10%	1.00E+00	1.09E-07	1	small leak
TANK	failure	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.09E-08	0	catastrophic failure
LAPD Tank w/o vent.											
TANK	leak	1	1.09E-07	D	1.09E-07	2415	0.00%	1.00E+00	1.22E-11	0	small leak
TANK	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.22E-12	0	catastrophic failure
Condenser w/ vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	4.10%	1.00E+00	1.09E-07	1	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.09E-08	0	catastrophic failure
Condenser w/o vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	0.00%	1.00E+00	1.22E-11	0	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.22E-12	0	catastrophic failure
N2 Phase Sep. w/ vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	4.10%	1.00E+00	1.09E-07	1	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.09E-08	0	catastrophic failure
N2 Phase Sep. w/o vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	0.00%	1.00E+00	1.22E-11	0	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.22E-12	0	catastrophic failure
Argon Pump w/ vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	4.10%	1.00E+00	1.09E-07	1	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.09E-08	0	catastrophic failure
Argon Pump w/o vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	2415	0.00%	1.00E+00	1.22E-11	0	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.22E-12	0	catastrophic failure
Filter Vessels w/ vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	242	19.31%	0.00E+00	0	0	small leak
VESSEL	failure	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.09E-08	0	catastrophic failure
DRAIN / VENT VALVE	error	4	1.00E-08	A	4.00E-08	1000	14.00%	1.11E-04	4.42E-12	0	human error - opens vent valve
Filter Vessels w/o vent.											
VESSEL	leak	1	1.09E-07	D	1.09E-07	242	0.00%	1.00E+00	1.22E-11	0	small leak
VESSEL	rupture	1	1.09E-08	B	1.09E-08	-	0.00%	1.00E+00	1.22E-12	0	catastrophic failure
DRAIN / VENT VALVE	error	4	1.00E-08	A	4.00E-08	1000	0.00%	1.00E+00	4.48E-12	0	human error - opens vent valve
PIPING											
N2 Supply w/ vent.											
PIPES < 2"	leak, small	50	3.05E-10	B	1.53E-08	234	19.36%	0.00E+00	0	0	
PIPES < 2"	leak, large	50	3.05E-11	B	1.53E-09	11719	0.00%	1.00E+00	1.52E-09	0	
PIPES < 2"	break	50	9.14E-12	B	4.57E-10	11760	0.00%	1.00E+00	4.57E-10	0	
VALVE	leak	4	1.00E-08	A	4.00E-08	234	19.36%	0.00E+00	0	0	small leak
N2 Supply w/o vent.											
PIPES < 2"	leak, small	50	3.05E-10	B	1.53E-08	234	0.00%	1.00E+00	1.71E-12	0	
PIPES < 2"	leak, large	50	3.05E-11	B	1.53E-09	11719	0.00%	1.00E+00	1.71E-13	0	
PIPES < 2"	break	50	9.14E-12	B	4.57E-10	11760	0.00%	1.00E+00	5.12E-14	0	
VALVE	leak	4	1.00E-08	A	4.00E-08	234	0.00%	1.00E+00	4.48E-12	0	small leak
Argon Loop w/ vent.											
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	242	19.31%	0.00E+00	0	0	
PIPES < 2"	leak, large	100	3.05E-10	B	3.05E-08	12080	0.00%	1.00E+00	3.05E-08	0	
PIPES < 2"	break	100	3.05E-10	B	3.05E-08	14730	0.00%	1.00E+00	3.05E-08	0	
VALVE	leak	12	1.00E-08	A	1.20E-07	3060	0.00%	1.00E+00	1.20E-07	1	small leak
Argon Loop w/o vent.											
PIPES < 2"	leak, small	100	3.05E-10	B	3.05E-08	242	0.00%	1.00E+00	3.42E-12	0	
PIPES < 2"	leak, large	100	3.05E-10	B	3.05E-08	12080	0.00%	1.00E+00	3.42E-12	0	
PIPES < 2"	break	100	3.05E-10	B	3.05E-08	14730	0.00%	1.00E+00	3.42E-12	0	
VALVE	leak	12	1.00E-08	A	1.20E-07	3060	0.00%	1.00E+00	1.35E-11	0	small leak
Vent Pipes w/ vent.											
PIPES < 2"	leak, small	300	3.05E-10	B	9.15E-08	35	20.76%	0.00E+00	0	0	
PIPES < 2"	leak, large	300	3.05E-10	B	9.15E-08	2085	6.41%	1.00E+00	9.15E-08	0	vents inside instead of outside
PIPES < 2"	break	300	3.05E-10	B	9.15E-08	1710	9.03%	6.68E-01	6.12E-08	0	vents inside instead of outside
PIPES > 2"	leak, small	30	3.05E-10	B	9.15E-09	35	20.76%	0.00E+00	0	0	
PIPES > 2"	leak, large	30	3.05E-10	B	9.15E-09	2085	6.41%	1.00E+00	9.15E-09	0	vents inside instead of outside
PIPES > 2"	break	30	3.05E-10	B	9.15E-09	1710	9.03%	6.68E-01	6.12E-09	0	vents inside instead of outside
Vent Pipes w/o vent.											
PIPES < 2"	leak, small	300	3.05E-10	B	9.15E-08	35	0.00%	1.00E+00	1.03E-11	0	
PIPES < 2"	leak, large	300	3.05E-10	B	9.15E-08	1000	0.00%	1.00E+00	1.03E-11	0	vents inside instead of outside
PIPES < 2"	break	300	3.05E-10	B	9.15E-08	1000	0.00%	1.00E+00	1.03E-11	0	vents inside instead of outside
PIPES > 2"	leak, small	30	3.05E-10	B	9.15E-09	35	0.00%	1.00E+00	1.03E-12	0	
PIPES > 2"	leak, large	30	3.05E-10	B	9.15E-09	1000	0.00%	1.00E+00	1.03E-12	0	vents inside instead of outside
PIPES > 2"	break	30	3.05E-10	B	9.15E-09	1000	0.00%	1.00E+00	1.03E-12	0	vents inside instead of outside
Sample Tubing w/ vent.											
Small Dia. Tubing	leak, small	300	3.05E-10	B	9.15E-08	200	19.60%	0.00E+00	0	0	
Small Dia. Tubing	leak, large	300	3.05E-10	B	9.15E-08	200	19.60%	0.00E+00	0	0	
Small Dia. Tubing	break	300	3.05E-10	B	9.15E-08	200	19.60%	0.00E+00	0	0	
Sample Tubing w/o vent.											
Small Dia. Tubing	leak, small	300	3.05E-10	B	9.15E-08	200	0.00%	1.00E+00	1.03E-11	0	
Small Dia. Tubing	leak, large	300	3.05E-10	B	9.15E-08	200	0.00%	1.00E+00	1.03E-11	0	
Small Dia. Tubing	break	300	3.05E-10	B	9.15E-08	200	0.00%	1.00E+00	1.03E-11	0	

Total Fatality Rate:	**8.41E-07**
Overall ODH Class:	**1**

SOURCES

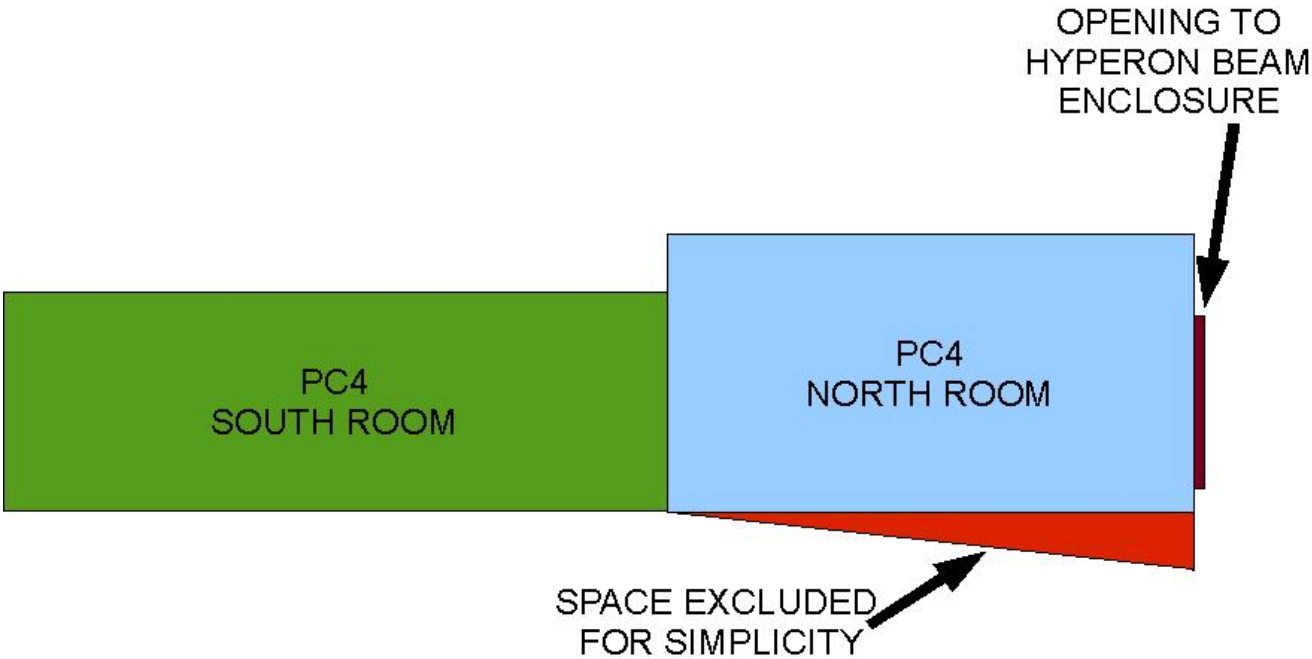
A FESHM Chapter 5064, rev. 05/2009
B Risk Analysis for Process Plant, Pipelines and Transport, 1994.
C Guidelines for Process Equipment Reliability Data, with Data Tables, CCPS, 1989
D Source C and B are combined to provide a conservative failure rate and reasonable difference between failure risk and leak risk.

NOTES

1 Piping risk data is per ft per hour. Number of items for piping is estimated number of feet of piping. For piping with many bends or fittings, the estimate is increased by 50% to account for increased complexity. Outside piping is excluded.
2 Piping risk data is for pipes less than 2". Small leak and break risk for 2" to 6" is same as for less 2".
3 Vent piping that has a large leak or breaks, would be the same as just venting inside the building. The leak rate would be equal to the maximum Ar purge flowrate.
4 All relief valves vent to the outside.
5 LAPD tank is welded per ASME code and all welds were x-rayed, like a pressure vessel. This makes the probability of failure similar to a
6 For the LAPD tank leak risk, a large leak flow is used, even though the risk is for a small leak.

PC4 Volume

PC4 (P Central in original drawings) is comprised of 3 distinct sections, with no partitions or walls separting the sections. For simplicity only the 2 large rooms are included in the volume calculation.



Height (for ODH Analysis)

$H := 6 \cdot ft$

LAPD is working with heavier than air gases so only the floor to 6 ft, people space is used for the ODH analysis.

APPENDIX

PC4 Room dimension data from Drawing 8-4-4-PS-2, Rev A/B, Jan 4, 1974, Titled Proton Laboratory Phase G.

South Section

$L_S := 100 \cdot ft$ $W_S := 28 \cdot ft$ $V_{south} := L_S \cdot W_S \cdot H = 16800 \cdot ft^3$

North Section

$L_N := 80.5 \cdot ft$ $W_N := 43 \cdot ft$ $V_{north} := L_N \cdot W_N \cdot H = 20769 \cdot ft^3$

Hyperon Enclosure

$L_H := 180 \cdot ft$ $W_H := 21 \cdot ft$ $V_{hyperon} := L_H \cdot W_H \cdot H = 22680 \cdot ft^3$

Total PC4 Volume

The Hyperon Enclosure is not counted as part of the PC4 space even though it has no wall or partition separting it.

$V_{PC4} := V_{south} + V_{north} = 37569 \cdot ft^3$

ODH Blower Failure Rate

The ODH exhaust blower fails if
the power fails or
the motor fails or
a fuse prematurely opens
or the ODH monitoring system fails.

General failure rate data from FESHM 5064

Note: All failure rates are per hour

Electrical Power Failure

$F_{elec.pow} := 10^{-4}$ per hr

Fuse - Premature Open

$F_{fuse.p_open} := 10^{-6}$ per hr

Electric Motor - Failure to Run - Normal Envir. (fan motor inside PC4 building)

$F_{elec.mot.norm} := 10^{-5}$ per hr

ODH Monitoring System Failure

$F_{ODH.sys} := \frac{10^{-2}}{(365 \cdot 24)} = 1.14 \times 10^{-6}$ per hr

Using a probability of failure on demand of 10^-2 which is the high end of a SIL 1.

Exhaust Blower Failure Rate

$F_{elec.pow} + F_{elec.mot.norm} + F_{fuse.p_open} + F_{ODH.sys} = 1.121 \times 10^{-4}$ per hr

Filter Drain / Vent Valve - Human Error Analysis

An Argon release would occur if an operator opened the drain / vent valve for one of the filter vessels while the system contained Argon.

Filter changes or regenerations are not a daily operation.

It is assumed that 90% of the operating time for LAPD does not involve filter changes or regenerations.

Failure rate data from FESHM 5064

Human Error of Commission

$$Err_{Human} := \frac{3 \cdot 10^{-3}}{24} \text{ per hr}$$

Normal Operation Time (Without Filter Changer or Regen, as percentage)

$$Normal_{op} := 90 \cdot \%$$

Filter Manual Valve Opened - Error Rate

$$F_{MVO} := Err_{Human} \cdot (1 - Normal_{op}) = 1.25 \times 10^{-5} \text{ per hr}$$

Tank / Vessel Failure

Several sources of tank / vessel catastrophic failure data were reviewed and evaluated. All failure data was converted to a per hour failure rate.

From: Guidelines for Process Equipment Reliability Data (CCPS, 1989)

This source has mean catastrophic failures, reported as failures per 10^6 hours.

Pressurized Vessel, Mean Failures

$$\frac{0.0109}{10^6 \cdot \text{hrs}} = 1.09 \times 10^{-8} \quad \text{per hr}$$

Atmosphere Vessel, Mean Failures

$$\frac{0.985}{10^6 \cdot \text{hrs}} = 9.85 \times 10^{-7} \quad \text{per hr}$$

From: Risk Analysis for Process Plant, Pipelines and Transport, 1st ed

This source has catastrophic failure rates, reported as failures per annum and failures per 10^6 hours.

Pressurized Vessel, Mean Failures

The source listed failure rate data per annum and per 10^6 hours. Both are shown converted to per hour.

$$\frac{\left(3 \cdot 10^{-6}\right)}{365 \cdot 24} = 3.42 \times 10^{-10} \quad \text{per hr}$$

$$\frac{2.5 \times 10^{-4}}{10^6 \cdot \text{hrs}} = 2.5 \times 10^{-10} \quad \text{per hr}$$

Pressurized Vessel, Small Leak

The source listed failure rate data per annum and per 10^6 hours. Both are shown converted to per hour.

$$\frac{\left(3 \cdot 10^{-5}\right)}{365 \cdot 24} = 3.42 \times 10^{-9} \quad \text{per hr}$$

$$\frac{2.5 \times 10^{-3}}{10^6 \cdot \text{hrs}} = 2.5 \times 10^{-9} \quad \text{per hr}$$

Note that the difference between the vessel failure rate and the vessel leak rate is an order of magnitude.

The more conservative CCPS failure rate is more conservative. The two sources will be combined, using the more conservative CCPS failure rate combined with the order of magnitude difference to delineate between vessel catastrophic failure and vessel leak.

Pipe Failure

Piping can fail by developing a leak or totally breaking.

From: Risk Analysis for Process Plant, Pipelines and Transport, 1st ed

This source has various failure rates for small piping (<2 inches), reported as failures per m per 10^6 hours.

Small Leak is defined as a small crack or pinhole, 10 mm^2 or less.
Large Leak is defined as a crack or hole, 10 mm^2 to 1000 mm^2.

Small Leak, in Pipe <2"

$$\frac{\frac{0.001}{10^6 \cdot \text{hrs}}}{\text{m}} = 3.05 \times 10^{-10} \cdot \text{ft}^{-1} \text{ per hr}$$

Large Leak, in Pipe <2" per hr

$$\frac{\frac{0.0001}{10^6 \cdot \text{hrs}}}{\text{m}} = 3.05 \times 10^{-11} \cdot \text{ft}^{-1}$$

Break, in Pipe <2"

$$\frac{\frac{0.00003}{10^6 \cdot \text{hrs}}}{\text{m}} = 9.14 \times 10^{-12} \cdot \text{ft}^{-1} \text{ per hr}$$

Use of the above chemical/refinery data is conservative because cryogenic piping does not experience the corrosion or corrosion stress cracking of piping in chemical/refinery service.

Pipe leaks and Break - Argon Pump Loop

This calculation determines the Argon leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure is taken as the discharge pressure of the Argon pump. This results in the worst case Argon flows. The calculations are performed as flow across an orifice of the leak or pipe size.

Argon Data

Argon physical properties from NIST REFPROP

Argon Liquid Density

$Ldens_{Ar} := 1395 \cdot \frac{kg}{m^3}$

Argon Gas Density @ standard conditions

$Vdens_{Ar.STD} := 0.10535 \cdot \frac{lbm}{ft^3}$

Available Pressure - Across Orifice

$\Delta P := 50 \cdot psi - 0 \cdot psi$

Orifice Flow Coefficient (squeare edged orifice)

$C := 0.62$

Pipe ID - 1" sched 10

$Pipe_{ID} := 1.097 \cdot in$

$Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 0.945 \cdot in^2$

$Area_{S.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$

$Area_{L.leak} := 500 \cdot mm^2 = 0.775 \cdot in^2$

Average large leak size will be used for the calcs.

Flow from Pipe Break - Argon Pump Loop

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 3624 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - Argon Pump Loop

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 59 \cdot \frac{ft^3}{min}$$

Flow from Large Leak - Argon Pump Loop

$$\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 2971 \cdot \frac{ft^3}{min}$$

Full Argon Pump flow to Gas

$$15 \cdot gpm \cdot 150\% \cdot \frac{Ldens_{Ar}}{Vdens_{Ar.STD}} = 2486 \cdot \frac{ft^3}{min}$$

The argon pump cannot deliver enough argon to sustain the large pump loop leak rate.

Pipe Leaks and Break - Argon Vent Pipes

This calculation determines the Argon leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure for vents pipes is 1 psig or less. The calculations are performed as flow across an orifice of the leak or pipe size.

Available Pressure - Across Orifice

$\Delta P := 1 \cdot psi - 0 \cdot psi$

Vent pipe is assumed to be 1" so the earlier pipe area calc applies.

Flow from Pipe Break - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 512 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 8 \cdot \frac{ft^3}{min}$$

Flow from Large Leak - Argon Vent Pipe

$$\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 420 \cdot \frac{ft^3}{min}$$

LAPD Tank Leak

This calculation determines the Argon leak rate for a small leak (10 mm^2), and a large leak (10 mm^2 to 1000 mm^2) from the LAPD tank. The available pressure is significantly lower than that of the Argon pump loop. The calculations are performed as flow across an orifice of the leak or pipe size.

Available Pressure - Across Orifice

$$\Delta P := 2 \cdot psi - 0 \cdot psi$$

Flow from Small Tank Leak

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 12 \cdot \frac{ft^3}{min}$$

Flow from Large Tank Leak

$$\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{Ar}}} \cdot Ldens_{Ar}\right)}{Vdens_{Ar.STD}} = 594 \cdot \frac{ft^3}{min}$$

Calc of Nitrogen pipe leaks and break

This calculation determines the Nitrogen leak rate for a small leak (10 mm^2), a large leak (10 mm^2 to 1000 mm^2) and a pipe break. The available pressure is taken as high side of the Nitrogen trailer delivery pressure range. This results in the worst case Nitrogen flows. The calculations are performed as flow across an orifice of the leak or pipe size.

N2 Data

Physical properties from NIST REFPROP

N2 Liquid Density

$Ldens_{N2} := 807 \cdot \frac{kg}{m^3}$

N2 Gas Density @ standard conditions

$Vdens_{N2.STD} := 1.183 \cdot \frac{kg}{m^3}$

Available Pressure - Across Orifice

$\Delta P := 40 \cdot psi - 0 \cdot psi$

Orifice Flow Coefficient (squeare edged orifice)

$C := 0.62$

Pipe ID - 1", K Copper Tube

$Pipe_{ID} := 0.995 \cdot in$

$Area_{pipe} := \pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2 = 0.778 \cdot in^2$

$Area_{S.leak} := 10 \cdot mm^2 = 0.0155 \cdot in^2$

$Area_{L.leak} := 500 \cdot mm^2 = 0.775 \cdot in^2$

Average large leak size will be used for the calcs.

Flow from Pipe Break - N2 Spply Pipe

$$\frac{\left(C \cdot Area_{pipe} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 11755 \cdot \frac{ft^3}{min}$$

Flow from Small Leak - N2 Supply Pipe

$$\frac{\left(C \cdot Area_{S.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 234 \cdot \frac{ft^3}{min}$$

Flow from Large Leak - N2 Supply Pipe

$$\frac{\left(C \cdot Area_{L.leak} \cdot \sqrt{2 \cdot g \cdot \frac{\Delta P \cdot 1 \frac{lbm}{lbf}}{Ldens_{N2}}} \cdot Ldens_{N2}\right)}{Vdens_{N2.STD}} = 11717 \cdot \frac{ft^3}{min}$$