Fermilab

Particle Physics Division

Mechanical Department Engineering Note

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Project: Lab 6 ODH Analysis (Clean room)

Title: Lab 6 Clean Room Nitrogen Delivery System ODH Analysis

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Abstract Summary:

Lab 6 has a nitrogen delivery system which feeds nitrogen into the Lab 6 Clean room. A flow restricting orifice has been placed on the inlet line which feeds all of Lab 6's nitrogen nozzles. Calculations show the flow of nitrogen could reach nearly 5.1 SCFM and risk analysis of the clean room was conducted following procedures of FESHM 5064, which yielded a fatality factor greater comparable to ODH class Zero.

Layout of Lab 6 Clean Room:

The following table 1 shows only the room where at least one nitrogen port is present, the room volumes and the number of nitrogen ports. Table 2 gives the air flow from the ventilation system.

Table 1: Lab 6 Room volumes with nitrogen ports

Room Name	Nitrogen Ports	Room Volume (ft^3)
Clean Room	1	6380

Table 2: Lab 6 Room ventilation rates

Room Name	Minimum air flow (SCFM)	Minimum fresh flow (SCFM)
Clean Room	250	25

Nitrogen System Description:

The Supply is a 600 Gallon Liquid Nitrogen Tank located outside the building. The nitrogen goes through two vaporizers and a regulator panel where the pressure is set at 30 psig. From there, a ¾" stainless steel tube enters the building and branches out with ¾" tube to the ports in table 1. The flow restricting orifice is placed in this main line before branching out, so the flow is restricted to all lines together. The restrictor has been sized to limit the flow to 5.07 SCFM. Flow and calculations are shown in appendix A, pages A1 and A2.

Ventilation Rates:

The Clean Room has a dedicated air handler unit with the control box. Since flow capacity of the unit was not readily available, as the unit was installed in the 1980's, flow estimations were made, by observing the flow through the exhaust ports. These were set as an extremely conservative 250 SCFM, and a 10% fresh air exchange rate.

Natural ventilation was determined from previous walkthroughs of Lab 6 rooms and other building similar to Lab 6, which state an air exchange every 6 hours is more than reasonable.

ODH analysis:

In this analysis all oxygen concentrations were calculated at the Limit as time approaches infinity.

The following 4 scenarios were analyzed and their contributing fatality factors displayed as well

1. Infinite Nitrogen leak of 5.07 SCFM into room with ventilation.
    a. Fatality Factor 1 = 4.245×10^{-8}
2. Infinite Nitrogen leak of 5.07 SCFM into room with ventilation failure.
    a. Fatality Factor 1 = 8.459×10^{-9}
3. Infinite Nitrogen leak of 5.07 SCFM into room from piping failure.
    a. Fatality Factor 1 = 4.03×10^{-15}
4. Infinite Nitrogen leak of 5.07 SCFM into room with ventilation and human error failure.
    a. Fatality Factor 1 = 2.719×10^{-8}

Total fatality factor of these four scenarios combined yields a Room fatality factor of 7.8×10^{-8} which can be classified as an ODH class zero, even with the multiple conservative assumptions. See appendix A for detailed calculations.

Recommendations / Procedures:

It is recommended and necessary that whenever the nitrogen supply line is used in the Lab 6 clean room, operators check to make sure the air handling system is operational and flowing before opening the nitrogen supply valve. The clean room has air handling monitor gauges visible from the nitrogen supply valve, and the air handling system can easily be heard running in the room by anyone without major hearing damage. If the air handling system fails while the nitrogen supply valve is open, the valve should be immediately shut, and not opened until the air handling system is again operational.

Appendix A

Regulator is set at 30 psig, so maximum pressure drop across the orifice could be 30 psid

Crane 4.10 equation 6.32

$$Max_{flow} = \frac{40700}{60} Y_{critical} \cdot d_1^{\,2} \cdot C \cdot \sqrt{\frac{\Delta P \cdot P_1}{T_1 \cdot S_g}}$$

diameter of orifice

$$d := 0.097in \qquad d_1 := \frac{d}{in} = 0.097$$

Discharge Coefficient

$$C := .6 \quad \text{typical}$$

diameter of tube

$$D := .75in \qquad \beta := \frac{d}{D} = 0.129$$

Claim pressure Drop across orifice

$$\Delta P := 30psi$$

Area of orifice

$$A_i := \frac{\pi}{4} \cdot d^2 = 0.0074 \cdot in^2 \qquad A := \frac{A_i}{ft^2} = 5.132 \times 10^{-5}$$

$$P_2 := 14.3$$

$$P_1 := 30 + 14.3 \qquad \frac{P_2}{P_1} = 0.323$$

we are below the critical pressure ratio which is: $r_c := .535$

$$\Delta P := P_1 \cdot (1 - r_c) = 20.599$$

this value will be used in calculation

$k := 1.54$ Refprop gives 1.54

Net expansion Factor of claimed Pressure Drop and actual (critical) pressure drop

$$Y := 1 - \left(0.351 + .256 \cdot \beta^4 + 0.93 \cdot \beta^8\right) \cdot \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}}\right] = 0.817$$

$$Y_{critical} := 1 - \left(0.351 + .256 \cdot \beta^4 + 0.93 \cdot \beta^8\right) \cdot \left[1 - \left(r_c\right)^{\frac{1}{k}}\right] = 0.883$$

this value will be used in calculation

Temperature of Nitrogen (coldest ambient possible)

$T_1 := (-40 + 460)$ (Rankine)

Specific gravity WRT air

$$S_g := \frac{28}{29}$$

Crane 4.10 equation 6.32

$$MaxFlow := \frac{40700}{60} Y_{critical} \cdot d_1^{\,2} \cdot C \cdot \sqrt{\frac{\Delta P \cdot P_1}{T_1 \cdot S_g}} \cdot SCFM = 5.07 \cdot SCFM$$

The original calculation used wrong Y-value, wrong ΔP, and wrong temperature. This resulted in the equation being off by a factor of 1.25. If the flow needs to be limited to a value of 4 SCFM, the size of the orifice should be at maximum a diameter of 0.0861 inches:

diameter of orifice

$d := 0.0861\text{in} \qquad d_1 := \frac{d}{in} = 0.086$

diameter of tube

$D := .75\text{in} \qquad \beta := \frac{d}{D} = 0.115$

Discharge Coefficient

$C := .6$ typical

Claim pressure Drop across orifice

$\Delta P := 30\text{psi}$

Area of orifice

$A_i := \frac{\pi}{4} \cdot d^2 = 0.0058 \cdot in^2 \qquad A := \frac{A_i}{ft^2} = 4.043 \times 10^{-5}$

$P_2 := 14.3$

$P_1 := 30 + 14.3 \qquad \frac{P_2}{P_1} = 0.323$

we are below the critical pressure ratio which is: $r_c := .535$

$\Delta P := P_1 \cdot (1 - r_c) = 20.599$

This value will be used in calculation

$k := 1.54$ RefProp gives 1.54

Net expansion Factor of claimed Pressure Drop and actual (critical) pressure drop

$$Y := 1 - (0.351 + .256 \cdot \beta^4 + 0.93 \cdot \beta^8) \cdot \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}}\right] = 0.817$$

$$Y_{critical} := 1 - (0.351 + .256 \cdot \beta^4 + 0.93 \cdot \beta^8) \cdot \left[1 - (r_c)^{\frac{1}{k}}\right] = 0.883$$

this value will be used in calculation

Temperature of Nitrogen (coldest ambient possible)

$T_1 := (-40 + 460)$ (Rankine)

Specific gravity WRT air

$S_g := \frac{28}{29}$

Crane 4.10 equation 6.32

$$MaxFlow_4 := \frac{40700}{60} Y_{critical} \cdot d_1^2 \cdot C \cdot \sqrt{\frac{\Delta P \cdot P_1}{T_1 \cdot S_g}} \cdot SCFM = 4 \cdot SCFM$$

Calculations of fatality factors and oxygen concentrations for the previous (correct) flow rate of nitrogen of 5.07 SCFM follow.

Scenario 1

Clean Room Calculations

$Height := 10ft + 8in$

$Length := 26ft$

$Width := 23ft$

$BldgVolume := Height \cdot Length \cdot Width = 6379ft^3$

$$Natural_{intoRoom} := \frac{BldgVolume}{6hr} = 17.719 \cdot cfm$$

$$Ventilation_{intoRoom} := 250cfm \cdot 10\% = 25 \cdot cfm$$

$$oxygen_{intoRoom} := \left(Ventilation_{intoRoom} + Natural_{intoRoom}\right) \cdot 21\% = 8.971 \cdot cfm$$

$$Total_{intoRoom} := Natural_{intoRoom} + Ventilation_{intoRoom} + MaxFlow = 47.79 \cdot cfm$$

$$O_{2Percent} := \frac{oxygen_{intoRoom}}{Total_{intoRoom}} = 18.771 \cdot \%$$

$$PO2 := O_{2Percent} \cdot 739 = 138.721$$

$$F_f := 10^{\left(6.5 - \frac{PO2}{10}\right)} = 4.245 \times 10^{-8}$$

Class Zero

$$Class(F_f) := \begin{cases} 0 & \text{if } F_f < 10^{-7} \\ 1 & \text{if } \left| \begin{array}{l} F_f < 10^{-5} \\ F_f > 10^{-7} \end{array} \right. \\ 2 & \text{if } \left| \begin{array}{l} F_f < 10^{-3} \\ F_f > 10^{-5} \end{array} \right. \\ 3 & \text{if } F_f > 10^{-3} \end{cases}$$

$Class(F_f) = 0$

$F_{f\_CR\_w.Vent} := F_f$

Scenario 2

Ventilation Failure

$$oxygen_{intoRoom} := \left(Natural_{intoRoom}\right)\cdot 21\% = 3.721\cdot cfm$$

$$Total_{intoRoom} := Natural_{intoRoom} + MaxFlow = 22.79\cdot cfm$$

$$O_{2Percent} := \frac{oxygen_{intoRoom}}{Total_{intoRoom}} = 16.327\cdot\%$$

$$PO2 := O_{2Percent}\cdot 739 = 120.656$$

$$F_f := 10^{\left(6.5-\frac{PO2}{10}\right)} = 2.719\times 10^{-6}$$

Failure Rate of Ventilation system

Ventilation system can fail if:

1. Power Outage $\quad FR_{power} := \frac{10^{-4}}{hr}$
2. Circuit Breaker/fuse Fails $\quad FR_{circuit} := \frac{10^{-6}}{hr}$
3. Motor failure $\quad FR_{motor} := \frac{10^{-5}}{hr}$
4. Handler turned off $\quad FR_{off} := \frac{3\cdot 10^{-3}}{hr}$

$$FR_{ventilation} := FR_{power} + FR_{circuit} + FR_{motor} + FR_{off} = 3.111\times 10^{-3}\cdot\frac{1}{hr}$$

$$FatalityFactor := F_f\cdot FR_{ventilation}\cdot hr = 8.459\times 10^{-9}$$

$$Class(FatalityFactor) := \begin{cases} 0 & \text{if } FatalityFactor < 10^{-7} \\ 1 & \text{if } FatalityFactor < 10^{-5} \wedge FatalityFactor > 10^{-7} \\ 2 & \text{if } FatalityFactor < 10^{-3} \wedge FatalityFactor > 10^{-5} \\ 3 & \text{if } FatalityFactor > 10^{-3} \end{cases}$$

$$Class(FatalityFactor) = 0$$

$$F_{fVentFail} := FatalityFactor$$

Scenario 3

Piping Failure

Piping is 165 feet long and has 20 ball valves

$num_{valves} := 20$

Failure rate of ball valves (rupture) $FR_{ballValves} := \frac{10^{-8}}{hr} \cdot num_{valves} = 2 \times 10^{-7} \cdot \frac{1}{hr}$

$l_{pipe} := 165ft$

Failure rate of pipe (rupture) $F_{Pipe\_Rupture} := \frac{\frac{0.00003}{10^{6} \cdot hr}}{m} \cdot 165ft = 1.51 \times 10^{-9} \cdot \frac{1}{hr}$

FailureRate of piping system

$FR_{pipingSystem} := FR_{ballValves} + F_{Pipe\_Rupture} = 2.015 \times 10^{-7} \cdot \frac{1}{hr}$

FailureRate of piping system and Ventilation system

$FR_{PS\_a\_VS} := FR_{pipingSystem} \cdot FR_{ventilation} \cdot \left(2.719 \times 10^{-6}\right) \cdot hr = 1.705 \times 10^{-15} \cdot \frac{1}{hr}$

Assuming all the nitrogen leaks into the Clean Room, the oxygen percentage and associated risk would be:

$Ventilation_{intoRoom} := 500cfm \cdot 10\% = 50 \cdot cfm$

$Natural_{intoRoom} := \frac{BldgVolume}{6hr} = 17.719 \cdot cfm$

$oxygen_{intoRoom} := \left(Ventilation_{intoRoom} + Natural_{intoRoom}\right) \cdot 21\% = 14.221 \cdot cfm$

$Total_{intoRoom} := Natural_{intoRoom} + Ventilation_{intoRoom} + MaxFlow = 72.79 \cdot cfm$

$O_{2Percent} := \frac{oxygen_{intoRoom}}{Total_{intoRoom}} = 19.537 \cdot \%$

$PO2 := O_{2Percent} \cdot 739 = 144.378$

$F_{f\_PipeSystemO2} := 10^{\left(6.5 - \frac{PO2}{10}\right)} = 1.154 \times 10^{-8}$

Fatality Factor of piping system failure and leaking into the Long Box Room with ventilation

$$F_{f\_PipingFailure} := FR_{pipingSystem} \cdot F_{f\_PipeSystemO2} \cdot hr = 2.326 \times 10^{-15}$$ Class Zero

$$F_{f\_PipingFailure} + FR_{PS\_a\_VS} \cdot hr = 4.03 \times 10^{-15}$$

Scenario 4

Human Error Analysis:
Operator enters room after ventilation fan has already failed, and does not notice there is no ventilation into the room, and uses nitrogen valve anyway.

General human error of omission where there is no display in the control room of the status of the item omitted, e.g., failure to return manually operated test valve to proper configuration after maintenance

$$F_{human} := 10^{-2} \frac{1}{demand}$$

$$oxygen_{intoRoom} := \left(Natural_{intoRoom}\right) \cdot 21\% = 3.721 \cdot cfm$$

$$Total_{intoRoom} := Natural_{intoRoom} + MaxFlow = 22.79 \cdot cfm$$

$$O_{2Percent} := \frac{oxygen_{intoRoom}}{Total_{intoRoom}} = 16.327 \cdot \%$$

$$PO2 := O_{2Percent} \cdot 739 = 120.656$$

$$F_f := 10^{\left(6.5 - \frac{PO2}{10}\right)} = 2.719 \times 10^{-6}$$

In this case, the rate of ventilation failure and frequency of this scenario are inversely proportional, so the demand rate has no effect on this scenario.

$$F_{f\_h\_Error} := F_f \cdot F_{human} = 2.719 \times 10^{-8}$$

Total Supply Line Fatality factor

$$FF_{supplyLine} := F_{f\_CR\_w.Vent} + F_{fVentFail} + F_{f\_PipingFailure} + FR_{PS\_a\_VS} \cdot hr + F_{f\_h\_Error}$$

$$Class(FF_{supplyLine}) := \begin{cases} 0 & \text{if } FF_{supplyLine} < 10^{-7} \\ 1 & \text{if } \begin{cases} FF_{supplyLine} < 10^{-5} \\ FF_{supplyLine} > 10^{-7} \end{cases} \\ 2 & \text{if } \begin{cases} FF_{supplyLine} < 10^{-3} \\ FF_{supplyLine} > 10^{-5} \end{cases} \\ 3 & \text{if } FF_{supplyLine} > 10^{-3} \end{cases}$$

$$FF_{supplyLine} = 7.81 \times 10^{-8}$$

$$Class(FF_{supplyLine}) = 0$$

The Supply Line shows a total ODH risk which falls under the class zero classification