T962 PAB ODH ANALYSIS ANALYSIS

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(1.0) Introduction

This document presents the T962 LAR TPC PAB ODH analysis. Plare may be operating in PAB at the same time as T962. The MINOS hall and Acess tunnel Please refer to the Flare 12-07-07 safety report for supporting documentation.

(2.0) General Information

(2.1) Equipment Failure Rates

FESHM 5064.TA pages 4-5, Table 2, NRC Equipment Failure Rate Estimates

```
Pfdew  =  1e-6**(1/hr)      (probability of dewar rupture)
```

FESHM 5064.TA page 3, Table 1, Fermilab Equipment Failure Rate Estimates

```
Pfp  =  1e-9**(1/hr)      (probability of pipe section failure)
Pfv  =  1e-8**(1/hr)      (probability of valve external leak)
Pfr  =  1e-5**(1/hr)      (probability of premature opening of relief valve)
Pfw  =  3e-9**(1/hr)      (probability of weld failure)
Pfg  =  3e-7**(1/hr)      (probability of gasket failure)
Pfms  =  3e-4      (probability of motor failure to start on demand)
Pmoterfail  =  1e-5**(1/hr)      (probability of running motor failure)
Ppowerout  =  1e-4**(1/hr)      (probability of a power outage)
Pdieselfail  =  3e-2      (probability of diesel plant not starting on demand)
```

Fan failure

Use the existing PAB ODH analysis on the Flare Safety Report page 52, as a sourse of information for the fan failure. The fan availability is:

```
FanAvail  =  0.9993
```

By definition, the fan has failed to run when it is not available. The probabilty of a fan failure is 1 minus the fan availability.

```
Pffan  =  1-FanAvail
Pffan  =  0.0006999999
```

(2.2) Fluid Properties

From Airco Industrial Gases Data Handbook (AGG 1077C), the following data was acquired. Listed are the densities at standard conditions (70 F and 1 ATM) of helium. nitrogen and air. Also there is the density of Liquid nitrogen at 1 ATM and the conversion of gallons of liquid nitrogen to cubic feet of nitrogen gas at standard conditions.

```
RhoStdAir  =  0.07493**(lb/ft^3)      (density of air at standard conditions)
RhoStdAr  =  0.1034**(lb/ft^3)      (density of argon at standard conditions)
CpAr  =  0.1244**(BTU/(lb*R))      (specific heat of argon gas)
CpAir  =  0.2406**(BTU/(lb*R))      (specific heat of air)
RhoLAr  =  1.3936**(lb/L)      (density of liquid argon at 1 atm)
```

density of water

```
rhoH2O  =  62.4**(lb/ft^3)
```

density and viscosity of saturated vapor argon at 1 atm. AIRCO Industrial Gases Data Book

```
RhoArVap  =  0.35976**(lb/ft^3)      (argon vapor density)
MuArVap  =  72.4e-6**(gm/(cm*s))      (argon vapor viscosity)
```

From NIST at 2.5 psig, or 17.2 psia , for saturated vapor argon, the density and viscosity are:

```
rhoArV25  =  0.4163**(lb/ft^3)
muArV25  =  4.909e-6**(lb/(ft*s))
```

(2.3) Ventilation Rates

Use the existing PAB ODH analysis on the Flare Safety Report page 52, as a sourse of information for the ventilation rate:

```
Qmixfan  =  2000**(ft^3/min)
```

(2.4) PAB Dimensions

PAB main hall height:

PAB main hall width:

PAB main hall length:

Volume of PAB main hall.

```
Vol  =  Hpab*Lpab*Wpab
Vol  =  122500**(ft^3)
Vol2  =  2**ft*Lpab*Wpab
Vol2  =  9800**(ft^3)
```

(2.5) Cryostat Data

Dimensions and volume of cryostat

```
InnerOD  =  30**in       (outside diameter of inner vessel)
Convert(ToFt)InnerOD
InnerOD  =  2.5**ft
```

Inner vessel wall. PHPK 07-2032-BM-6501C, item 3

```
InnerWall  =  (3/16)**in
```

From PHPK DRW # 07-2032-6501, SHEET 2 of :

```
InnerL  =  (49+15/16)**in      (overall length of inner vessel)
InnerL  =  49.9375**in
Convert(ToFt)InnerL
InnerL  =  4.1614583333**ft
```

Use a Conservative formula to calculate the liquid argon volume.

```
VLar  =  InnerL*Pi*InnerOD^2/4
VLar  =  0.2042751082e2**(ft^3)
Convert(ToLiter)VLar
VLar  =  0.5784427599e3**L
```

By itself a single 160L liquid argon dewar used in filling the main dewar, has a liquid volume of:

```
M160  =  V160*RhoLAr      (mass of 160L liquid argon dewar)
M160  =  0.222976e3**lb
Q160  =  M160/RhoStdAr      (160 L dewar,  cubic feet of argon)
Q160  =  2156.4410058027**(ft^3)
```

At the end of filling operations, there could still be a partial 160 L portable dewar left in PAB. Assume a full 160 L dewar connected to a full 500L stationary dewar.

```
TVLAr  =  0.7384427599e3**L      (total volume of liquid argon)
TMAr  =  TVLAr*RhoLAr      (total mass of argon)
TMAr  =  0.102909383e4**lb
TQAr  =  TMAr/RhoStdAr      (total standard cubic feet of argon)
TQAr  =  9952.551549486**(ft^3)
```

(2.6) Cryogenic System Data

The Flow schematic 9219.000-MD-444703 27 valves on the system that come in contact with argon in PAB. Asume a larger number so that this analysis remains valid even if small changes are made to the system.

```
NumArV  =  40      (number of argon valves)
```

FESHM 5064 lists failure rates of piping as per section of pipe. Generally pipes come in 20 ft sections. Assume 100 ft of pipe and tubing.

```
SecArPipe  =  5      (sections of argon piping)
```

The number of relief valves that vent into PAB.

```
NumArRV  =  0      (number of argon relief valves)
```

Number of welds on the argon piping system.

```
NumArWelds  =  150      (number of welds on argon piping)
```

There will be one traditional piping gaskets on the system. But there will be a number of connections with metal to metal seals or orings. The probability of failure for gaskets, listed in FESHM 5064, for these connections.

```
NumArGasket  =  12      (number of joints with seals)
```

(2.7) Depressurizing The Dewar After Piping Failure

Assume the dewar is full of liquid and under 3 bar pressure and there is a sudden cryogenic system piping failure causing the dewar to rapidly depressurize and vent argon into PAB. Determine the mass fraction of that is vaporized and vented into PAB.

Argon Properties

The internal energy and density of the liquid in the dewar at 3 bar before the piping failure is:

```
uL3  =  82.2382**(J/gm)
rhoL3  =  1.349**(gm/cm^3)
```

After the piping failure the enthalpy of the vapor leaving the cryostat at the average pressure of 2 bar is:

```
hV2  =  238.2252**(J/gm)
```

After the dewar is depressurized, the liquid and vapor properties at 1 bar is:

```
uL1  =  73.677**(J/gm)
uV1  =  218.3639**(J/gm)
rhoL1  =  1.393**(gm/cm^3)
rhoV1  =  0.005705**(gm/cm^3)
```

Calculate Volume Fraction

In the following formula, y is the volume fraction of the dewar that is vapor after the dewar is depressurized from 3 bar to 1 bar. This formula was derived from an energy and mass balance on the dewar volume. The derivation assumed the enthalpy of the vapor departing the dewar is the saturated vapor enthalpy at 2 bar. It will be shown that this formula satisfies a mass balance and energy balance equations on the the control dewar.

```
y  =  (rhoL3*uL3-rhoL1*uL1-rhoL3*hV2+rhoL1*hV2)/(rhoV1*uV1-rhoL1*uL1-rhoV1*hV2+rhoL1*hV2)
y  =  0.820121702e-1
```

Mass Balance

The control volume in these calculations is the original volume of the liquid in the dewar.

```
Vdew  =  VLar
Vdew  =  0.5784427599e3**L
Convert({L<-cm^3})Vdew
Vdew  =  0.5784427599e3**(cm^3)
```

The Total mass in the dewar when it is 100% liquid at 3 bar.

```
Mtotal  =  rhoL3*Vdew
Mtotal  =  0.7803192831e3**gm
```

Mass of vapor argon remaining in the dewar when it is at 1 bar, after vapor has vented from the dewar.

```
MV1  =  y*rhoV1*Vdew
MV1  =  0.2706414693**gm
```

Mass of liquid argon remaining in the dewar when it is at 1 bar, after vapor has vented from the dewar.

```
ML1  =  (1-y)*rhoL1*Vdew
ML1  =  0.7396877554e3**gm
```

Mass of argon remaining in the dewar when it is at 1 bar.

```
M1  =  ML1+MV1
M1  =  0.7399583969e3**gm
```

Mass of argon vapor exiting the dewar into PAB.

```
Me  =  Mtotal-M1
Me  =  0.4036088618e2**gm
```

Perform a mass balance on the dewar. Mass that was in the dewar before it was depressurized should equal the mass left in the dewar afterward plus the mass that exits the dewar.

```
Mtotal==M1+Me
0.7803192831e3**gm==0.7803192831e3**gm
```

The Mass baance is satisfied.

Energy Balance

The Total energy in the dewar, in the before state, when it is 100% liquid at 3 bar.

```
Etotal  =  Mtotal*uL3
Etotal  =  0.6417205327e5**J
```

Energy of argon vapor exiting the dewar into PAB.

```
Ee  =  Me*hV2
Ee  =  0.9614980182e4**J
```

Energy left in dewar after it is depressurized.

```
E1  =  MV1*uV1+ML1*uL1
E1  =  0.5455707308e5**J
```

Energy balance

```
Etotal==E1+Ee
0.6417205327e5**J==0.6417205327e5**J
```

The energy balance is satisfied. The equations used above to determine the mass of argon vaporized when depressurizing are correct. The mass fraction of the total argon that is vented.

```
Mfraction  =  (Mtotal-M1)/Mtotal
Mfraction  =  0.5172355349e-1
```

(3.0) Preliminary Calculations

(3.1)

Void Section

(3.2)

Void Section

(3.3)

Void Section

(3.4) After Piping Failure, Mixing in the Bottom 2 ft of the PAB main hall

Assume the cryogenic piping system fails causing the dewar to depressurize. As discussed in section 2.7, ony a small fraction of the dewar contents will be vented due to the depresurrizing process. Assume this vent rate, for a short time overwems the mixing system. Determone the fatality factor in the bottom 2 fet.

```
Qair  =  Vol2-Mfraction*TQAr      (standard cubic feet of air)
Qair  =  9285.2186675564**(ft^3)
ocr  =  0.21*Qair/Vol2      (oxygen concentration)
ocr  =  0.1989689714
```

Fatality factor:

```
FatalityFactor(ocr)  =  0.0**fatalities
```

There is no ODH problem for the initial release from a piping failure.

(3.5) Complete Mixing of 160L Dewar in the Bottom 2 ft of the PAB main hall

The issue of 160L dewars was addressed in the Flare PAB ODH analysis.

(3.6) Normal Boil Off From Dewar

There is a 350 W electric heater inside the cryostat. The heat load on the cryostat is expected to be 100W. The Cryocooler that cools the cryostat has only a 350W capacity. Determine the sustained boiloff from the dewar if there is a piping leak. Assume there is a large leak o the piping above the cryostat. Assume for instance, the top 18 inch flange on the cryostat is unbolted or a 1/2 inch cryogenic line is severed into two pieces. Section 3.5 above, shows that the initial pressurization of the dewar would at most boilf off less than 6% of the argon liquid. What is the maximum sustained boilf off from the cryostat after such an accident.

Assume the cryostat is venting into PAB. Assume tat liquid argon in the cryostat is at 14.7 psia and the heater is at full power. Assume the external heat load on the cryostat is twice the expected 100W. The normal heat load Qn, on the cryostat would then be:

```
Qn  =  350**W+2*100**W
Qn  =  550**W
```

For saturated vapor argon at 14.7 psia, the enthalpy is:

```
hg  =  43.6193**(J/gm)
```

For saturated liquid argon at 14.7 psia, the enthalpy is:

```
hf  =  (-0.117517e3)**(J/gm)
```

The release rate from the dewar open to the atomosphere in PAB is:

```
RRn  =  Qn/((hg-hf)*RhoStdAr)
RRn  =  33.0102462087**((W*gm*ft^3)/(lb*J))
Convert({ToLb,ToJS,ToMin})RRn
RRn  =  4.3665078438**(ft^3/min)
```

(3.7)

Void Section

(3.8) Release Rate From Dewar Inner Vessel Failure

Assume the dewar inner vessel fails. The vacuum jacket will fill with argon and its relief valve will open venting to the surface. Detrmine the leak rate rate out of the vacumm jacket flanges into PAB.

End Flange

This assumes an internal dewar leak

Flange dimensions are below. PHPK 07-2032-BM-6502C, item 15

```
flangeid  =  41.5**in
flangeod  =  48.0**in
```

Machining tolerances are on PHPK drawing 07-3032-6502 sheet 4.0

```
gap  =  0.010**in
wd  =  Pi*(flangeid+flangeod)/2      (average width of the flow path)
wd  =  0.1405862712e3**in
a  =  wd*gap
a  =  0.0140586271e2**(in^2)
Le  =  (flangeod-flangeid)/2
Le  =  3.25**in
```

The pressure drop across the flange is the internal pressure rating of vacuum jacket.

```
dp  =  5**psi
```

fluid properties, use the average pressure in the flow path.

```
rho  =  rhoArV25      (density)
rho  =  0.4163**(lb/ft^3)
mu  =  muArV25      (viscosity)
mu  =  4.909e-6**(lb/(ft*s))
```

Hydraulic diameter is 4 times the flow area divided by the perimeter of the flow path.

```
dh  =  4*a/(2*wd)
dh  =  0.2e-1**in
```

Assume f

```
f  =  0.0411      (assume a friction factor)
```

input K factors

```
Kin  =  0.5
Kout  =  1.0
Kl  =  f*Le/dh
Kl  =  6.67875
Ktotal  =  Kin+Kl+Kout      (total K factor)
Ktotal  =  8.1787499999
```

Calculate Velocity

```
v  =  ((dp*2*gc)/(Ktotal*rho))^0.5      (velocity)
v  =  9.7208861474**((psi^0.5*ft^2.)/(lbf^0.5*s))
v  =  Convert({{psi<-1*lbf/in^2},ToFt})v
v  =  116.6506337687**(ft/s)
```

Confirm that correct friction actor was used. The Reynolds number is:

```
Re  =  dh*v*rho/mu      (Reynolds number)
Re  =  0.1978474591e6**(in/ft)
Re  =  Convert({ToFt,ToSec,ToLb})Re
Re  =  0.1648728825e5
epsilon  =  epsilon      (pipe roughness)
```

```
f  =  FrictionFactor3(Re,epsilon,id)      (confirm assumed friction factor)
f  =  FrictionFactor3(0.1648728825e5,0.00015**ft,id)
```

outputs

```
w  =  a*v*rho      (mass flow)
w  =  0.6827102541e2**((lb*in^2)/(ft^2*s))
```

Mass flow rate through end flange

```
wef  =  Convert(ToFt)w
wef  =  0.4741043431**(lb/s)
```

(3.9) Case 3, Piping Component Failure

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

The release rate RRpipe ; see section 3.2.

```
W3  =  224**(lb/hr)
RR3  =  W3/RhoStdAr      (case 3 release rate)
RR3  =  2166.3442940039**(ft^3/hr)
Convert(ToMin)RR3
RR3  =  36.1057382334**(ft^3/min)
```

Side Flange

Flange dimensions are below. PHPK 07-2032-BM-6502C, items 20 and 25

```
flangeid  =  14.0**in
flangeod  =  18.0**in
wd  =  Pi*(flangeid+flangeod)/2      (average width of the flow path)
wd  =  0.5026548245e2**in
a  =  wd*gap
a  =  0.0502654824e1**(in^2)
Le  =  (flangeod-flangeid)/2
Le  =  2.**in
```

Hydraulic diameter is 4 times the flow area divided by the perimeter of the flow path.

```
dh  =  4*a/(2*wd)
dh  =  0.2e-1**in
```

Assume f

```
f  =  0.0411      (assume a friction factor)
```

input K factors

```
Kin  =  0.5
Kout  =  1.0
Kl  =  f*Le/dh
Kl  =  4.11
Ktotal  =  Kin+Kl+Kout      (total K factor)
Ktotal  =  5.6100000001
```

Calculate Velocity

```
v  =  ((dp*2*gc)/(Ktotal*rho))^0.5      (velocity)
v  =  11.7372915563**((psi^0.5*ft^2.)/(lbf^0.5*s))
v  =  Convert({{psi<-1*lbf/in^2},ToFt})v
v  =  140.8474986762**(ft/s)
```

Confirm that correct friction actor was used. The Reynolds number is:

```
Re  =  dh*v*rho/mu      (Reynolds number)
Re  =  0.2388869981e6**(in/ft)
Re  =  Convert({ToFt,ToSec,ToLb})Re
Re  =  0.1990724984e5
epsilon  =  epsilon      (pipe roughness)
f  =  FrictionFactor3(Re,epsilon,id)      (confirm assumed friction factor)
f  =  FrictionFactor3(0.1990724984e5,0.00015**ft,id)
```

outputs

```
w  =  a*v*rho      (mass flow)
w  =  0.2947307199e2**((lb*in^2)/(ft^2*s))
```

Mass flow rate through side flange

```
wsf  =  Convert(ToFt)w
wsf  =  0.204674111**(lb/s)
```

Combined mass flow rate through flanges.

```
wf  =  wef+wsf
wf  =  0.6787784542**(lb/s)
RRvflange  =  wf/RhoStdAr      (volumetric flow at standard conditions)
RRvflange  =  6.5645885322**(ft^3/s)
RRvflange  =  Convert(ToMin)RRvflange
RRvflange  =  393.8753119367**(ft^3/min)
```

(3.9) Case 3, Simultaneous Piping Failure and Loss of Vacuum

From the dewar engineering note, the mass flow rate in the vent system for a loss of vacuum is:

```
W3  =  224**(lb/hr)
```

If there were a piping failure at the same time, the release rate into the hall would be:

```
RR3  =  W3/RhoStdAr      (case 3 release rate)
RR3  =  2166.3442940039**(ft^3/hr)
Convert(ToMin)RR3
RR3  =  36.1057382334**(ft^3/min)
```

(4.0) Probability of Events That Cause Large Argon Releases

(4.1) (Case 1) Dewar Inner Vessel Failure

This dewar is unusual in that the inner vessel is not entirely welded; it has a large internal flange with a metal seal. The probability of a failure of the inner vessel will be then be the normal dewar failure rate used at Fermilab plus a gasket failure rate to account for the possibility of the flange seal leaking.

```
Pr1  =  Pfdew+2*Pfg      (case probability)
Pr1  =  0.16e-5**(1/hr)
```

(4.2) (Case 2) Simultaneous Inner vessel and Vacuum Vessel Failure

This is the probability of an inner vessel failure from case 1 times the probability of a vacuum vessel failure. The vacuum vesel failure rate is assumed to be the same as a dewar.

```
Pr2  =  Pfdew*1**hr*(Pfdew+2*Pfg)      (case probability)
Pr2  =  0.16e-11**(1/hr)
```

(4.3) Case 3, Probability of Failed Argon Piping

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
Pr3  =  Pfp*SecArPipe+Pfv*NumArV+Pfw*NumArWelds+Pfg*NumArGasket      (case 3 probability)
Pr3  =  0.4455e-5**(1/hr)
```

(5.0) Calculate ODH Classification

Look at four different cases.

(5.1) Case 1 Dewar Internal Vessel Failure

The dewar inner vessel fails and argon leaks from the vacuum jacket flanges.

```
ocr  =  0.21*Qmixfan/(Qmixfan+RRvflange)      (O2 concentration with fan)
ocr  =  0.1754477344
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.2194926173e-6**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi1  =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1  =  0.1120350942e-8**(fatalities/hr)
```

(5.2) Case 2 Simultaneous Cryostat Vacuum Vessel and Inner Vessel Failure

Assume a fatality factor of 1.0 for this rare event :

```
FF  =  1.0**fatalities
Phi2  =  Pr2*FF
Phi2  =  0.16e-11**(fatalities/hr)
```

(5.3) Case 3, Piping Component Failure

assume a simultaneous loss of vacuum. Use the release rate calulated in section 3.10

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr  =  0.2062761241
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi3  =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3  =  0.31185e-8**(fatalities/hr)
```

(5.4) Case IV, Flare

From the existing PAB ODH analysis on the Flare Safety Report page 57 (lower right hand corner), the total phi for all of Flare is:

```
PhiFlare  =  4.24e-9**(fatalities/hr)
```

(5.5) ODH Classification

```
Phitotal  =  Phi1+Phi2+Phi3+PhiFlare
Phitotal  =  0.8480450942e-8**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 0
```

PAB has an ODH 0 classiication with both T962 and Flare operating in it.