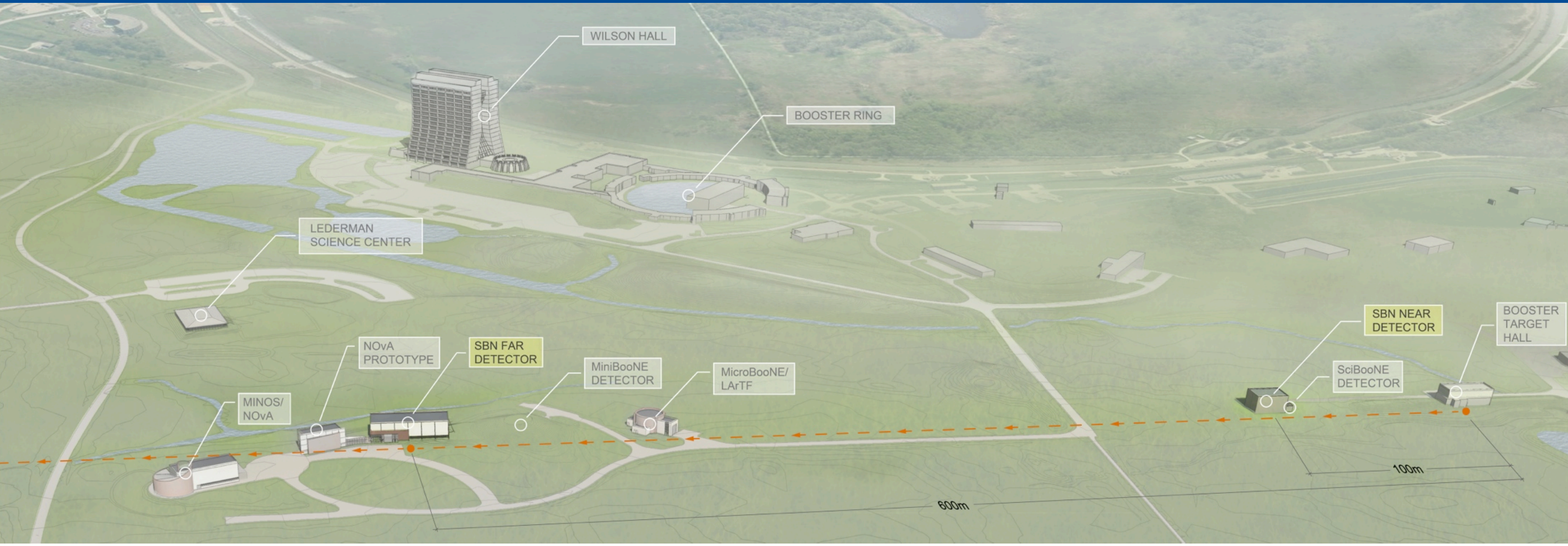


Safety ODH Planning for MINERvA CAPTAIN Cryogenics in MINOS Hall

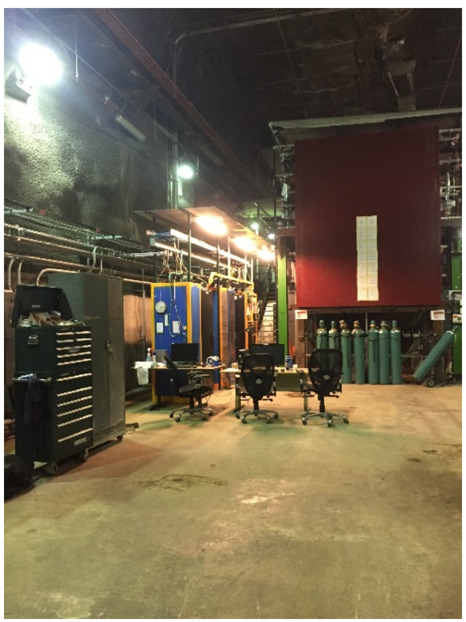
Roza Doubnik and Michael Geynisman (with contribution from K. Haaf)

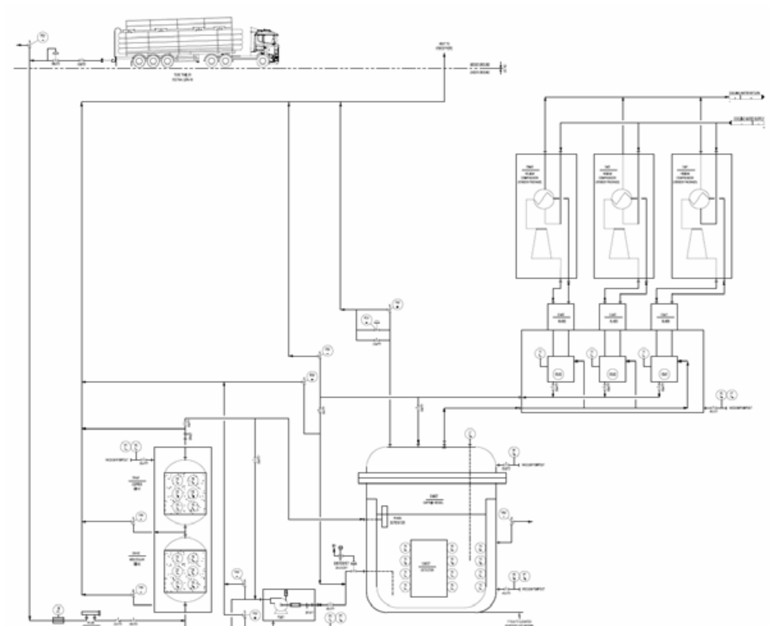
April 2016

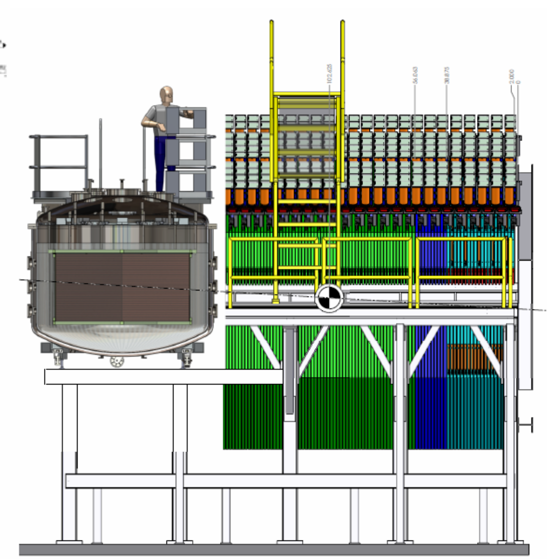
Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

CAPTAIN (*Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos*) is a liquid argon TPC currently being built at Los Alamos National Laboratory to be installed in the MINERvA cavern at Fermilab.

CAPTAIN detector will be installed in place of the existing MINERvA helium target (shown below). CAPTAIN detector would fit conveniently in front of the MINERvA detector and could be supported from below to be centered on the neutrino beam. The helium Gifford-McMahon refrigerators will stay in the cavern to re-condense argon boil-off.







Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

The goal for the MINOS Hall detector buildings is to engineer the facilities for ODH0 classification.

Therefore, this preliminary ODH analysis investigates three major subjects:

1. Fatality calculations and ODH risk assessment per FESHM 4240TA;
2. Proposed engineering solutions for ventilation and containment of spilled argon;
3. Proposed ODH controls measures.

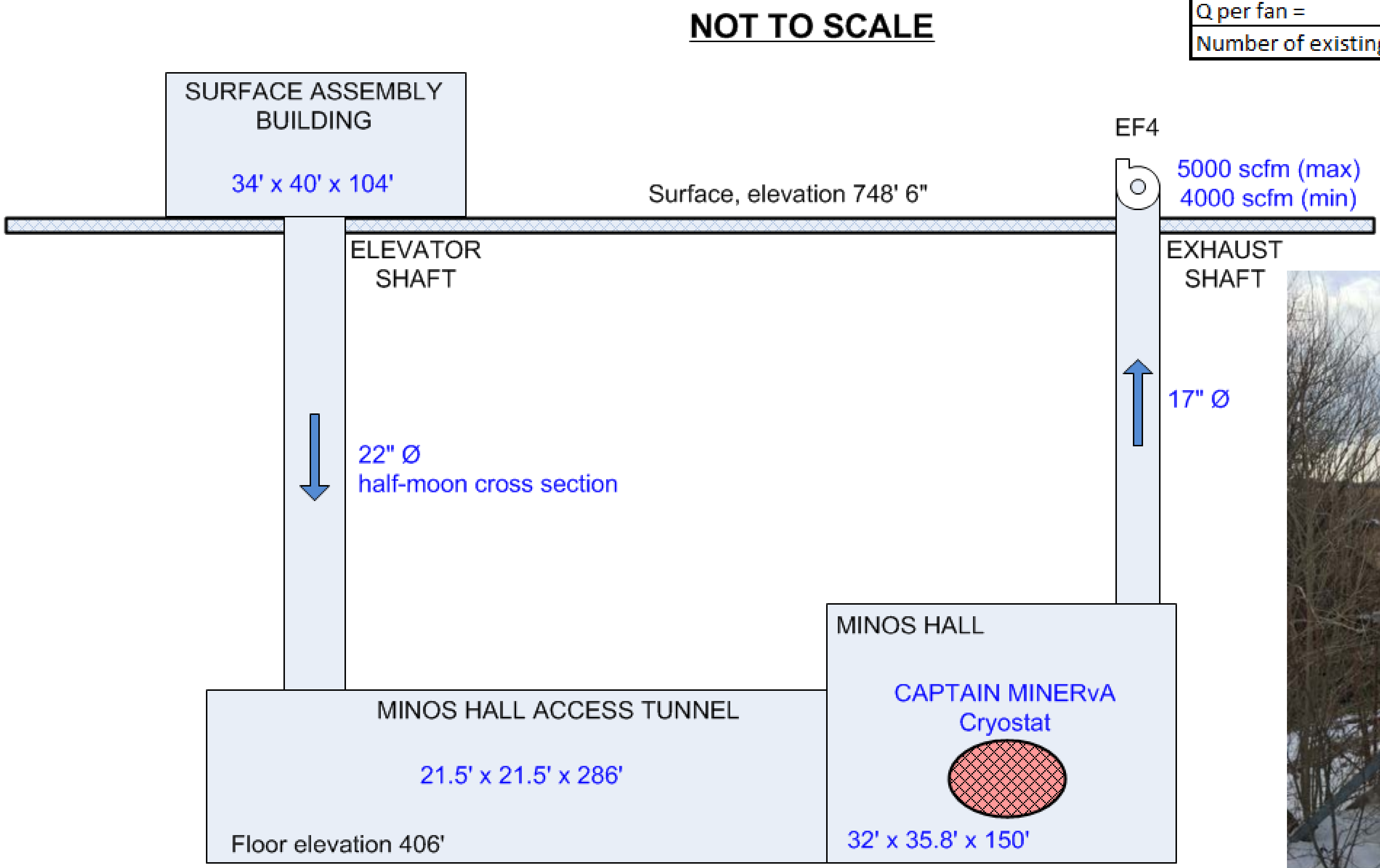
While the total fatality rate may be calculated to be less than 10^{-7} event/hr., this area shall have ODH control measures to allow for personnel warning for oxygen concentration below 19.5% and reliable evacuation to the surface or higher ground.

Notification via FIRUS and assistance from Fire department is typically required for the ODH 0 engineered areas at Fermilab.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Basic configuration of the halls is shown below:

Parameter	Units 1	Values 1
V.max.cryostat.LAr	ft^3	271.9
Cryogen Volume, Vc =	ft^3	215,641
Cavern Volume =	ft^3	304,044
Equipment Volume =	ft^3	101,348
People Space, Vp =	ft^3	202,696
Q per fan =	CFM	4,000
Number of existing fans =		1



Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Spill sources:

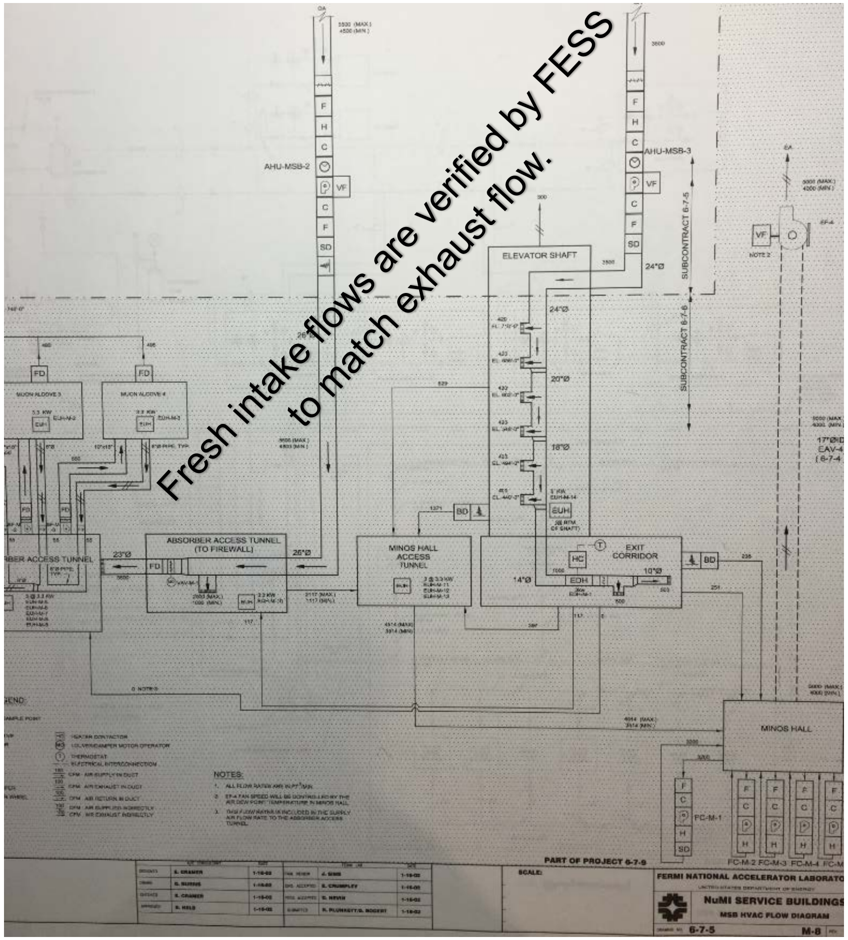
- The helium spill is defined by the maximum helium inventory of approximately one high-pressure helium cylinder of 285 std. cf. We will neglect the effect of helium as it will rise to the ceiling and will occupy less than 3 inches of space in the ceiling height. The source of this helium is the Gifford-McMahon refrigerators.

- The argon spills are defined by the maximum argon inventory of approximately 7700 liters (total capacity of the cryostat, though operations, will typically be at 5,000 liters). The argon spills are defined by the configuration of the cryogenic system, a number of vessels, pumps, pipe sizes, etc. and shown on the next slide.

As the area of the MINOS hall (with the Minos Hall Access Tunnel) is ~10,950 ft^2, the 4 ft. high volume is ~ 43,800 ft3, which equates to ~ 1470 liters (out of 7700 liters available) of spilled liquid argon vaporized and warmed up to 60F. If not mitigated through engineering, including containment and ventilation, a catastrophic spill of argon can result in the fatality.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Ventilation sources in the cavern are defined by available intake and exhaust air flows (shown on FESS dwg. 6-7-5, M-8).



Ventilation air intake is provided with:

- ~4500 scfm with AHU-MSB-3 (on generator) via duct in the MINOS elevator shaft
- ~ 2000 scfm with and AHU-MSB-2 (not on generator) to the absorber access tunnel routed back to MINOS Hall

Ventilation air exhaust is provided with:

- up to 5000 scfm (typically 4000) via 17”dia duct to the EF-4 fan located on the ground level. The intake to the duct is located at the ceiling level, mostly engineered to remove helium from the MINOS Hall.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

We assume the most conservative case, as the spilled argon will not mix and stratify, but remain accumulated at the lowest level. Therefore, both, the oxygen cells and ventilation intake, should be installed at the floor level.

The proposed solutions:

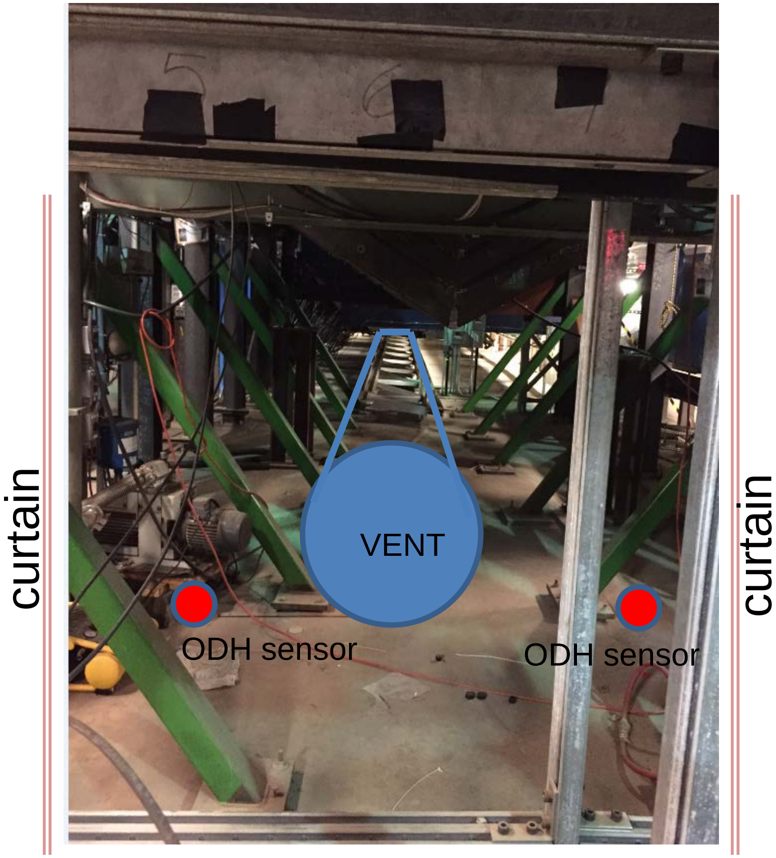
- To make sure that EF-4 to be on generator power and be able to move 5000 scfm Ar. The fan should be ON at all times and should have a flow sensor installed in the ventilation duct. Failure of the fan should be alarmed and repairs initiated. Additionally, ODH classification for the MINOS hall may be changed temporarily to restrict non-qualified ODH personnel from access before the fan is back online (spare fan unit should be available at storage).

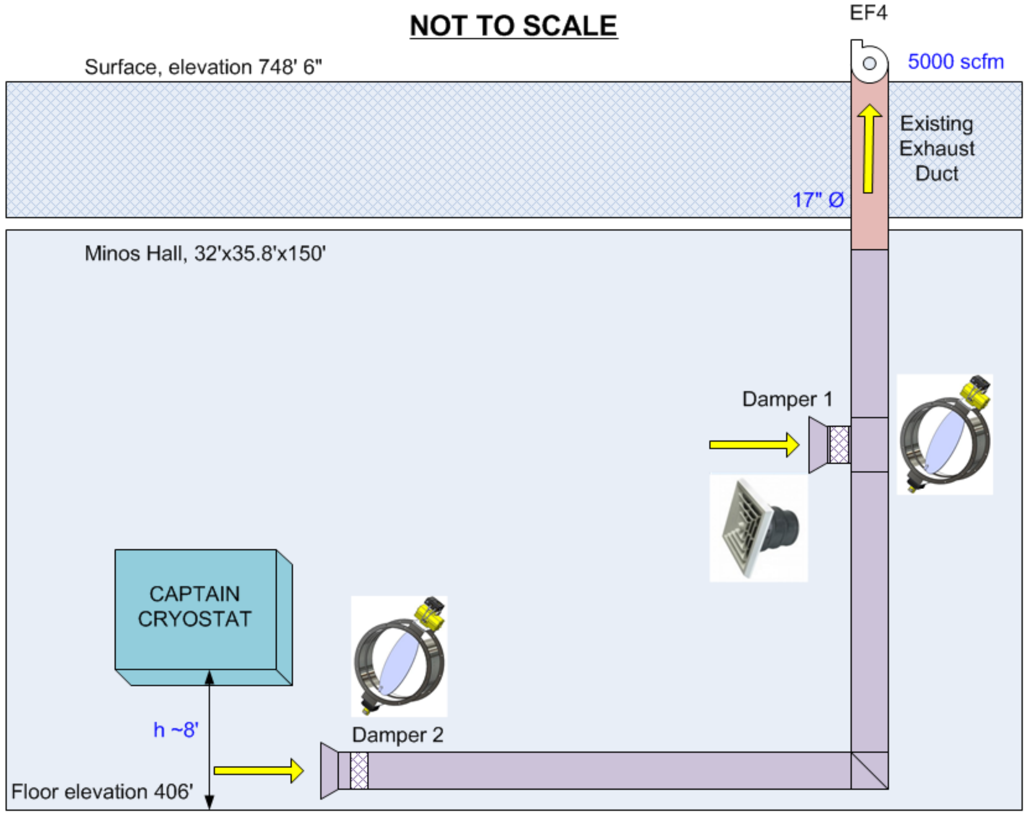
- Drop the 17”dia duct from the ceiling level to the platform level where it would split into two 17”dia ducts equipped with automated louvers (shown schematically on the next slide):
  - ✓ One duct is at the platform level and is normally opened except when ODH alarm is present
  - ✓ Second duct is routed below the detectors at the floor level (for argon/air mixture) and is normally closed except when ODH alarm is present

  The location of the vent duct is advantageous, as it creates the ventilation flow in the direction opposite to the way of egress.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

The ~ 20' x 30' area around the cryostat and associated cryogenic equipment will be curtained off by 6' high fire retardant plastic curtains. ODH sensors will be installed under the cryostat inside the curtained area and at the platform on both sides of the detector. Similar to other installations at Fermilab, where such curtains are used to cordon ODH areas or clean rooms, this will contain spilled warm argon and provide expedited ODH alarming and venting out air/argon mixture, thus allowing personnel more time to escape.





Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

An example the curtains at Fermilab

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

ODH assessment is done with very conservative assumptions for the spill rates. Assumptions for piping lengths and components are based on the proposed flow diagram. The results are shown on the next two slides for two cases, with & without 4,000 scfm available ventilation for the leaks shown below.

Parameter	Units	Value
Cd		0.62
Max. cryostat pressure	psi g	30
Operational system pressure	psi g	60

$$\dot{V}_{STP} = C_d A_{leak} \frac{\rho_{fluid}}{\rho_{STP}} \sqrt{\frac{2\Delta P}{\rho_{fluid}}}$$

at20°C & P_{atm}

Pipe	Fluid	Gas/Liquid	Oper. Pres.	Abs.	Pipe ID		Thickness		Pipe Area		Small Leak Area		Large Leak Area		ρ	ρSTP	Small Leak Rate		Large Leak		Rupture Rate	
			(psig)	(MPa)	(in)	(m)	(in)	(m)	(m^2)	(mm^2)	(mm^2)	(m^2)	(mm^2)	(m^2)	(kg/m^3)	(kg/m^3)	(m^3/s)	(SCFM)	(m^3/s)	(SCFM)	(m^3/s)	(SCFM)
Pressure Vessel (cryostat)																						
Cryostat - Ullage	argon	G	30	0.3082	2.157	0.0548	0.1090	0.0028	0.0024	2357.53	50	0.00005	100	0.0001	16.10	1.66	0.05	102.01	0.10	204.02	2.27	4809.84
Cryostat - LAr	argon	L	30	0.3082	1.097	0.0279	0.1090	0.0028	0.0006	609.78	50	0.00005	100	0.0001	1317.86	1.66	0.44	922.90	0.87	1845.79	5.31	11255.22
Pressure Vessels (filtration skid)																						
Pressure Vessel: GAr-2 in	argon	G	60	0.5150	2.157	0.0548	0.1090	0.0028	0.0024	2357.53	5	0.000005	10	0.00001	26.07	1.66	0.01	18.36	0.02	36.72	4.09	8655.88
Pressure Vessel: LAr-1 in	argon	L	60	0.5150	1.097	0.0279	0.1090	0.0028	0.0006	609.78	5	0.000005	10	0.00001	1270.44	1.66	0.06	128.15	0.12	256.29	7.38	15628.25
Fluid Lines (recirculation pumps)																						
LAr-1 in ID	argon	L	60	0.5150	1.097	0.0279	0.1090	0.0028	0.0006	609.78	5	0.000005	10	0.00001	1270.44	1.66	0.06	128.15	0.12	256.29	7.38	15628.25
Liquid Lines																						
LAr pipe - 1 in	argon	L	30	0.3082	1.097	0.0279	0.1090	0.0028	0.0006	609.78	5	0.000005	10	0.00001	1317.86	1.66	0.04	92.29	0.09	184.58	5.31	11255.22
LAr pipe - 1 in	argon	L	60	0.5150	1.097	0.0279	0.1090	0.0028	0.0006	609.78	5	0.000005	10	0.00001	1270.44	1.66	0.06	128.15	0.12	256.29	7.38	15628.25
Gaseous Lines																						
GAr pipe - 2 in	argon	G	30	0.3082	2.157	0.0548	0.1090	0.0028	0.0024	2357.53	5	0.000005	10	0.00001	16.10	1.66	0.00	10.20	0.01	20.40	2.27	4809.84
GAr pipe - 2 in	argon	G	60	0.5150	2.157	0.0548	0.1090	0.0028	0.0024	2357.53	5	0.000005	10	0.00001	26.07	1.66	0.01	18.36	0.02	36.72	4.09	8655.88

The probability that the fan is operational, provided the power is available, depends on its failure rate, λ fan (from Table 2 of the FESHM ODH chapter):

Fans		
λ_{fan}	9.00E-06	(1/hr)

The fan is ON at all time, thus is not affected by λodh.

The failure rate for power in the building is taken straight from the FESHM chapter, Table 1.

Power	
PFOD_power	3.00E-04

This is conservative assumption as all ODH equipment will be on backup power

Probability of each combination of operational fans:

P_All	P_None
0.999691003	3.09E-04

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Scenario 1: Full exhaust ventilation   ***Q= 4000 CFM***

Equipment	Failure Type	length, m	#	Ind. Failure Rate	Total Fail Rate	V_STP (SCFM)	C(O2)	Fi	P*F (1-hr)
Pressure Vessel: LAr-1 in	leak		1	8.00E-08	8.00E-08	922.90	0.1620	1.53E-06	1.23E-13
(Cryostat)	rupture		1	5.00E-09	5.00E-09	11255.22	0.0725	1.00E+00	5.00E-09
Pressure Vessel: LAr-1 in	leak		2	8.00E-08	1.60E-07	128.15	0.2033	0.00E+00	0.00E+00
(Filtration Skid)	rupture		2	5.00E-09	1.00E-08	15628.25	0.0725	1.00E+00	1.00E-08
Fluid line (very conservative)	leak		1	5.00E-07	5.00E-07	128.15	0.2033	0.00E+00	0.00E+00
(Recirculation pump)	rupture		1	2.00E-08	2.00E-08	15628.25	0.0725	1.00E+00	2.00E-08
LAr-1 in ID 30 psig line	small leak	1		1.00E-09	1.00E-09	92.29	0.2052	0.00E+00	0.00E+00
	large leak	1		1.00E-10	1.00E-10	184.58	0.2003	0.00E+00	0.00E+00
	rupture	1		3.00E-11	3.00E-11	11255.22	0.0725	1.00E+00	3.00E-11
LAr-1 in ID 60 psig line	small leak	13		1.00E-09	1.30E-08	128.15	0.2033	0.00E+00	0.00E+00
	large leak	13		1.00E-10	1.30E-09	256.29	0.1965	0.00E+00	0.00E+00
	rupture	13		3.00E-11	3.90E-10	15628.25	0.0725	1.00E+00	3.90E-10
GAr-2 in ID 30 psig line	small leak	6		1.00E-09	6.00E-09	10.20	0.2095	0.00E+00	0.00E+00
	large leak	6		1.00E-10	6.00E-10	20.40	0.2089	0.00E+00	0.00E+00
	rupture	6		3.00E-11	1.80E-10	4809.84	0.0725	1.00E+00	1.80E-10
GAr-2 in ID 60 psig line	small leak	7		1.00E-09	7.00E-09	18.36	0.2090	0.00E+00	0.00E+00
	large leak	7		1.00E-10	7.00E-10	36.72	0.2081	0.00E+00	0.00E+00
	rupture	7		3.00E-11	2.10E-10	8655.88	0.0725	1.00E+00	2.10E-10
LAr-1 in ID 30 psig line welds	small leak		1	2.01E-10	2.01E-10	92.29	0.2052	0.00E+00	0.00E+00
	large leak		1	2.01E-11	2.01E-11	184.58	0.2003	0.00E+00	0.00E+00
	rupture		1	6.04E-12	6.04E-12	11255.22	0.0725	1.00E+00	6.04E-12
LAr-1 in ID 60 psig line welds	small leak		14	2.01E-10	2.82E-09	128.15	0.2033	0.00E+00	0.00E+00
	large leak		14	2.01E-11	2.82E-10	256.29	0.1965	0.00E+00	0.00E+00
	rupture		14	6.04E-12	8.45E-11	15628.25	0.0725	1.00E+00	8.45E-11
GAr-2 in ID 30 psig line welds	small leak		8	3.96E-10	3.17E-09	10.20	0.2095	0.00E+00	0.00E+00
	large leak		8	3.96E-11	3.17E-10	20.40	0.2089	0.00E+00	0.00E+00
	rupture		8	1.19E-11	9.50E-11	4809.84	0.0725	1.00E+00	9.50E-11
GAr-2 in ID 60 psig line welds	small leak		27	3.96E-10	1.07E-08	18.36	0.2090	0.00E+00	0.00E+00
	large leak		27	3.96E-11	1.07E-09	36.72	0.2081	0.00E+00	0.00E+00
	rupture		27	1.19E-11	3.21E-10	8655.88	0.0725	1.00E+00	3.20E-10
valves on liquid lines	leak		7	1.00E-08	7.00E-08	128.15	0.2033	0.00E+00	0.00E+00
	rupture		7	5.00E-10	3.50E-09	15628.25	0.0725	1.00E+00	3.50E-09
valves on gas lines	leak		2	1.00E-08	2.00E-08	18.36	0.2090	0.00E+00	0.00E+00
	rupture		2	5.00E-10	1.00E-09	8655.88	0.0725	1.00E+00	1.00E-09
flanges on liquid lines	leak		8	4.00E-07	3.20E-06	128.15	0.2033	0.00E+00	0.00E+00
	rupture		8	1.00E-09	8.00E-09	15628.25	0.0725	1.00E+00	8.00E-09
flanges on gas lines	leak		4	4.00E-07	1.60E-06	18.36	0.2090	0.00E+00	0.00E+00
	rupture		4	1.00E-09	4.00E-09	8655.88	0.0725	1.00E+00	4.00E-09
									5.28E-08

The leak rate, V_STP, is calculated on the previous sheet.
The fatality factor for each leak is calculated using the formula in Figure 1 of the ODH chapter (note that the oxygen concentration is converted to a partial pressure in the formula):

$$F_i = 10^{(6.5 - 760\, C(t\to\infty)/10)}$$

ODH fatality rate per hour:

$$\Phi = \sum_{i=1}^{N} P_{vent,i} P_{leak,i} F_i$$

For limited cryogen supply, the equation for t = Vc / V (cryogen stp volume divided by stp spill rate):

$$for\ V > Q \Rightarrow 0.21 * \exp\left(-\frac{Vc}{Vp}\right), for\ V \le Q \Rightarrow 0.21 * [1 - \frac{V}{Q} * \left(1 - \exp\left(-\frac{Q*Vc}{V*Vp}\right)\right)]$$

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Scenario 2: No ventilation ***Q= 0 (CFM)***

Equipment	Failure Type	length, m	#	Ind. Failure Rate	Total Fail Rate	V_STP (SCFM)	C(O2)	Fi	P*F (1-hr)
Pressure Vessel: LAr-1 in	leak		1	8.00E-08	8.00E-08	922.90	0.0725	1.00E+00	2.47E-11
(Cryostat)	rupture		1	5.00E-09	5.00E-09	11255.22	0.0725	1.00E+00	1.54E-12
Pressure Vessel: LAr-1 in	leak		2	8.00E-08	1.60E-07	128.15	0.0725	1.00E+00	4.94E-11
(Filtration Skid)	rupture		2	5.00E-09	1.00E-08	15628.25	0.0725	1.00E+00	3.09E-12
Fluid line (very conservative)	leak		1	5.00E-07	5.00E-07	128.15	0.0725	1.00E+00	1.54E-10
(Recirculation pump)	rupture		1	2.00E-08	2.00E-08	15628.25	0.0725	1.00E+00	6.18E-12
LAr-1 in ID 30 psig line	small leak	1		1.00E-09	1.00E-09	92.29	0.0725	1.00E+00	3.09E-13
	large leak	1		1.00E-10	1.00E-10	184.58	0.0725	1.00E+00	3.09E-14
	rupture	1		3.00E-11	3.00E-11	11255.22	0.0725	1.00E+00	9.27E-15
LAr-1 in ID 60 psig line	small leak	13		1.00E-09	1.30E-08	128.15	0.0725	1.00E+00	4.02E-12
	large leak	13		1.00E-10	1.30E-09	256.29	0.0725	1.00E+00	4.02E-13
	rupture	13		3.00E-11	3.90E-10	15628.25	0.0725	1.00E+00	1.21E-13
GAr-2 in ID 30 psig line	small leak	6		1.00E-09	6.00E-09	10.20	0.0725	1.00E+00	1.85E-12
	large leak	6		1.00E-10	6.00E-10	20.40	0.0725	1.00E+00	1.85E-13
	rupture	6		3.00E-11	1.80E-10	4809.84	0.0725	1.00E+00	5.56E-14
GAr-2 in ID 60 psig line	small leak	7		1.00E-09	7.00E-09	18.36	0.0725	1.00E+00	2.16E-12
	large leak	7		1.00E-10	7.00E-10	36.72	0.0725	1.00E+00	2.16E-13
	rupture	7		3.00E-11	2.10E-10	8655.88	0.0725	1.00E+00	6.49E-14
LAr-1 in ID 30 psig line welds	small leak		1	2.01E-10	2.01E-10	92.29	0.0725	1.00E+00	6.22E-14
	large leak		1	2.01E-11	2.01E-11	184.58	0.0725	1.00E+00	6.22E-15
	rupture		1	6.04E-12	6.04E-12	11255.22	0.0725	1.00E+00	1.87E-15
LAr-1 in ID 60 psig line welds	small leak		14	2.01E-10	2.82E-09	128.15	0.0725	1.00E+00	8.71E-13
	large leak		14	2.01E-11	2.82E-10	256.29	0.0725	1.00E+00	8.71E-14
	rupture		14	6.04E-12	8.45E-11	15628.25	0.0725	1.00E+00	2.61E-14
GAr-2 in ID 30 psig line welds	small leak		8	3.96E-10	3.17E-09	10.20	0.0725	1.00E+00	9.78E-13
	large leak		8	3.96E-11	3.17E-10	20.40	0.0725	1.00E+00	9.78E-14
	rupture		8	1.19E-11	9.50E-11	4809.84	0.0725	1.00E+00	2.94E-14
GAr-2 in ID 60 psig line welds	small leak		27	3.96E-10	1.07E-08	18.36	0.0725	1.00E+00	3.30E-12
	large leak		27	3.96E-11	1.07E-09	36.72	0.0725	1.00E+00	3.30E-13
	rupture		27	1.19E-11	3.21E-10	8655.88	0.0725	1.00E+00	9.91E-14
valves on liquid lines	leak		7	1.00E-08	7.00E-08	128.15	0.0725	1.00E+00	2.16E-11
	rupture		7	5.00E-10	3.50E-09	15628.25	0.0725	1.00E+00	1.08E-12
valves on gas lines	leak		2	1.00E-08	2.00E-08	18.36	0.0725	1.00E+00	6.18E-12
	rupture		2	5.00E-10	1.00E-09	8655.88	0.0725	1.00E+00	3.09E-13
flanges on liquid lines	leak		8	4.00E-07	3.20E-06	128.15	0.0725	1.00E+00	9.89E-10
	rupture		8	1.00E-09	8.00E-09	15628.25	0.0725	1.00E+00	2.47E-12
flanges on gas lines	leak		4	4.00E-07	1.60E-06	18.36	0.0725	1.00E+00	4.94E-10
	rupture		4	1.00E-09	4.00E-09	8655.88	0.0725	1.00E+00	1.24E-12
									1.77E-09

Total: 5.46E-08

ODH Class: 0

$$C(t \to \infty) = for\ V > Q => 0.21 * \exp(-\frac{Vc}{Vp}),\ for\ V \le\ Q =>\ 0.21 * (1 - \frac{V}{Q} * (1 - \exp\left(-\frac{Q*Vc}{V*Vp}\right)))$$

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

While ODH is assessed as ODH class 0, the cavern can still be inerted and some spill scenarios (though at low probabilities) may result in fatality rates.

Therefore, **<u>ODH control</u>** measures should be implemented.

1. Additional two oxygen MSA UltimaX Gas Monitors will be installed at the floor level on each side of the Captain detector. They will be set to alarm at 19.5%.
2. A removable curtain will be installed around the captain detector and its cryogenic components to alleviate exhaust of air/argon mixture.
3. As shown before, forced ventilation will be enhanced to allow reliable exhaust of gaseous argon from the floor level in case of ODH alarm (from any oxygen sensor).
4. All ODH equipment, including the ODH monitoring equipment and fan EF-4, will be on generator power.
5. As the area will be engineered to be ODH class 0, notification of the emergency center and fire department via FIRUS will be implemented. The procedure for the fire department to enter MINOS hall for rescue will be developed later, as the logistics of using designated elevators for fire personnel and operating personnel will need to be clarified.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

6. The single most expensive item for the improved ODH controls is the installation of the new stainless steel pressure relief vent vertical header. The existing vent header (the vertical part) is the 6” carbon steel, and is routed via the elevator shaft. Therefore, it is questionable if it could be re-used. As shown further, this cost alone is ~ $70K.

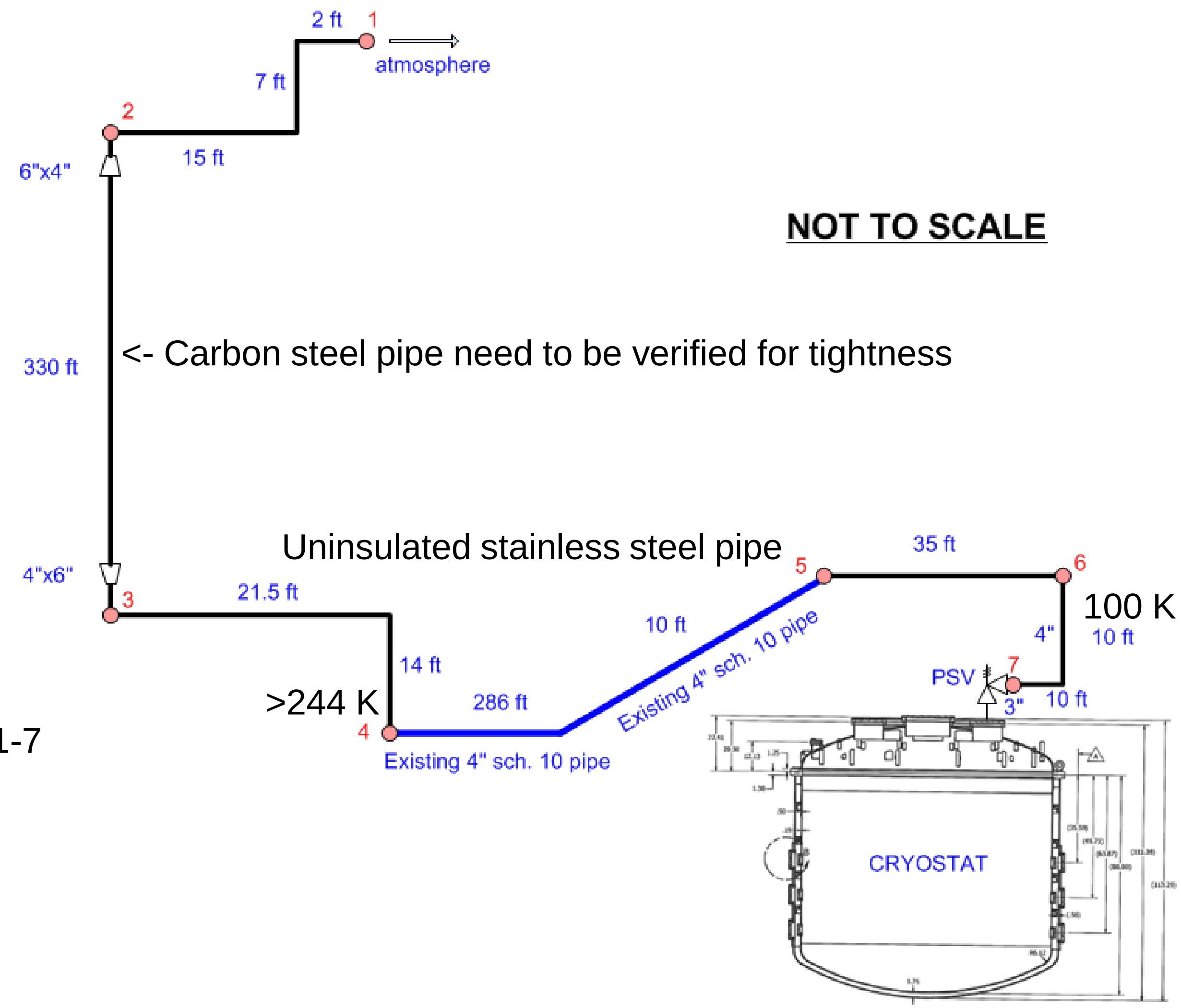
   Nevertheless, if existing vent header is allowed to be re-used as it is, the calculated ~ 1.03 kg/s of argon vent flow (most conservative fire conditions for the CAPTAIN cryostat) can be vented via existing 4” sch. 10 pipe to the ground level.

   That is calculated for 1.03 kg/s flow at std. conditions (most conservative case). The rupture disk will be installed on the Captain vessel. Also need to check possibility to put PRV on the tank instead of the rupture disk. MAWP for the cryostat is 15 psig, and pressure losses expected such as 10.16 psid.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Pressure losses in the argon pressure relief line

Schematic CAPTAIN Vent Pipe



Initial parameters:

P inlet =	24.85	psia	
T inlet =	100.00	K	
Tambient =	300.00	K	
Length =	225.55	m	
Flow =	1.09	kg/s	
ID =	0.108204	m	*4in Sch 10
ID_2 =	0.1614678	m	*6in Sch 10

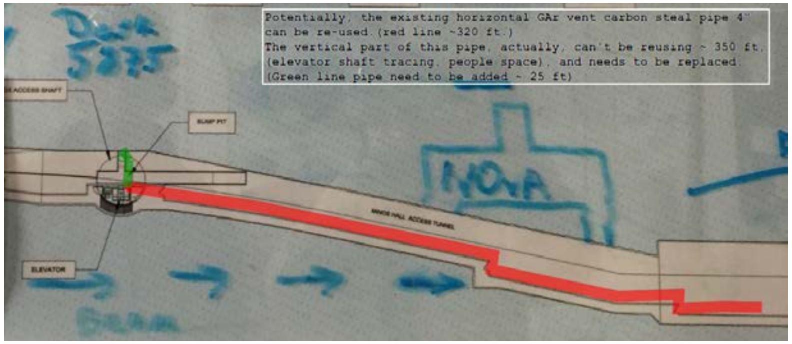
Pressure losses in the pieces 1-7

Final parameters:

P outlet=	14.69	psia
T outlet =	299.97	K
Length =	225.55	m
Flow =	1.09	kg/s
ID =	0.108204	m
ID =	0.1614678	m
Pressure Loss =	10.16	psid

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Alternatively, if the 6" piping inside the elevator shaft is not allowed to be re-used, then only the horizontal a portion of the 4" header can be preserved. The vertical 6" stainless steel ~350 ft. portion would need to be installed as new and would cost ~ $70K. See photos below to illustrate.



Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Below is the rough guestimate of the cost to implement additional ODH control measures in the Minos hall (M&S + Labor):

1. Four oxygen monitors with wiring to ODH chassis (using existing PLC) — $20K
2. Removable curtains — $10K
3. Vent header for argon reliefs (with replacement of parts of vertical 6" pipe) — $20K
4. Replacement EF-4 (2 x 5500cfm VFD 20hp fans) — $75K
   [*at 10"SP, with manual transfer switch at the surface, (only one can operate on the EG at a time), new wiring back to the panel near the bottom of the Minos shaft, new conduit from back of hall to the panel, increase concrete pad size at surface fans, new breaker at panel*]
5. Ductwork with two automated louvers — $25K
6. Ductwork under the detectors to the curtained space — $10K
7. FESS and HVAC T&M — $15K
8. FESS and electricians T&M — $15K
9. Controls, FIRUS, PLC labor — $5K
10. Additional contingencies — $20K

Total: 215K

Total duration 4-6 month. Gantt chart and labor Resources can be provided at the next design state.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

While the cavern can be inerted (though at very low probability corresponding to ODH0 classification), the allowable escape times are reasonably long:

1. For a large 2584 scfm argon (100 mm^2 leak of 60-psi liquid argon pipe), the time to fill ~10,950 ft^2, the 4 ft. high volume is 43,800 ft^3 is 17 min. This leak is grossly conservative and has a probability of 10^{-9} 1/hr. The time to fill the same volume for the 10 mm^2 leak is closer to 170 min. As the walking time, trough the escape corridor is less than 5 min and elevator wait time is < 4 min, there is more than enough time to escape the oxygen deficiency hazard.

1. There is another way to calculate time to escape before space's oxygen concentration is depleted from C_{normal}=19.5% to C_{crit} =15% (no ventilation scenario): $t_{escape} = \frac{-V}{R} \ln\left(\frac{C_{crit}}{C_{normal}}\right) = \frac{0.262V}{R}$. This calculation assumes argon mixing in the available people space V_p=202696 ft^3. Then $t_{escape} = \frac{0.262\ x\ 202696}{2584} = 20\ \text{min}$.

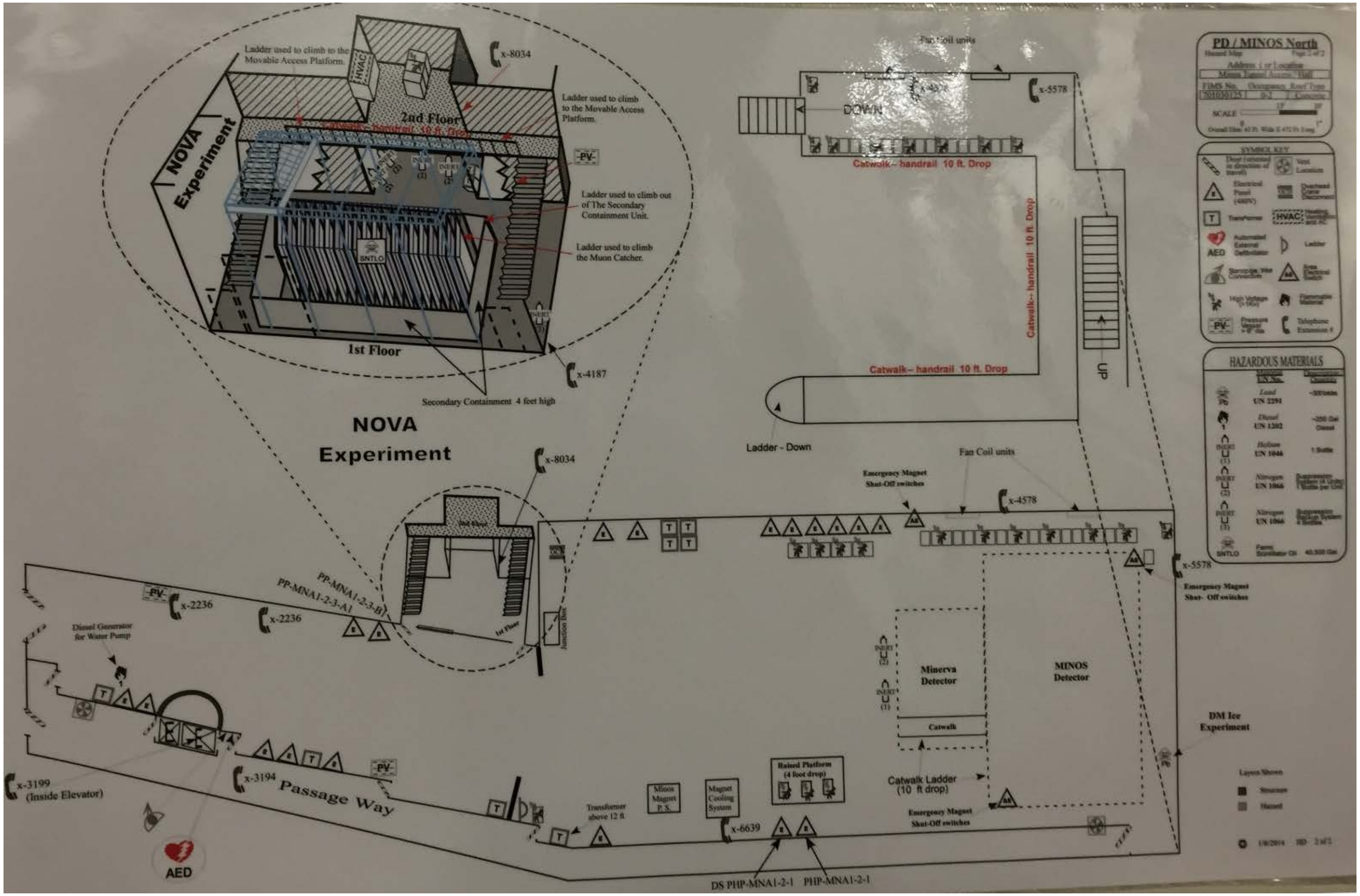
3. Therefore, the escape time with for the scenario of the large spill and no ventilation will be somewhere between 17 and 20 min.

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

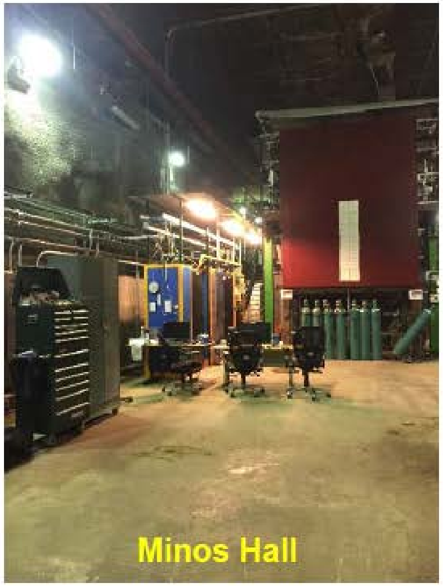
While the cavern can be inerted (though at very low probability corresponding to ODH0 classification), safe and reliable escape routes exist (shown on the next two slides).

1. The egress direction is always away from the argon spill sources around Captain cryostat to the doors to the escape tunnel (both upstream and downstream of the cryostat).
2. The MINOS cavern has a well-engineered way of egress and escape plan:
   - While a possibility to escape exists via the MINOS access tunnel and absorber access tunnel up to the higher ground, this is not the preferred escape route.
   - The preferred escape route is via the escape corridor, which leads to the MINOS elevator hall. There are several doors leading to the escape corridor from the MINOS access tunnel. While the doors are not seal-tight as they have the drainage gutters on the ground, the escape corridor is pressurized with air and should minimize seeping of gaseous argon from the hall to he corridor.
   - There are two elevators (both on emergency power – need to check). The personnel elevator has 20-person capacity. This should be the maximum number of people admitted to the MINOS hall at all times when Captain is operating.

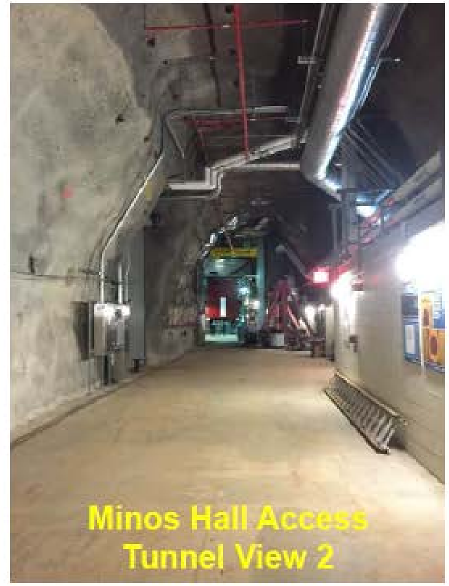
Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern



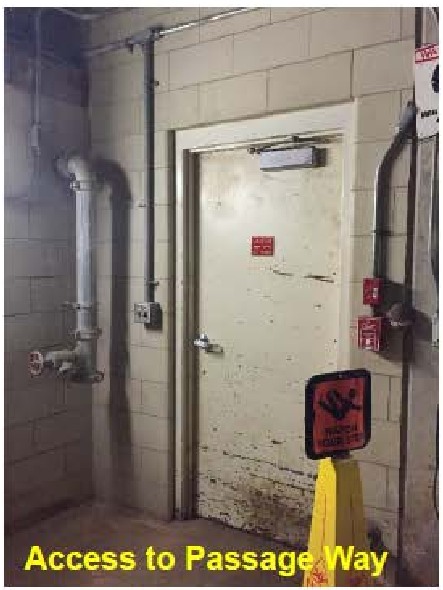
Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern


Minos Hall


Minos Hall Access Tunnel View 1


Minos Hall Access Tunnel View 2


Elevator Half Moon Shaft


Access to Passage Way

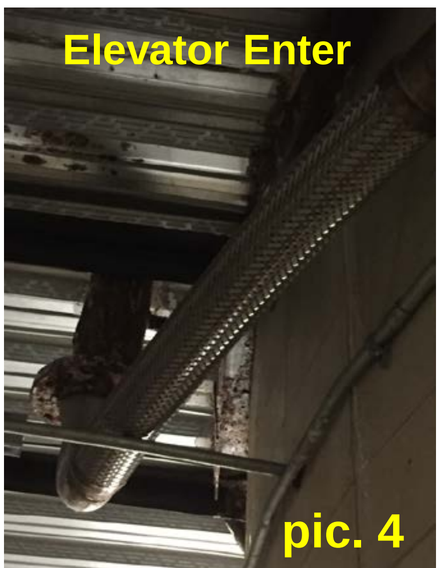

Passage Way


Escape Tunnel View 1

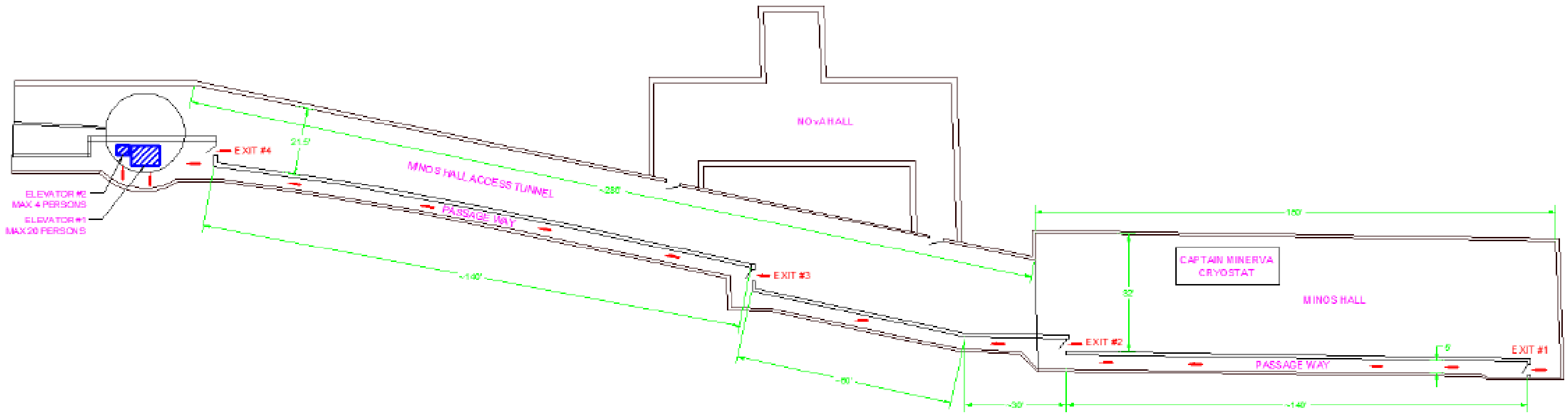

Escape Tunnel View 2

Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern

Existing Vent Pipe Tracing



Preliminary ODH Analysis for Captain Detector in MINOS/MINERvA Cavern



Conclusions:

- ❑ The ODH classification of he MINOS hall with the Captain liquid argon cryostat and helium refrigeration system can be engineered for ODH class 0.
- ❑ Existing ODH system should be modified and enhanced (with the approximate cost of $215K).
- ❑ Safe escape routes exist from the Minos hall to reliably evacuate personnel away from space inerted by leaking argon.

Recommendations:

- ❑ Install additional ODH sensors on the platform and provide FIRUS connection.
- ❑ Verify leak tightness of vertical header and modify to reduce end dP losses.
- ❑ Come up with scenario of liquid argon fill and ODH consequances (TBD)