COUPP - 60 CF3I Hazard Levels

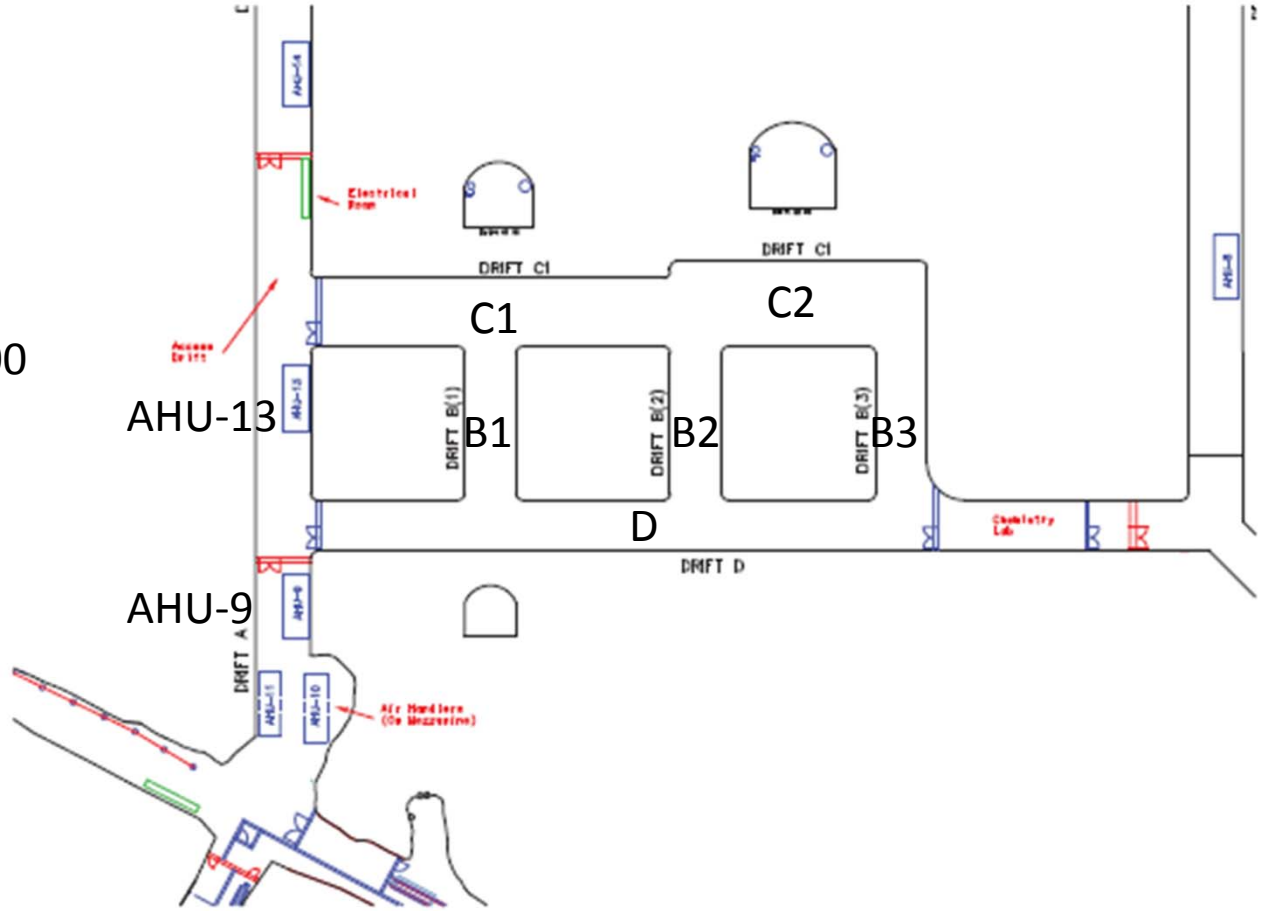
- Acceptable Occupational Exposure Limits
  - Evaluated and accepted by the US EPA
  - TWA (Time Weighted Average over 8 hour shift) = 150 ppm
  - STEL (Short-Term Exposure Limit) = 450 ppm (30 min max)
  - C (Ceiling) = 750 ppm (should never be exceeded)
- Toxicity for Cardiac Sensitization
  - Set by legislation and American Industrial Hygienists Association
  - NOAEL – No Observed Adverse Effect Level
    - 2000 ppm (to 3000 ppm for up to 5 min max)
  - LOAEL – Lowest Observed Adverse Effect Level
    - 4000 ppm (Do Not Exceed)

COUPP - 60 ODH and CF3I hazard analyses

- ODH analysis
  - Worst case assuming gas is well mixed in air
  - C1 drift volume = 33,900 ft^3
  - Maximum CF3I volume = 336 ft^3
  - 0.21*(33,900-336)/(33,900) = 20.8 % oxygen
- CF3I analysis
  - Same assumptions as above
  - 336/33,900 = 0.99 % (9900 ppm) CF3I in air
- CF3I analysis
  - Total underground volume = 1,000,000 ft^3
  - 336/1,000,000 = 336 ppm CF3I in air

COUPP - 60 Ladder Labs – Volumes & Ventilation

- Volumes, ft^3
- C1 = 33,900
- C2 = 40,800
- B = 25,600
- D = 49,800
- Ventilation, cfm
- AHU-13(C1+C2) = 12,600
  - Fresh air < 10%
  - measured at 390 cfm
  - Increase to 1000 cfm
- AHU-9(B+D) = 12,500
  - Fresh air < 10%



COUPP - 60 ODH Analysis Method

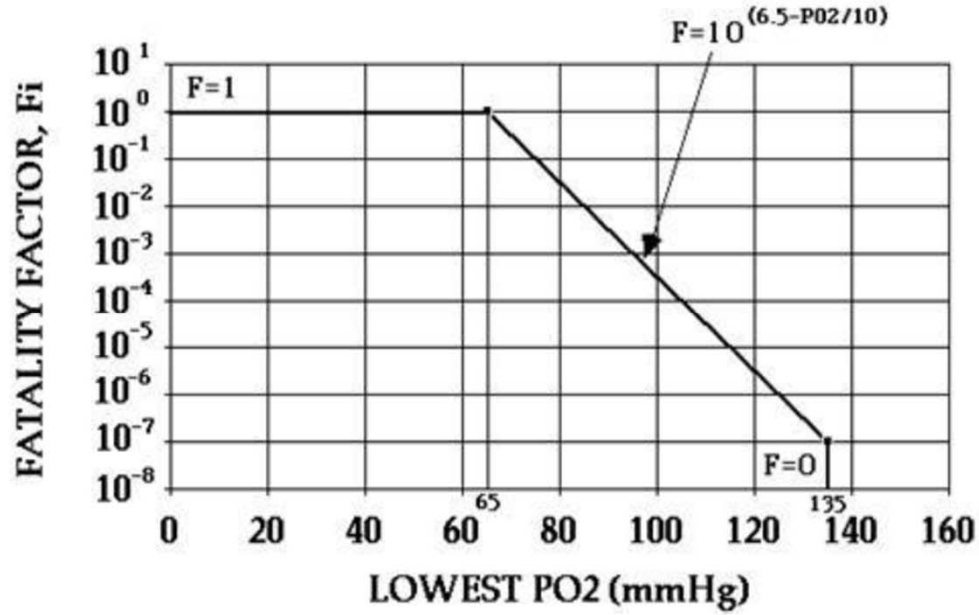
The oxygen deficiency hazard fatality rate is defined as:

$$\phi = \sum_{i=1}^{n} P_i F_i$$

where $\emptyset$ = the ODH fatality rate (per hour),

P_i = the expected rate of the ith event (per hour), and

F_i = the probability of a fatality due to event i.



Oxygen Deficiency Hazard Class

ODH Class	[Ø] (hr^{-1})
0	$<10^{-7}$
1	$> 10^{-7}$ but $<10^{-5}$
2	$> 10^{-5}$ but $<10^{-3}$

COUPP - 60 CF3I Analysis Method

The CF3I adverse exposure rate is defined as:

$$X = \sum P_i D_i$$

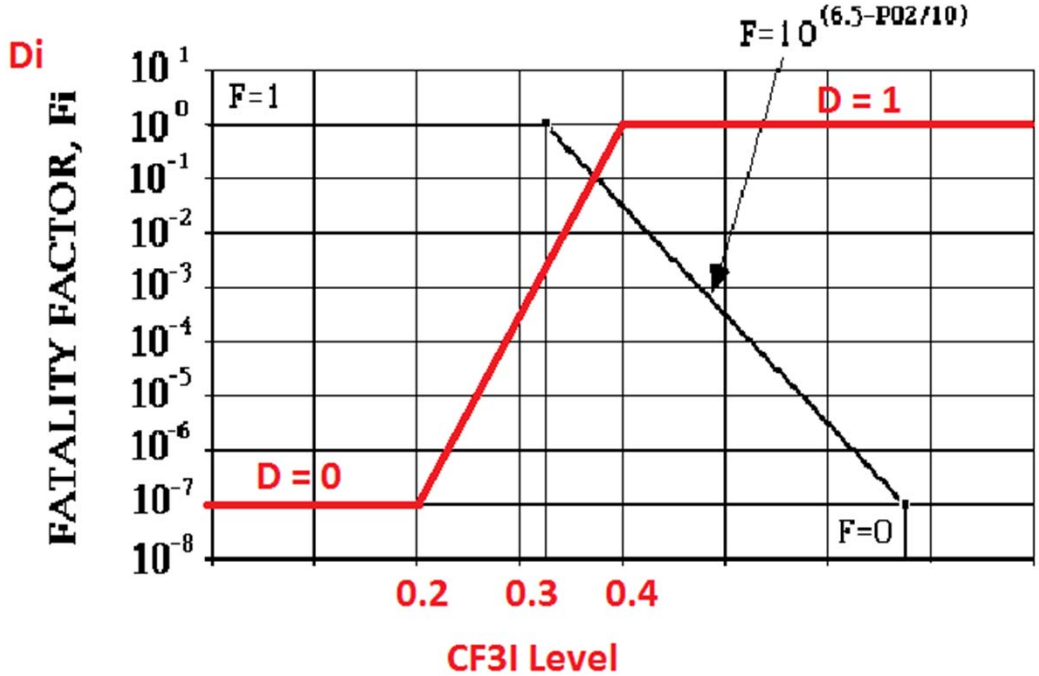
where **X** = the adverse exposure rate (per hour),

P_i = the expected rate of the ith event (per hour), and

D_i = the probability of an exposure due to event i.

CF3I Hazard Class

Hazard Class	[Ø] (hr^{-1})
0	$<10^{-7}$
1	$> 10^{-7}$ but $<10^{-5}$
2	$> 10^{-5}$ but $<10^{-3}$



COUPP - 60

CF3I release into Drift during Normal Operations

CF3I Analysis in C1 Drift for COUPP 60 Experiment

Normal operations with the bubble chamber isolated

Air Exhaust	Q	TC, min.	V/Q
1,000	cfm	34.00	
Volume	**V**	**Elevation**	**Pressure**
34,000	ft^3	-6600 ft	945 mmHG

ITEM	in/outside of enclosures	TYPE	N	P FAIL RATE	GROUP FAIL RATE	R, cfm leak rate	Q/R LEAK/VENT	Time (t1) min.	fCF3I{t1} FRACT CF3I	Time (t2) min.	fCF3I{t2} FRACT CF3I	D(t2) Exposure Factor	Rate without mitigation X Exp. Rate	Rate with mitigation X* Exp. Rate
BC 1" tube	inside	Bubble Ch.	1	1.00E-09	1.00E-09	684	0.6840	0.25	0.50%	0.50	1.00%	1.00	1.0E-09	1.0E-14
BC 1" Valve	inside	Bubble Ch.	1	1.00E-08	1.00E-08	684	0.6840	0.25	0.50%	0.50	1.00%	1.00	1.0E-08	1.0E-13
BC Valves	inside	Bubble Ch.	2	1.00E-08	2.00E-08	29	0.0290	5.00	0.40%	10.00	0.74%	1.00	2.0E-08	2.0E-13
BC Bellows	inside	Bubble Ch.	1	1.00E-08	1.00E-08	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-14
conn. rupture	inside	Bubble Ch.	5	1.00E-08	5.00E-08	29	0.0290	5.00	0.40%	10.00	0.74%	1.00	5.0E-08	5.0E-13
conn. leak	inside	Bubble Ch.	5	1.00E-08	5.00E-08	0.2	0.0002	5.00	0.00%	10.00	0.01%	0.00	0.0E+00	0.0E+00
instruments	inside	Bubble Ch.	1	1.00E-08	1.00E-08	29	0.0290	5.00	0.40%	10.00	0.74%	1.00	1.0E-08	1.0E-13
welds	inside	Bubble Ch.	6	3.00E-09	1.80E-08	29	0.0290	5.00	0.40%	10.00	0.74%	1.00	1.8E-08	1.8E-13
Pipes	inside	hydraulic	13	1.00E-09	1.30E-08	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	3.6E-09	3.6E-14
Pipes	outside	hydraulic	1	1.00E-09	1.00E-09	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.7E-10	2.7E-15
Elbows	inside	hydraulic	30	3.00E-07	9.00E-06	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.5E-06	2.5E-11
Tees	inside	hydraulic	25	3.00E-07	7.50E-06	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.1E-06	2.1E-11
Valves	inside	hydraulic	50	1.00E-08	5.00E-07	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	1.4E-07	1.4E-12
Valves	outside	hydraulic	1	1.00E-08	1.00E-08	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-14
connections	inside	hydraulic	200	1.00E-08	2.00E-06	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	5.5E-07	5.5E-12
connections	outside	hydraulic	2	1.00E-08	2.00E-08	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	5.5E-09	5.5E-14
hoses	inside	hydraulic	7	3.00E-06	2.10E-05	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	5.8E-06	5.8E-11
hoses	outside	hydraulic	1	3.00E-06	3.00E-06	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	8.2E-07	8.2E-12
instruments	inside	hydraulic	10	1.00E-08	1.00E-07	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.7E-08	2.7E-13
instruments	outside	hydraulic	1	1.00E-08	1.00E-08	10	0.0100	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-14
		TOTAL											**1.2E-05**	**1.2E-10**

Exhaust Fan: 1 event in 10 years

*Note: Mtigation is achieved using localized ventilation of tank and hydraulic valve box.
The tank air space, hydraulic valve box and fill/empty cart must be exhausted to the air raise.
Hydraulic Valve closes in the case of a hydraulic leak in the cart.

COUPP - 60

CF3I release into Drift during Fill/Empty

CF3I Analysis in C1 Drift for COUPP 60 Experiment
During the Batch Fill or Batch Empty procedure

Air Input	Q	TC, min.	V/Q
1,000	cfm	34.00	
Volume	**V**	**Elevation**	**Pressure**
34,000	ft^3	-6600 ft	945 mmHG

ITEM	in/outside of enclosures	TYPE	N	P FAIL RATE	GROUP FAIL RATE	R leak rate	Q/R LEAK/VENT	Time (t1) min.	fCF3I{t1} FRACT CF3I	Time (t2) min.	fCF3I{t2} FRACT CF3I	D(t2) Exposure Factor	X Exp. Rate (Rate without mitigation)	X* Exp. Rate (Rate with mitigation)
BC 1" tube	tank is open	Bubble Ch.	1	1.00E-09	1.00E-09	684	0.7	0.25	0.50%	0.50	1.00%	1.00	1.0E-09	1.0E-09
BC 1" Valve	tank is open	Bubble Ch.	1	1.00E-08	1.00E-08	684	0.7	0.25	0.50%	0.50	1.00%	1.00	1.0E-08	1.0E-08
BC Valves	tank is open	Bubble Ch.	2	1.00E-08	2.00E-08	29	0.0	5.00	0.40%	10.00	0.74%	1.00	2.0E-08	2.0E-08
BC Bellows	tank is open	Bubble Ch.	1	1.00E-08	1.00E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-09
Conn. Rupture	tank is open	Bubble Ch.	5	1.00E-08	5.00E-08	29	0.0	5.00	0.40%	10.00	0.74%	1.00	5.0E-08	5.0E-08
Instruments	tank is open	Bubble Ch.	1	1.00E-08	1.00E-08	29	0.0	5.00	0.40%	10.00	0.74%	1.00	1.0E-08	1.0E-08
Welds	tank is open	Bubble Ch.	6	3.00E-09	1.80E-08	29	0.0	5.00	0.40%	10.00	0.74%	1.00	1.8E-08	1.8E-08
transfer line	outside	CF_3I	1	3.00E-06	3.00E-06	17	0.0	5.00	0.23%	10.00	0.43%	1.00	3.0E-06	3.0E-06
Cart tubes	inside	CF_3I	10	1.00E-09	1.00E-08	17	0.0	5.00	0.23%	10.00	0.43%	1.00	1.0E-08	1.0E-13
Cart elbows	inside	CF_3I	10	3.00E-07	3.00E-06	17	0.0	5.00	0.23%	10.00	0.43%	1.00	3.0E-06	3.0E-11
Cart tees	inside	CF_3I	10	3.00E-07	3.00E-06	17	0.0	5.00	0.23%	10.00	0.43%	1.00	3.0E-06	3.0E-11
Cart valves	inside	CF_3I	15	1.00E-08	1.50E-07	17	0.0	5.00	0.23%	10.00	0.43%	1.00	1.5E-07	1.5E-12
Cart connections	inside	CF_3I	30	1.00E-08	3.00E-07	17	0.0	5.00	0.23%	10.00	0.43%	1.00	3.0E-07	3.0E-12
Cart instruments	inside	CF_3I	3	1.00E-08	3.00E-08	17	0.0	5.00	0.23%	10.00	0.43%	1.00	3.0E-08	3.0E-13
Pipes	inside	hydraulic	13	1.00E-09	1.30E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	3.6E-09	3.6E-14
Pipes	outside	hydraulic	1	1.00E-09	1.00E-09	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.7E-10	2.7E-15
Elbows	inside	hydraulic	30	3.00E-07	9.00E-06	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.5E-06	2.5E-11
Tees	inside	hydraulic	25	3.00E-07	7.50E-06	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.1E-06	2.1E-11
Valves	inside	hydraulic	50	1.00E-08	5.00E-07	10	0.0	5.00	0.14%	10.00	0.25%	0.27	1.4E-07	1.4E-12
Valves	outside	hydraulic	1	1.00E-08	1.00E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-14
Connections	inside	hydraulic	200	1.00E-08	2.00E-06	10	0.0	5.00	0.14%	10.00	0.25%	0.27	5.5E-07	5.5E-12
Connections	outside	hydraulic	2	1.00E-08	2.00E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	5.5E-09	5.5E-14
Hoses	inside	hydraulic	7	4.00E-08	2.80E-07	10	0.0	5.00	0.14%	10.00	0.25%	0.27	7.7E-08	7.7E-13
Hoses	outside	hydraulic	1	4.00E-08	4.00E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	1.1E-08	1.1E-13
Instruments	inside	hydraulic	10	1.00E-08	1.00E-07	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.7E-08	2.7E-13
Instruments	outside	hydraulic	1	1.00E-08	1.00E-08	10	0.0	5.00	0.14%	10.00	0.25%	0.27	2.7E-09	2.7E-14
		TOTAL											**1.5E-05**	**3.1E-06**

Exhaust Fan: 1.3 events in 10 years

*Note: Mtigation is achieved using localized ventilation of tank and hydraulic valve box.
The tank air space, hydraulic valve box and fill/empty cart must be exhausted to the air raise.
Hydraulic Valve closes in the case of a hydraulic leak in the cart.

COUPP - 60

CF3I release into Tank during Fill/Empty

CF3I Analysis for Inside Empty Water Tank

During the Batch fill or Batch empty procedure

Air Input	Q	TC, min.	V/Q
1,000	cfm	0.53	
Volume	**V**	**Elevation**	**Pressure**
530	ft^3	-6600 ft	945 mmHG

ITEM	TYPE	N	P FAIL RATE	GROUP FAIL RATE	R leak rate	Q/R LEAK/VENT	Time (t1) min.	fCF3I{t1} FRACT CF3I	Time (t2) min.	fCF3I{t2} FRACT CF3I	D(t2) Exposure Factor	X Exp. Rate
BC 1" tube	Bubble Ch.	1	1.00E-09	1.00E-09	684	0.6840	0.25	22.26%	0.50	32.32%	1.00	1.00E-09
BC 1" Valve	Bubble Ch.	1	1.00E-08	1.00E-08	684	0.6840	0.25	22.26%	0.50	32.32%	1.00	1.00E-08
BC Valves	Bubble Ch.	2	1.00E-08	2.00E-08	29	0.0290	0.50	1.75%	1.00	2.41%	1.00	2.00E-08
BC Bellows	Bubble Ch.	1	1.00E-08	1.00E-08	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	1.00E-08
Conn. Rupture	Bubble Ch.	5	1.00E-08	5.00E-08	29	0.0290	0.50	1.75%	1.00	2.41%	1.00	5.00E-08
Conn. Leak	Bubble Ch.	5	1.00E-08	5.00E-08	0.2	0.0002	0.50	0.01%	1.00	0.02%	0.00	0.00E+00
instruments	Bubble Ch.	1	1.00E-08	1.00E-08	29	0.0290	0.50	1.75%	1.00	2.41%	1.00	1.00E-08
welds	Bubble Ch.	6	3.00E-09	1.80E-08	29	0.0290	0.50	1.75%	1.00	2.41%	1.00	1.80E-08
transfer line	CF3I	1	3.00E-06	3.00E-06	17	0.0170	0.50	1.03%	1.00	1.43%	1.00	3.00E-06
Pipes	hydraulic	5	1.00E-09	5.00E-09	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	5.00E-09
Elbows	hydraulic	10	3.00E-07	3.00E-06	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	3.00E-06
Tees	hydraulic	4	3.00E-07	1.20E-06	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	1.20E-06
Valves	hydraulic	10	1.00E-08	1.00E-07	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	1.00E-07
Conn. Rupture	hydraulic	20	1.00E-08	2.00E-07	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	2.00E-07
Conn. Leak	hydraulic	20	1.00E-08	2.00E-07	0.2	0.0002	0.50	0.01%	1.00	0.02%	0.00	0.00E+00
Hoses Rupture	hydraulic	4	3.00E-06	1.20E-05	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	1.20E-05
Hoses Leak	hydraulic	4	3.00E-06	1.20E-05	0.2	0.0002	0.50	0.01%	1.00	0.02%	0.00	0.00E+00
instruments	hydraulic	0	1.00E-08	0.00E+00	10	0.0100	0.50	0.61%	1.00	0.84%	1.00	0.00E+00
	TOTAL											**1.96E-05**

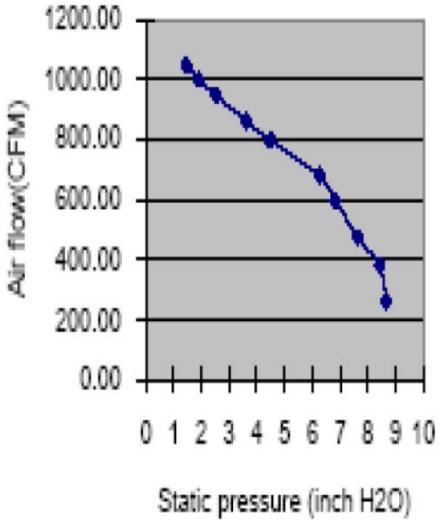
Exhaust Fan: 1.8 events in 10 years

COUPP - 60 Mitigation

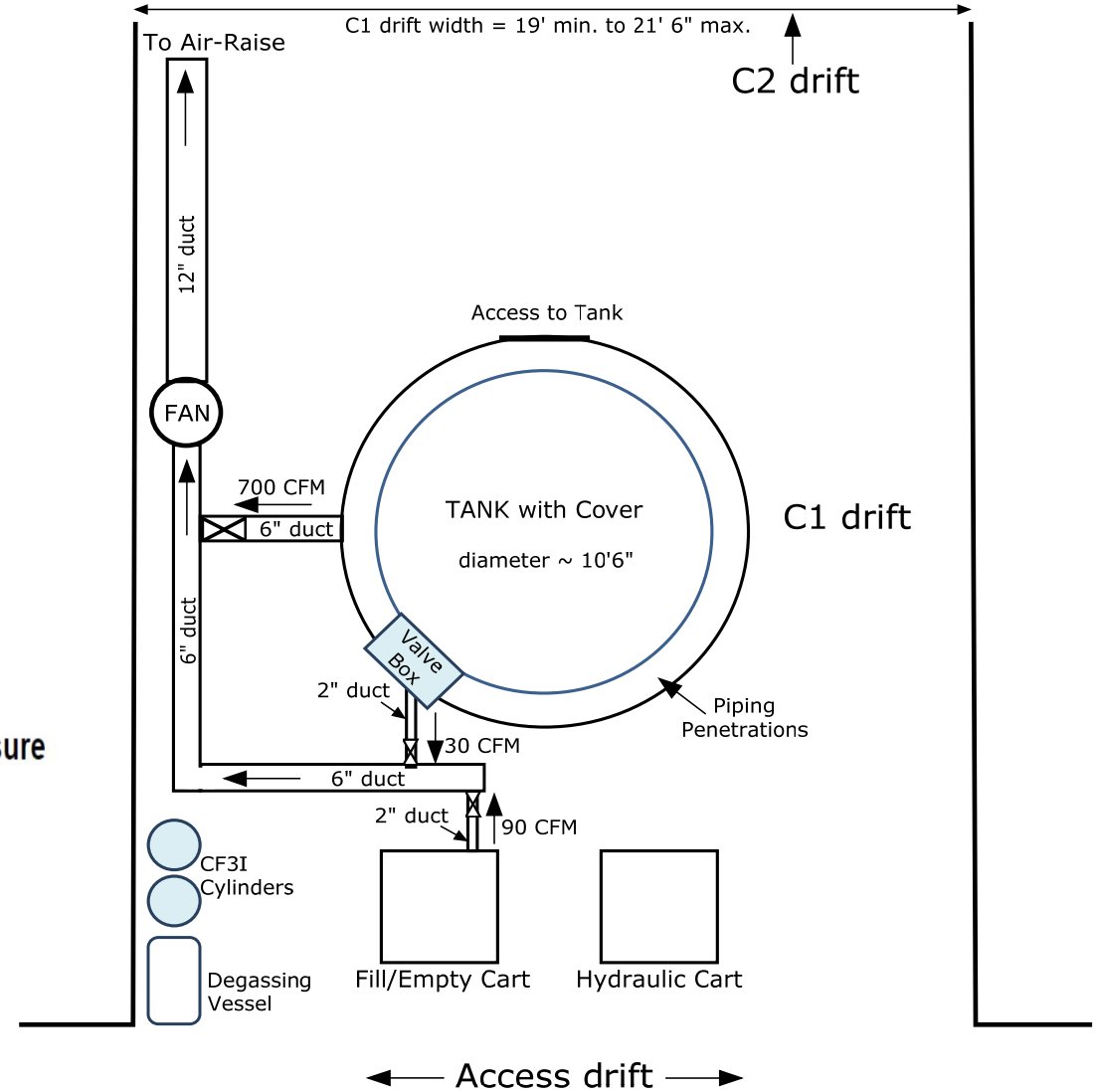
- Localized Ventilation
- Hydraulic Valve closes in case of Leak at Hydraulic Cart

Enclosure	Estimated Maximum Leak Rate, CFM	Exhaust Rate, CFM
Hydraulic Valve Box	10	30
Fill/Empty Cart	29	90
Tank	684	700

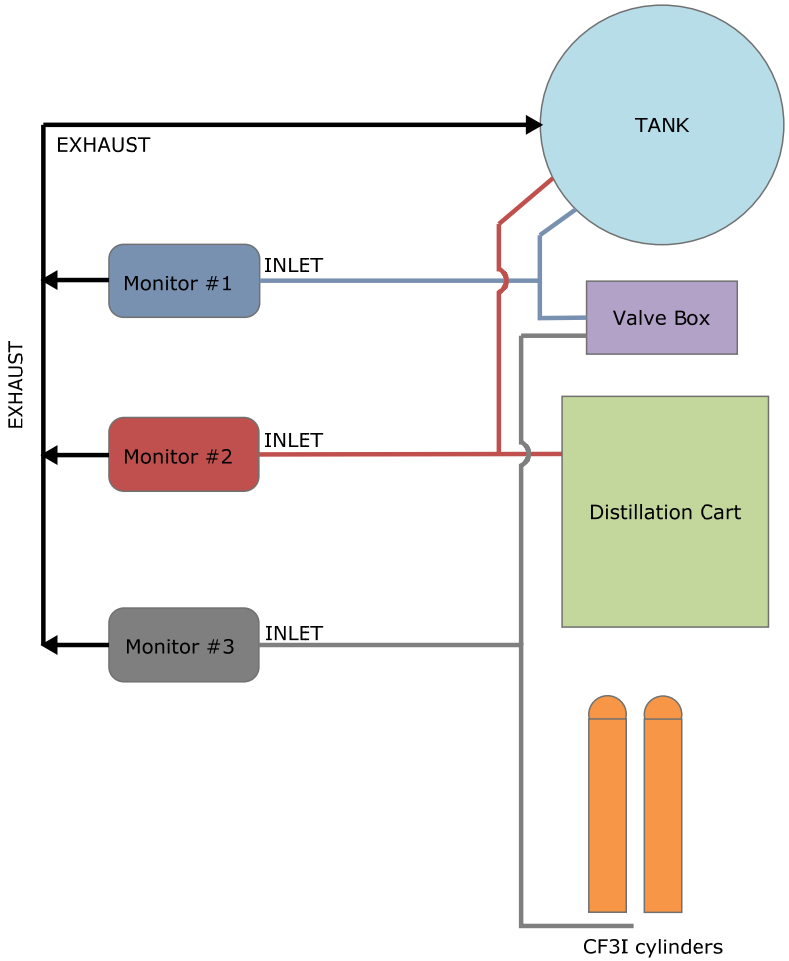
COUPP - 60 Localized Ventilation



Performance Curve: Airflow vs. Static Pressure



COUPP - 60 CF3I Monitoring Scheme



- Monitors 1 and 2 in alarm = Leak inside the Tank
- Monitors 1 and 3 in alarm = Leak inside the Valve box
- Monitor 2 only in alarm = Leak in the distillation cart
- Monitor 3 only in alarm = Leak at the CF3I cylinders
- Any other alarm combination would indicate a catastrophic failure or at least one faulty monitor.

COUPP - 60 Hardwired Interlock Logic

- If any of the CF3I monitors alarms
  - The local audible alarm sounds
  - The local strobe flashes
  - The CF3I exhaust fan turns on
- If the level sensor in the pan beneath the hydraulic cart senses level
  - The valve on the hydraulic recompression line inside the valve box closes

COUPP - 60 Hazard Risk 1 in C1 Drift

- Recommended Requirements
  - Two person rule
  - CF3I exhaust fan on during this procedure
  - Warning signs indicating Operating Status, Hazard Class and any special instructions
  - 1000 CFM fresh air ventilation into the C1/C2 drift
  - Medical approval for all personnel in the vicinity of the COUPP 60 experiment
  - Training on the hazards of CF3I, the COUPP 60 experiment, and the evacuation plan
  - Personal hazardous atmosphere monitor for each individual working on COUPP 60
  - Self-rescue supplied atmospheric respirator (escape pack) – Don if CF3I level > 450 ppm
  - Additional precautions may be required by the Snolab management.

COUPP - 60 Hazard Risk 1 inside Tank

- Recommended Requirements
  - Multiple personnel required (three minimum, one inside the tank)
  - CF3I exhaust fan on during this procedure
  - Warning signs indicating Operating Status, Hazard Class and any special instructions
  - 1000 CFM fresh air ventilation into the C1/C2 drift
  - 1000 CFM fresh air ventilation into the tank (exhaust air from the bottom of the tank)
  - Medical approval for all personnel in the vicinity of the COUPP 60 experiment
  - Training on the hazards of CF3I, the COUPP 60 experiment, and the evacuation plan
  - Personal hazardous atmosphere monitor for each individual working on COUPP 60
  - Self-rescue supplied atmospheric respirator (escape pack) – Don if CF3I level > 450 ppm
  - Confined space requirements
  - Additional precautions may be required by the Snolab management.

COUPP - 60 Confined Space Requirements

- Gas detection monitoring inside the tank
- Unexposed observer
- Means to rescue without entry in the tank
- Forced fresh air ventilation
- Confined space work permit to be issued by Snolab safety organization
- An approved Work Hazard Analysis which addresses the required PPE, description of work, list of hazards, the precautions to be taken, and a checklist of the steps to be taken in the procedure. A knowledgeable and competent person shall review and approve the analysis prior to its execution. All personnel involved in the work procedure must read then sign the Hazard Analysis prior to performing the work.

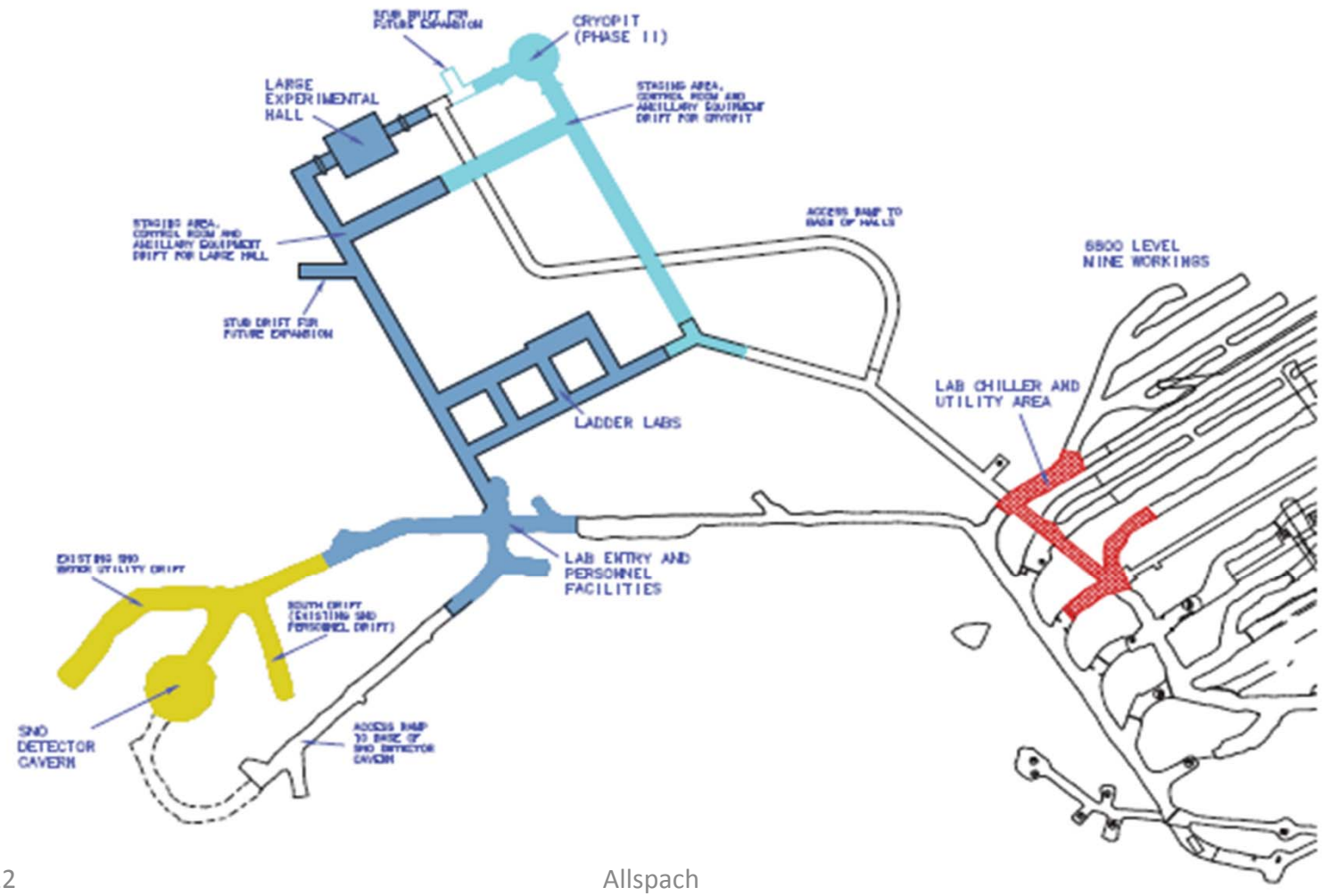
COUPP - 60 Responses to CF3I Alarm

During Normal Operations

- Personnel working in the ladder labs and adjacent drifts immediately report to the safe room until the leak is isolated and the CF3I level in the C1 drift is below 150 ppm.
- Personnel working in other experimental halls must keep out of the Ladder Labs and the adjacent drifts until the same conditions are met.
- The lab supervisor or COUPP 60 expert is expected to announce the hazardous condition to all personnel in the underground lab via the intercom.
- Check the CF3I monitor readings on the i-Fix monitor in the safe room.
- Assess the readings and determine if the leak is contained within the enclosures (tank, cart or valve box).
- If the leak appears to be contained and the CF3I exhaust fan is on, two personnel that are appropriately trained may approach the COUPP 60 area each with a personal handheld CF3I sensor.
- If either or both handheld sensors exceed 450 ppm at any time, the personnel must immediately return to the safe room and wait until the CF3I monitor readings approach zero.
- If the handheld sensors remain below 450 ppm, the personnel may work to determine the cause of the leak and isolate it.
- If the handheld sensors read > 150 ppm and < 450 ppm during this access time, the personnel exposure time may not exceed 30 minutes.
- Work activities following the event require an approved work hazard analysis prior to returning to normal operations.

COUPP - 60 Responses to CF3I Alarm

<u>During Distillation Cart and Bubble Chamber Fill/Empty Procedures</u>

- During these procedures the exhaust fan will be switched on to run continuously.
- The COUPP 60 experts (two person rule is in effect) may remain in the area to troubleshoot the alarm for a maximum of 30 minutes if all handheld sensor readouts remain below 450 ppm.
- At least two handheld sensors must be in use by the experts and at least one sensor for each specific area occupied in the drift.
- Other personnel working in the ladder labs and adjacent drifts immediately report to the safe room until the leak is isolated and the CF3I level in the C1 drift is below 150 ppm.
- The lab supervisor or a COUPP 60 expert is expected to announce the hazardous condition to all personnel in the underground lab via the intercom.
- Personnel working in other experimental halls must keep out of the Ladder Labs and the adjacent drifts until the same conditions are met.
- If any of the handheld sensors read above 450 ppm, the COUPP 60 experts must immediately report to the safe room.
- If the leak is readily understood and isolated the personnel may continue with the procedure.
- If the leak is the result of an unexpected or unresolved issue, an approved work hazard analysis is required prior to resuming system work activities.

COUPP - 60 SNOLAB Layout