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Project: COUPP 60

Title: CF3I Safety Review for the COUPP 60 Installation at SNOLAB

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Abstract: This note serves as the CF3I safety analysis for the installation of COUPP 60 in the Snolab underground laboratory. Consideration for the safe use of propylene glycol in this system is also given.

**Introduction**

The COUPP 60 experiment move from Fermilab to the Snolab underground laboratory will introduce some new safety concerns for Snolab. These concerns result primarily from the use of CF3I and propylene glycol in larger quantities than at present. Methods to reduce the hazards associated with these fluids have been developed and are presented below.

The limits for CF3I released into the ambient air have been developed by various agencies (ref. 1) and have been accepted by Snolab for the COUPP 4 experiment now operating in their underground lab. The limits associated with a planned local release are:

* 150 ppm for a Time Weighted Average (TWA) during an eight hour shift,
* 450 ppm for a Short-Term Exposure Limit (STEL) for a maximum of 30 minutes, and
* 750 ppm Ceiling (C) should never be exceeded.

Concerns for accidental release of CF3I are primarily associated with cardiac sensitization. Limits have been set by legislation and the American Industrial Hygienists Association (ref. 2). These are:

* 2000 ppm NOAEL (No Observed Adverse Effect Level) and
* 4000 ppm LOAEL (Lowest Observed Adverse Effect Level).

**COUPP 60 Installation at Snolab**

The COUPP 60 experiment will be located in the Ladder Labs C1 drift. See Figure 1. If the air in this drift is contaminated with 4000 ppm CF3I, the oxygen concentration in the drift would be reduced by 0.1%. A reduction of oxygen by this small amount is not considered an oxygen deficiency hazard. Thus, this analysis will focus on methods to assure that the CF3I hazard is mitigated and as a result, there will be no oxygen deficiency concerns.

The volume of the C1 drift is 33,900 cubic feet. Air Handling Unit (AHU) #13 ventilates the C1 and C2 drifts. The AHU is capable of providing 1000 CFM of fresh air to these drifts. The recirculation rate of AHU-13 is much higher at 12,600 CFM. This rate helps to assure that a CF3I leak into the drift mixes with the ambient air quickly. AHU-9 provides similar ventilation for the neighboring ladder labs B and D. Although it is clear that the air volumes of the ladder labs communicate with each other, the rate is not defined and so the analysis conservatively considers the ventilation and volume of only the C1 drift in determining the CF3I concentrations resulting from various types of leaks.



Figure 1. SNOLAB Ladder Labs

**Hazard Analysis**

The CF3I hazard is evaluated by determining the CF3I adverse exposure rate for the COUPP-60 experiment installed and operated in the Snolab C1 drift. The exposure rate is measured in events per hour where an exposure causes cardiac arrest and possible death to the victim. This analysis method is similar to the one Fermilab has adopted for determining oxygen deficiency hazard fatality rates. Further explanation and justification for using this technique are described in reference 3. The exposure rate is a summation of individual rates determined by considering the expected rate of an event with the probability of a fatality due to the event occurring. The expected rates are based on actual failure rates published for various types of piping system components (ref. 4). The probability of cardiac arrest/death is determined using the NOAEL as the point at which cardiac arrest will not occur and the LOAEL as the point where victims exposed to the leak will go into cardiac arrest and possibly die. This analysis method was used for the COUPP 60 installation in the Fermilab MINOS Hall (ref. 3). The graph specifying the relationship between the CF3I concentration and the exposure rate, Di, is shown in figure 2.

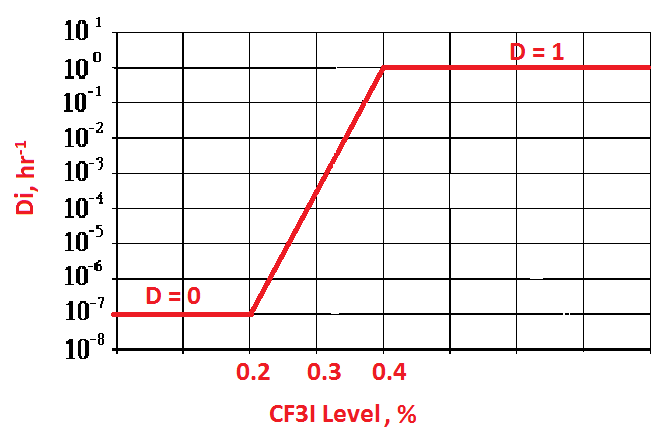


Figure 2. CF3I Concentration vs. Exposure Rate, Di

The Total Exposure Rate determined by analysis is given a hazard classification based on its value. A class rating of zero indicates a safe system while class 1 and class 2 systems are more dangerous and require precautions for operation. The hazard class for CF3I is shown in Table 1 below.



Table 1. Hazard Class vs. Total Exposure Rate, Ø

There are three operating cases that are important to analyze. These include:

* CF3I release into the C1 drift during normal operations,
* CF3I release into the C1 drift during a Fill or Empty procedure, and
* CF3I release into the Tank during a Fill or Empty procedure.

It is highly desirable to design the system installation such that the CF3I hazard class is zero during normal operations. Based on the analysis of this installation, it was determined that this would not be possible without some type of additional mitigation as compared to the COUPP 60 installation in MINOS Hall. See Table 3 of this report. Safety measures assumed include 1000 CFM of fresh air supplied to drift C1. With the additional mitigation in place, the normal operations scenario is concluded to be hazard class zero. The additional mitigation requires that the Fill/Empty cart and the Hydraulics Valve Box be enclosed and that the water tank be covered. These air spaces are to be monitored with gas detectors and interlocked such that if a leak is detected, an exhaust fan will be energized in order to vent the air spaces and exhaust the contaminated air directly to the air raise.

**Tank, Hydraulic Valve Box and Fill/Empty Cart Exhaust Plan**

In the case of a CF3I leak, the air space in the Tank, the Hydraulic Valve Box and the Fill/Empty Cart will be ventilated with the exhaust routed to the Air-Raise. In any of the operating modes, the most likely location of a leak is in one of these three locations. The ventilation rate for these spaces should be equal to or exceed the estimated maximum leak rate for the given enclosure. The estimated leak rates and proposed exhaust rates for the enclosures are summarized in Table 2 below. At these rates, the time required to displace the contaminated air will be short after the leak stops. Using a single blower to ventilate the three spaces requires a blower with a capacity of 820 CFM air. During the leak and after, this exhaust rate and resulting pressure differential will help to prevent the CF3I gas from leaking into the drift.

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

Table 2. Enclosure Leak and Exhaust Rates

An exhaust fan that can be used for this application is a Dayton fume hood fan (model 3AA22) sold by Grainger. The flow capacity at 4”H2O static pressure is about 820 CFM. See figure 3. The characteristics of this fan allow use of a 12 inch diameter duct from drift C1 to the air raise (~900’ distance). See figure 4. A flow restriction will be installed between each air space and the fan inlet manifold in order to establish the proper flow from each space.



Figure 3. Grainger Performance Curve for Dayton Fan Model 3AA22

Using a 12 inch ID duct with a smooth surface finish over the 900 feet from the fan to the air raise will impose a 1.4”H2O pressure drop at 820 CFM air. This assumes no significant impedance from bends, joints, etc.

An exhaust tube, 2 inch ID and a few feet in length, routed from the Distillation (Fill/Empty) Cart will impose a pressure drop of 1”H2O at 30 CFM. An exhaust tube of similar size routed from the Valve Box will impose a pressure drop of 0.13”H2O at 10 CFM. Including a valve or damper in each line will provide a means to balance the flows from each enclosure.

In order to effectively exhaust a CF3I gas leak from the tank, valve box and cart, this equipment must be enclosed. The lower portion of the box and cart enclosure walls should be solid sheeting where possible while the upper portions should be fabricated from plastic strip curtains to allow for manipulation of valves or other equipment located within the carts. The plastic strip curtains should impose a slight impedance to the air flow. Since the CF3I gas has a density twice that of air, the exhaust pipe inlet point must be located near the bottom of the enclosure. Fresh air supply should be from the upper portion of each enclosure. The tank lid will also need to enclose the air space. The path for fresh air to enter will be via two 6 inch diameter ducts that penetrate the lid through the perimeter plates. An appropriate enclosure design must minimize the pressure drop for ventilation while assuring that leaks are contained.



Figure 4. Top View of Drift C1 at Snolab

After system installation, the flow through each exhaust line must be measured. The valves/damper must be adjusted and securely set in order to achieve the required exhaust flow rates. Verification of the exhaust flows should be repeated periodically and in particular if any design changes are made to an enclosure or the ventilation ducting.

The enclosures (tank air space, hydraulic valve box and fill/empty cart) will be monitored for CF3I leaks. The CF3I concentration will also be monitored in the C1 drift near the CF3I gas cylinders. The CF3I monitor will trigger the exhaust fan and strobe light to operate in the case of an alarm. Any CF3I gas that leaks into an enclosure will be quickly directed through the ducting to the air raise. The CF3I monitor alarm relay will be wired to signal the fan to run. It will also trigger an audible evacuation alarm. The alarm circuits are designed in a manner such that they are fail safe. The CF3I detectors purchased will monitor all four locations continuously.

The CF3I monitoring scheme is shown in Figure 5 below. It indicates that the locations of concern during normal operations are monitored by three CF3I detectors. This redundancy is desirable to ensure the safety of personnel in the Snolab underground.



Figure 5. CF3I Monitoring Scheme

Based on Figure 5, the following is true:

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

Any CF3I gas that needs to be vented as a step in the fill or empty procedure should have its vent port routed to the inlet of the exhaust fan ducting in the Fill/Empty Cart. The exhaust from the tank CF3I monitor sample flow will be returned to the tank in order to limit the possibility of venting CF3I directly to the drift.

The hardwired interlock logic for this system consists of the following:

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

The closing of the hydraulic valve will help to prevent excess propylene glycol from spilling. It will also help to contain the CF3I in the tank or valve box should the bubble chamber begin to leak. Any propylene glycol spilled at the hydraulic cart is contained inside the pan beneath the cart.

The following actions are recommended requirements for the case of a CF3I alarm.

During Normal Operations

1. 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.
2. Personnel working in other experimental halls must keep out of the Ladder Labs and the adjacent drifts until the same conditions are met.
3. The lab supervisor or COUPP 60 expert is expected to announce the hazardous condition to all personnel in the underground lab via the intercom.
4. Check the CF3I monitor readings on the i-Fix monitor in the safe room.
5. Assess the readings and determine if the leak is contained within the enclosures (tank, cart or valve box).
6. 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.
7. 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.
8. If the handheld sensors remain below 450 ppm, the personnel may work to determine the cause of the leak and isolate it.
9. If the handheld sensors read > 150 ppm and < 450 ppm during this access time, the personnel exposure time may not exceed 30 minutes.
10. Work activities following the event require an approved work hazard analysis prior to returning to normal operations.

During Distillation Cart and Bubble Chamber Fill/Empty Procedures

1. During these procedures the exhaust fan will be switched on to run continuously.
2. 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.
3. 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.
4. 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.
5. 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.
6. Personnel working in other experimental halls must keep out of the Ladder Labs and the adjacent drifts until the same conditions are met.
7. If any of the handheld sensors read above 450 ppm, the COUPP 60 experts must immediately report to the safe room.
8. If the leak is readily understood and isolated the personnel may continue with the procedure.
9. 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.

**Hazard Analysis Results**

The CF3I adverse exposure rates are determined for the three operational scenarios to assure the safety of personnel working near COUPP 60 at Snolab.

Case 1 addresses the hazard for the air space in the C1 drift. The operational status of COUPP-60 in this case is normal operations. It assumes a fresh air supply flow of 1000 CFM to the drift.



Table 3. Hazard Analyses Results for CF3I release into the drift during normal operations

The analysis shows, for no special mitigation other than the fresh air supplied to the drift, that the hazard exposure rate is 1.2 E-05. Referencing Table 1, it is seen that this exposure rate results in a hazard class 2. This is undesirable during normal operations as it would require that personnel who need to work in the area receive special training and wear special personal protective equipment (PPE). The last column in the table reflects the exposure rate with the “ventilated enclosure” and “hydraulic valve closure” mitigation described above. It shows that the hazard level is reduced to Class Zero. This will allow personnel working in the underground and the C1 drift in particular to perform their work without other special precautions so long as the COUPP 60 experiment is in normal operations mode. If the ventilation system or special mitigation equipment is not operable, the C1 drift will revert to a hazard class 2 area.

Case 2 also addresses the hazard for the air space in the C1 drift. The operational status of COUPP-60 in this case is that the fill/empty procedure is in progress. It assumes a fresh air supply flow of 1000 CFM to the drift.



Table 4. Hazard Analyses Results for CF3I release into the drift during fill/empty procedure

The analysis shows, for no special mitigation other than the fresh air supplied to the drift, that the hazard exposure rate is 1.5 E-05. Referencing Table 1, it is seen that this exposure rate results in a hazard class 2. The last column in the table reflects the exposure rate with the “ventilated enclosure” mitigation described above for the valve box and cart only and the “hydraulic valve closure” mitigation. During the fill/empty procedure the tank lid will be removed. The additional ventilation improves the exposure rate and reduces the risk to hazard class 1. Appropriate PPE will be required for personnel in the C1 drift during this procedure. If the ventilation system or special mitigation equipment is not operable, the C1 drift will revert to a hazard class 2 area. The recommended Hazard Risk 1 safety requirements for personnel in the underground lab drift C1 during the fill/empty procedure include:

1. Two person rule
2. CF3I exhaust fan on during this procedure
3. Warning signs indicating Operating Status, Hazard Class and any special instructions
4. 1000 CFM fresh air ventilation into the C1/C2 drift
5. Medical approval for all personnel in the vicinity of the COUPP 60 experiment
6. Training on the hazards of CF3I, the COUPP 60 experiment, and the evacuation plan
7. Personal hazardous atmosphere monitor for each individual working on COUPP 60
8. Self-rescue supplied atmospheric respirator (escape pack) – Don if CF3I level > 450 ppm

Additional precautions may be required by the Snolab management.

Case 3 addresses the hazard for the air space in the tank. The operational status of COUPP-60 in this case is that the fill/empty procedure is in progress. It assumes a fresh air supply of 1000 CFM to the tank.



Table 5. Hazard Analyses Results for CF3I release into the tank during fill/empty procedure

The analysis shows that the hazard exposure rate inside the tank is 1.96 E-05. Referencing Table 1, it shows that this exposure rate results in hazard class 1. During the fill/empty procedure the tank lid will be removed and a blower will pull 1000 CFM minimum from the floor of the tank to keep the tank properly ventilated. Appropriate PPE will be required for personnel in the tank during this procedure. The tank is considered a confined space and a special set of rules must be followed in order to access the tank during this procedure. The recommended Hazard Risk 1 safety requirements in the tank during the fill/empty procedure include:

1. Multiple personnel required (three minimum, one inside the tank)
2. CF3I exhaust fan on during this procedure
3. Warning signs indicating Operating Status, Hazard Class and any special instructions
4. 1000 CFM fresh air ventilation into the C1/C2 drift
5. 1000 CFM fresh air ventilation into the tank (exhaust air from the bottom of the tank)
6. Medical approval for all personnel in the vicinity of the COUPP 60 experiment
7. Training on the hazards of CF3I, the COUPP 60 experiment, and the evacuation plan
8. Personal hazardous atmosphere monitor for each individual working on COUPP 60
9. Self-rescue supplied atmospheric respirator (escape pack) – Don if CF3I level > 450 ppm
10. Confined space requirements

Additional precautions may be required by the Snolab management.

Safety precautions for confined space include:

1. Gas detection monitoring inside the tank
2. Unexposed observer
3. Means to rescue without entry in the tank
4. Forced fresh air ventilation
5. Confined space work permit to be issued by Snolab safety organization
6. 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.

**Conclusions**

The COUPP 60 experiment can be safely operated in the Snolab underground laboratory. In addition to the existing ventilation, a system which monitors and ventilates the tank, hydraulic valve box and distillation cart as well as the hydraulic valve closure mitigation will provide the safety measure needed to keep the hazard level to an acceptable level in the C1 drift during normal operations. Special precautions will be required during the fill/empty procedures including confined space safety when entering the tank.

**References**

1. Skaggs, S. R., and Rubenstein, R., “Setting the Occupational Exposure Limits for CF3I,” Halon Options Technical Working Conference, Albuquerque, NM, pp. 254-261, 1991.
2. National Research Council, Committee on Toxicology, Subcommittee on Iodotrifluoromethane, “Iodotrifluoromethane: Toxicity Review.” (National Academies Press, 2004), p. 3.
3. Rucinski, R., “ODH & CF3I Safety Analysis for E-961, COUPP 60 kg,” April 29, 2010 revision, <http://coupp-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=182>.
4. Fermi National Accelerator Laboratory ES&H Manual chapter 5064, May 2009 revision, <http://www-esh.fnal.gov/FESHM/5000/5064.htm>.