Transportation of Cryogenic Materials in Elevators at the Life Sciences Centre (UBC).

The UBC Life Sciences Centre's Health and Safety Office has completed an extensive and detailed risk assessment in response to some concerns expressed regarding the transportation of cryogenic materials in elevators at the UBC Life Sciences Centre. The UBC School of Environmental Health was issued a contract to do a thorough investigation of the risks of transporting liquid nitrogen and dry ice in LSC elevators and has issued a report of its findings (see attached).

It is the opinion of the LSC Health and Safety Advisor and the UBC Department of Health, Safety and Environment that liquid nitrogen and dry ice can be safely transported in LSC elevators, providing that all of the recommendations of the report are met. The report's recommendations - upon which the corresponding Standard Operating Procedures are based - are as follows.

Given the results of the CO2 and N2 elevator tests, the following recommendations are made:

1. **No more than 2 kg of dry ice should be transported in an elevator at one time.**
   The mass of dry ice has a direct effect on the concentration of CO2 within the elevator. With 25 passengers and 2 kg of dry ice, there would be at least 35 minutes before CO2 levels would reach the STEL. For masses of dry ice heavier than 2 kg, the container should be sent in the elevator alone.

2. **All dry ice should be transported in a well-insulated container with the lid securely in place.**
   Dry ice should not be transported in an airtight container because of the risk of a pressure build-up and container rupture. It was clear that at lighter masses of dry ice, lids were effective.

3. **The internal elevator fan should remain ON at all times.**
   The elevator fan provided approximately 10X air/min when activated. Keeping the fan on is good practice and can provide additional ventilation during normal operating procedures as well as during emergency situations where the elevator is still powered.

4. **A system should be established so that at least one other person is aware when dry ice is being transported in an elevator.**
   Keeping others informed as to when dry ice leaves and arrives will ensure that the transporter has not become trapped in a disabled elevator. In the event that the elevator does malfunction, emergency personnel can be informed immediately that dry ice is in the elevator.

5. **Liquid nitrogen should continue to be transported in Dewar containers with the lid in place.**
   The results from the N2 tests demonstrated that the risk posed to exposure from a properly used and functioning Dewar container is minimal.

6. **Reassessments should be conducted with elevators of differing volumes and air exchange rates or if conditions in the evaluated elevators change.**
   The results from this study should not be directly applied to elevators of different volume and air exchange rates. Both are critical factors in the accumulation of CO2 and new calculations should be conducted to reflect any changes.

Report to the Life Sciences Centre (LSC): Evaluation of recommendations for the transport of dry ice (CO_2) and liquid nitrogen (N_2) in LSC elevators

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EXECUTIVE SUMMARY

In response to concerns regarding carbon dioxide (CO2) and nitrogen gas (N2) accumulation within Life Sciences Centre (LSC) elevators, a comprehensive air quality assessment was conducted. Elevated concentrations of CO2 or N2 can displace oxygen in enclosed spaces leading to various health effects ranging from dizziness and difficulty breathing to unconsciousness and death. Because of the frequent transport of dry ice and liquid nitrogen in LSC elevators, the development of such conditions could be possible. It was the purpose of this assessment to determine if and in what manner such situations may arise.

Two worst-case scenarios were evaluated for both CO2 and N2 exposure. The first involved emergency operations and was defined as a powerless and stationary elevator transporting 25 passengers along with either dry ice (in a cooler) or liquid nitrogen (in a 20 L Dewar container). The second involved standard operations where an elevator was transporting 25 passengers and either of the two hazards for the maximum distance possible without the doors opening. To evaluate the potential for CO2 accumulation in each scenario, various masses of dry ice were placed in the elevator and the real-time build-up of CO2 was recorded. The theoretical contribution from respired CO2 from 25 passengers was determined and combined with the dry ice data to determine the time it would take for the concentration to reach the WorkSafeBC 15-minute short-term exposure limit (STEL) of 15,000 ppm (WorkSafeBC, 2010). To evaluate the hazard posed by N2 in each scenario, samples of elevator air were taken at various time intervals and analyzed to determine the percent composition of N2 in the elevator. The values were then compared to those typically found in the atmosphere.

In terms of CO2, the mass of dry ice was the determining factor in how quickly elevator concentrations reached the STEL. For emergency operations, an elevator containing 25 passengers and 4.5 kg (10 lbs) of dry ice reached the STEL in 10-12 minutes. With a 2.2 kg (5 lbs) mass of dry ice, this time increased to 35 minutes. Placing a lid over the cooler only made a difference in limiting CO2 accumulation with the lighter mass of dry ice. For standard operations, the 20-second elevator trip was not long enough for CO2 concentrations to reach dangerous concentrations. In terms of N2, the Dewar container was effective in keeping levels in the elevator comparable to atmospheric values, i.e. 78% N2, during both scenarios.

Based on these findings, a number of recommendations were made to ensure that CO2 and N2 levels remain low at all times. Most importantly, no more than 2 kg of dry ice should be transported in an elevator at one time. When transporting dry ice, it should be placed in a well-insulated container with the lid securely in place. Further, fellow workers should be informed when transport is occurring to ensure a disabled elevator is quickly reported. In addition, internal elevator fans should always remain activated as they provide a substantial source of ventilation and all liquid nitrogen should continue to be transported in Dewar containers. Finally, a reassessment should be conducted if conditions in these elevators happen to change. Implementing a variety of these engineering and administrative controls should be able to keep CO2 and N2 at acceptable levels during standard and emergency elevator operations. 3

INTRODUCTION

Carbon dioxide (CO_2) is a common atmospheric gas that typically exists at concentrations of ≈350 ppm in outdoor air. CO_2 levels inside buildings tend to be greater and WorkSafeBC begins to regulate these concentrations once they become 650 ppm higher than those outdoors, i.e. approximately 1000 ppm (WorkSafeBC, 2005). CO_2 is a product of respiration and ubiquitous in the environment, however, at high enough concentrations, severe adverse health effects can result, as illustrated in Table 1. The IDLH (immediately dangerous to life and health) concentration for CO_2 has been established by NIOSH to be 40,000 ppm (72,000 mg/m3) (http://www.cdc.gov/niosh/idlh/124389.html accessed June 2, 2010).

Table 1. Health effects of CO_2 at various levels of exposure (CCOHS, 1997). **CO2 (ppm)**	**Timeframe**	**Health Effect**
<20,000	Short-term	None
33,000 – 54,000	15 Minutes	Labored breathing
75,000	15 Minutes	Dizziness, increased heart rate, headache, disorientation
65,000 – 75,000	20 Minutes	Lower mental performance
100,000	90 Seconds	Muscle twitches
>100,000	Several Minutes	Difficulty breathing, nausea, vomiting, sweating
>100,000	15 Minutes	Unconsciousness
>200,000	Minutes	Unconsciousness and death

The toxic effects of CO_2 are further accentuated by the ability of the gas to displace oxygen (CCOHS, 1997). This ability to push oxygen out of a space is also shared by nitrogen gas (N_2). N_2 is an inert gas and does not have specific toxic properties. However, at high levels, the creation of an oxygen-deficient environment is a serious concern, which can lead to asphyxiation (WorkSafeBC, 2007). WorkSafeBC has set an 8-hour, time-weighted average (TWA) exposure limit of 5,000 ppm and a 15-minute short-term exposure limit (STEL) of 15,000 ppm for CO_2. An 8-hour TWA is defined as, “the time weighted average (TWA) concentration of a substance in air which may not be exceeded over a normal 8 hour work period” (WorkSafeBC, 2010). A STEL is defined as, “the time weighted average (TWA) concentration of a substance in air which may not be exceeded over any 15 minute period, limited to no more than 4 such periods in an 8 hour work shift with at least one hour between any 2 successive 15 minute excursion periods” (WorkSafeBC, 2010). N_2 is listed as a “Simple Asphyxiant”, which means there is no defined exposure limit since it is the amount of remaining oxygen that is of most importance (WorkSafeBC, 2010).

Given the frequent transport of dry ice and liquid nitrogen within the Life Sciences Centre (LSC) elevators, there exists the possibility of creating an environment with low oxygen, high carbon dioxide or both. Elevators are not considered to be confined spaces. However in certain situations, it is possible that a disabled and crowded elevator that is also transporting dry ice and/or liquid nitrogen, may quickly resemble one. It was the purpose of this assessment to evaluate the worst-case scenario regarding elevator usage in the LSC to determine the possibility of creating such an atmosphere as well as to outline recommendations to prevent such an occurrence.

MATERIALS & METHODS

To assess the impact of transporting dry ice and liquid nitrogen in LSC elevators, two types of modeling were conducted. The first involved worst-case sampling during emergency operations. Worst-case sampling in this case was defined according to the following criteria:

1. The elevator had lost power, i.e. immobile and internal fan deactivated
2. Rescue operations would take 60 minutes
3. 25 people were trapped
4. The elevator was transporting dry ice or a 20 L Dewar container of liquid nitrogen

The second type of modeling involved worst-case sampling during standard operations. This was defined as the following:

1. The internal elevator fan remained deactivated
2. The elevator travelled the furthest distance possible without doors opening, i.e. from floor B3 to floor 5.
3. 25 people were travelling the elevator
4. The elevator was transporting dry ice or a 20 L Dewar container of liquid nitrogen

Prior to sampling, the number of air changes per hour within the elevator was determined using a real time, portable, infra-red spectrophotometer (MIRAN; Wilks Enterprise, Inc., East Norwalk, CT) using sulfur hexafluoride (SF6) tracer gas decay analysis (Bearg, 1993). The volume of air flowing into the elevator via the internal ventilation fan, both when it was on and off, was determined using a TSITM VelociCalc Plus (St. Paul, MN) air velocity meter and the elevator dimensions were also recorded. All experiments were conducted in LSC elevator #2.

CO2 Sampling

Model 1: Emergency Operations

To model a worst-case scenario during emergency operations, 4.5 kg (10 lbs) of dry ice in a cooler was placed in the elevator. A TSITM Q-TrakTM (St. Paul, MN) was placed in the elevator and the doors were closed with the internal fan deactivated. The Q-TrakTM recorded the CO2 concentration in the elevator for 60 minutes at 1-minute intervals. To further create a worst-case situation, the lid of the cooler in which the dry ice was stored was slightly ajar. To evaluate the effectiveness of placing a lid over the container holding the dry ice, a second test was conducted in the same manner for 30 minutes with the lid of the cooler closed. Due to the results observed from these two experiments, a third 30-minute test was conducted in the same manner with 2.2 kg (5 lbs) of dry ice.
These three experiments captured the CO2 contribution from the dry ice only. The addition of respired CO2 from 25 individuals was then added using standard literature values outlined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE).

Model 2: Standard Operations

To model a worst-case scenario during standard operations, 2.2 kg of dry ice was placed in the elevator and transported for the longest distance possible without opening the doors. One technician operated the elevator while one researcher collected CO2 spot samples using the TSI Q-TrakTM. Samples were taken as the elevator travelled from floor B3 to floor 5 and back, for a total of 2 samples.

N2 Sampling

Model 1: Emergency Operations

To model a worst-case scenario, a 20 L Dewar container full of liquid nitrogen was placed in the elevator. The internal fan was turned off and the door was closed with one researcher inside. 1 L air samples were taken every 15 minutes for 60 minutes, i.e. 4 total samples, using SKC (PA, USA) pumps and Tedlar sampling bags. During this opportunity, a TSI Q-TrakTM was also placed into the elevator to determine the CO2 contribution of one individual.
Model 2: Standard Operations

To model a worst-case scenario during standard operations, N_2 samples were taken in the same manner as the elevator travelled from floor B3 to floor 5 and back for a total of 2 samples.

RESULTS

Prior to sampling for CO_2 and N_2, it was determined that 1.8 air changes per hour (ACH) occur within the stationary elevator with the internal fan deactivated. In essence, this meant that the air within the elevator was being completely replaced 1.8 times every hour due to passive ventilation in the elevator shaft. Using this rate and considering the 14.34 m^3 elevator volume, this was equivalent to a volumetric flow rate of 0.43 m^3/min of air movement into the elevator.
The volume of air entering the elevator via the internal elevator fan was also calculated. The average amount of air entering the elevator through the fan duct with the fan off was 1.8 m^3/min, while 16.8 m^3/min air was supplied with the fan on, approximately a 10X increase in flow rate. This rate only indicated the amount of air entering via the fan and did not account for how quickly the air exited the elevator (the number of air changes per hour encompasses both factors). However, it did provide some perspective on fan efficiency.

CO_2 Sampling

Model 1: Emergency Operations

A total of three tests were conducted to evaluate elevator CO_2 concentrations given the aforementioned emergency conditions. It should be noted that the third test was conducted since the Q-TrakTM reached the maximum detection limit of 6,000 ppm in each of the first two tests. The mass of dry ice was therefore halved to reflect a more typical amount of dry ice that would be transported. The most important piece of information obtained in each test was the rate of sublimation from solid CO_2 into the gaseous phase. This was determined by plotting the change in CO_2 concentration as a function of time and calculating the slope of the most linear portion of the graph (Figures A1 - A3 in the Appendix). This was done because using the most linear portion of the graph is the most conservative approach towards determining how quickly a given concentration can reach critical levels. The generation rate of CO_2 was then calculated by factoring in the volume of the elevator. Using mass-balance equations, the time required to reach the WorkSafeBC STEL of 27,000 mg/m^3 (15,000 ppm) was calculated for the dry ice only, 25 simulated passengers only who produce 0.31 L/min of CO_2 (at a room temperature of 250C) and a combination of both. Comparing to the STEL is appropriate from an occupational viewpoint, and additionally provides a reasonable timeframe within which emergency workers would be able to extricate the passengers. The STEL is determined to be a conservative CO_2 concentration where health effects are still minimal. Table 2 outlines the results of all three tests. Although the data for lid “ajar” and lid “closed” appear to be different, the measured concentrations represent the normal variance of concentration data, and can be visualized as a range of the same condition, e.g. the lid ajar did not generate significantly more CO_2 gas.

Table 2. CO_2 results from the three worst-case emergency operations test scenarios.

Dry Ice (kg)	Cooler Lid	Generation Rate: Dry-Ice Only (g/min)	Time to STEL: Dry-Ice Only (min)	Generation Rate: 25 Passengers Only (g/min)	Time to STEL: 25 Passengers Only (min)	Generation Rate: Dry-Ice + 25 Passengers (g/min)	Time to STEL: Dry-Ice + 25 Passengers (min)
4.5	**Ajar**	**22.48**	**23**	**13.94**	**58**	**36.42**	**12**
4.5	**Closed**	**28.65**	**16**	**13.94**	**58**	**42.59**	**10**
2.2	**Closed**	**3.28**	**Never**	**13.94**	**58**	**17.22**	**35**

Model 2: Standard Operations

The time required for the elevator to travel from floor B3 to 5 was too short to utilize the recording capability of the Q-TrakTM. As such, CO_2 concentration spot measurements were taken once the elevator doors closed and just before they opened. Table 3 outlines the results taken from the two tests as the elevator traveled from floors B3 to 5 and back.

Table 3. CO_2 results from the worst-case standard operations test scenarios (cooler lid closed).

Dry Ice (kg)	Start Floor	End Floor	CO_2 Concentration (ppm)		Elevator Travel Duration (sec)
			Pre	**Post**	
2.2	B3	5	1003	997	20.29
2.2	5	B3	903	911	20.63

N_2 Sampling

Model 1: Emergency Operations

Elevator air samples were collected every 15 minutes for 60 minutes using 1 L-sampling bags and analyzed for N_2 (as well as O_2 and CO_2) using a Fisher-Palmer Gas Partitioner. Values were reported as a percent composition and are outlined in Table 4.

Table 4. N_2 (and other atmospheric gases) results from the four worst-case emergency operations test scenarios

. Sample Time (min)	N_2 Concentration (%)	O_2 Concentration (%)	CO_2 Concentration (%)
15	78.36	21.58	0.06
30	78.44	21.47	0.09
45	78.26	21.67	0.07
60	78.34	21.59	0.07

Model 2: Standard Operations

Air samples were collected using 1 L-sampling bags as the elevator travelled from floor B3 to 5 and back. Samples were analyzed for N_2, as well as the other atmospheric gases, using a Fisher-Palmer Gas Partitioner. Values were reported as a percent composition and are outlined in Table 5.

Table 5. N_2 (and other atmospheric gases) results from the two worst-case standard operations test scenarios

. Start Floor	End Floor	N_2 Concentration (%)	O_2 Concentration (%)	CO_2 Concentration (%)
B3	5	78.46	21.54	<0.03
5	B3	78.38	21.62	<0.03

DISCUSSION

The transport of dry ice and liquid nitrogen is a frequent occurrence in the LSC. While CO_2 and N_2 are often considered to be benign, there is a serious concern for the accumulation of these gases leading to toxic and/or oxygen-deficient atmospheres in the elevators. This situation is particularly possible during emergency situations where elevator passengers, and their dangerous cargo, become trapped for extended periods of time. It was the purpose of this assessment to evaluate this situation and determine if and in what manner CO_2 and N_2 can create these environments.

Two types of worst-case scenarios were investigated, one pertaining to emergency operations and the other involving standard operations. Both cases involved the transport of either dry ice or liquid nitrogen, a full elevator (25 people) and the deactivated internal elevator fan. The elevator was held stationary during the emergency situation and travelled the maximum distance with the doors closed during the standard operations portion of the assessment.

CO2 Assessment

Model 1: Emergency Operations

At high concentrations, CO2 can cause serious injury, unconsciousness and death. As such, a key question in this study was, given the two worst-case scenarios, how long would it take for elevator CO2 levels to become dangerously high? Three different experiments were conducted to answer this question. The first tested 4.5 kg of dry ice in a cooler with the lid slightly ajar while the second tested the same mass of dry ice with the lid closed. The final test used 2.2 kg of dry ice, also with the cooler lid closed. Upon calculating the CO2 generation rates, it was clear that for heavier amounts of dry ice, the placement of the lid made no difference in limiting the amount of CO2 that accumulated in the elevator. In contrast, the lid may have had more of an effect with the lighter amount of dry ice, as evidenced by the dramatic drop in the CO2 generation rate during the third test. This was a key finding given that LSC policy dictates that lids must be securely fixed to hazardous materials being transported via elevator. In this instance, the cooler in which the dry ice was stored did not offer a complete seal. Styrofoam containers, which are also commonly used to transport CO2, would also act in a similar fashion. Both types of containers are in line with recommendations advising against using airtight containers for dry ice transport to prevent a build-up of pressure and a possible rupture (Praxair, 2010). The results of the tests suggested that container lids were less effective with heavier amounts of dry ice, possibly due to the rapid production of CO2 that quickly negated the effect of the lid.
The Federal Aviation Administration (FAA) has conducted numerous studies involving CO2 shipments within aircraft and has modeled amounts of dry ice allowed on flights by the following formula (FAA, 2006):

Mass of Dry-Ice = ([CO2] x Aircraft Volume x Air Changes/hr) / CO2 Sublimation Rate

This formula can be rearranged and more appropriately altered to the following:

[CO2] Elevator = (CO2 Sublimation Rate x Mass of Dry Ice) / (Volume Elevator x Air Changes/hr)

In this instance, the elevator volume and number of air changes per hour were both constant. The sublimation rate of CO2 is a dynamic property that can fluctuate with a number of factors including the mass of dry ice, the ambient temperature (higher temperatures lead to increased rates) and the type of transport container (insulated containers lower sublimation rates) (Imperial College: London, 2004). While the sublimation rate may have changed slightly during these tests, it was clear both through the experiment results and this equation, that the mass of dry ice was the critical factor contributing to the concentration of CO2 in the elevator. With such a large mass of dry ice in the initial tests, it was evident how CO2 levels reached the STEL quickly and why the cooler lid likely proved ineffective. However, with the lighter mass of dry ice, not only was less CO2 produced but the lid was able to make more of a difference. The equation predicts a proportional decrease in CO2 as the mass of dry ice decreases. However, the decrease in CO2 was not proportional, which could be attributed to the effectiveness of the lid.

What was also evident through this equation was the effect that ventilation can have on CO2 concentrations since a greater number of air changes per hour would result in lower CO2 levels. The number of air changes per hour was only measured in a stationary elevator with the internal fan deactivated. Unfortunately, the number of changes was not evaluated with the fan activated or with the elevator moving. However, the volume of air entering the elevator via the fan was measured under both “on” and “off” conditions. Given the drastic change in the amount of air entering the elevator per second when the fan was on (approximately 10X more), it was very likely that the concentration of CO2 in the elevator would have been much lower had the fan been activated during each of the tests. It should be noted that the LSC elevator fan was off even during normal operations.

Accounting for the CO2 contribution from elevator passengers was another key aspect to this assessment. ASHRAE provides a CO2 respiration rate of 0.31 L/min for sedentary persons (ASHRAE, 2007). Even though the elevator is capable of transporting 5000 lbs, it is likely that the amount of floor space in the elevator is the limiting factor for how many people can be transported. As such, a 25-passenger capacity was used as the limit for each model. Examining the individual contributions of the dry ice and 25 passengers, considerably more CO_2 was generated by the 4.5 kg mass of dry ice compared to passengers. However, with the 2.2 kg mass of dry ice, the passenger contribution became the primary source of CO_2. Combining this amount of dry ice with the passenger contribution, it would take 35 minutes to reach the STEL. This 35-minute timeframe would be enough time for emergency crews to extricate the passengers, given their 10-minute response time. While this 10-minute window would theoretically also be enough if there were 25 passengers and 4.5 kg of dry ice in the elevator, it would not be the most precautionary approach.

Model 2: Standard Operations

In terms of the worst-case scenario during standard operations, there was no change in CO_2 levels during the 20-second trip from B3 to floor 5 and back with a 2.2 kg mass of dry ice. This indicated that during the maximum-distance trip with the doors closed, the dry ice was not a substantial source of CO_2 and that it would be the passengers who would be the primary sources. Given the short elevator trip and a moving elevator, i.e. a likely increase in natural ventilation, the chances of approaching the STEL are remote.

N_2 Assessment

Model 1: Emergency Operations

The composition of gases in the atmosphere, by percentage, is 78% N_2 and 21% O_2 with the rest being a mix of other trace gases, including CO_2 (between 0.01-0.1%) (NASA, 2003). In terms of emergency operations, it was clear that the amount of N_2 (and CO_2 produced by only one person) remained constant and within normal parameters. This indicated that either the N_2 was evaporating at a much slower rate, was not escaping from the Dewar container at a high rate, or was entering the elevator at a rate in which it could be efficiently removed by the air change rate. In either case, the 20 L Dewar container was sufficient in containing the N_2 gas.

Model 2: Standard Operations

In terms of the tests run during standard operations, the N_2 levels also remained constant. As demonstrated by the emergency operations test, the Dewar container properly contained the N_2. It would therefore be expected that with such short elevator travel times, no increase in N_2 would occur.

LIMITATIONS

The primary limitation of this assessment was the inability to directly measure CO_2 concentrations at higher levels. This was a result of necessary safety precautions. Collecting bag samples along with real-time data collection would have been ideal, however that would have required placing a person inside the elevator. The risk of asphyxiation negated this possibility, which resulted in the use of instruments with the ability to only detect concentrations up to 6,000 ppm. Regardless, extrapolating to the 15,000 ppm STEL through mathematical modeling is a valid and conservative approach.

Another limitation was the inability to allow CO_2 levels to return completely to background (approximately 600 ppm in the LSC) before running the next test. Ideally, allowing the environment in the elevator to equilibrate would have been ideal. However, the starting concentration of CO_2 for each test was taken into account by the models used, and generation rates were determined from the most linear (and stable) portion of the concentration curve.

RECOMMENDATIONS

Given the results of the CO_2 and N_2 elevator tests, the following recommendations are made:

1. **No more than 2 kg of dry ice should be transported in an elevator at one time.**
   The mass of dry ice has a direct effect on the concentration of CO_2 within the elevator. With 25 passengers and 2 kg of dry ice, there would be at least 35 minutes before CO_2 levels would reach the STEL. For masses of dry ice heavier than 2 kg, the container should be sent in the elevator alone.

1. **All dry ice should be transported in a well-insulated container with the lid securely in place.**
   Dry ice should not be transported in an airtight container because of the risk of a pressure build-up and container rupture. It was clear that at lighter masses of dry ice, lids were effective.

1. **The internal elevator fan should remain ON at all times.**
   The elevator fan provided approximately 10X air/min when activated. Keeping the fan on is good practice and can provide additional ventilation during normal operating procedures as well as during emergency situations where the elevator is still powered.

1. **A system should be established so that at least one other person is aware when dry ice is being transported in an elevator.**
   Keeping others informed as to when dry ice leaves and arrives will ensure that the transporter has not become trapped in a disabled elevator. In the event that the elevator does malfunction, emergency personnel can be informed immediately that dry ice is in the elevator.

1. **Liquid nitrogen should continue to be transported in Dewar containers with the lid in place.**
   The results from the N_2 tests demonstrated that the risk posed to exposure from a properly used and functioning Dewar container is minimal.

1. **Reassessments should be conducted with elevators of differing volumes and air exchange rates or if conditions in the evaluated elevators change.**
   The results from this study should not be directly applied to elevators of different volume and air exchange rates. Both are critical factors in the accumulation of CO_2 and new calculations should be conducted to reflect any changes.

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APPENDIX

Figures A1 - A3 outline the recorded CO2 concentrations for each of the three emergency operations tests as a function of time. From these graphs, the rate of CO2 generation was calculated. The generation rate from the 25 passengers was based on individuals emitting, on average, 0.31 L/min of CO2 (ASHRAE, 2007). Using the density of CO2 at 250C (1.799 kg/m3), the mass of CO2 produced by each person taken to be 557.7 mg/min for a total of 13,942 mg/min. The total generation rate was a summation of both the passenger contribution and that from each st. Table A1 illustrates each of these values and outlines how the time to the 15,000 ppm 7,000 mg/m3) STEL was determined.

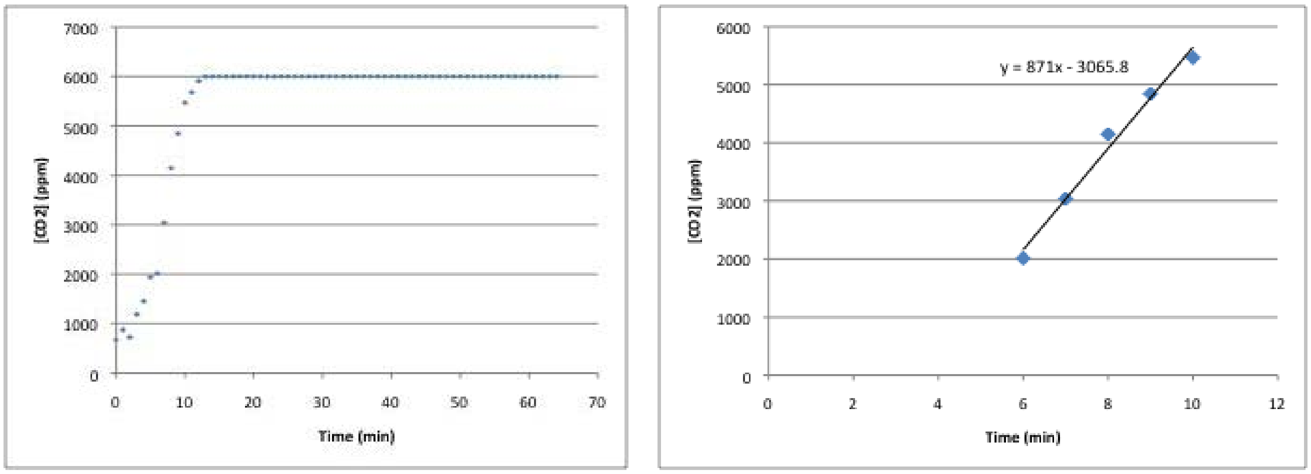

Figure A1. These graphs illustrate CO2 measurements over a 60-minute timeframe for the 4.5 kg mass of dry ice in the cooler with the lid ajar, i.e. the first emergency operations test. The graph on the left shows each measurement with the 6,000 ppm instrument limit being reached in the first 14 minutes of the test. The graph on the right focuses on the concentrations between 6 and 10 minutes of the test where the most linear portion of the graph occurs. The slope of this line, 871 ppm/min or 1,567.8 mg/m3/min was the rate of sublimation. Accounting for the 14.34 m3 elevator volume, the CO2 generation rate from the dry ice alone was calculated to be 22,482.25 mg/min. Combining the passenger contribution of 13,942.25 mg/min, the total CO2 generation rate for this test (G) was 36,424.5 mg/min.

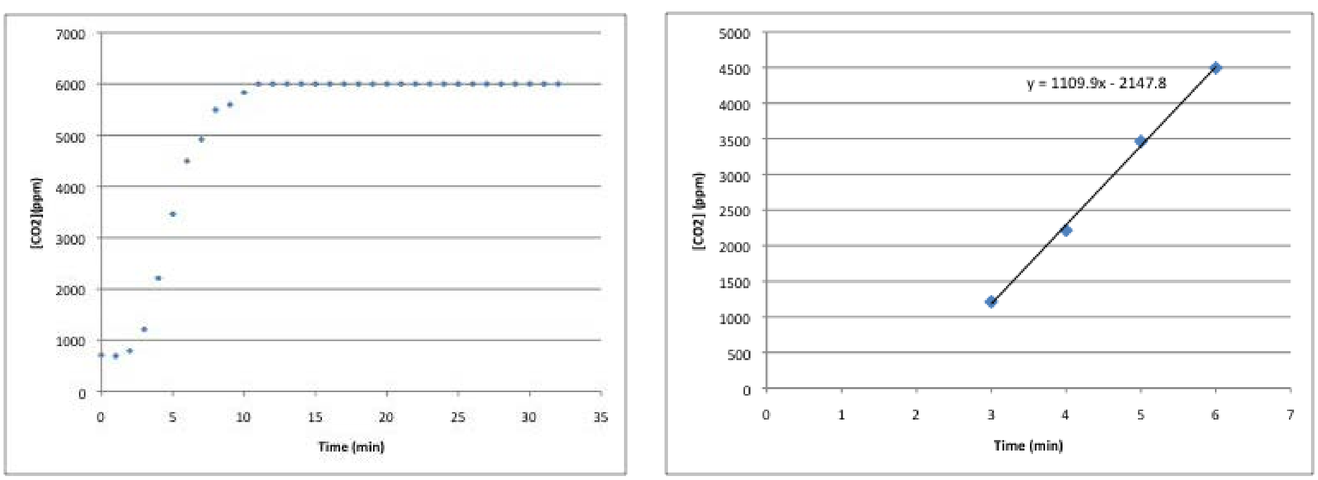

Figure A2. These graphs illustrate CO2 measurements over a 30-minute timeframe for the 4.5 kg mass of dry ice in the cooler with the lid closed, i.e. the second emergency operations test. The graph on the left shows each measurement with the 6,000 ppm instrument limit being reached in the first 12 minutes of the test. The graph on the right focuses on the concentrations between 3 and 6 minutes of the test where the most linear portion of the graph occurs. The slope of this line, 1,109.9 ppm/min or 1,997.8 mg/m3/min was the rate of sublimation.

Accounting for the 14.34 m3 elevator volume, the CO2 generation rate from the dry ice alone was calculated to be 28,648.74 mg/min. Combining the passenger contribution of 13,942.25 mg/min, the total CO2 generation rate for this test (G) was 42,590.99 mg/min.

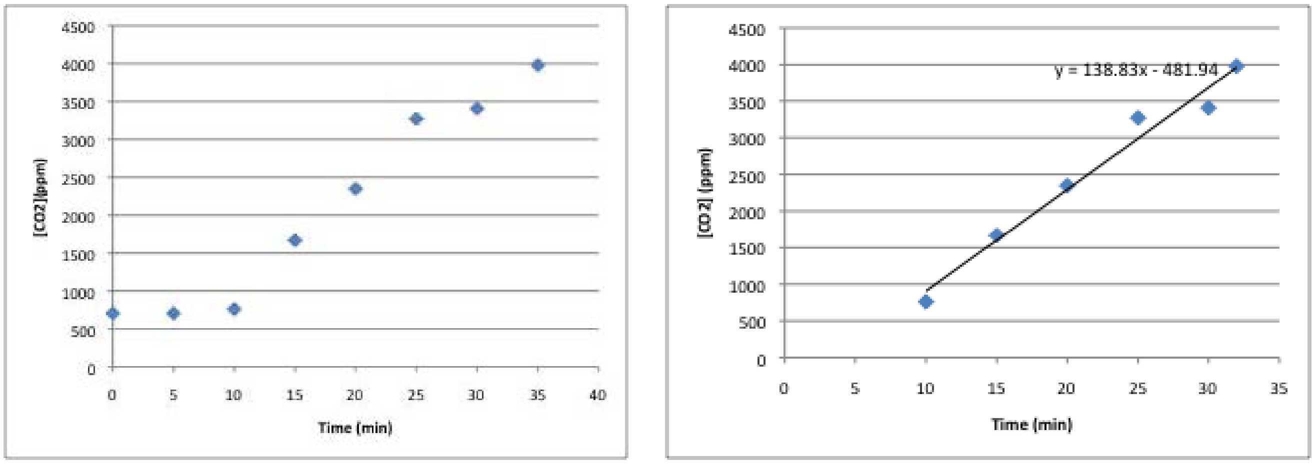

Figure A3. These graphs illustrate CO2 measurements over a 30-minute timeframe for the 2.2 kg mass of dry ice in the cooler with the lid closed, i.e. the third emergency operations test. The graph on the left shows each measurement over 5-minute averaged intervals with the 6,000 ppm instrument limit never being reached. The graph on the right focuses on the concentrations starting 10 minutes into the test where the most linear portion of the graph occurs. The slope of this line, 138.83 ppm/min or 249.89 mg/m3/min was the rate of sublimation. Accounting for the 14.34 m3 elevator volume, the CO2 generation rate from the dry ice alone was calculated to be 3,583.48 mg/min. Combining the passenger contribution of 13,942.25 mg/min, the total CO2 generation rate for this test (G) was 17,525.73 mg/min.

Table A1. CO2 generation rates, elevator volumetric flow rates and initial CO2 concentrations for each of the three emergency operations tests. The volume (V) of the elevator was 14.34 m3.

Dry Ice (kg)	**Cooler Lid**	**Total CO2 Generation Rate (G) (mg/min)**	**Elevator Volumetric Flow Rate (Q) (m3/min)**	**Initial CO2 Elevator Concentration (C1) (mg/m3)**	**Time to STEL (min)***
4.5	Ajar	36,424.50	0.43	1,206.00	12
4.5	Closed	42,590.99	0.43	1,272.60	10
2.2	Closed	17,525.72	0.43	1,267.20	35