Monitoring Carbon Dioxide

Note: This protocol is subject to revision. This version is as of Wednesday, 19 June 2002.

Exposure Limits

In the United States, the current OSHA permissible exposure limit (PEL) for carbon dioxide is 0.5% time-weighted-average, for an eight-hour period. There is also a higher short term exposure limit (STEL) of 3% time-weighted average for a period of no more than 15 minutes. There is a proposal to raise the OSHA PEL from 0.5%, to 1%, and that is expected to be approved soon, but right now the eight-hour limit is 0.5%

Measuring – the General Idea

Carbon dioxide levels are monitored in ESTA's fog testing program by using the Crowcon Safegard II. This machine gives instantaneous readings of CO_2 levels up to 5%. It flashes a red light and sounds a beeping alarm at 0.5% up to 1%. At 1% and above, it shows the red light and sounds the alarm continuously. The meter uses infrared absorption technology to measure the amount of carbon dioxide. The sensor is located behind the small grill above the display, and light behind the grill pulses while the Safegard is on.

Dry ice fogs and low-lying glycol fog machines that use liquid carbon dioxide put CO_2 into the air. The carbon dioxide is present in the fog effects, and is also released into the air by dry ice while in storage and by liquid carbon dioxide while stored in low-pressure dewars. Carbon dioxide is heavier than air, particularly when cold, and this released carbon dioxide, besides being in the fog on stage, can collect in low-lying areas where the fog settles, and in storage spaces where dry ice or liquid CO_2 dewars are kept. Carbon dioxide levels that are too high can be hazardous, so steps should be taken to monitor CO_2 levels.

It’s not very useful to try to measure all the air everywhere, so practical monitoring focuses on measuring the air people are likely to breathe in the fog effect, in low-lying areas where the fog settles, and in storage areas. If the results of these measurements give you numbers within appropriate limits, you are set. If those measurements give you numbers outside appropriate limits, the fog effect, the location of the people, or the ventilation needs to be changed.

Note: Fog is by nature variable, so it’s recommended that users run the tests three times and take the average reading.

Measuring the Fog Effect – Step-by-Step

1. Figure out who is in the densest fog or in the fog the most time. Don't forget to consider the backstage crew members as well as the cast. Note where the mouth and nose of that person is while he or she is in the fog.

2. Set up the show conditions — the conditions that will exist when the person is in the fog.

    Make sure that the air conditioning or heating is on or off, as the case may be, that scenery and curtains are where they are when the person is in the fog, or are moving if that's what they do during the cue. Make sure that doors normally closed are closed, and that doors normally open are open.

3. Turn on the Safegard.

Press the big black button with the yellow ring on the front of the unit. The display will show
Crowcon
Safegard
for about 20 seconds. The display will then change to show
Crowcon
x.xx%CO2 (Where x.xx equals some percentage.)
The unit will beep every 30 seconds to show that it's on.

4. Run the fog cue with the Safegard in the fog where the person will be, and measure the CO_2 in the fog.

Run the fog cue under show conditions with the monitor near where the person's mouth and nose will be during the cue. If the person walks into the fog, out of the fog, or moves through it, move the monitor to duplicate those moves. Try to duplicate the person's speed and timing; don't rush and don't linger. Make sure that you don't block the air intake port above the display or breathe into it. Note if the Safegard's alarm goes off at any time.

5. If the alarm never sounds.

If the alarm never sounds, the CO_2 level is never above 0.5%, and the OSHA PEL is not exceeded. There is so little CO_2 in the fog that nothing needs to be done about it, and you can go on to measuring the CO_2 in the places where the fog settles and in the dry ice or liquid CO_2 storage areas.

6. If the alarm sounds.

If the alarm sounds, you need to collect data to determine the time-weighted average levels. After clearing the air, note the ambient level of CO_2. Then run the fog cue again, but this time note the readings on the Safegard every 30 seconds. Stop noting the readings when the fog cue is over and the CO_2 is back to ambient levels. Record the total time you took readings.

NOTE: If the CO_2 levels are 5% or higher, leave the area. The CO_2 level is too high to read with the Safegard, and may be at a level that is an immediate serious hazard. Levels above 7% can cause unconsciousness in a few minutes. Higher levels can cause death.

7. Turn off the Safegard.

Press the big black button and hold it for three seconds. The Safegard will give a sustained beep, and then shut off.

Fog is by nature variable, so it's recommended that users run the tests three times and take the average reading.

Judging the Eight-Hour TWA Exposure Levels

The data collected in step 6 needs to be converted to a time-weighted average. If the data is collected at regular intervals, this simple formula will give the time-weighted average over the sampling period:

$$(C_1 + C_2 + C_3 + \ldots + C_N)/N = C_{TWA}$$

Where C is the concentration at a moment in time and N is the number of samples.

The 8-hour time-weighted average needs to be calculated from the results of the above calculation and the ambient CO_2 levels. Remember that people are never away from CO_2 even when they are out of the fog. The ambient level of CO2 in the open air is about 0.03%, but indoors it can be well above 0.1% simply from people breathing.

$$(C_{TWA}T_{fog} + C_{ambient}T_{ambient})/480 = E$$

Where:

E is the equivalent 8-hour exposure

C_{TWA} is the TWA CO_2 level during the measured period of time in the elevated levels due to the fog effect, T_{fog}

T_{fog} is the measured period of time in the elevated levels due to the fog effect expressed in minutes

$C_{ambient}$ is the ambient TWA CO_2 level

$T_{ambient}$ is the time expressed in minutes in which the person is in the ambient CO_2 environment during an 8-hour (480-minute) period during which the fog cue is run. For example, if the elevated levels (T_{fog}) lasted 15 minutes, the time at ambient levels ($T_{ambient}$) is 465 minutes.

If the person is in the fog several times during the day, you need to compute the cumulative exposure with the following formula:

$$E_{8\text{-hour}} = (C_aT_a + C_bT_b + \ldots C_nT_n + C_{ambient}T_{ambient})/480$$

In this case, C_aT_a, C_bT_b, and so on, are the TWA CO_2 levels and exposure times in minutes for each of the fog cues.

If the eight-hour TWA level is below the OSHA PEL, this is good news, and you can move on to judging the short-term exposure. If the eight-hour TWA is above the OSHA PEL, you need to do something to reduce the person's exposure to CO_2. Since carbon dioxide is heavier than air and tends to hug the floor in a fog effect, simply raising the person's face further from the floor may solve the problem. For example, it's generally not a good idea to have a performer lie down in dry ice fog because that puts the performer's face close to the floor where the CO_2 is the most concentrated. Moving the person away from the fog machine's outlet may also do the trick. It may be necessary to lighten the fog effect by using less dry ice or less liquid CO_2, or to shorten the duration of the effect. Careful siting of the fog equipment and the use of hoses, ducts or fans can put the fog in front of or around a person, and leave the person in a relatively fog free area. Careful use of lights can make a small amount of fog look denser than a lot of fog, poorly lit. Alternatively, if the ambient level of CO_2 is fairly high, the eight-hour TWA can be improved by increasing the ventilation and thus lowering the ambient level of CO_2 in the air. Whatever you do to control the exposure, write it into the operating procedures for the show so it will be done consistently.

Judging the 15-Minute Short-Term Exposure Levels

Take a look at the data you collected during the fog cue. If none of the levels is 3% or above, you can meet the requirements of the OSHA STEL be simply making sure that the time period where the CO_2 level is above the PEL is 15 minutes or less. If you recorded several levels at 3% or any above 3%, you need to calculate the time-weighted average short-term exposure over a 15-minute period.

To calculate the short-term exposure, look at the data you collected and note any 15-minute periods that seems to have high peak levels. Using the measurements you took during these 15-minute periods, calculate the time-weighted average over the sampling periods.

$$(C_1 + C_2 + C_3 + \ldots + C_N)/N = C_{TWA}$$

The concentration should not exceed the OSHA STEL, which is 3%. If it is higher, you need to do something to reduce the person's exposure to CO_2. Since carbon dioxide is heavier than air and tends to hug the floor in a fog effect, simply raising the person's face further from the floor may solve the problem. Moving the person away from the fog machine's outlet may also do the trick. It may be necessary to lighten the fog effect by using less dry ice or less liquid CO_2, or to shorten the duration of the effect. Careful siting of the fog equipment and the use of hoses, ducts or fans can put the fog in front of or around a person, and leave the person in a relatively fog free area. Careful use of lights can make a small amount of fog look denser than a lot of fog, poorly lit. Whatever you do to control the exposure, write it into the operating procedures for the show so it will be done consistently.

Measuring Fog Where It Settles

Low-lying fog effects have a tendency to run off the stage into orchestra pits and other low-lying areas, carrying carbon dioxide with them. These areas should be checked. Use the procedure outlined for "Measuring the Fog Effect – Step-by-Step" but check the levels for all the people who might be in these low-lying areas, not only those who look like the most fog is falling on them. Judge both the levels against both the OSHA PEL and STEL.

If the levels are above the OSHA limits, something needs to be done to lower the exposure levels, but the options available are a little different than they are for dealing with a fog effect on stage. For example, if excessive CO_2 levels are found in an orchestra pit, it is usually not practical to move the musicians out of the pit, although that would solve the problem. However, it is often practical to increase the flow of fresh air into the pit or to block the flow of the fog and CO_2, either with a low barrier at the edge of the stage, or with fans opposing the flow of the fog and diverting it elsewhere. Whatever is done, write it into the operating procedures for the show so it is done consistently every time. Be particularly careful of solutions that involve adding or increasing mechanical ventilation. It is easy to solve the problem by increasing the fan speed on the air conditioning, only to have someone else turn down the fan later to reduce noise.

Measuring Fog Storage Areas

Dry ice and liquid carbon dioxide in dewars should not be stored in confined areas, particularly confined areas with poor ventilation. In any case, areas where dry ice or liquid carbon dioxide in dewars are kept should be checked for excessive carbon dioxide levels. The solid dry ice will slowly turn to gas and add CO_2 to the air around it. The low-pressure dewars hold cold liquid CO_2, which, as it gains heat from the surroundings, evaporates and builds pressure inside the dewar. To control the pressure, a vent releases CO_2 into the air. If the dry ice or dewar is stored in a place with poor ventilation, high levels of CO_2 may result in the storage area.

Turn on the Safegard while away from the CO_2 storage area. Then, with the Safegard turned on, go the storage area and use the procedure outlined for "Measuring the Fog Effect – Step-by-Step" to check the levels for anyone who might enter the area. If you find levels that are above the PEL but below the STEL, do not assume that you don't have to address the situation because no one goes into the storage area for longer than 15 minutes. Unless you have a reliable way of controlling access to the storage area, it is better

to assume that someone might go there and stay all day. Thus, it would be appropriate to work to stay below the PEL and not the higher STEL.

NOTE: If during your measurements, or at any time while the Safegard is on, the CO_2 level is 5% or higher, leave the area immediately. The CO_2 level is too high to read with the Safegard, and may be at a level that is an immediate serious hazard. Levels above 7% can cause unconsciousness in a few minutes. Higher levels can cause death. Do not try to re-enter the area until you have ventilated it to reduce the CO_2 level.

If the CO_2 level is higher than the PEL, reducing the entry of CO_2 into the air in the storage area is likely to be impossible, so increasing the ventilation will be the solution. However, if this is done with mechanical ventilation, make sure that it can't be turned off. It is not uncommon for ventilation in a theatre to be shut off during the day, which could result in the accumulation of high CO_2 levels by evening. Natural ventilation is more reliable; a drafty loading dock is often a better storage space than is an unused dressing room in a theatre's basement. Also, a little carbon dioxide added to a large space will have much less effect than the same amount added to a small space, so a large storage area is much better than a small one. Avoid confined spaces.

Questions?

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