January 20, 2010

XXX XXXXX
Safety Consultant
XXXX XXXXX
XXXXXXXXXXXXX.
Lakewood, CO 80227

Dear Mr. XXXXX:

On Thursday, January 14, 2010, Forensic Applications Consulting Technologies, Inc. (FACTs), visited the XXXX facility located at XXXX. in Denver, CO. The purpose of the visit was to test the concentration of carbon monoxide in three SCBA tanks used at the facility.

EXECUTIVE SUMMARY

Following reports of carbon monoxide exposure, FACTs was engaged to perform air sampling on bottled air associated with SCBAs. Standard industrial hygiene methodologies were employed to determine the concentration of carbon monoxide (CO) in three standard SCBA air bottles.

Using standard industrial hygiene monitoring equipment, we determined that the CO concentrations in each of the bottles was below 0.5 ppm and well within the 1987 and 1997 CGA Grade-D air specifications.

The measured CO concentrations confirm that elevated CO was not present in the SCBA bottles, and that the air within the bottles tested was not responsible for any unusual exposures to CO.

The concentration of the blood component carboxyhemoglobin (COHb), as measured in the employee's blood, was marginally out of range (high) at the time of the draw. The COHb concentration was within the range normally expected from an otherwise healthy smoker.

The COHb concentration steadily declines with time in a predictable fashion, allowing an estimate of the concentrations of CO exposure prior to the time of the blood draw. The minimum concentration of CO present, in a steady state, needed to result in a COHb concentration as seen in the employee two and a half hours following exposure is about 25 to 50 parts of CO per million parts of air (25-50 ppm), at which time, the COHb levels may have been as high as 3.5% (which is also within the expected range of a smoker.)

INTRODUCTION

Based on information presented to FACTs, we understand that an XXXX employee donned a standard SCBA to perform repair work in a trench. After a period of time, the employee began to experience symptomology and exited the work area and doffed the SCBA.

Approximately 150 minutes later, the employee entered a medical facility where a blood draw was performed. The results of the blood draw indicated very slightly elevated levels of COHb, not normally associated with CO "poisoning."

TOXICOLOGY

CO rapidly alters blood chemistry and interferes with the blood's ability to release oxygen to the surrounding cells in need of that oxygen. The oxygen carrying structure in human blood is the heme ring which has an altering shape. The shape of the ring changes to affect the oxygen affinity of the structure, a phenomenon known as "cooperativity."

CO has an higher affinity to the ring than oxygen, and has the ability to lock the ring structure into its highest affinity for oxygen. It is for this reason that individuals experiencing CO induced cytotoxic hypoxemia have very high levels of oxygen in their blood – the heme group holds tight to the available oxygen and won't release it.

The relationship between the severity of clinical signs and symptoms of acute CO poisoning and COHb levels is not well correlated.[1] According to the information provided to FACTs by XXXX, the COHb in the exposed employee's blood was 2.3% approximately 150 minutes following cessation of exposure. Generally, in healthy individuals, mild carbon monoxide poisoning that requires medical intervention is associated with COHb levels that are greater than 20%. Adult males who smoke cigarettes typically have COHb levels of about 8% but may be as high as 12%.

Using a qualitative estimate of the half-life of the COHb of 300 minutes,[2] we can <u>roughly</u> estimate that at the moment of cessation of exposure, the employee's COHb could have been about 3.3%; correlating to an ambient steady state exposure to about 25 ppm CO. Discussions with some our medical colleagues have concurred with our estimate and suggested that an exposure of 50 ppm for 45 minutes occurring during heavy manual exertion could result in a 2.3% COHb concentration 150 minute following cessation of the exposure.

The association between time of exposure, time since exposure, concentration of CO in the air during the exposure and COHb concentrations are described by the "*Coburn-Forster-*

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[1] Toxicological Profile For Carbon Monoxide (DRAFT), U.S. Department Of Health And Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, September 2009

[2] Documentation of the Biological Exposure Indices, Carbon Monoxide in End-Exhaled Air Index, (BEI 66-68) Not Dated.

Kane differential." This model can be used to better quantify the various parameters associated with CO exposures. However, application of the model is complex and unwieldy. Nevertheless, the relationship between COHb, time of exposure, and concentration of CO (ppm) in the air, has been approximated[3] for varying levels of CO in ambient air and are provided in the graphic below.

The graphic below contains several assumptions known not to be applicable in this case; however, the graph is still useful and indicates that for a 45 minute exposure, for a male at sea level, with a COHb of 3.3%, the employee could have been exposed to as much as about 180 ppm CO. Therefore, we suggest an initial exposure range of somewhere between 25 ppm to 180 ppm for 45 minutes – with all data suggesting greater confidence in the lower portion of the range.

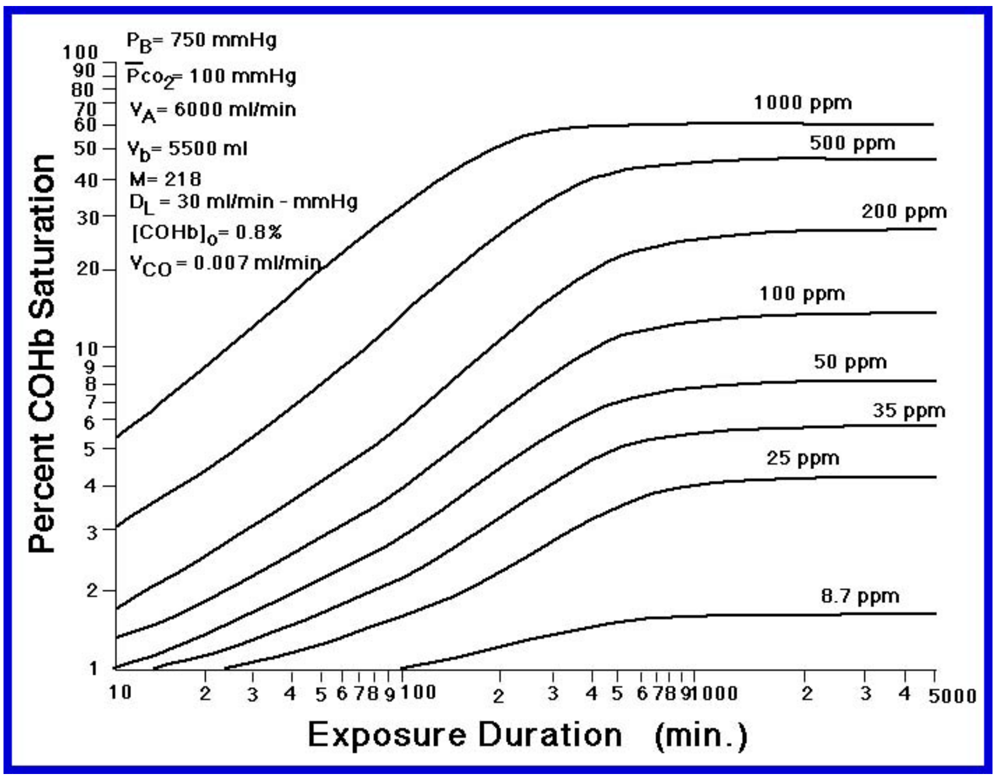

Figure 1

Log-log plot of CO uptake as computed from the Coburn-Forster-Kane Differential[4]

Taken the higher end of the possible range, (180 ppm), the employee's 8 hour TWA exposure would have been about 17 ppm CO (assuming just the 45 minute exposure).

[3] Peterson, J.E. & Stewart, R.D., 1975, Predicting the carboxyhemoglobin levels resulting from carbon monoxide exposures. J. Appl. Physiol., 39, 633-638

[4] Taken from Peterson, J.E., Stewart, R.D., 1975, *Predicting the carboxyhemoglobin levels resulting from carbon monoxide exposures*. J. Appl. Physiol., 39, 633-638

Confounders

The primary confounders and variables are going to include the employee's weight, smoking habits, ventilation rate, the fact that the CFK differential graph above is based on a barometric pressure of 29.95 inches of mercury, whereas the XXXX employee was operating at a barometric pressure of 24.5 inches of mercury (which in turn significantly effects the half life of COHb, and pushes the estimates of initial exposure down). Nevertheless, the estimates of initial exposure are within reasonable limits.

Other confounders, however, may be unidentifiable at this point. For example, other compounds and exposure scenarios can also result in elevated COHb levels even in the absence of CO. For example, methylene chloride (MC) exposures can result in elevated COHb levels that continue to increase after cessation of exposure, due to the MC being sequestered in fatty tissues, and then slowly re-entering systemic circulation. A competing dynamic equilibrium therefore is established where COHb is increasing as MC is metabolized, but decreasing according to a half-life dependant on the atmospheric pressure of O2. A physiologically based pharmacokinetic model of MC estimated that a 1-hour exposure to 340 ppm of MC at a ventilation rate of 9 liters/min would result in a peak blood COHb level similar to that seen in the XXXX employee; 2%.[5] The California Ambient Air Quality Standard for CO is based on a blood COHb level of 2%.

Other scenarios can result in elevated CO, even where CO is not normally expected to occur. For example, employees of a brewery experienced CO poisoning while cleaning a fermentation tank with lye. The lye reacted with residual reducing sugars in the tank generating CO. The employees would never have considered monitoring for CO for this task, since CO was not expected to be present, even though the potential hazard has been known for decades.[6]

Other confounders could include the endogenous CO production rate of the employee. Most people produce about 10 ml of CO gas phase per day by normal heme catabolism. People with an hemolytic disorder can have a dramatically higher rate. Therefore, in order to properly quantify the initial exposure, we would need to know if the subject had such a disorder. Other factors influencing endogenous CO production include recent trauma, sickle cell disease, hemolytic anemia (due to favism, certain drug/antibiotic usage) or recent surgery or blood transfusions.

Therefore, while investigating this exposure scenario, FACTs cautions XXXX Safety Personnel to cast a broad net and keep an open mind about the possible causes, and not focus on the low hanging fruit of possibilities.

AIR BOTTLE TEST

FACTs personnel tested the air contained in three SCBA bottles presented to us during our site visit.

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[5] State of California Office of Environmental Health Hazard Assessment *Methylene Chloride Chronic Toxicity Summary* (Not dated)

[6] Geraldine V. Cox, PhD, Manufacturing Chemists Association, Letter to Joseph Miranda, Assessment Division, Office of Toxic Substances, US EPA, June 4, 1979

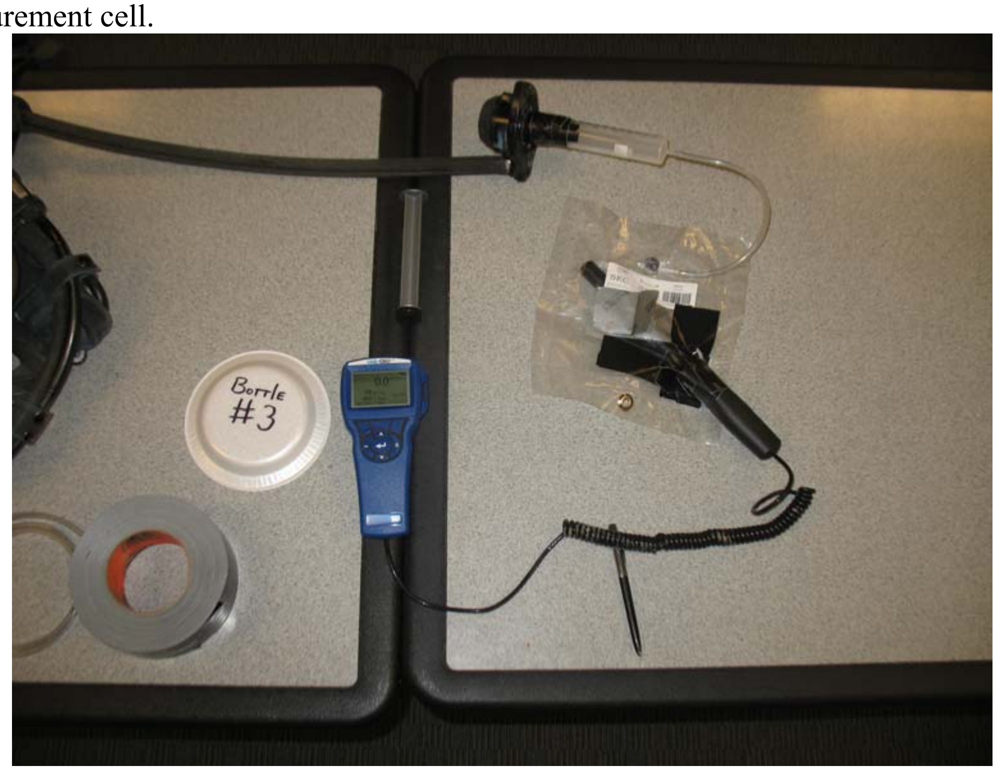
SET UP

FACTs was presented with three separate SurvivAir 4500 psi SCBA tanks. The tanks bore the identifiers found in Table 1

Tank #	Visible Identifiers	Pressure Reading (psig)
1	G-151, 11 A1 69 07, PN920342, LN7141	0
2	G-151, 2 A1 69 07, PN920312, LN3525	5 k
3	Naranjo, A B 5 8, 04 B9 72 01, 4 A1 69 8, LN8670	41 k

Table 1
Identification of Tanks

A 100 cm3 syringe was attached to the final down regulator of a standard SCBA harness. The flow of air through the final regulator was arbitrarily established at 22 cm3/sec. The probe from a factory calibrated TSI IAQ-Calc Model 7545 was plumbed into a 500 ml Tedlar® gas bag. To avoid negative bias, the end of the probe was not tightly sealed, thus allowing sampled air to pass across the measurement probe within a confined measurement cell.



Photograph Number 1
Sampling Train Assembly

Prior to collecting air from a bottle, we expelled all the air from the collection bag. We then assembled a test bottle onto the sampling train and allowed three bed volumes of bottled air to flush through the sampling train prior to collecting the readings.

We set the instrument to simultaneously measure carbon monoxide, carbon dioxide, and dew point. We selected dew point as a surrogate analyte to ensure that we were measuring bottled air and not ambient air which has a significantly greater dew point than seen in Grade D air.

Included with this discussion is a DVD/CD of digital photographs collected during the test.

The tests were conducted in a large conference room at the facility. The barometric pressure (station pressure) was 24.95 inches of mercury, and the ambient room air temperature (dry bulb) was about 72°F; Dew Point was 25 °F. In the table below, we have presented a summary of our observations.

Source	CO2 (ppm)	CO (ppm)	DP (°F)
Bottle #1	469	<0.1	-4
Bottle #2	500	<0.1	-40
Bottle #3	298	<0.1	-40
Conference Room Air	500-700	<0.1	+ 25.5

Table 2
Identification of Tanks

The surrogate parameter (dew point, in °F), provides us with confidence that the air being measured was that air delivered from the bottle, and not ambient air. Although the pressure gauge from Bottle #3 indicated no pressure, there was sufficient pressure to deliver sufficient air into the sampling train.

Data Quality Objectives

Precision and Accuracy

Our *a priori* data quality objectives were primarily focused on CO. Since each of the readings was below the detection limit of the instrument, a statement of bias and precision cannot be made. Due to the fast response time needed by the client, external standards were not employed. However, a secondary method of semi-quantitative measures was collected using GasTech colorimetric length-of-stain detectors. The GasTech detector tube readings were consistent with the CO and CO2 values reported by the instrument for the ambient conditions.

Representativeness

The integration time of the TSI instrument was less than one second, and each bottle was allowed to deliver air to the sampling train for at least one minute. The fluctuations in the readings from the instrument were stable indicating that the data were representative for the bottle being tested. (The application of Pascal's law, Roult's Law and the ideal gas law ensure homogeneity of the sample drawn from the bottle.)

Comparability

The results of the data thus collected were compared against known regulatory compliance levels, and established toxicological thresholds and markers. The primary decision threshold values were:

CO: 10 ppm (1997 CGA Grade-D air specifications)
CO2: 1,000 ppm (1997 CGA Grade-D air specifications)
D.P. °F: 0°F (FACTs arbitrary level for ensuring bottled air, not room air, was being tested).

Completeness

All available information indicates that the DQOs were met, to the extent that no information exists to challenge the completeness of the data.

CONCLUSIONS

Based on the best information available to us, and based on our direct observations, the bottled air did not contain sufficient CO to result in a COHb concentration observed in the employee.

FACTs did not measure the concentration of methylene chloride or any other contaminant in the bottles that may be metabolized producing elevated COHb.

RECOMMENDATIONS

From an industrial hygiene perspective (not a medical perspective) the employee should be tested for COHb again within the week. If COHb remains elevated, smoking or a medical condition is likely. If COHb goes to the 0.5 to 1.5% COHb range, the subject is normal, and the work situation should be considered more strongly as the environment causing the slightly elevated COHb levels.

Sincerely,

Caoimhín P. Connell
Forensic Industrial Hygienist