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Interim Report

December 5, 2002

Michael Ward, D.O.
Medical Director, Emergency Medical Services
Havasu Regional Medical Center
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Havasu, Arizona 86403

Dear Dr. Ward:

Thank you for the opportunity to work collaboratively to evaluate boat-related carbon monoxide (CO) exposures at Lake Havasu, Arizona. The purpose of this letter is discuss the results of our preliminary collaborative work during the 2002 Labor Day holiday weekend. This letter summarizes our findings and conclusions. Detailed information about the health effects of exposure to CO and related evaluation criteria are included in Attachments 1 and 2.

General Background

On August 23, 2002, you requested assistance from the National Institute for Occupational Safety and Health (NIOSH) in performing field-testing for CO. Your concern stemmed from the fact that you and your partners had seen four to six patients in the Emergency Department (ED) over the past several years who had been poisoned by their exposure to CO while in the London Bridge channel at Lake Havasu. These patients had carboxyhemoglobin (COHb) concentrations greater than 30%, indicating severe poisoning. Your request delineated concern that Police and Fire Department personnel that patrol the waterway may be exposed to high levels of CO on holiday weekends when the boat traffic is excessive. You also pointed out that many people are unaware of the deadly potential of unrecognized CO poisoning, and that data were necessary to characterize any hazards that might exist. You asked for help in measuring airborne CO and expired (exhaled) CO levels in Fire and Police personnel as well as willing visitors in your waterways during the upcoming Labor Day holiday weekend.

Although we were unable to coordinate employee exposure monitoring upon such short notice, NIOSH was able to assist you in gathering other preliminary exposure assessment data. NIOSH provided Emergency Department staff with equipment to measure CO in exhaled breath of patients that had been boating prior to coming to the hospital for treatment. NIOSH also worked with hospital staff to concurrently measure airborne CO concentrations along the London Bridge channel. The purpose of this preliminary work was to determine if there was a need to collect more extensive data in a future research effort.

CO Air Sampling Methods and Results

CO concentrations in the channel were measured using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) equipped with CO sensors. These monitors are direct-reading instruments that record data that is then transferred to a computer through an optical interface. The monitors have an accurate detection range from 0 parts of CO per million parts of air (ppm) to 1000 ppm. The monitors were calibrated before and after each day's use according to the manufacturer's recommendations.

On August 31st, I walked along both sides of the London Bridge channel to measure CO concentrations along the walkway. I walked along the area of the channel most congested with operating and moored boats and people (South from the bridge to the open lake). The walkway is 100 feet or more from the center of the channel. Throughout the day, the channel was filled with vacationers on moored boats along the water's edge and vacationers immersed in the water near the exhaust of the numerous boats moving through the channel. Numerous law enforcement officers patrolled the shore line as well as the congested channel waterway. (See Figure 1.) I measured ambient CO concentrations as high as 177 ppm, which was higher than World Health Organization (WHO) recommended limits for short term exposures (Attachment 2).

Figure 11. Law enforcement officers in the London Bridge Channel, Lake Havasu AZ

On September 1st, data-recording CO monitors were placed at various locations on a platform boat to gather information about CO exposures that boat occupants such as law enforcement officers might experience while in the channel. One monitor was also suspended from the bow of the boat near vacationers in the water to determine the range of CO concentrations at these stationary locations along the channel. The boat was then moved through the entire length of the channel twice,

returning to travel twice again through the most congested part of the channel.
Table 1 shows the average and highest CO concentration measured from within the boat during the time we spent in the channel. The measured concentrations were averaged to estimate exposures of boat occupants (such as law enforcement officers) moving through the channel during high traffic periods.

Table 1. CO concentrations measured on the moving boat, London Bridge Channel

Location of monitor	Duration of sampling (minutes)	Average CO Concentration (ppm)	Highest CO Concentration (ppm)
Rear seat of boat (opposite helm) during two passes through the most congested part of the channel only	21	131	439
Rear seat of boat (opposite helm) during two passes through the entire length of the channel	38	93	250
Personal sample (boat occupant moving around in the boat) during two passes through the entire length of the channel	39	77	277
Cup holder on the boat during two passes through the most congested part of the channel only	24	114	293
Personal sample (boat occupant seated at the bow of the boat) during two passes through the entire length of the channel	41	77	277
Personal sample (boat occupant seated at the bow of the boat) during two passes through the most congested part of the channel only	22	114	293

Figures 2 and 3 show the CO concentrations measured at water level from the bow of our boat as we moved through the most congested part of the channel (again, the portion of the channel South of the London Bridge). These CO concentrations are not averaged because they were intended to provide point measurements of CO exposure where vacationers were positioned either on moored boats or standing in the water along the channel. Because these vacationers were not moving, their average exposure concentration would be in the range of the concentration measured where they were positioned.

Figure 2. CO Concentrations at various locations along the most congested part of the London Bridge Channel - *Havasu, AZ - September 1, 2002*

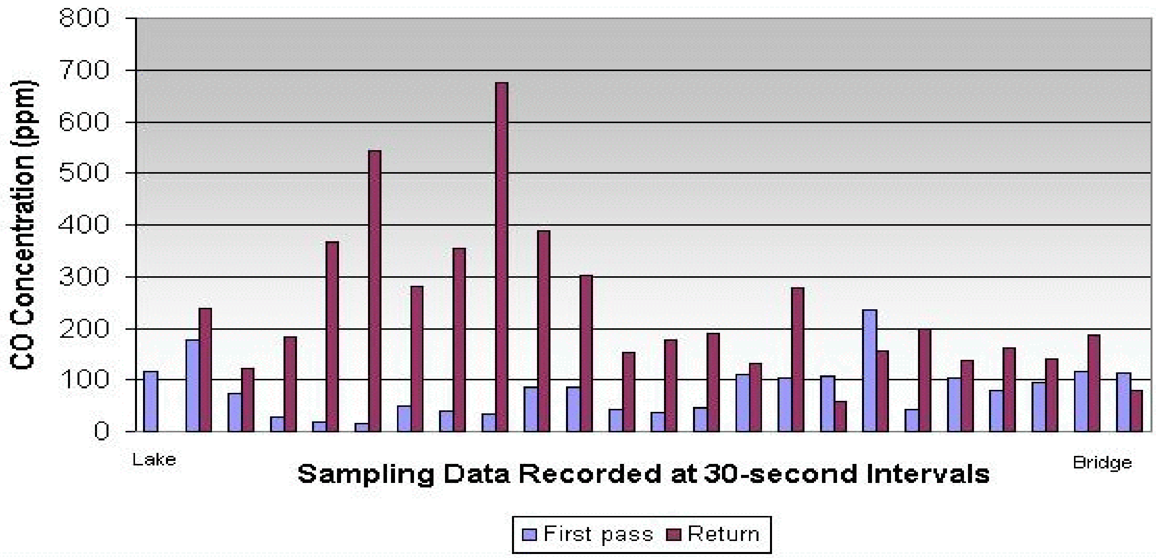
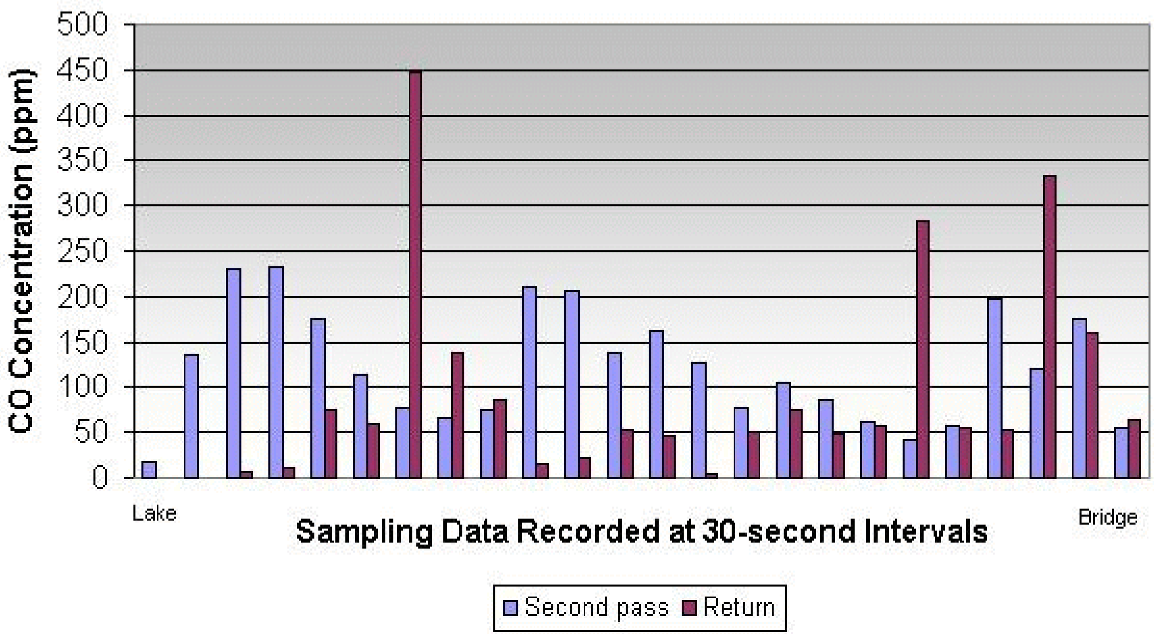


Figure 3. CO Concentrations at various locations along the most congested part of the London Bridge Channel - *Havasu, AZ - September 1, 2002*



Expired CO Measurement Methods and Results

The ED was provided with two monitors that measure CO in exhaled breath. These monitors allow estimation of carboxyhemoglobin (COHb) concentrations. ED staff were trained in the proper use of these monitors to evaluate COHb concentrations of patients who had been boating prior to reporting to the hospital for emergency care. The ED staff measured CO in exhaled breath for 13 patients on August 31st and September 1st. All of the patients were non-smokers, and had sought ED care for a variety of reasons. Four of these 13 patients had COHb concentrations greater than 9%.

The patient with the highest COHb concentration was an 18-year-old female that lost consciousness on September 1st, just after we completed air sampling for CO in the channel. She had been in the channel all day and was positioned at the back of a boat when her eyes rolled back and she began to convulse. A bystander caught her as she collapsed. It is not clear if she was on a boat that was moored or moving, and the precise source of her exposure (whether it was operating engines on the boat she occupied, or on boats moving by her) was not specified. Upon arrival at the ED, after 27 minutes of oxygen therapy, her COHb was 28.3%. A computer program is available that allows calculation of COHb concentration before it is reduced by oxygen therapy. Using this program, we calculated that her COHb would have been 40% when she lost consciousness, a concentration that is certainly sufficient to cause this symptom of severe poisoning. (See the discussion of CO poisoning symptoms and related COHb concentrations presented in Attachment 1.)

Discussion

Outdoor boat-related CO poisonings have been poorly defined and likely poorly detected in the past. Unfortunately, it is becoming apparent that acute, severe, and fatal poisonings outside of boats are not as rare as originally thought (see the listing of reported incidents and related information at internet website http://safetynet.smis.doi.gov/COhouseboats.htm).

The data collected during these two days at Lake Havasu indicate that employees and vacationers spending lengthy periods within the London Bridge Channel during days of high traffic may be experiencing CO poisoning more frequently than has previously been recognized. This statement is based upon the following:

- A severe poisoning occurred during the second day of sampling. If the hospital had not been conducting exhaled CO measurements as part of this research, this patient's loss of consciousness may well have been attributed to other factors, such as heat stress, dehydration, etc.

- Thirty one percent of patients reporting to the emergency department had COHb concentrations greater than 9%. Guidelines related to general population CO exposure recommend that COHb concentrations not exceed 2.5 % (WHO) or 2.1 % (EPA). As we discussed by telephone, it would useful to review the records of these patients to determine why they reported to the hospital.

- Spot checks of CO concentrations near vacationers on and near moored boats in the channel were well in excess of every short term exposure evaluation criteria listed in Attachment 2. The impact of exposure depends on a number of factors, including: the concentration of exposure; how physically active the person is while being exposed; and how long the person is exposed. For example, if a lightly active non-smoker was standing in one of the locations where we measured 100 ppm CO, it could take as long as 300 minutes for their COHb concentration to rise to 10%, a level at which you would expect symptoms of CO poisoning. At 300 ppm, it could take only about 60 minutes to reach the same COHb concentration (10%), and at 600 ppm, it could take about 30 minutes.

- The average CO concentrations measured over a short duration (20 to 40 minutes) on the moving boat indicate that employees who spend lengthy periods patrolling the channel or responding to incidents may be overexposed to CO. It must be remembered, however, that law enforcement officers would not be moving straight through the channel as we did. They would be more likely to stop within the channel near operating boats as they conduct their duties. As such, their actual exposures could be much higher than those measured here. Conversely, their average exposures could be lower overall depending on how much of their workshift is spent in the channel.

Recommendations

1. Full workshift CO exposures of law enforcement officers patrolling the channel and EMS staff who respond to medical events in the channel should be measured to determine if they are overexposed to CO during high traffic days. Pre- and post-shift exhaled CO should also be measured. Employees should also be interviewed to determine if they experience symptoms of CO overexposure during their duties within the channel.

2. The possibility of collecting further information about visitor CO exposures within the channel should be explored. Possible approaches would be to measure CO in exhaled breath of visitors, and/or to place stationary CO air sampling monitors at fixed locations among the moored boats where visitors linger during high traffic days.

3. The hospital should consider routinely measuring COHb on ED patients who have been boating in the channel during high traffic days. This recommendation is based on the likelihood of high CO exposures, the number of elevated COHb concentrations measured by the hospital during this two-day period, and the previously detected CO poisonings reported by the hospital.

4. The hospital should work with appropriate local public health officials to develop a more comprehensive research and intervention program related to the issue of boat-related CO exposures.

We were pleased to provide this assistance in addressing mutual concerns about employee health. If you have any questions about information contained in this report, or further collaborative evaluation, please don't hesitate to call me.

Sincerely,

Jane Brown McCammon, CIH
Director, NIOSH Denver Field Office

Enclosures

Attachment 1
Health Effects of Exposure to Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials such as gasoline or propane fuel. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, or nausea. Symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. If the exposure level is high, loss of consciousness may occur without other symptoms. Coma or death may occur if high exposures continue.(1-6) The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes.

Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb). Once exposed, the body compensates for the reduced bloodborne oxygen by increasing cardiac output, thereby increasing blood flow to specific oxygen-demanding organs such as the brain and heart. This ability may be limited by preexisting heart or lung diseases that inhibit increased cardiac output.

Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body. Once absorbed into the bloodstream, the half-time of CO disappearance from blood (referred to as the "half-life") varies widely by individual and circumstance (i.e., removal from exposure, initial COHb concentration, partial pressure of oxygen after exposure, etc.). Under normal recovery conditions breathing ambient air, the half-life can be expected to range from 2 to 6.5 hours.(7) This means that if the initial COHb level were 10%, it could be expected to drop to 5% in 2 or more hours, and then 2.5% in another 2 or more hours. If the exposed person is treated with oxygen, as happens in emergency treatment, the half-life time is decreased again by as much as 75% (or to as low as approximately 40 minutes). Delivery of oxygen under pressure (hyperbaric treatment) reduces the half-life to approximately 20 minutes.

Severity of symptoms does not correlate well with measured COHb concentrations because of individual variability. However, the following general guidelines are often cited:

COHb Concentration (%)	Symptoms/Comments
<2	Normal COHb concentration for non-smoking adults
10	Headache, nausea, dizziness, confusion, etc.
30 - 50	Impaired judgement, confusion, loss of consciousness, muscle weakness, visual disturbance, vomiting, etc.
>50	Convulsions, coma, death

Altitude impacts the toxicity of CO. With 50 ppm CO in the air, the COHb level in the blood is approximately 1% higher at an altitude of 4,000 feet than at sea level. This occurs because the partial pressure of oxygen (the gas pressure causing the oxygen to pass into the blood) at higher altitudes is less than the partial pressure of CO. Furthermore, the effects of CO poisoning at higher altitudes are more pronounced. For example, at an altitude of 14,000 feet, a 3% COHb level in the blood has the same effect as a 20% COHb at sea level.(8)

References

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Attachment 2
Evaluation Criteria

Occupational criteria for CO exposure are applicable to employees who have been shown to be at risk of boat-related CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities) because occupational standards do not provide the same degree of protection they do for the healthy worker population. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin.(1) Standards relevant to the general population take these factors into consideration, and are listed following the occupational criteria.

Occupational Exposure Criteria. As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, or a pre-existing medical condition. In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),(2) (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®), (3) and (3) the legal requirements of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs),(4)) Employers are encouraged to follow the more protective criterion listed.

A TWA exposure refers to the average airborne concentration of a substance during a normal 8-to-10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

The NIOSH REL for CO is 35 ppm for full shift TWA exposure, with a ceiling limit of 200 ppm which should never be exceeded.(5,6) The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[1] NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm.(7) An IDLH value is defined as a concentration at which an immediate or delayed threat to life exists or that would

interfere with an individual's ability to escape unaided from a space.
The ACGIH recommends an eight-hour TWA TLV of 25 ppm based upon limiting shifts in COHb levels to less than 3.5%, thus minimizing adverse neurobehavioral changes such as headache, dizziness, etc, and to maintain cardiovascular exercise capacity.(8) ACGIH also recommends that exposures never exceed 5 times the TLV (thus, never to exceed 125 ppm).

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.(9)

Health Criteria Relevant to the General Public.
The US EPA has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a one-hour average.(10) The NAAQs for CO was established to protect "the most sensitive members of the general population" by maintaining increases in carboxyhemoglobin to less than 2.1%.

The World Health Organization (WHO) had recommended guideline values and periods of time-weighted average exposures related to CO exposure in the general population.(11) WHO guidelines are intended to ensure that carboxyhemoglobin levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

100 mg/m^3 (87 ppm) for 15 minutes
60 mg/m^3 (52 ppm) for 30 minutes
30 mg/m^3 (26 ppm) for 1 hour
10 mg/m^3 (9 ppm) for 8 hours

References

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