DEPARTMENT OF HEALTH & HUMAN SERVICES U.S. Public Health Service

Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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October 3, 2002

HETA 2002-0340
Final

Allison Stock, PhD, MPH
EIS Officer
National Center for Environmental Health
APRHB/DEHHE
1600 Clifton Road, E-17
Atlanta, Georgia 30333

Dear Dr. Stock:

On July 8th, 2002, the National Center for Environmental Health (NCEH) requested technical assistance from the National Institute for Occupational Safety and Health (NIOSH) in conducting an investigation of carbon monoxide (CO) exposures among recreational boaters participating in the "Raft Off" event to be held on July 27th at Lake Norman in North Carolina. NIOSH responded to your request by measuring CO concentrations on boats during this event, assisting NCEH and the North Carolina Department of Health with measurements of CO concentrations in exhaled breath among lake visitors that either participated in the event or in other recreational activities. As NCEH is responsible for analysis and reporting of the data from the exhaled breath analyses, the purpose of this letter is to transmit the results of airborne CO measurements. A copy of this letter will also be sent to each participant that allowed NIOSH to measure CO on their boat.

Background
This annual fund-raising event involves hundreds of widely varying boats. Event participants register, then motor to a string of boats tied to one another. The participant rafts-up (ties to the last boat in the string, side-by-side), with the string building throughout the event. During this year's event, more than 700 boats were connected in this configuration.

Methods
CO concentrations were measured using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. The CO monitors were calibrated before and after use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode, with a one-minute sampling interval. The instruments have a nominal range from 0 ppm to 500 ppm with the highest instantaneous reading of between approximately 1,000 and 1,200 ppm.

One or two of these instruments were provided for individual boat users. Our initial intent was to correlate airborne CO measurements with exhaled breath levels. NCEH applied identification wrist bands to participants who agreed to have their exhaled breath measured. Technical barriers prevented us from measuring personal exposures to airborne CO, however, because most participants in this study were expected to spend much of their boating day in the water. Electrochemical sensors and other electronics in the CO monitors must be kept relatively dry. Our compromise was to ask that the instruments be placed in the occupied area of the boat, preferably near the back where people would be sitting if they were in the boat. Thus, CO concentrations at one location on each boat were measured (referred to as "area measurements"), as compared to CO exposures of boat occupants (referred to as "personal exposure measurements"). Because CO exposures vary drastically based upon proximity to exhaust, these area measurements cannot be extrapolated to estimate personal exposure measurements.

One CO monitor was placed on an employee at the Yacht Club. We were unable to ascertain if the employee wore it throughout his shift, as he was not available when we retrieved the instrument.

Evaluation Criteria
Relevant evaluation criteria and health effects related to carbon monoxide exposure are included in Enclosures 1 and 2.

Results

Weather conditions during this event were: high temperature of 94 degrees Fahrenheit at 4:00 pm and a low of 71 degrees. Wind during the day averaged 12 miles per hour, peaking at 16 mph. Humidity was 60% at noon and 45% at 4:00 pm. There was no precipitation.

Gathering CO measurements proved to be a logistical challenge. There were difficulties distributing CO monitors, difficulties gathering necessary information, technical challenges presented by the activities of the day, and difficulties retrieving CO monitors. The difficulties in retrieving the monitors resulted in the loss of data (CO monitors retrieved by mail well after the initial data had been overwritten because of storage capacity of the monitor). Data from CO monitors that were retrievable from instruments placed on boats in the Raft Off event are shown in Figures 1 - 8. A discussion of each data set follows the relevant figure.

We were able to gather little information about the relationship between the location of boat occupants in relation to the location of the monitor. For example, Figure 1 shows data from the boat, but interview of at least one occupant revealed that after they rafted up, everyone spent the day in the water and not on the boat.

Figure 1.

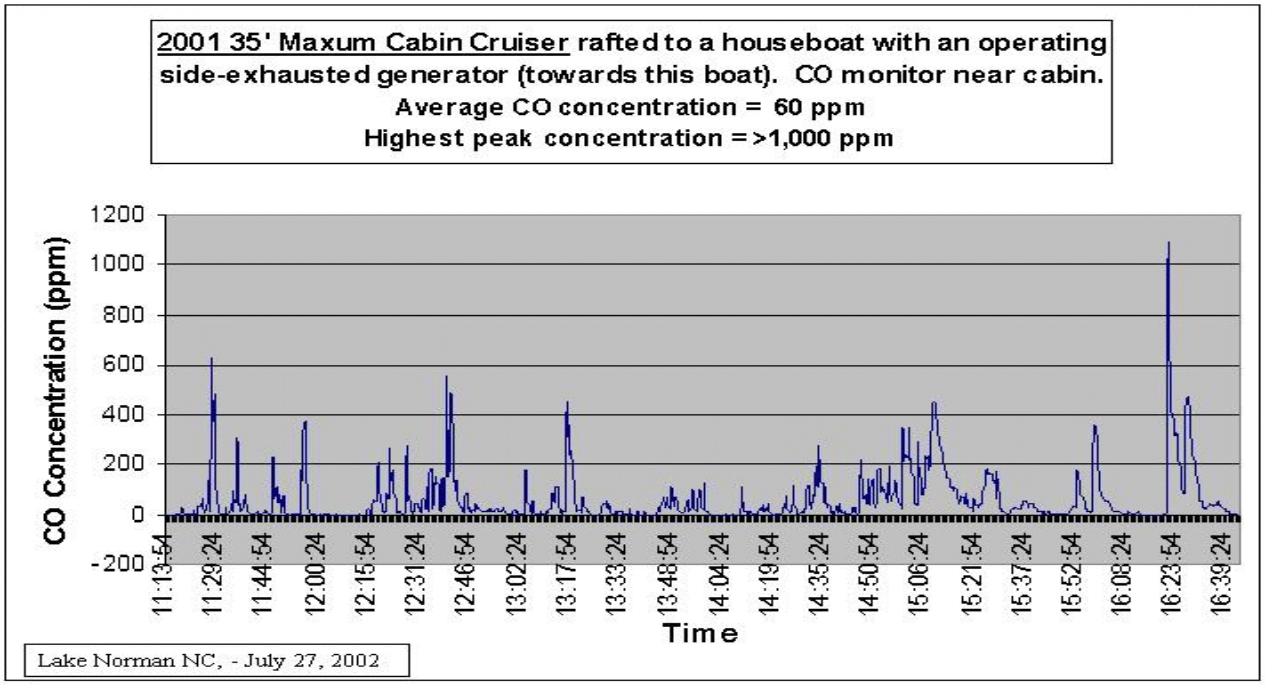


Figure 1 displays data from a boat on which no people were wearing NCEH identification wrist bands (indicating that NCEH did not measure exhaled breath before the boat went out). These data confirm earlier concerns about rafting boats together and operating a side-exhausted generator. [See website http://safetynet.smis.doi.gov/COhouseboats; click on "Technical Reports and Articles"; open the following reports - "AIHA Journal Article on Engineering Controls", "Text of NIOSH Technical Report on Emission Control Devices", "HETA 2000-0400, November 21, 2000"]

Often during the day, CO concentrations where this monitor was located in the seating area of the boat exceeded the NIOSH ceiling limit for occupational exposures (200 parts of CO per million parts of air [ppm]), and on one occasion approached the NIOSH IDLH (Immediately Dangerous to Life and Health) concentration. Further, the average CO concentration over the five-hour period shown here was well above relevant CO exposure criteria (i.e., those of the World Health Organization and EPA), and also exceeded less stringent occupational limits.

Proximity of people to the exhaust is a vital consideration when looking at any such data. Previous studies related to emissions from boat generators indicate that concentrations at the exhaust terminus of generators on boats can be as high as 80,000 ppm. [See website http://safetynet.smis.doi.gov/COhouseboats; click on "Technical Reports"; open the following report - "AIHA Journal Article on Engineering Controls"] The CO monitor on this boat was likely 10 feet or more away from the exhaust terminus of the operating generator on the next boat. Even though the concentrations measured here were high, exposure concentrations would rise as you approach the exhaust terminus. Thus, if the boat occupant was seated or swimming near the terminus, there would be severe risk of CO poisoning.

Figure 2.

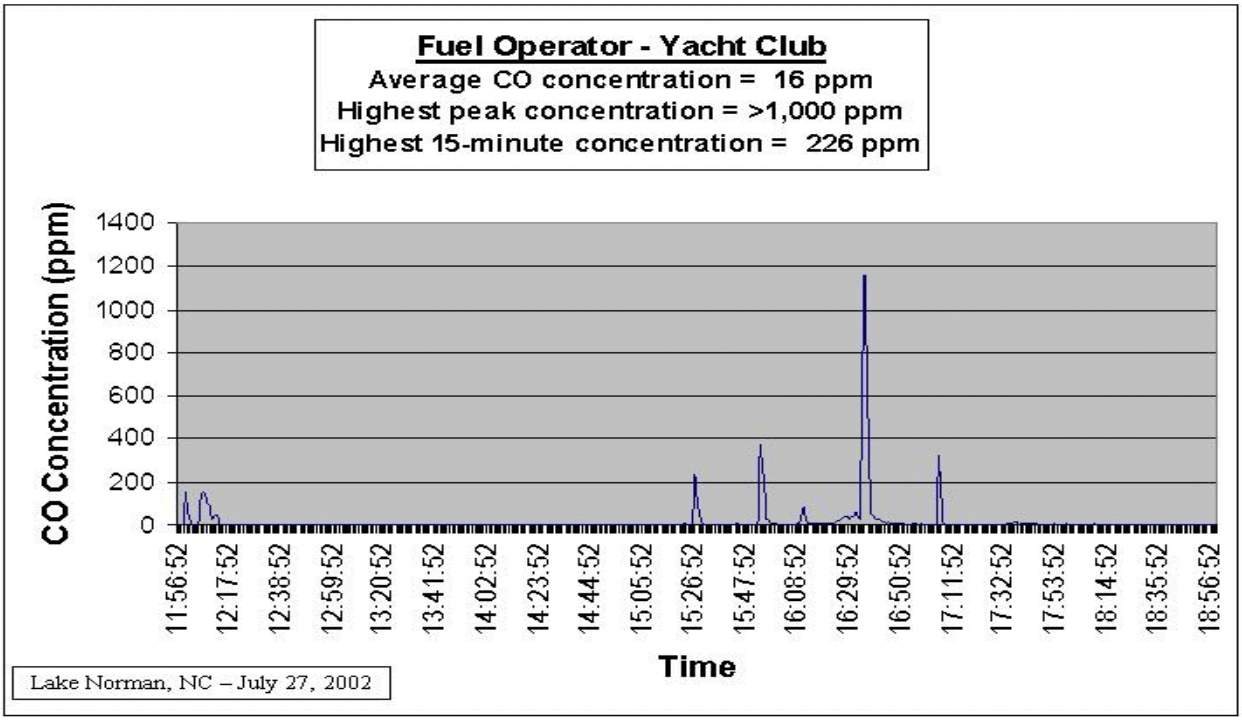
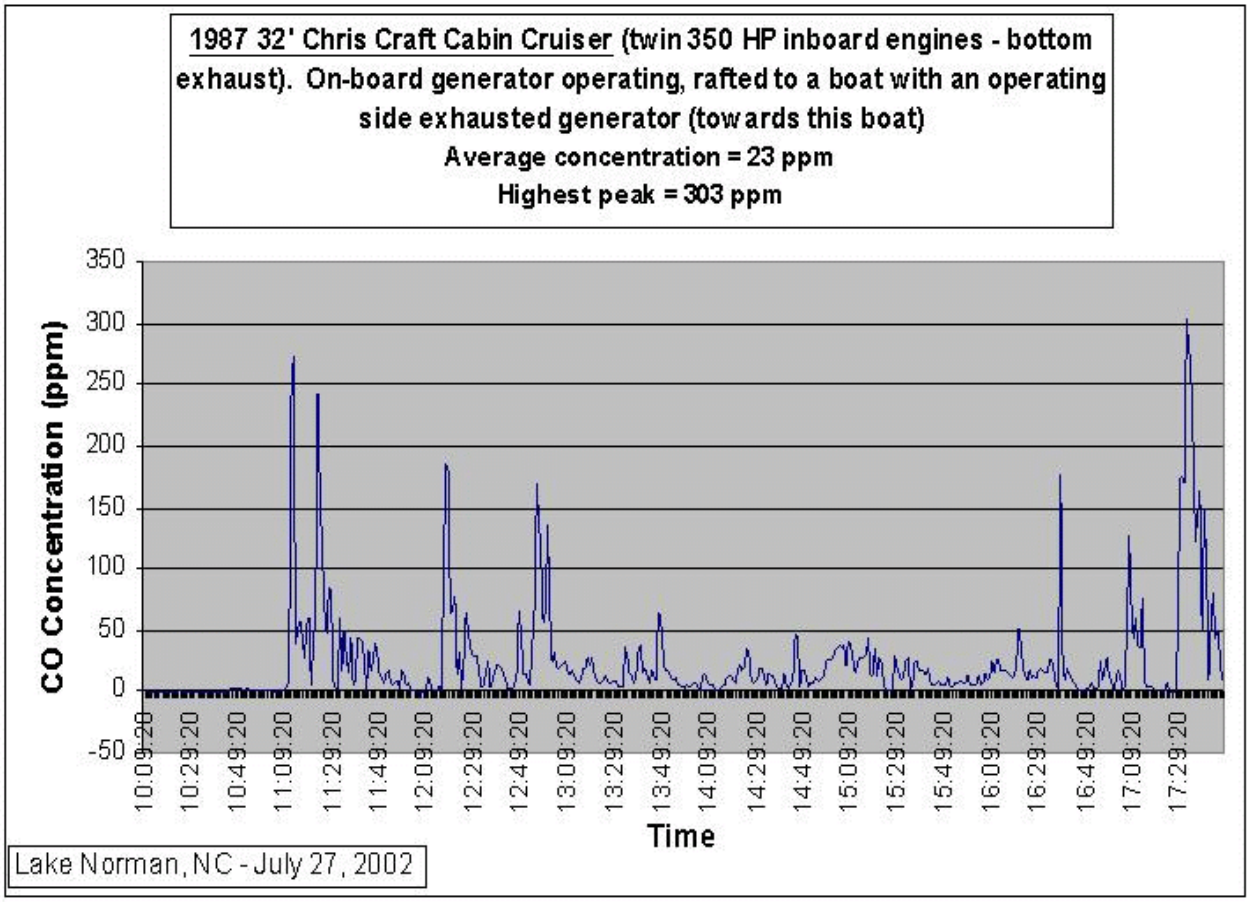


Figure 2 shows data related to exposures of a person fueling boats at the Yacht Club. These data indicate that such employees experience brief periods of very high CO exposure during their shift. Although this employee's exposure was not in violation of the permissible exposure limit required by the Occupational Safety and Health Administration, there were short periods during which exposure exceeded the NIOSH ceiling, and once when the NIOSH IDLH concentration was approached. Such peak exposures indicate that fuel operators should avoid proximity to operating engines as much as possible, and that boat operators should be required to terminate engine operation (whether the generator or the propulsion engines) as soon after the boat is docked as possible. For further information on boat-related CO exposures of fuel dock workers, please refer to internet website http://safetynet.smis.doi.gov/COhouseboats: click on "Technical Reports and Articles "; open the report labeled "NIOSH technical report on occupational exposures".

Figure 3.



This figure relates to CO concentrations on a boat occupied by the person wearing wrist band number 804005. These concentrations were surprisingly low compared to what has been measured on other boats under the conditions described in the figure. According to the boat operator, this monitor was placed on his body for a while, and then in the rear cup holder of the boat after they rafted up. The three peak concentrations that exceed the NIOSH ceiling limit for occupational exposures were of short duration. During the period of 5:30 to 5:45, the average concentration on the boat was 132 ppm, which was above the WHO recommended limit of 87 ppm for a 15-minute period. These measurements indicate the potential for high exposure under certain circumstances. Again, these are not measurements of personal exposure, and cannot be extrapolated to assess exposure of the person whose exhaled CO was measured.

Figure 4.

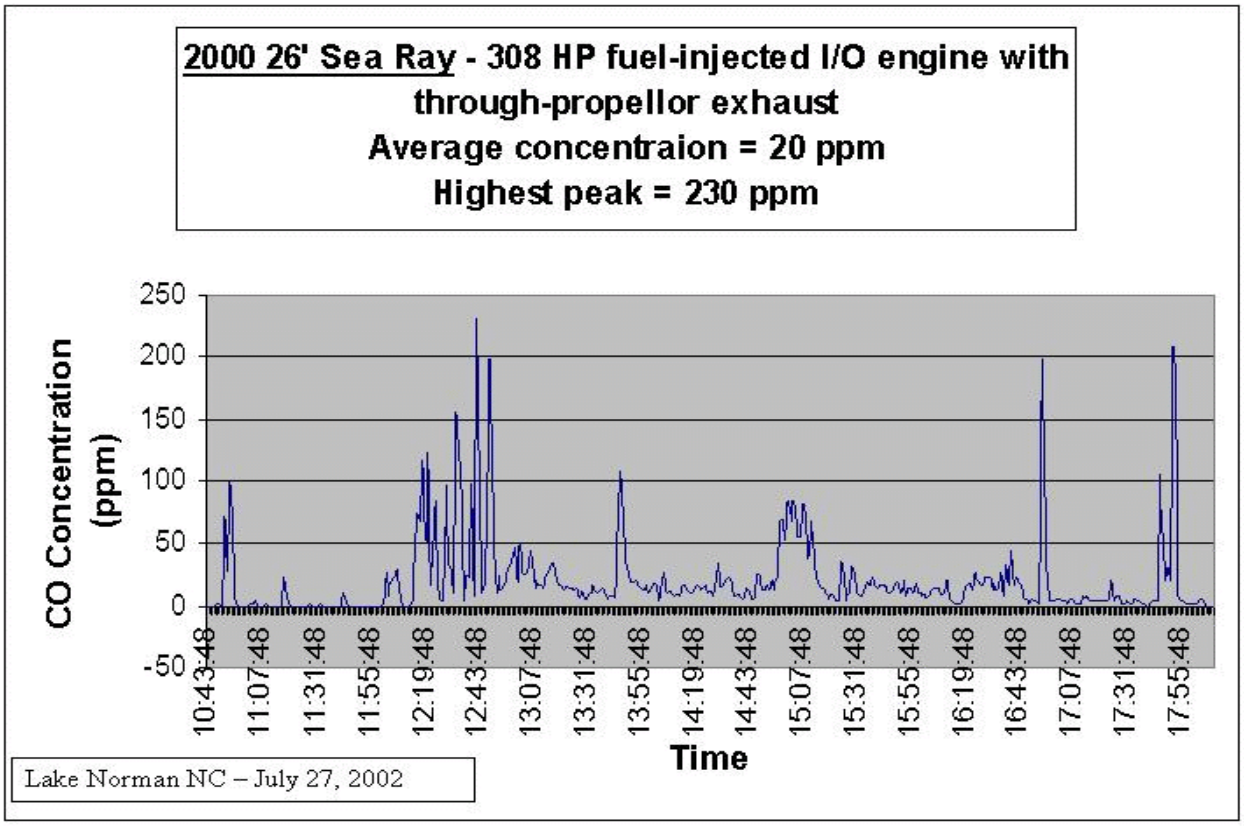


Figure 4 represents CO concentrations on the boat occupied by the person wearing wrist band number 804007. This boat had no on-board generator, and so the only CO source was the propulsion engine and other boats in proximity to this one. Twice in the day, CO concentrations on the boat briefly exceeded the NIOSH ceiling limit for brief periods of time. Concentrations between 12:15 and 12:50 averaged 62 ppm, which was the highest concentration in the day. If this period represented personal exposures, this was in excess of the World Health Organization's recommended limit of 52 ppm for a 30-minute period. Again, these data are not measurements of exposures of boat occupants, but of potential exposure if someone on the boat spent time where the monitor was placed.

Figure 5. (Companion to Figure 6 in which data from outside the cabin of the same boat is reported.)

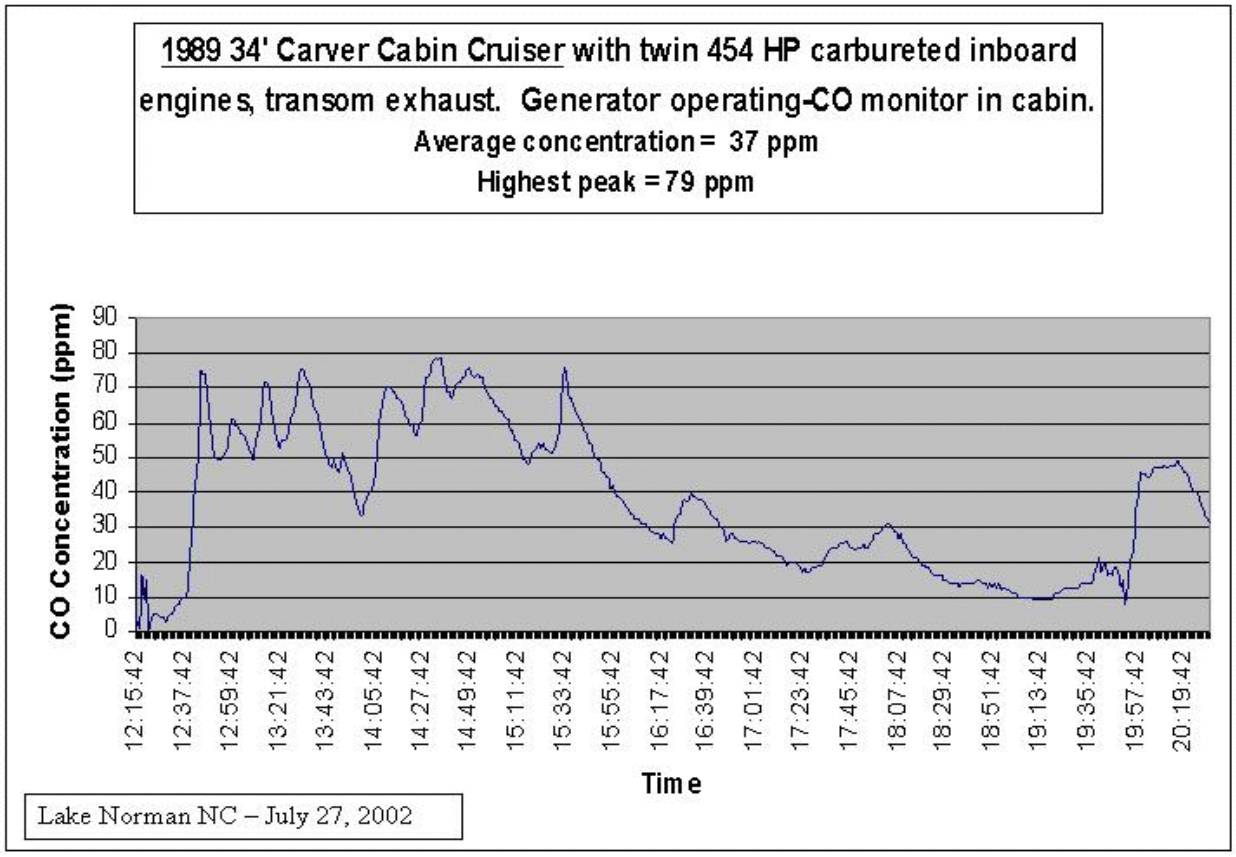


Figure 5 illustrates the CO concentration in the cabin of the boat occupied by the person wearing wrist band number 804350. These data indicate that CO accumulates in the cabin of the boat as the propulsion and generator engines operate, and that concentrations over the 8-hour period represented here were well above the WHO and EPA limits of 9 ppm for that duration. It must be remembered, though that this would only be relevant if people are occupying the cabin for that long, as would be the case for sleepers in the cabin. It is not clear when the propulsion engines operated (how long this boat was underway) versus when the generator only was operating, so it is difficult to determine the exact source of the CO accumulating in the cabin. It is possible that some of the CO was coming from other boats.

During at least three different 1-hour periods, CO concentrations in the cabin exceeded the WHO 1-hour limit of 26 ppm (concentration being at least double that from 12:41 to 13:41, 14:10 to 15:10).

Figure 6. (Companion to Figure 5 in which data from inside the boat's cabin is reported.)

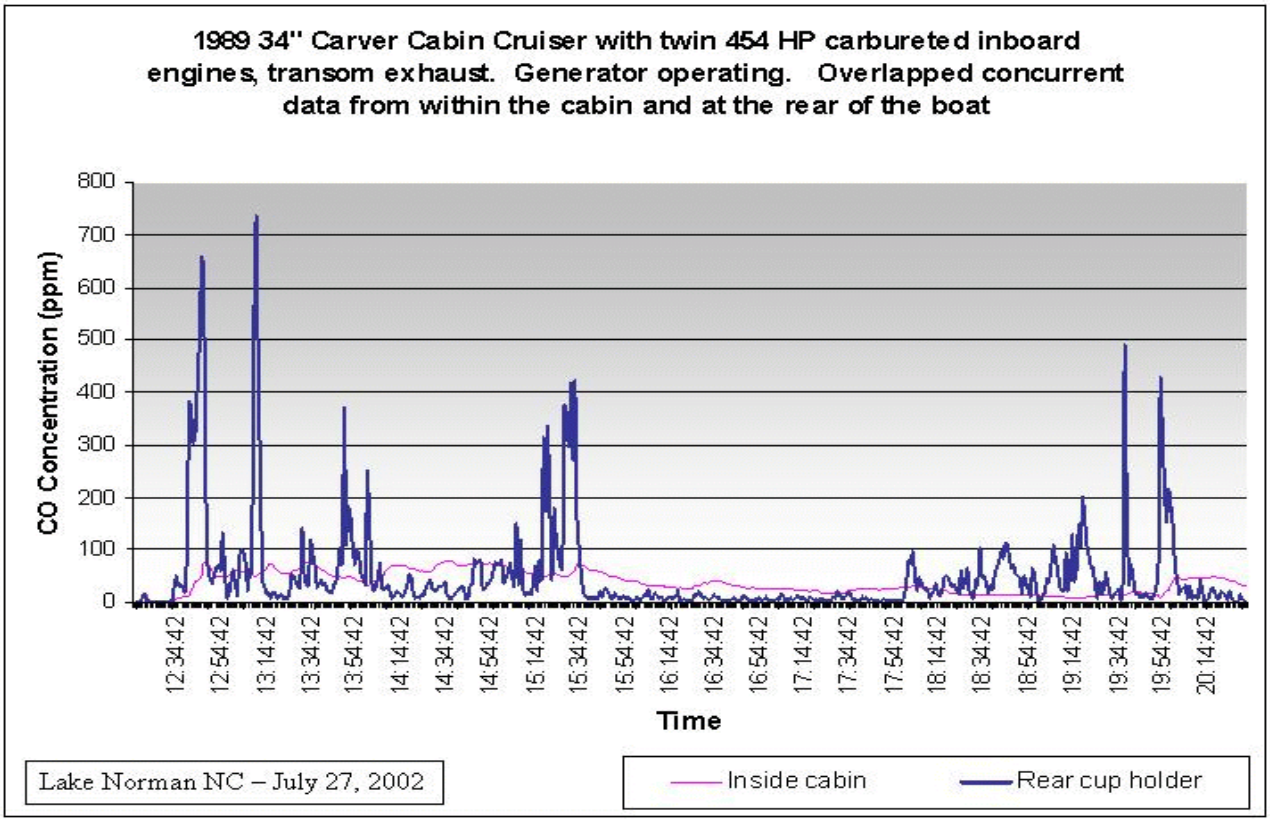


Figure 6 illustrates overlapped data from two locations on the boat also discussed in Figure 5 and related text. This is the CO concentration at the rear of the cabin cruiser of the boat occupied by the person wearing wrist band number 804350, overlapped with the concurrent data from Figure 5. This overlap was done to illustrate how much higher CO concentrations were outside the cabin compared to inside the cabin. All examined parameters were higher outside the boat than inside.

- The highest peak at the rear of the boat was 734 ppm, as compared with the highest peak inside the cabin of boat.
- The average CO concentration at the rear of the boat over the entire 8-hour period represented here was 51 ppm, as compared to 37 ppm over that period inside the cabin.
- There were numerous peaks in excess of 200, 400, and 600 ppm outside the boat, and the highest peak inside the boat was 79 ppm.
- There were a number of times during sampling outside the boat that the 15-minute averaged CO concentration was nearly 3 times the WHO limit of 87 ppm for that length of time.

As with all the other figures, these data represent potential exposures as it is unclear where boat occupants were during the sampling period.

Figure 7.

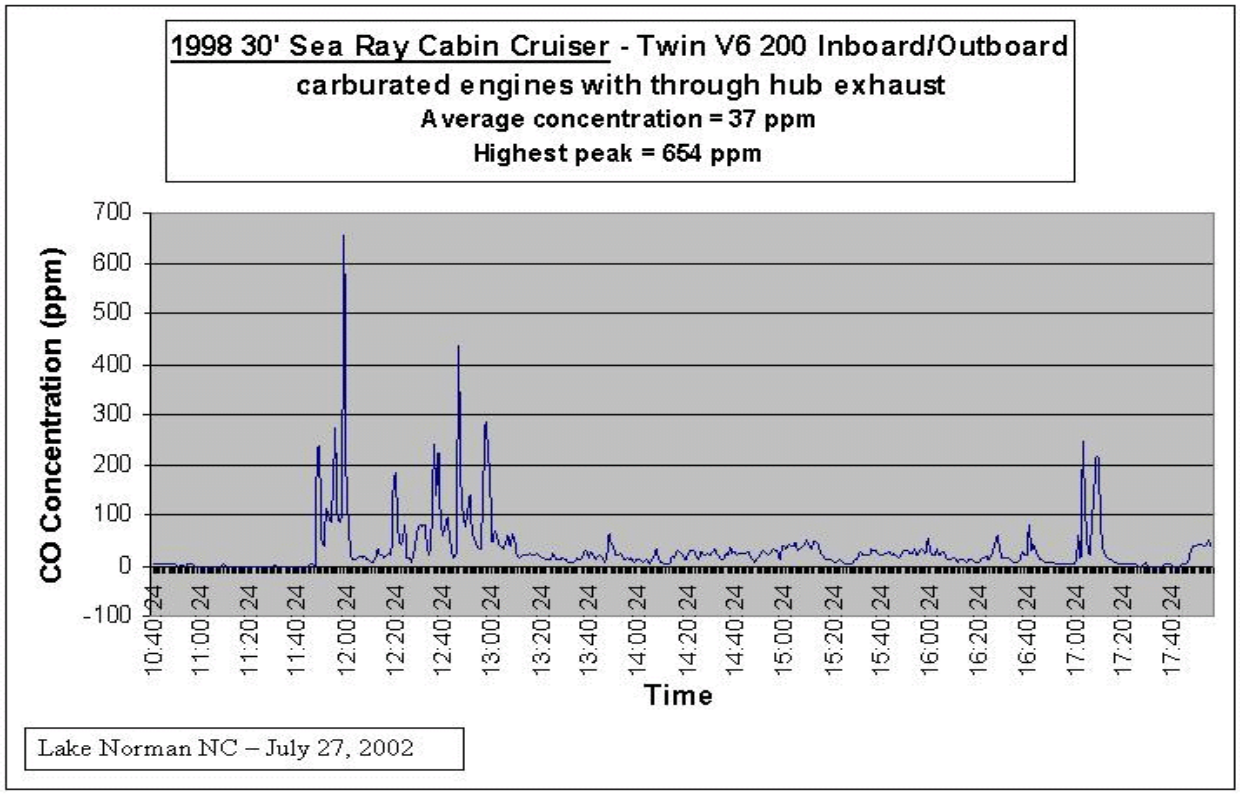


Figure 7 illustrates data from the boat occupied by the person wearing wrist band 804006. The occupant of this boat expressed concern that the alarm on this CO monitor sounded all day for no apparent reason, and that the numbers on the display made no sense compared with what was happening on the boat. The alarm likely sounded because both the peak value of 200 ppm preset for the alarm and the STEL (short term exposure limit) of 125 ppm preset for the alarm been exceeded. This would have caused the instrument to display the values triggering the alarm during the rest of the time that the alarm sounded, although datalogging would not have been impacted. The instruction sheet given the participant erroneously indicated that the alarm would stop sounding when the CO concentration dropped again, thus causing understandable confusion for the participant.

Several peak concentrations were in excess of the NIOSH ceiling limit of 200 ppm. The average CO concentration (during the 6-hour time period of boat use reflected in these data) was 37 ppm, which is just above the NIOSH recommended occupational limit of 35 ppm, and is well above the WHO and EPA limits of 9 ppm for extended durations. There were at least three 15-minute periods during which averaged CO concentrations were in excess of the WHO limit of 87 ppm for that duration.

Figure 8.

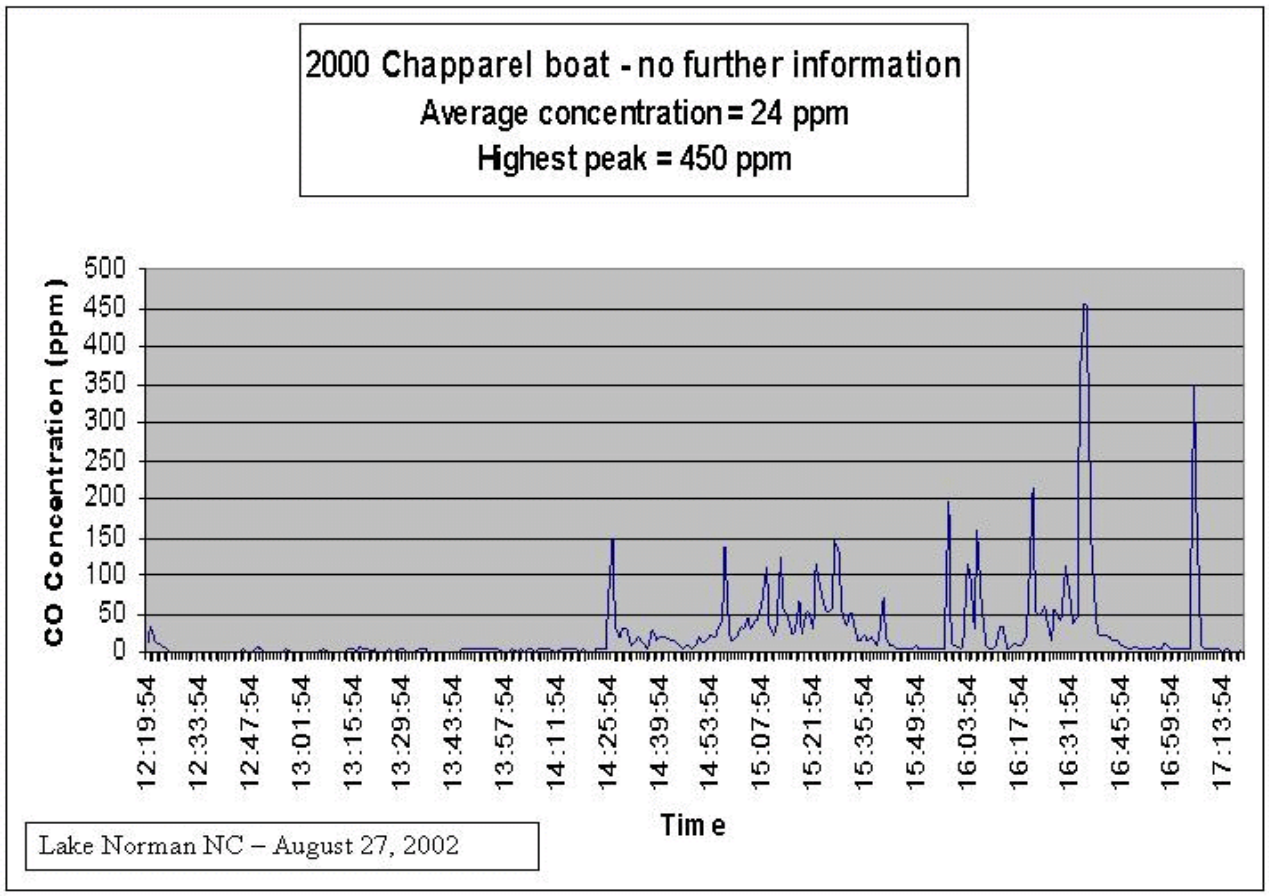


Figure 8 illustrates data from the boat occupied by the person wearing wrist band number 804336. Little information about this boat was provided by the participant, and measurement of CO concentrations were of shorter duration than in Figures 1 - 7. There were three short-duration peak CO concentrations in excess of the NIOSH ceiling limit of 200 ppm during the sampling period, with the highest being twice that concentration. There were two 1-hour periods during which the average CO concentration was 1.5 and 2 times the WHO limit of 26 ppm for that duration.

Again, these are CO concentrations on the boat, and do not necessarily represent exposure of the participant.

Discussion and Recommendations
NIOSH has been involved in investigations of fatal and non-fatal CO poisonings occurring on or near boats of many types since September 2000. That work began when two brothers drowned within minutes of being exposed to exhaust from a gasoline-powered on-board electrical power generator as a result of CO poisoning at Lake Powell (AZ/UT). Since then, more than 360 boat-related CO poisonings related to exposure to generator and/or propulsion engine exhaust have been reported to the interagency group investigating this issue. More than 60 of these poisonings have quickly resulted in death, and more than 40 of those deaths occurred outside the boat cabin. An additional 49 people outside the cabin area and 37 people inside the boat cabin lost consciousness as a result of CO poisoning. Thirty-three of the people that lost consciousness outside the boat cabin did so while in the water, and many were near-drownings but for the presence of witnesses who rescued them from the water and from further exposure to CO. Many of these fatal and non-fatal boat-related poisonings, particularly those occurring outdoors, were the result of exposures that were only minutes in duration. The reported poisonings have raised concerns about many CO-related issues, including: exposures of employees who maintain, repair, and fuel boats; exposures of recreational boaters in general; the need for a clearer definition of safe and unsafe practices related to CO exposures; and boat design features that encourage proximity to exhaust sources.

Data presented in this letter provide snapshots of CO concentrations outside (and in one case inside) of boats of various types during a recreational boating day. The “raft off” is not a typical boating activity, and it is difficult to say if the exposures of participants during the event are representative.

Measurements of CO on boats during this event and on other waterbodies confirmed again that rafting of boats with operating side-exhausted generators presents a significant risk of exposure to high concentrations of CO for boat occupants. Based on these potential exposures and the severity of the possible consequences of these exposures, we recommend that boat operators immediately deactivate all internal combustion engines as quickly as possible when rafting up in the manner described here.

Measurements presented in Figure 6 also illustrate that contrary to what is intuitive, potential for CO exposure is much greater outside the cabin than inside (under the conditions present during this investigation).

We appreciated the chance to assist you, your NCEH collegues, and the wonderful people from the North Carolina Department of Health in this investigation. If you have any questions about the data presented here, please call me in my office at (303) 236-5944 or on my cell phone at (303) 809-4252.

Sincerely,

Jane Brown McCammon, CIH
NIOSH Denver Field Office Director

Enclosures

cc: Richard Hartle, NIOSH/HETAB
Study participants who allowed testing on their boats

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, seizures, 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). 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-life of bloodborne CO at sea level and standard pressure is approximately four to five hours. This means that an initial COHb level of 10% could be expected to drop to 5% in five hours, and then 2.5% in another five hours. If oxygen is administered to the exposed person, as happens in emergency treatment, the COHb concentration drops more quickly. 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.

References

1. NIOSH [1972]. Criteria for a recommended standard: occupational exposure to carbon monoxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 73-11000.

2. NIOSH [1977]. Occupational diseases: a guide to their recognition. Revised ed. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-181.

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4. Proctor NH, Hughes JP, Fischman ML [1988]. Chemical hazards of the workplace. Philadelphia, PA: J.B. Lippincott Company.

5. ACGIH [1996]. Documentation of threshold limit values and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

6. NIOSH [1999]. Pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 99-115.

Attachment 2
Evaluation Criteria

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency, and cannot ignore the overlapping exposure concerns in this type of setting. Occupational criteria for CO exposure are applicable to workers conducting tasks related to their job. The general boating public, however, may range from infant to aged, be in various states of health and susceptibility, and be functioning at a higher rate of metabolism because of increased physical activity. The effects of CO are more pronounced in a shorter time if the person is physically active, very young, very old, or has preexisting health conditions such as lung or heart disease. 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] The occupational exposure limits noted below should not be used for interpreting general population exposures because they would not provide the same degree of protection they do for the healthy worker population.

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] (3) the legal requirements of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs);[4] and (4) the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard for ventilation for acceptable indoor air quality.[5] 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.[6,7] 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.[8] 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 exposure unaided.

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.[9] 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.[10]

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.[11] 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.[12] WHO's 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

1. Kales SN [1993] Carbon monoxide intoxication. American Family Physician 48(6):1100-1104.

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3. ACGIH [2000]. 2000 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents. Cincinnati, OH: American Conference of Governmental industrial Hygienists.

4. Code of Federal Regulations [1997]. 29 CFR 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register.

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6. CDC [1988]. NIOSH recommendations for occupational safety and health standards 1988. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control; National Institute for Occupational Safety and Health. MMWR 37 (supp. S-7).

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9. ACGIH [1992]. Threshold limit values and biological exposure indices for 1992-1993. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

10. 29 CFR 1910.1000 Table Z-1: Limits for air contaminants. Code of Federal Regulations, Department of Labor, Chapter XVII - Occupational Safety and Health Administration.

11. US Environmental Protection Agency [1991]. Air quality criteria for carbon monoxide. Publication No. EPA-600/8-90/045F. Washington, D.C.

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