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HETA 20000400
Interim Report

July 31, 2001

US National Park Service
ATTN: Kayci Cook Collins, Assistant Park Superintendent
Glen Canyon National Recreational Area
P.O. Box1507
Page, Arizona 86040

Dear Ms. Collins:

At the request of you and the US Coast Guard, the National Institute for Occupational Safety and Health (NIOSH) conducted an investigation of a fatal carbon monoxide (CO) poisoning that occurred on June 25th, 2001, behind a ski boat on Lake Powell. This letter reports our evaluation methods, findings, and conclusions related to the 18-year-old boy's death.

In summary, this boy succumbed to exposure to extremely high concentrations of CO within five minutes of beginning an activity called "teak surfing". This activity is reportedly common among wake boarders and others, and is made possible by specific design features of this and other ski boats (an extended teakwood swim platform and recessed propellor - both of which allow and/or encourage occupancy of an environment rich in CO). We are aware of four other similar fatal poisonings nationwide, and at least two non-fatal CO poisonings resulting in loss of consciousness also associated with similar activities and boats. This boat had been used an estimated 100 times for teak surfing. No symptoms of CO poisoning had ever been reported by boat occupants or teak surfers in any of these 100 times.

CO concentrations as high as 23,800 parts per million (ppm) were measured in the unobstructed airspace above the extended swim platform where the teak surfers' breathing zone would be during the activity. Engine maintenance conducted between the first and second day of air sampling did not reduce CO concentrations enough to have prevented this death. When the airflow above the platform was obstructed by a form simulating the shape of the upper torso of a person with extended arms, CO concentrations above the platform were consistently between 10,000 and 26,700 ppm after engine maintenance was conducted (this testing was not conducted prior to engine maintenance and thus comparison is not possible).

The boy's measured carboxyhemoglobin (COHb) was reported by the coroner as 56%. Using this COHb concentration and an exposure time of 5 minutes, his calculated CO exposure was between 10,000 and 16,000 ppm (with confidence ranges from 7,000 to 21,000 ppm). The measured CO concentrations were in close agreement with these calculated exposure estimates.

These measured and estimated CO concentrations were certainly high enough to quickly cause unconsciousness and death. The question remaining is how so many incidents of teak surfing could have taken place before this without anyone experiencing symptoms of CO poisoning.

A number of things were made obvious by this investigation. Your issued statement to the press warning that “surfing or hanging onto the back of a vessel while the engines are running is an extremely dangerous activity” was very accurate. Boat manufacturers should be made aware of the fact that the presence of this extended, easy-to-access platform in combination with a recessed propellor is encouraging boat passengers to occupy an environment that is very rich in CO. Boat users should be made aware of the very real hazard of fatal outdoor CO poisonings associated with this and other activities that involve occupancy of this platform when the boat engine is operating.

We were pleased to provide this assistance as part of the ongoing interagency investigation of outdoor boat-related CO poisonings. If you have any questions about information contained in this report, please call me right away at (303) 236-5944.

Sincerely,

Jane Brown McCammon, CIH
Director, NIOSH Denver Field Office

Enclosure

cc: Phil Cappel, US Coast Guard

Investigation of a Fatal Outdoor Poisoning on a Master Craft Ski Boat

Glen Canyon National Recreation Area - Lake Powell

General Background

On June 26th, 2001, the National Park Service (NPS) requested assistance from the National Institute for Occupational Safety and Health (NIOSH) in investigating a fatal carbon monoxide (CO) poisoning that occurred on Lake Powell within the Glen Canyon National Recreation Area (GLCA). The fatality had occurred outdoors while the victim was being pulled through the water while holding onto the swim platform of a ski boat. On June 29th, the US Coast Guard (USCG) also asked NIOSH to collect data relevant to the fatality on Lake Powell. NIOSH responded to both requests by traveling to GLCA on June 30, 2001, to assist in the investigation.
Since September 2000, NIOSH has been providing assistance to the US Department of Interior (DOI), NPS, and USCG in an ongoing effort to identify and prevent boat-related CO poisonings occurring on Lake Powell and nation-wide. The interagency effort was triggered by the fatal CO poisoning of two brothers in August 2000.

The investigation of boat-related CO poisonings is ongoing, and thus the numbers of poisonings identified is expected to change. However, as of this investigation, the team had identified 111 fatal and nonfatal CO poisonings occurring between 1990 and 2000 on or near boats on Lake Powell. Most of these poisonings (74/111) were related to houseboat occupancy, and primarily gasoline-powered generators (64/74) used to power air-conditioners and other electrical appliances on those houseboats. However, the remaining poisonings for which a boat type was identified (33/111) were related to other pleasurecraft, including cabin cruisers and ski boats. Data related to these poisonings were examined before this investigation to determine if there had been other similar poisonings at Lake Powell. Information from a preliminary analysis of the data related to these 33 poisonings is listed below:

33 people were poisoned in 16 separate incidents on pleasurecraft other than houseboats
- 6 of the 33 people were poisoned in 1 incident by CO in generator exhaust. This was a cabin cruiser- related incident.
- 27 of the 33 people were poisoned in 15 incidents by CO in propulsion engine exhaust.
    - 15 of these 27 people were poisoned while in a cabin or canopy enclosure.
    - 12 of these 27 people were poisoned outdoors.

The circumstances regarding the outdoor poisonings were further evaluated to determine if there was a relationship between those poisonings and the current fatality. That evaluation revealed the following information:
- 6 of the 12 people poisoned outdoors on a pleasurecraft other than a houseboat were riding in a moving boat (again, no canopy or other type of enclosure was involved in these poisonings).
- 3 of the 12 people were outside in a boat being towed by another boat.
- The remaining 3 of 12 people poisoned outdoors were in the water when they were poisoned, as was the current victim.

Review of these three records revealed the following:

One occurred while the person was “holding onto a swim deck and handle while being towed.” This person lost consciousness within 5 minutes of beginning this activity, was recovered from the water and revived.

Circumstances of the second incident were described as follows: “swimming behind a boat for 10-15 minutes.” This person lost consciousness and had a carboxyhemoglobin (COHb) measurement of 32%. Again, this person regained consciousness.

The circumstances of the remaining incident were described as: “behind a boat with motors running for 2 hours.” This person lost consciousness but lived, and had a COHb of 18%.

Incident Background

The incident summary listed below is a compilation of information gathered during the NPS investigation and through NIOSH interviews of witnesses. It is interesting to note that when this fatality was first investigated by NPS, the Park Ranger in charge of that investigation did not immediately think about CO poisoning as a cause of this drowning. His first thought was that it was related to head trauma, or that the boy tired during the activity and drowned. After several interviews, it began to occur to him that CO might have been a factor because others had experienced neurologic symptoms as well. This Park Ranger had been active in the investigation of CO poisonings on this lake for years.

On Monday, June 25th, an 18-year-old passenger of a 1993 21' Master Craft ProStar 205 ski boat drowned in Lake Powell as a result of CO poisoning. There were 10 passengers on the boat at the time, and the rear of the boat was weighted with two commercially-obtained water bladders that are tubular in shape, approximately 50" long (fitting snugly in the width of the interior of the boat) and approximately 18" in diameter (see Figure 1). The rear seat (full width of the boat) had been removed and replaced by these bladders. The purpose of the bladders is to lower the stern of the boat in the water, thus resulting in a larger wake for wake boarding and other activities.

At the time of the death, three of the 10 passengers were being pulled behind the boat in a maneuver commonly referred to as “teak surfing”. This activity, shown in Figure 2, is a common activity according to the boat occupants, who described it as “what wake boarders do when they are not on their board.” Other families interviewed by Park Service staff indicated that their children “do it all the time.” The operator of the boat, another 18-year-old hosting the group, reported having been teak surfing on this boat at least 15 times, and his father reported that the activity had been done by others on this boat at least a hundred times.

Several features of this and other similar ski boats allow for this activity. First, the presence of an extended (65" wide, 18" from transom to rear edge) slotted teakwood swim platform provides a ready surface for this activity. Second, the single propellor is well-removed from the swimming area behind the boat. The boat is powered by an inboard engine (285 horse power) with direct drive and thus the propellor is under the boat hull approximately 1 foot before the transom (measured to be 3 feet forward of the rear edge of the swim platform - see figure 3). The location of the propellor reduces the fear of propellor strikes.

To teak surf, one to four people place their upper torso on the teakwood swim platform and are pulled through the water at a speed of approximately 10 - 12 miles per hour (mph). At this speed, a large following wake or trough of water parallel to the transom of the boat is created (see Figure 4). The goal is to create conditions that allow the surfer to release their hold on the platform while angling their body upward and then briefly body surf the following wake. When the surfer slips too far back, they again grab the platform and pull themselves forward. Their upper body remains on or angled near or above the swim platform most of the time, with their breathing zone in close proximity (within 2 feet) of the two engine exhaust ports that are directly under the platform (see figure 3).

On the day of the incident, three people were being pulled behind the boat. None of these people were wearing a personal floatation device (PFD). They had been on the boat for 2 ½ hours before they started this five-minute round of teak surfing, which was the first time they had done it that day. Wind conditions on the day of the incident (as reported by NPS investigators and boat occupants) were very calm.

Shortly after beginning teak surfing (estimated less than 2 minutes by an NPS investigator that repeated the course of the boat several times), one of the teenagers was unable to maintain her hold on the platform. She was reported as having “jerky arm movements” and difficulty in communicating. She lost consciousness, and was pulled into the boat by the passengers, where she recovered. Another teen took her position on the platform, and they began teak surfing again.

Approximately 1-2 minutes later, two of the three teens began to experience unspecified symptoms, and pulled themselves up onto the swim platform. The third surfer, still in the water with his torso on the platform, laid his head down, appearing to the others to be resting as the boat continued to move forward. His head then slipped into the water face down as he continued to hold onto the platform. The others thought he was cooling his head in the water. He then slipped from the platform. At this point, they realized that he was unconscious. They had traveled away from him, but turned the boat to retrieve him. He sank beneath the surface before they could get to him.

The other teak surfers who experienced symptoms of acute CO poisoning refused EMS transport to the local hospital. Because Park Rangers are not equipped to assess expired CO concentrations, and no other carboxyhemoglogin (COHb) measurements were made, the association between CO exposure and this drowning could not be confirmed until the body was recovered from the water three days later. The coroner reported that the victim’s COHb concentration was 56%. His estimated maximum exposure time during this incident was 5 minutes.

NPS immediately requested participation of the owner of this boat in evaluating circumstances that led to the fatality, specifically requesting that the boat be impounded until CO measurements could be obtained under similar operating circumstances. The owner readily agreed to have the boat tested, with the caveat that he and other family members be present during the testing.

CO Evaluation Criteria and Exposure Health Effects
Information about the above can be found in Attachment 1 and 2.

Methods and Materials
The boat owner and other family members assisted in all sampling conducted, as did NPS staff. The person that operated the boat on the day of the incident assisted throughout the first day of sampling. He and other family members were extensively interviewed about similar and varying circumstances on the day of the incident compared to previous times they had been teak surfing.

The air above the swim platform (see Figure 5) was characterized using a KAL Equip Model 5000 Four Gas Emissions Analyzer. This analyzer measures CO, carbon dioxide (CO_2), hydrocarbons, and oxygen content of air. All measurements are expressed as percentages. [1% of contaminant is equivalent to 10,000 parts per million (ppm).] Measurements were collected at locations throughout the swim platform at 1-foot increments away from the transom. Guidance for locations of measurements was provided by the person who was piloting the boat on the day of the incident. The highest measurement observed during each 1-minute period of sampling was recorded.

Airborne CO concentrations were measured at several locations on the boat (in the bow of the bow-rider boat, at the helm, on a passenger in the front passenger seat, at the inboard engine cover, and on two passengers who were primarily at the stern of the boat collecting air samples) using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. All ToxiUltra CO monitors were calibrated before and after each use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. With one exception, the instruments were operated in the passive diffusion mode, with a 30-second sampling interval. The instruments have a detection range from 0 ppm to 1000 ppm. If the sensor is exposed to CO concentrations above 1000 ppm for an extended period of time, damage may result. The exception to the passive diffusion mode follows. Plastic hoses were attached in three locations to the transom of the boat approximately 1 foot above the swim platform. These hoses were connected to the negative pressure side of sampling pumps operating at a flow-rate of 1 liter per minute. Tubing connected to the positive pressure side of these pumps were then attached to calibration cups on the sensors of three monitors. This allowed active sampling air across the sensor while protecting the sensor from water.

CO concentrations in the air above the swim platform were also measured with detector tubes [Drager CO, CH 29901– range 0.3 % (3,000 ppm) to 7 % (70,000 ppm)]. The detector tubes are used by drawing air through the tube with a bellows–type pump. The resulting length of the stain in the tube (produced by a chemical reaction with the sorbent) is proportional to the concentration of the air contaminant.

Grab samples were collected during both site visits using Mine Safety and Health Administration (MSHA) 50–mL glass evacuated containers. These samples were collected by snapping open the top of the glass container and allowing the air sample to enter. The containers were sealed with wax–impregnated MSHA caps. The samples were then sent by overnight delivery to the MSHA laboratory in Pittsburgh, Pennsylvania where they were analyzed for CO using a HP6890 gas chromatograph equipped with dual columns (molecular sieve and porapak) and thermal conductivity detectors.

On July 1st, measurements were collected under varying circumstances as follows: 1) with the boat engine operating at idle; 2 and 3) with the boat moving at 7 and 11 miles per hours (mph) without the water bladders in the rear; and 4) with the boat operating at 11 mph and loaded with full water bladders. Air samples were collected above the unobstructed swim platform (no people on the platform as there were on the day of the death) using the emissions analyzer probe attached to a pole that was marked in 1-foot increments. Detector tube and evacuated glass vial samples were first collected above the swim platform using devices designed for this evaluation. Because these devices did not function as well as was hoped, these samples were then collected by hand until it was clear that this sampling could not be continued in a safe manner.

Air distribution patterns above the swim platform were visually examined through the use of 45-second smoke bombs placed on the platform while the boat was moving at 11 mph weighted with the water bladders.

Between July 1st and July 11th, the boat owner delivered the boat to a maintenance shop where the following work was conducted:
visual inspection
mechanical inspection
compression test
carburetor evaluation
water and fuel leak check
engine tune up
oil pressure check
timing and idle adjustment
adjustment of air mixture screws
replacement of merc filter, oil, oil filter, transmission fluid, and spark plugs
carburetor jet tune up

On July 11th, the boat was retested for CO concentrations in the same locations as the previous evaluation. This time, the water bladders were not available. The boat was operated only at 12 mph, and without the weighting of the full bladders. There were 7 passengers during this testing, four of which were children. During this evaluation, two additional changes were made. A ToxiUltra monitor was placed at the center rear of the boat. In addition, a personal floatation device (PFD) was strapped to the swim platform in an arch similar to that created by the arms and upper torso of a teak surfer. The boat was then again operated at 12 mph and air samples were collected within the airspace created by the PFD to assess the impact of obstructing the airflow above the deck.

Data from this incident were entered into a computer application developed by the Occupational Safety and Health Administration (OSHA) to calculate an estimated exposure concentration of the victim. This application uses the Coburn-Forster-Kane relationship for modeling uptake and elimination of CO (see Attachment 3 for more information on the computer application). The following data were used to calculate a range of estimated exposure: an exposure time of 5 minutes, a measured COHb of 56%, three different activity levels during exposure (moderate, heavy, and very heavy); an altitude of 3,600 feet; height and weight of the victim. Three activity levels were used as it was difficult to compare teak surfing with other examples of activities.

Results

Interviews:

Based upon witness interviews, there was nothing different about the teak surfing circumstances on the day of this fatality than the many other times that they had done it before. They had often pulled three people behind the boat. The boat engine was operating as always. There was little wind, but that was not unusual. They were using the water bladders, but had often had teak surfed with those in the boat. They had not teak surfed earlier in the day, but had participated in other water sports from the boat. Again, this was not unusual. They had never had a boat passenger or teak surfer express any symptom of CO poisoning before this incident, let alone lose consciousness. No clear explanation arose for why this round of teak surfing resulted in a fatal poisoning when other times had not.

Air sampling:

After the propulsion engines were activated, the air sampling pumps pulling air from above the swim platform to ToxiUltra CO monitors in the boat were activated. Within 30 seconds, the upper measuring capacity of the ToxiUltra monitors (1,000 ppm) used to characterize CO concentrations above the swim platform was exceeded. The sampling apparatus was deactivated to protect the sampling equipment. Spot checks with these instruments throughout each sampling day consistently indicated CO concentrations greater than 1,000 ppm in that airspace.

During the first day of sampling, 12 detector tube samples were collected at various locations above the swim platform while the boat was weighted with water bladders and operated at 11 mph. Two tubes indicated CO concentrations below the limit of detection for the tubes. Seven tubes indicated CO concentrations of approximately 3,000 ppm. Three tubes indicated CO concentrations of approximately 6,000 ppm.

Results of measurements collected with the emissions analyzer at various locations near the swim platform under four circumstances described earlier (operating the boat without water bladders at speeds of 7 and 11 mph, and with water bladders at 12 mph before maintenance; operating the boat at 12 mph without water bladders after maintenance) are graphically illustrated in Figures 6 - 10.

Results of measurements collected elsewhere in the boat are shown in Figures 11 - 14.

Measured CO concentrations were widely variable when the boat was moving through the water. This was likely due to the highly variable wind patterns created in the pocket of air behind the transom (see Figure 15 showing results of smoke tests in that airspace). Because of this variability, sampling was limited to range-finding characterization. Maximum CO concentrations measured at any point near the swim platform on the first day of sampling (July 1st) were as follows:

Boat Speed (mph)	**Boat Weighted With Bladders?**	**Range of Maximum CO Concentrations (ppm)**
7	no	0 - 3,200
11	no	500 - 23,800
11	yes	700 - 19,900

Maximum CO concentrations measured at any point near the swim platform on the day of sampling after boat maintenance (July 11th) were as follows:

Boat Speed (mph)	**Boat Weighted With Bladders?**	**Range of Maximum CO Concentrations (ppm)**
11	no	700 - 12,900

It occurred to investigators that the above measurements were collected above the swim platform *without* obstructions to airflow as would be caused by numerous people placing their upper torso near or above the platform (see Figure 2 for illustrations of how their body frame was placed and shaped relative to the platform). In an attempt to approximate the impact of such obstructions, investigators simulated their body frame placement and shape by placing a PFD in an upright position on the platform in a concave shape relative to the transom during the second day of sampling (after engine maintenance had been conducted). The sampling probe was placed in the airspace within the PFD and again maximum CO concentrations in each 1-minute period were recorded. In this configuration, measurements were much more consistent, with CO concentrations ranging between 10,000 and 26,700 ppm.

Results of smoke testing indicated that the air above the swim platform is primarily impacted by the intense turbulence created by the boat's forward motion (see Figure 15). The smoke hovered around the rear of the boat, remaining very concentrated in the pocket behind the transom and above the swim platform, creating a cloud encircling the rear of the boat and passengers in that area.

Results of laboratory analysis of the evacuated glass containers are not yet available. These results will be forwarded under a separate cover letter when they are received.

Results of the computer calculation of estimated exposure concentrations are presented in Attachment 3. In summary, the calculated exposure averaged over the entire five minutes ranged between 10,000 and 16,000 ppm (with confidence ranges from 7,000 to 21,000 ppm).

Discussion

The review of previously collected data from NPS Glen Canyon EMS records indicated that between 1990 and 2000 at Lake Powell there had been at least one, and possibly three poisonings that occurred under circumstances similar to the recent fatality. The circumstances of the Lake Powell incidents mirror those of 5 severe (4 fatal and 1 non-fatal) CO poisonings in other states that have been reported to the NIOSH/DOI/NPS/USCG investigative team during the course of their research on boat-related CO poisonings. The case reports are compiled in a National Case Listing that can be found at the following internet website:
http://safetynet.smis.doi.gov/COhouseboats.htm

Three fatalities are included in the current update of that listing.

1) **Bartlett Lake, Arizona** - In 1998, an 11-year-old boy and 3 children of similar age were being slowly pulled through the water while holding onto the wooden swim platform attached to the transom of a MasterCraft Ski-ProStar 205 boat. The propellor of the boat was centered at the rear underside of the watercraft. At one point, the boy was the only person being pulled through the water, with the three mates sitting immediately nearby on the platform and two adults located at the front of the boat. Signs of trouble occurred without warning within the time span of a few seconds. The boy lost hold of the platform and then disappeared under the water. His body was recovered the following day. The medical examiner's report showed 48% COHb. Cause of death was determined as "drowning due to carbon monoxide incapacitation due to inhalation of exhaust." The certificate of death listed drowning (but not CO poisoning) as the cause of death. Investigators' reports did not indicate malfunction of the boat or motor, nor did any witness describe the odor of fumes or exhaust. No other rider in the boat described becoming ill. (Source: Arizona Health Department)

2) **Lake Sylvan, Ohio** - In August 2000, an 11-year-old girl was riding on the swim platform of a 21' inboard Malibu ski boat with two friends who were near her age. The boat was moving slowly (operating under 10 miles per hour) while the children lay on their stomachs on the platform with their legs dangling in the water. The weather was calm and clear. The girl began to lose consciousness, falling from the boat. The 11-year-old girl disappeared from view and drowned. Her autopsy COHb was 50%. (Source: Ohio Division of Water Craft records)

3) **Ocoee Lake, Tennessee** - In June 1995, three girls were being towed at idle speed behind a 19' Malibu ski boat powered by a 1993 Mercruiser 5.7 liter engine. They were holding onto the swim board attached to the boat transom. One of the girls was wearing an adult-sized extra-large Type III personal flotation device (PFD) with the top of three buckles unfastened. She

commented to the others that she did not feel well. Just after making that statement, she lost consciousness, let go of the deck, slipped out of the PFD, drifted about two feet, and sank. Her body was recovered in 95' feet of water two days later. Her COHB concentration was 62%. (Source: Tennessee Boating Accident Investigation Record)

A fourth fatal CO poisoning occurring under similar circumstances has been recently reported to the team, but not yet added to the list. The fatal poisoning occurred in Alabama. It is important to remember that the CO poisonings in other states were randomly reported to the investigative team by individuals that had heard about the ongoing investigation of boat-related CO poisonings. There was no organized effort to identify such poisonings across the United States.

The NPS Park Ranger's initial confusion over the cause of drowning in this incident is a clear example of how the connection between CO exposure and drownings can easily be missed, even on Lake Powell. The circumstances of this fatality and the fact that CO poisoning as the actual cause of the drowning could have been so easily missed again points to the need for improved data collection to identify the scope of the problem of boat-related CO poisonings. Better data collection hinges on both improved case identification and improved case reporting. To improve case identification, the following are needed: training for EMS providers to help them recognize CO as a possible contributor and to give them guidance in collecting needed information about CO sources; information materials for the medical community (EMS, Emergency Department, and Coroners/Medical Examiners) that stress the need for immediate COHb measurements anytime a drowning occurs near a boat or boat passengers experience symptoms consistent with CO poisoning; improved information dissemination efforts. The need for improved case reporting is indicated by the fact that only one of the four previous similar CO poisoning deaths was found in incident and fatality data collected by the US Coast Guard.

In this incident, the boat owner and other family members were well aware of the hazards of exposure to CO. Their level of awareness was illustrated by the fact that they had moved their houseboat generator from the lower deck of the boat to the roof to avoid swimmer CO exposures. Because they or other family members and guests had been teak surfing behind the ski boat many times without any recognized symptom of poisoning, and they had never heard of another poisoning related to the activity, it is logical that they did not connect their knowledge of CO hazards to the practice of teak surfing. This reiterates the need to raise awareness of the very real hazard of outdoor CO poisonings.

The number of severe poisonings associated with one boat design feature and related activity indicates that this activity may be much more common than originally thought, and that prevention activities are clearly warranted.

We recognize that several things could have prevented this fatality. First, and foremost, preventing this activity certainly would have prevented this death. There are two ways to prevent this activity - behavior modification (inform people of the hazard and hopefully change their behavior; prohibit teak surfing and/or occupancy of the swim platform while engines are operating) and design modification (take the swim platform off the boat).

If the victim had been wearing a PFD, the likelihood of his drowning would have been dramatically reduced. He may still have died from CO poisoning, however, because his estimated exposure concentration and measured COHb were so high.

Recommendations

1) Legislators should consider rules prohibiting teak surfing (also referred to as "dragging").

2) The National Park Service should prohibit teak surfing on waterbodies under their control.

3) Boat manufacturers should be made aware of the fact that the presence of this extended, easy-to-access platform in combination with a recessed propellor is encouraging boat passengers to occupy an environment that is very rich in CO.

4) Manufacturers should immediately place warning labels on all boats with design features that encourage or allow occupancy of areas that are rich in CO. These labels should warn of the hazardous circumstances and specifically tell passengers to stay away from the rear of the boat when the engines are operating. No such labels were present on this boat. Information about the hazard of indoor and outdoor CO poisonings on boats should also be prominently placed in owner's manuals

5) Manufacturers should consider changing boat design features that encourage passengers to occupy an environment that is very rich in CO. Examples of such changes might include: removal of the swim platform, thus removing the opportunity to teak surf; changing the direction/location of the exhaust; working with engine manufacturers to explore the addition or development of emission control devices for marine engines.

6) Boat users should be made aware of the very real hazard of fatal outdoor CO poisonings associated with boats in general and specifically with this and other activities that involve occupancy of the swim platform when the boat engine is operating. Manufacturers and other appropriate agencies should develop educational materials and effective dissemination strategies to "get the word out."

7) Coroners/medical examiners should test for COHb concentrations any time a nontraumatic drowning occurs near a boat.

8) Emergency medical services on waterbodies with large concentrations of boaters should consider using expired CO monitors when responding to medical emergencies . This equipment

would allow improved case identification as well as improved case management. The practicality and cost-effectiveness of using this equipment could be evaluated through an initial pilot project in cooperation with NPS and USCG on Lake Powell where awareness of CO poisonings has been increased in the past year. This increased awareness has already led to an increase in symptom reporting among boat occupants. Symptoms of CO poisoning are similar to those of dehydration, excessive alcohol consumption, and many other illnesses. The use of expired CO monitors would allow medics to clearly assess CO poisonings and would also assist them in convincing patients to accept appropriate medical care.

Figure 1. Water bladders used to weight the rear of the boat

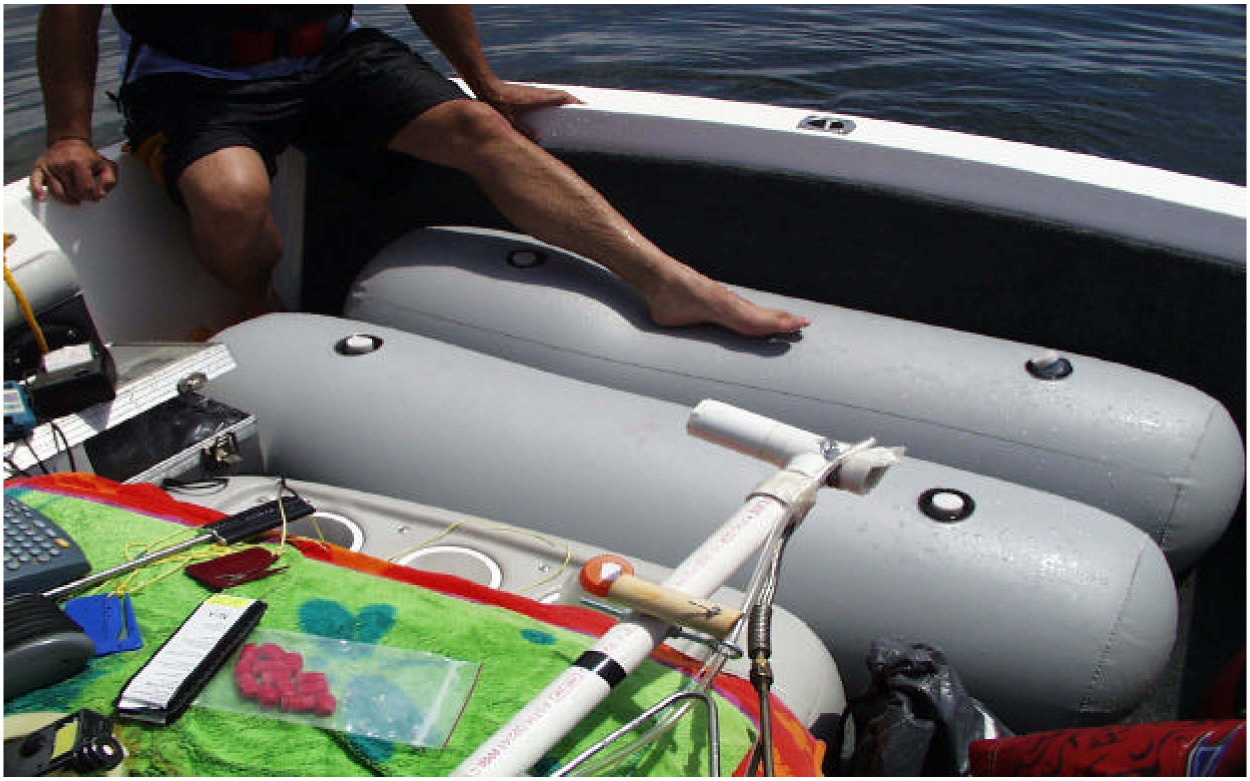


Figure 2. Teak surfing

Figure 3. Exhaust ports (blue arrows) and propeller (red arrow)

Figure 4. Following wake for teak surfing

Figure 5. Sampling carbon monoxide concentrations in the air above the swim platform

Figure 6. CO concentrations measured at various locations on the swim platform under specified operating conditions - *before engine maintenance*

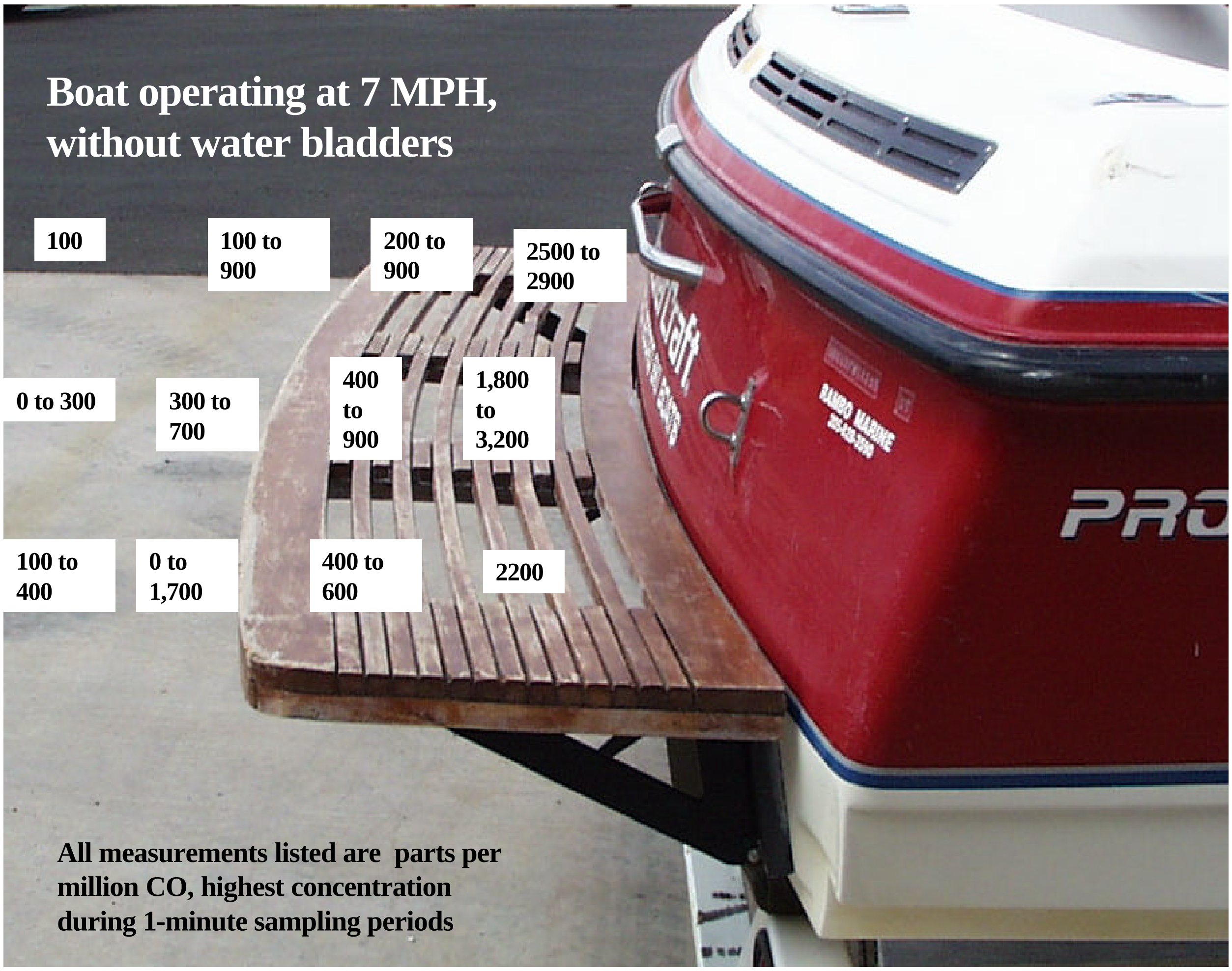


Figure 7. CO concentrations measured at various locations on the swim platform under specified operating conditions - *before engine maintenance*

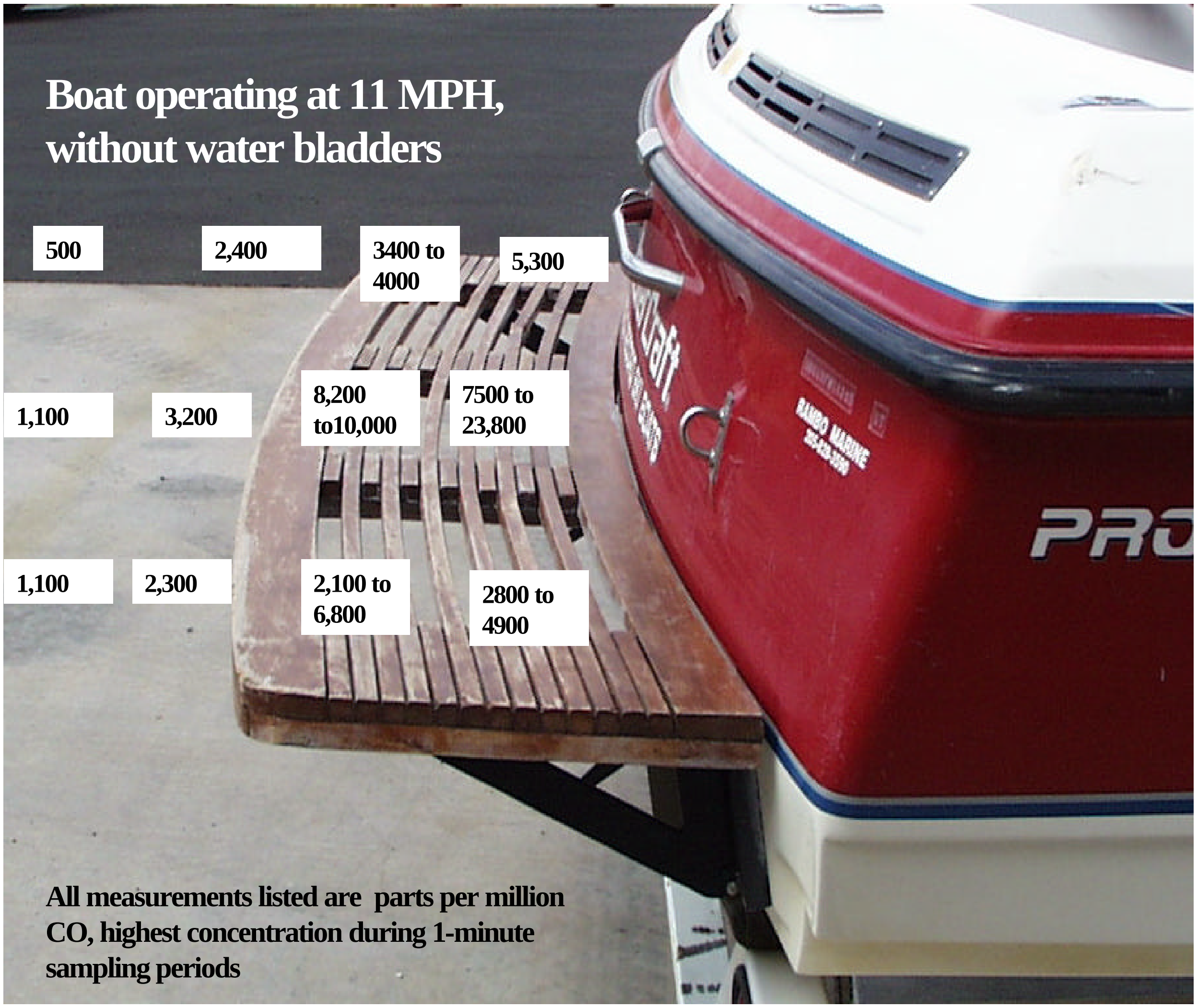


Figure 8. CO concentrations measured at various locations on the swim platform under specified operating conditions - *before engine maintenance*

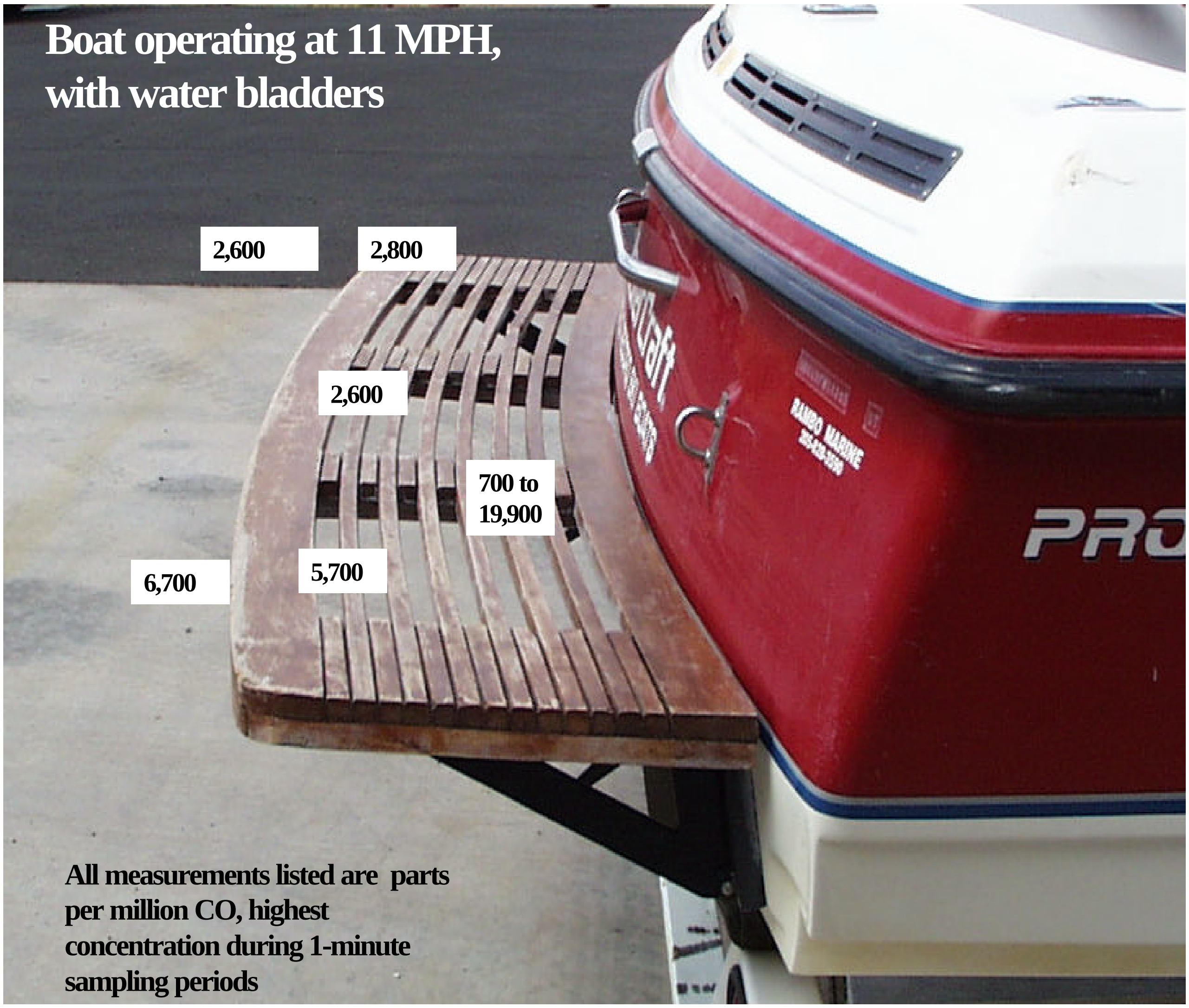


Figure 9. CO concentrations measured at various locations on the swim platform under specified operating conditions - *after engine maintenance* (for comparison, please refer to Figure 7)

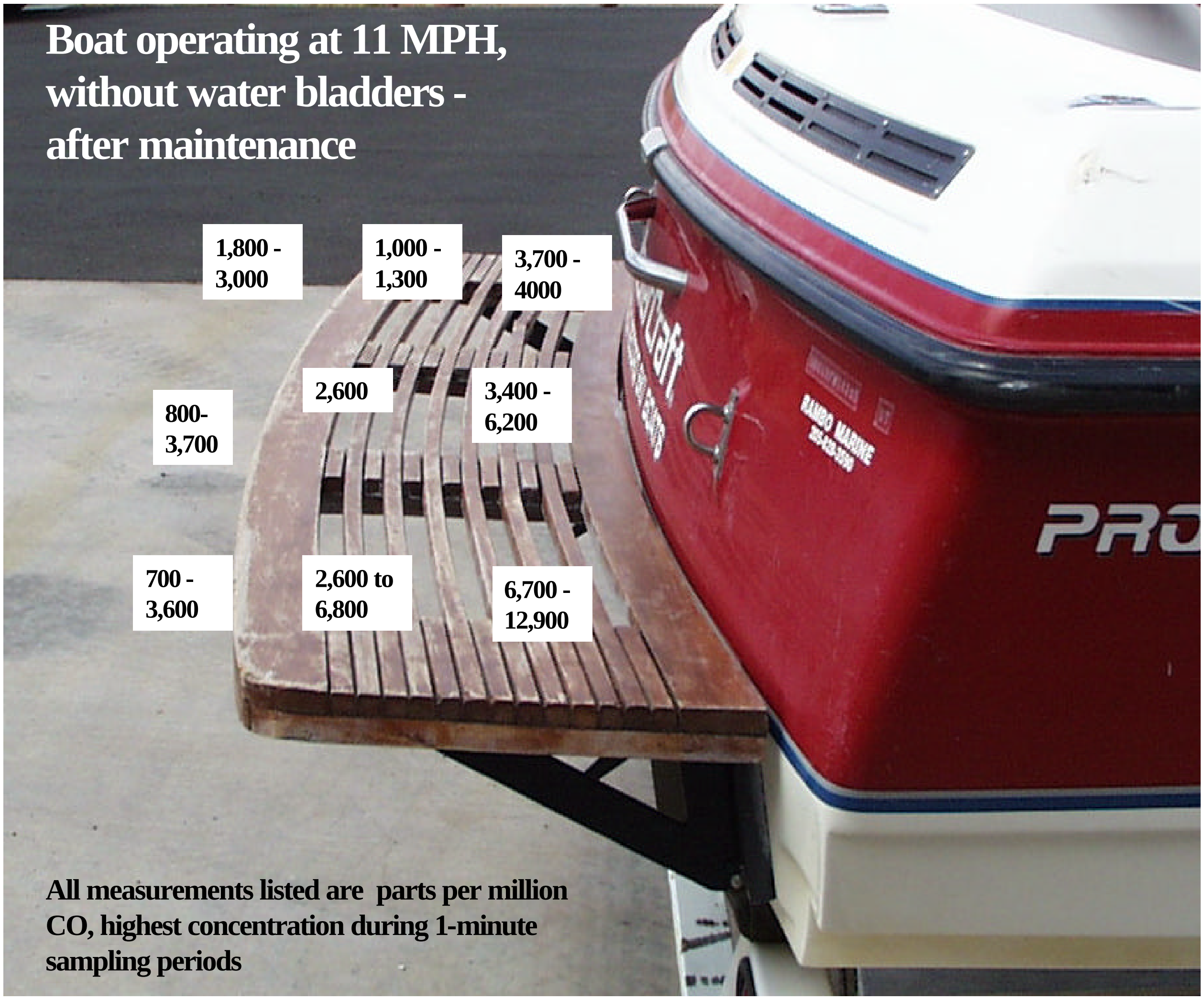


Figure 10. CO concentrations measured at approximate breathing zone of victim during simulation of obstructed airflow *(as would have been present when the surfers were on the platform)*

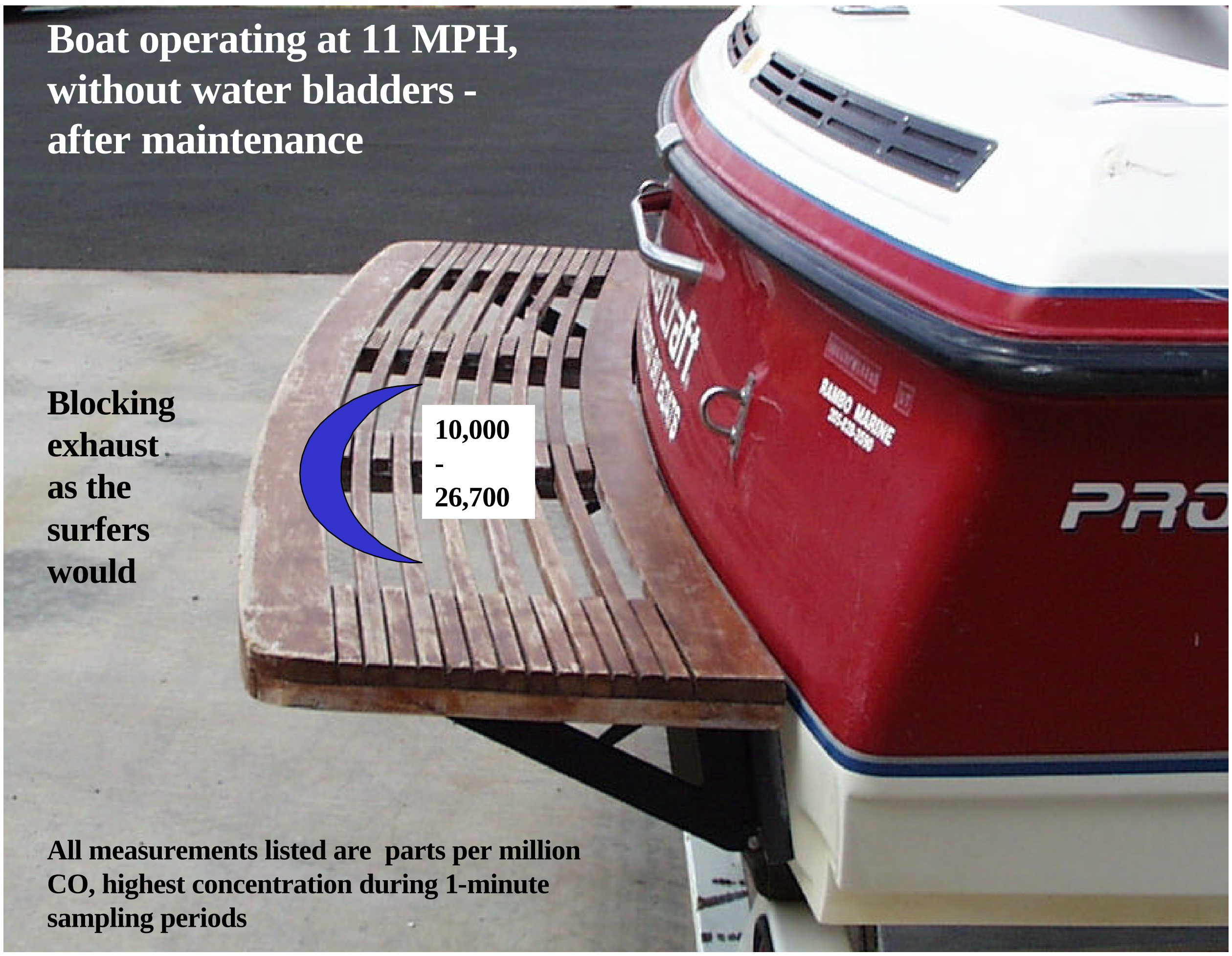
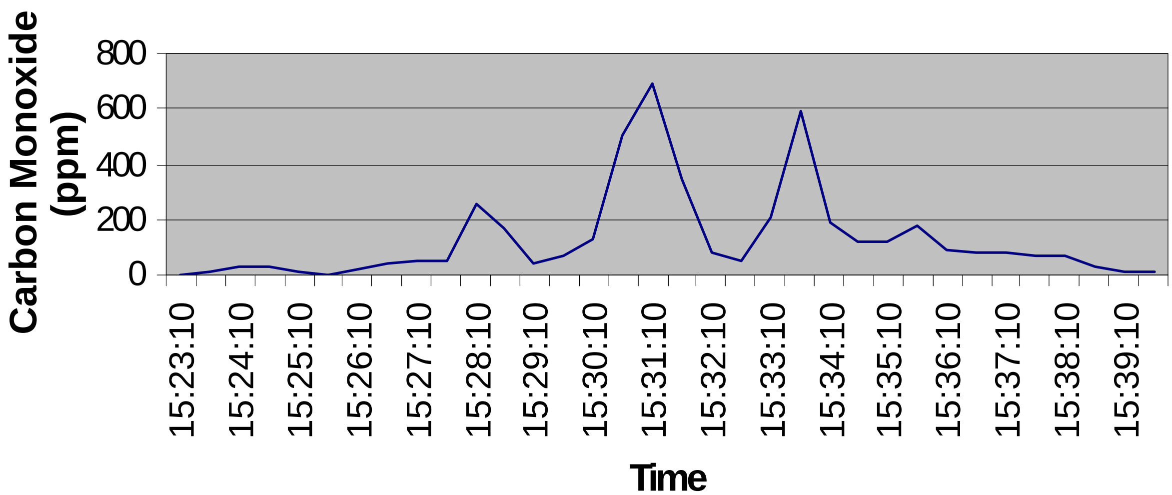


Figure 11. Carbon monoxide concentrations measured along the swim platform while engines operated at idle speed *(after engine maintenance)*



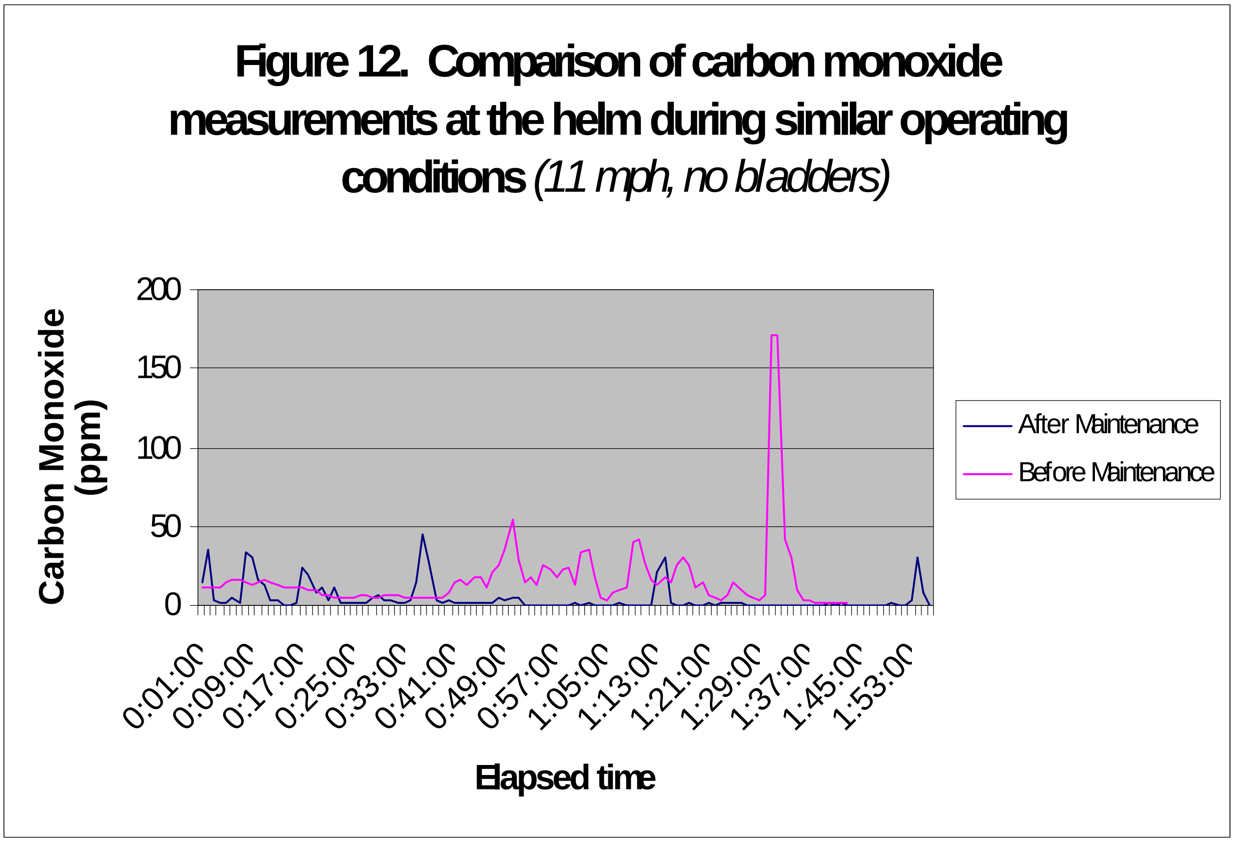
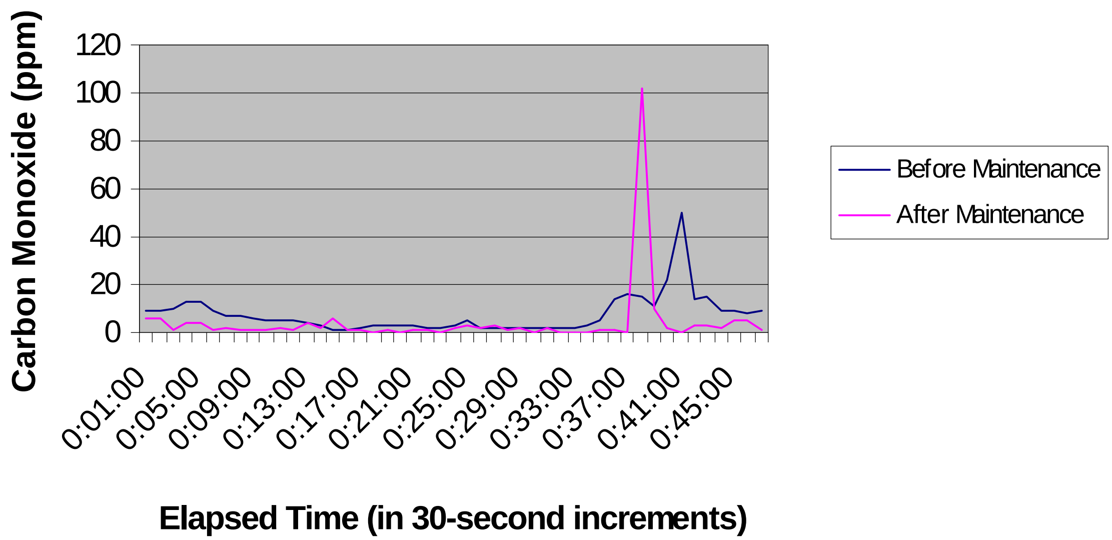


Figure 12. Comparison of carbon monoxide measurements at the helm during similar operating conditions (11 mph, no bladders)
Carbon Monoxide (ppm)
200
150
100
50
0
0:01:00
0:09:00
0:17:00
0:25:00
0:33:00
0:41:00
0:49:00
0:57:00
1:05:00
1:13:00
1:21:00
1:29:00
1:37:00
1:45:00
1:53:00
Elapsed time
After Maintenance
Before Maintenance

Figure 13. Comparison of carbon monoxide measured at the front passenger seat during similar operating conditions *(11 mph, no bladders)*



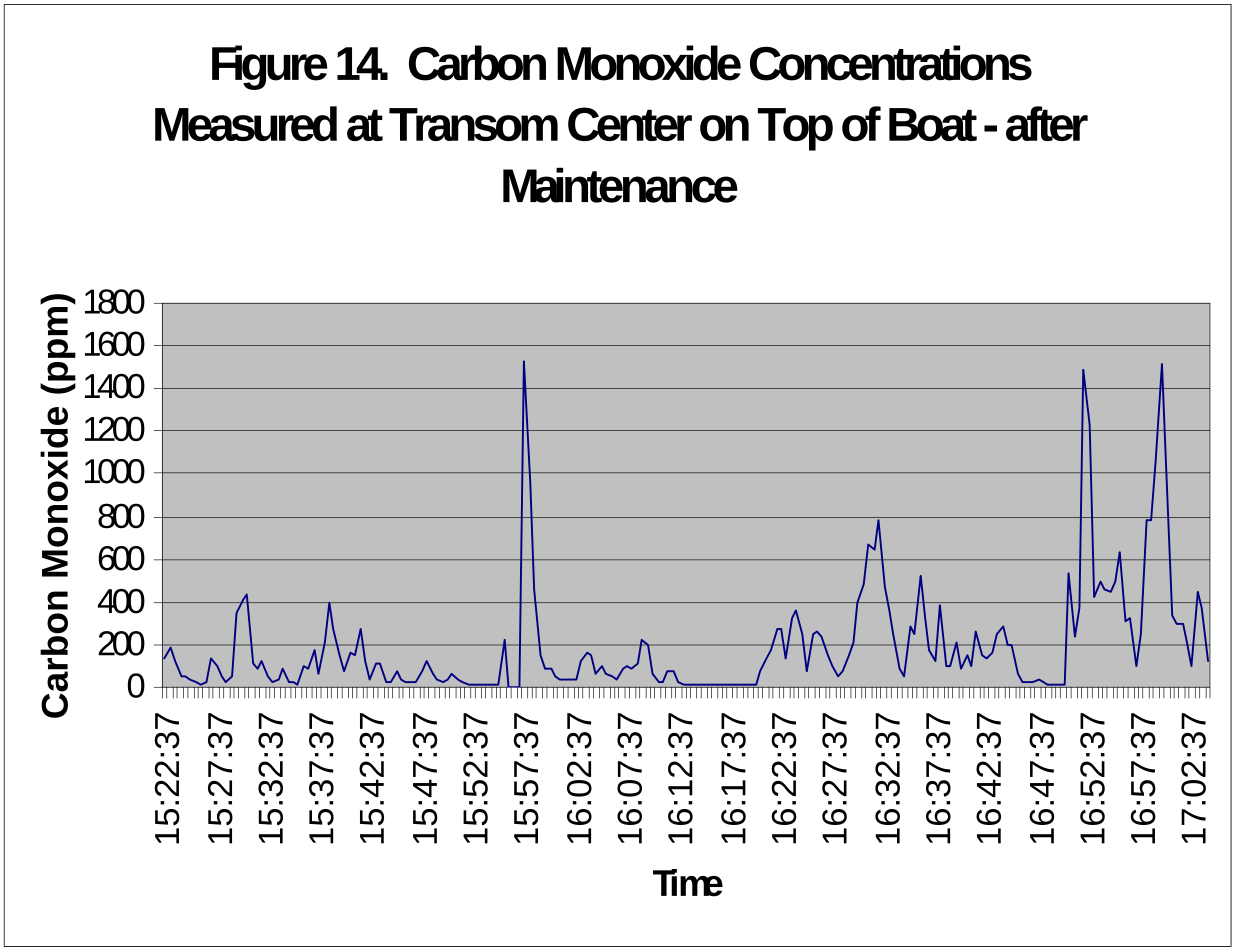


Figure 14. Carbon Monoxide Concentrations Measured at Transom Center on Top of Boat - after Maintenance
Carbon Monoxide (ppm)
1800
1600
1400
1200
1000
800
600
400
200
0
15:22:37
15:27:37
15:32:37
15:37:37
15:42:37
15:47:37
15:52:37
15:57:37
16:02:37
16:07:37
16:12:37
16:17:37
16:22:37
16:27:37
16:32:37
16:37:37
16:42:37
16:47:37
16:52:37
16:57:37
17:02:37
Time

Figure 15. Smoke showing the turbulent airflow capturing the engine exhaust at the rear of the boat, and moving it forward into the stern of the boat.

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). 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 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.

The altitude of this lake is 3,500 feet. Altitude effects 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.[7]

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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. Workers are typically healthier than the general population. Thus, occupational criteria applicable to NPS and concessionaire employees are higher than other environmental standards.

The general boating public 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 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.(9) ACGIH also discourages exposures above 125 ppm for more than 30 minutes during a workday.

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%.

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

Attachment 3

Calculation of CO Exposure

Information about OSHA’s Computer Model

Results of Calculations related to this Incident

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July 31, 2001

Jane B. McCammon, CIH
Director, NIOSH Denver Field Office
Denver Federal Center
P.O. Box 25226
Denver, CO 80225-0226

Dear Ms. McCammon

I received your FAX of July 31, 2001. As per your request, I have performed the OSHA back-calculation to estimate the probable CO exposure level. I used the 3,600 ft elevation figure you supplied me for Lake Powell, (UT and AZ), and I assumed that the elevation was good to the nearest 200 ft.

As per your request, I calculated the exposure for exposure activity levels of moderate (2), heavy (3), and very heavy (4) in which I used the default uncertainty that the estimate was good to the nearest one-half level. These are result files NIOSH02, NIOSH03, and NIOSH04 respectively. I also performed the calculation assuming an exposure activity level of heavy (3) with a large uncertainty (twice that for nearest full level). That result file is NIOSH05 which has a comparable uncertainty that includes NIOSH02 – NIOSH04. The NIOSH05 report perhaps most effectively describes the exposure scenario based on the available information.

The results for the 4 calculations are summarized below:

File	Activity Level	Calculated ppm CO; SAE (During Exposure)	Monte-Carlo Range ppm CO (101 Calculations)
NIOSH02	Moderate	16,100; 0.237	10,800 to 21,400
NIOSH03	Heavy	12,200; 0.260	7,880 to 16,900
NIOSH04	Very heavy	9,780; 0.240	7,170 to 13,200
NIOSH05	Heavy	12,200; 0.310	7,250 to 20,700

As I mentioned in our phone conversation, this calculation was not intended for very short exposures. That is because it takes time for the various blood pools in the body to mix well Tikuisis, P. ["Modeling the Uptake and Elimination of CO," in CRC Carbon Monoxide, edited by David G. Penney, (1999) pg 57] indicates that it takes about 2 minutes for all blood pools to become thoroughly mixed). For example, in the model, CO complexes both with hemoglobin and with myoglobin (in the muscles) [ibid, pg 54] which may take time to equilibrate.

If I can be of further assistance, please feel free to call.

Mike C. Rose

OSHA Occupational Safety & Health Administration U.S. Department of Labor

OSHA Evaluation of Occupational Exposure Based on Post-Exposure Clinical Sampling for Carboxyhemoglobin (COHb)

USDOL/OSHA Salt Lake Technical Center (SLTC)

Note: This computer application is subject to revision. This version (December 14, 2000) has been extensively tested and is similar to the version presented as a poster session at the AIHCE 2000 in Orlando, FL (May 20-25, 2000) where it was offered for public comment. Based on initial public comment, increased documentation and provision of an option for the user to enter an occupational exposure limit value have been added to this version. The associated software is currently in the format of text-driven DOS programs; future versions of the programs may incorporate a graphic user interface (GUI) to facilitate data entry and editing.

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SLTC is a resource for Federal and State OSHA programs. This computer application was created at SLTC for compliance purposes to meet the needs of OSHA compliance officers in addressing carbon monoxide (CO) overexposures, the most common cause of occupational poisoning. It may also find use in other forensic, indoor air quality, environmental, toxicological, and industrial hygiene applications. The limited ability to estimate CO exposures from %COHb levels in the blood based solely on relationships presented in the NIOSH Criteria Document (NIOSH, 1972) has been recognized by OSHA (Clark, 1991; Blais, 1997; Amr 1998) and others (including Tikuisis, 1987, 1996a, 1996b; Smith, 1996). This application addresses many of those limitations and implements needed corrections and modifications to the calculation presented in the NIOSH Criteria Document. The model implemented in this application has been validated using data from volunteers given short-term exposures to high CO ppm levels (Tikuisis, 1987). This application addresses the interference associated with CO from primary and secondary tobacco smoke before, during and after exposure. To address the effects that uncertainties in these sources of interference and the uncertainties in all other sampling data may have on the reliability of the calculated result, the calculation process uses a Monte-Carlo technique to estimate a sampling and analytical error (SAE). The expert system in this application includes overexposure and non-compliance assessment tools which can address the current OSHA Permissible Exposure Limit (PEL) of 50 ppm CO, the current ACGIH Threshold Limit Value (TLV) of 25 ppm CO, or any user-specified occupational exposure limit. Because it provides a reliable model for carbon monoxide exposures, it may be of use in developing new exposure standards. However, some compounds, e.g., methylene chloride, when inhaled or absorbed are converted to CO and COHb in the body and can interfere if present in a significant amount in the work environment. In order to resolve such interferences, additional monitoring information may be necessary which is not currently addressed automatically in this application. It is our experience from evaluating numerous exposures of this type that each exposure incident is unique. While this application cannot replace the need for technical expertise in this type of exposure assessment, it provides a valid means to estimate exposures to CO.

Introduction. Two different types of Industrial Hygiene (IH) applications involve the relationship of the CO concentration in the air (ppm CO) to the amount of carboxyhemoglobin saturation in the employee's blood (%COHb). The type of IH application is determined by which of the two values is available. If only one value is available, the other value can be calculated.

Applications where ppm CO was measured (e.g., CO monitoring to prevent CO overexposures). In order to meet their responsibility to prevent the injury or death of employees, employers must maintain a healthy work environment, monitor for toxic substances as needed, and prevent entry into unsafe areas. These applications generally require making direct measurements of the ppm CO concentration in the air. Various techniques can be used to directly assess employee exposure to CO, and perhaps the most currently popular are electronic devices that use electrochemical detectors.

Employers can also use computer models or well-reasoned statistical assumptions in lieu of or in addition to direct monitoring. A low-cost computer application available from the National Technical Information Service (NTIS) predicts how the employee's blood becomes saturated with CO. The NTIS application makes predictions based on exposures to stepped CO ppm levels. It is useful in modeling known CO exposure hazards associated with CO, e.g., it models how the employee's activity can accelerate CO intoxication (Diskette and Documentation AD-M000 669 can be purchased for about $69 US from the NTIS Sales Desk at 800-553-6847 or 703-605-6000).

Applications where %COHb was measured (e.g., assessing CO health emergencies). When prevention efforts fail, a health emergency can result. When the possibility of an overexposure to CO occurs, a blood sample is often drawn from the employee some time after the exposure. The blood is analyzed at the hospital or clinical laboratory to determine the amount of carboxyhemoglobin saturation in the employee's blood (%COHb). This sampling result is useful to the attending physician and forms a basis on which the OSHA compliance officer can estimate the CO air concentration that was present during the occupational exposure. The uptake and release of CO by the human body is a complex and dynamic process; so additional sampling information is needed for an accurate estimate of the employee's exposure. For example, the height and weight of the employee are needed to estimate the employee's blood volume, and the occupational exposure assessment is somewhat complicated by any use of tobacco before, during, and after exposure. The NTIS program described above can be used in an iterative process to determine the exposure level that results in a health emergency, but the process is tedious and does not provide the flexibility to estimate an SAE. The NTIS program was used for quality assurance purposes during the development phase of this application.

This application uses the Coburn-Forster-Kane (CFK) relationship that was employed by NIOSH to develop the NIOSH Recommended Exposure Limit (REL) at an air concentration (35 ppm CO) that would result in a low %COHb level (5 %COHb) having minor effects (NIOSH, 1972). This relationship is valid for modeling the uptake of CO during the occupational exposure and for modeling the elimination (or clearance) of CO by the body after the occupational exposure. The uptake and elimination periods are referred to in this application as exposure and washout periods, respectively. Variables used in this analysis are defined in the NIOSH Criteria Document for CO (NIOSH, 1972) and elsewhere (Tikuisis, 1996a, 1996b; Blais, 1997; etc.). Some terms are combined in order to reduce the complexity in subsequent equations:

$$\beta = \frac{1}{DLCO} + \frac{(PB - 47)}{VA}$$

$$ICO = \frac{PB - 47}{10^6}$$

$$PICO = ppmCO \cdot ICO$$

$$PCO2 = 0.21 \cdot (PB - 47 - PICO) - 49$$

This compliance-enforcement application is used in situations that require the %COHb in the employee's blood to be measured because the ppm CO level was not monitored at the occupational exposure. It provides a reliable estimate of the CO exposure when an exposure to CO is suspected as contributing to or resulting in a health emergency or death in the workplace.

$$\frac{d[COHb]}{dt} = \frac{VCO}{V_b} + \frac{1}{V_b \ \beta} \left(P_I CO - \frac{[COHb] \ P_C O_2}{[O_2Hb] \ M} \right)$$

The application was modified to correct known minor errors. For example, the alveolar ventilation (VA) rate and the diffusing capacity of the lung for CO (DLCO) occur in the literature referenced to two different standard conditions, respectively, body temperature and pressure and standard conditions (BTPS) and standard temperature and pressure and dry conditions (STPD). In medicine, these are useful ways of reporting VA and DLCO because the ratio of DLCO/VA is an important measure of lung function, and when these standard conditions are used, the ratio is independent of altitude [atmospheric pressure] (pg. 77 Morris, 1984). In order to use these data in the CFK calculation, these two respiratory rate parameters must be expressed in the same standard conditions (Tikuisis, 1987, 1996a, 1996b). So that both VA and DLCO are at STPD, the VA values are converted from BTPS to STPD conditions using a correction factor:

$$\text{Correction} := \left[\frac{(PB - 47)}{760}\cdot\frac{273.15}{310.15}\right]$$

The [O2Hb] concentration was replaced with [O2Hb] - [COHb] in order to account for the fact that the oxyhemoglobin concentration significantly decreases at the higher %COHb blood concentrations seen in health emergency-related exposures. These corrections and modifications are validated modifications to the CFK equation (Tikuisis, 1987, 1996a, 1996b).

The CFK equation as an integral is shown to determine the time it takes to go from a carboxyhemoglobin concentration A to a concentration B:

$$t = \int_A^B \frac{1}{\frac{VCO}{Vb} + \frac{1}{Vb\cdot\beta}\cdot\left[PICO - \frac{(COHb)\cdot PCO2}{(Con\cdot Hb - COHb)\cdot M}\right]}\,dCOHb$$

This equation can be integrated to obtain the following equation:

$$t = \frac{Vb\cdot\beta\cdot M}{Q^2}\cdot\left[Q\cdot(B - A) - Con\cdot Hb\cdot PCO2\cdot\ln\left[\frac{(M\cdot Con\cdot Hb\cdot(VCO\cdot\beta + PICO) - Q\cdot B)}{(M\cdot Con\cdot Hb\cdot(VCO\cdot\beta + PICO) - Q\cdot A)}\right]\right]$$

Where:

$$Q = VCO\cdot\beta\cdot M + PICO\cdot M + PCO2$$

The integration was performed using the symbolic manipulation feature of a commercially-available mathematics computer program (Mathcad, 1997). The integration was followed up by algebraic simplification. This is a non-linear relationship which <u>cannot</u> be rewritten in a simple general equation to be solved for either %COHb or ppm CO. It <u>can</u> however be rewritten to provide a criterion on which to base binary searches for exact solutions:

$$0 = e^{\frac{-t\cdot\frac{Q^2}{Vb\cdot\beta\cdot M} + Q\cdot(B - A)}{Con\cdot Hb\cdot PCO2}} - \frac{(M\cdot Con\cdot Hb\cdot(VCO\cdot\beta + PICO) - Q\cdot B)}{(M\cdot Con\cdot Hb\cdot(VCO\cdot\beta + PICO) - Q\cdot A)}$$

When the sampling data used in the calculation are consistent and compatible with the assumptions, the curve for the %COHb vs. time is monotonic (i.e., a single %COHb value corresponds to a single time value) for each exposure and washout period of the scenario. Under such conditions, an iterative binary search can be performed where the search range is successively halved until the difference of terms equals 0 as shown in the equation above. An error message results when the criterion does not converge to 0. Lack of convergence indicates that the sampling data are not consistent and compatible with the assumptions made.

The exact result is determined from the data provided by the compliance officer. Because a high degree of uncertainty would limit the utility of any result, an estimate of the uncertainty involved in the result should always be provided when modeling complex phenomena. It is common practice by OSHA to consider the amount of error associated with any measurement. In this application, an estimate of the sampling and analysis error (SAE) is made by statistically sampling the calculated exposures that result from data containing small independent random normally-distributed errors. [Because the respiratory parameters, DLCO and VA , are correlated at the several work and post-work activity levels, the errors for these contain both dependent and independent contributions. The degree of correlation was selected so that the coefficient of correlation (r) between DLCO and VA is about 0.8 to approximate the degree of correlation seen in the literature. (pg. 101, Morris, 1984)] The investigator who provides the data used in this calculation can also provide useful estimates of the error to account for the fact that the data for various situations have varying degrees of reliability. For example, a value for the concentration of hemoglobin in the blood (Hb) of the employee can have a reliability range based on instrument noise or from simple estimation. The following is listed from the most uncertainty to the least uncertainty:

1. Estimated Hb value based on the population of both males and females.
2. Estimated Hb value based on the gender of the employee.
3. Clinically measured Hb result for the employee using historical data for estimating interlaboratory error on a variety of instrument types.
4. Clinically measured Hb result where the laboratory using the laboratory's estimate of the uncertainty in the Hb result based on its quality assurance program that addresses the specific instrument(s) used in the analysis.

The process of statistically sampling a computer model is referred to as Monte-Carlo sampling. To provide good estimates of the SAE when using a small number of Monte-Carlo samplings, the statistic selected for this application is the standard error of the estimate from the exact solution rather than the standard deviation from the mean. The SAE is a one-sided 95% confidence interval used to determine the lower confidence limit (LCL).

Effect of Oxygen Use During First Aid:
NOTE: The recommended first aid treatment for CO poisoning begins with the administration of oxygen. Both first aid and subsequent recovery also dictate absolute rest to avoid possible complications of CO poisoning (ILO, 1983).
Oxygen administration is used because it increases the availability of oxygen to the tissues and decreases the biological half-life of the CO in the blood. Without oxygen administration, the half-life of CO can be 2-5 hours. When oxygen is administered at one atmosphere pressure to a resting person of average weight, the half life is decreased from several hours down to about 80 minutes. At three atmospheres pressure of oxygen, the biological half-life of CO may be reduced to about 24 minutes. When oxygen is administered during the first aid treatment after the exposure but prior to taking the blood sample, the clearance of CO from the blood is speeded up resulting in a lower %COHb value than would be expected if no first aid were provided. Unless this first aid is taken into account, the calculation produces an underestimate of the actual ppm exposure.

Because the effect in speeding up the clearance is similar to having a somewhat higher post-exposure activity level than indicated in the sampling data, the effect can addressed by the computer program increasing the effective post-exposure activity level from the level supplied by the compliance officer taking into account the duration of the oxygen administration, the total post-exposure duration, the atmospheric pressure, and the employee's body weight. NOTE: This is a mathematical adjustment designed to approximate the expected decreased biological half-life of CO when oxygen is administered. It is not meant to imply that exercise is a substitute for oxygen administration. Exertion also uses up oxygen reserves in the body. Carbon monoxide poisoning victims should not exert themselves or they risk complications in their recovery.

The post-exposure activity level when adjusted to compensate for oxygen administration is assumed to be good to one-full activity level. This higher level of uncertainty is used in order to compensate for additional uncertainty in the duration of administration and the concentration delivered. This uncertainty in the effective activity level might result in a decrease in the lower confidence limit (LCL) for the calculated exposure as compared to the calculated exposure without the adjustment. The effective biological half-life of CO resulting from the adjustment is then examined to see if it is reasonable, e.g., it should be reduced to about 80 minutes if the employee is of average weight and was given oxygen at one atmosphere pressure for most of the time following the exposure but prior to sampling. When more than one employee is involved in these situations, the adjustment approach can be checked to see that it is reasonable. (Because smoking tobacco is forbidden when oxygen is administered, CO from tobacco smoke is not a factor in slowing clearance of CO.)

How SLTC Reports CO Calculation Results:
When data are available to account for oxygen administration, the result that addresses the oxygen adminstration is the reported value unless it gives a lower confidence limit than the value that does not address oxygen administration. Both reports are provided to the compliance officer. The reports where the "Activity level after occ. exposure (0-4)" (shown in Table 1 below) has been adjusted to account for oxygen administration are distinguished by the addition of an O2 prefix to the SLTC sample tracking number used in form the name for the raw data and report files. For example, raw data and report files O2P67890.PRN and O2P67890.HTM address the O2 adjustment whereas P67890.PRN and P67890.HTM do not.

Case-by-case information is provided in supplemental reports for each sample.

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