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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Denver Federal Center
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303/236-6032

HETA 20020325
Interim Report

March 17, 2003

US National Park Service
ATTN: Kitty Roberts, Park Superintendent
Glen Canyon National Recreational Area
691 Scenic Drive
Page, Arizona 86040

Dear Ms. Roberts:

On May 8th, 2002, you requested that the National Institute for Occupational Safety and Health (NIOSH) continue providing assistance in monitoring both employee and visitor boat-related carbon monoxide (CO) poisonings occurring at Lake Powell within the US National Park Service (NPS) Glen Canyon National Recreation Area (GLCA). As part of the response to that request, NIOSH assisted certified industrial hygienists from the US Department of Interior, the Washington DC NPS office, and the US Coast Guard in gathering data related to a fatal poisoning that occurred at Lake Powell on September28th, 2002. This is an interim report for the overall response, and the final report of data for this specific investigation.

The purpose of this interagency investigation was to provide data about clearance of propulsion engine exhaust CO from the airspace beneath the extended stern deck of boats of the design shown in Figure 1. Summary information about the investigation is provided in this cover letter. More extensive detail is included in the attached full report.

Background

Several previous investigations have documented the accumulation of CO in the airspace beneath the stern deck of boats of this design. Reports related to these investigations are available at the following internet website:http://safetynet.smis.doi.gov/COhouseboats.htm. One report focused on issues related to entry procedures for this space. In a letter from Ron Hall and Jane McCammon of NIOSH to Joe Alston of Glen Canyon National Recreation

Area, dated November 21st, 2000[1], it was emphasized that when these houseboats are in the water, the area under the swim deck meets NIOSH and OSHA criteria for a permit-required confined space; therefore, permit-required confined space requirements must be followed before any workers enter this area. The report further pointed out that three CO poisonings (two fatal and one non-fatal) occurred on Lake Powell within the span of 12 days in August 1998 as a result of men entering the airspace beneath the swim deck for engine maintenance or clearing ropes from propellers. Another NIOSH report [2] provides data related to CO accumulation from propulsion engine and generator exhaust in this space, and documented that it took 8 minutes for the CO concentration to decay to 0 parts per million (ppm) following deactivation of both engines.

To-date, 17 poisonings have been identified (10 on Lake Powell and 7 on other water bodies) in which adults were accessing the outdrive of houseboats to conduct maintenance activities or free propellers from entanglements. Nine of these adults died as a result of their exposure. Three adults were employees engaged in occupational activities, and thus covered by confined space entry regulations.

Methods and Results

We conducted air sampling on two houseboats with extended stern decks, a lower swim platform the width of the boat, and propulsion engines exhausting into the airspace under the deck. For each sampling cycle, the boat propulsion engines were operated until a relatively stable concentration of CO accumulated in the airspace under the stern deck. The engines were then deactivated, with CO measurement continuing until the concentration decayed to 2 ppm or lower.

<u>Boat 1.</u> The boat used on the first day of sampling had side louvers (2" by 16") for venting the under deck airspace and two access ports (8" by 19") above the swim platform parallel to the transom of the boat. Wind speed was 0-2 miles per hour (mph), with gusts to 5 mph. Five cycles of sampling were conducted using different configurations of open and blocked louvers/ports. During these 5 sampling periods, the CO concentration in the airspace beneath the stern deck decayed to 2 ppm or less after a period of 10 to 30 minutes. Maximum peak concentrations in the airspace ranged from 15,100 to 62,500 ppm during the sampling periods.

<u>Boat 2.</u> The boat used on the second day of sampling was the one under which the recent fatality occurred. This extended stern deck was completely enclosed, with no openings other than 2" holes for the mounting bracket for personal water craft. Wind speed ranged from 4-12 mph, with gusts to 14 mph. Five cycles of sampling were conducted, with no changes in the airspace configuration. The CO concentration beneath the stern deck of Boat 2 decayed to 2 ppm or less after a period of 10-20 minutes during 5 sampling periods. Maximum peak concentrations in the airspace ranged from 27,800 to 88,200 ppm.

Conclusions

The measurements in this or previous investigations **do not** provide guidance for estimating clearance times for entry into this very hazardous confined space. In fact, the wide range of clearance times (from 8 minutes in a previous survey to as much as 30 minutes in this investigation) indicates that it is not possible for consumers or employees to accurately predict CO clearance times. Past incidents indicate that the risk of being wrong about those clearance times (given the wide range of boat configurations and environmental circumstances possible) is deadly.

The data collected here, as well as circumstances surrounding previous fatal and non-fatal poisonings indicate the following:

> Loss of directional control of the boat resulting from loss of propulsion thrust when the prop is fouled presents the boat occupant with an urgent need to correct the situation, especially if it is windy and the boat may be damaged due to the loss of directional control.
>
> It is not unusual for props to become fouled during attempts to anchor or otherwise moor boats, especially when it is windy and the boat is blown over the ropes. This requires entry into the under deck airspace to access the outdrive and alleviate the problems.
>
> Clearance of CO from this space is likely to take longer than the boat occupant will wait under these urgent circumstances, especially if the occupant is not fully aware of the potential consequences of entering that space.

The continuing occurrence of CO poisonings under these circumstances (attempting to access the outdrive of the propulsion engines) and the absence of entry procedures for consumers indicates a need to improve the design of this type of boat and/or develop safe entry procedures for consumers.

Recommendations

1. Manufacturers should examine options for modifying these boats to prevent the buildup of hazardous CO concentrations from any engine exhausting into the airspace under the deck. Design changes could include modification of the structure of the stern deck and/or sufficient pressurization of the airspace to reduce CO concentrations to safe concentrations within 1 minute of engine deactivation.

2. Boat manufacturers should enhance their existing warning and/or educational

materials for consumers to include guidelines for safe entry into the airspace beneath the stern deck.

3. Employers must require the use of confined space entry procedures described in Attachment 3 if workers enter the airspace beneath the stern decks of these boats when the boat is on the water.

We appreciate your continued concern about visitor and worker health, and hope you find this information useful. Please contact Jane McCammon if you have questions about anything included in this report.

Sincerely,

Jane B. McCammon , CIH NIOSH	Tim Radtke, CIH DOI	David P. Bleicher, CIH NPS

Enclosure

cc: Dr. Robert Baron
Richard Hartle, NIOSH/HETAB, Cincinnati

Investigation of Factors Related to a Fatal Carbon Monoxide (CO) Poisoning Outside the Cabin Area of a 2000 65' Sharpe Marine, Inc. Houseboat

Technical Assistance to the Glen Canyon National Recreation Area

HETA 20020325
Interim Report

Background

Since September 2000, NIOSH, DOI, and NPS have been working together with the US Coast Guard to identify and prevent boat-related CO poisonings occurring on Lake Powell. Lessons learned on Lake Powell will be applied nationwide. The interagency effort was triggered by the fatal CO poisoning of two brothers in August 2000.

From review of Emergency Medical Service (EMS) records, the team has identified 164 fatal and nonfatal CO poisonings occurring between 1990 and 2002 on or near boats on Lake Powell. Most of these poisonings were related to houseboat operation, and primarily gasoline-powered generators used to power air-conditioners and other electrical appliances on those houseboats. The remaining poisonings for which a boat type was identified were related to other pleasure craft (cabin cruisers and ski boats).

Including this recent death, we now know of 9 fatal and 8 non-fatal poisonings (10 on Lake Powell and 7 on other water bodies) of adults accessing the propulsion engines to conduct maintenance activities or free entanglements from the propellers. Three of these adults were employees engaged in occupational activities, and thus covered by Occupational Safety and Health Administration (OSHA) regulations, specifically the CO permissible exposure limit (PEL) and the confined space entry regulations. We know that at least four of the adults that died as a result of their exposure entered the airspace after the propulsion engines and/or generator had been deactivated.

Incident Description

Background materials provided for the investigation included: the NPS GLCA Case Incident Record (NPS 02-3904); the NPS GLCA Supplemental Incident Record; and autopsy records. According to the NPS investigative report, a fatal poisoning occurred at Lake Powell on September 28th , 2002 when the victim entered the airspace beneath the extended stern deck of a houseboat shortly after the inboard/outboard propulsion engines were deactivated.

Just prior to the incident, the boat occupants were attempting to moor the boat during windy weather. As they maneuvered the boat, the anchor ropes became entangled in the engine propellers. Just after the engines were deactivated (estimated to be more than 3 but less than 5 minutes), the victim entered the air space beneath the stern deck to remove the lines from the propellers. He was wearing a personal floatation device at the time. After his first entry into the airspace (estimated to have lasted about 2 minutes), he emerged and removed the PFD because he was unable to access the propellers. After approximately 2 minutes, he entered the space again, and stayed there about 2 minutes. He emerged for two minutes, and then reentered the space a third time. After about 2 - 3 minutes elapsed, he no longer responded to questions from the boat occupants and failed to emerge from the space. His overall time of exposure was thought to have been 6 minutes, with a total of approximately 15 minutes transpiring before he was no longer heard from. Although NPS divers made many attempts to find him, they were unsuccessful. His body floated to the surface on 10/1/2002. Autopsy results indicated that his carboxyhemoglobin (COHb) was 51%.

Methods

Computer Calculation of Exposure

Data related to this incident (including an exposure time of 6 minutes, a measured COHb of 51%, an altitude of 3,500 feet; and the height and weight of the man that died were entered into a computer application to calculate an estimated average CO exposure concentration during his exposure. This application developed by OSHA uses the Coburn-Forster-Kane relationship for modeling uptake and elimination of CO.

Air Sampling

NPS made arrangements with boat owners to facilitate measurement of CO on and near the boat on which the man died, as well as a second boat of similar design. Air sampling was conducted by certified industrial hygienists (CIH) from NIOSH (Jane McCammon), the Department of Interior (Tim Radtke), and NPS (David Bleicher) on October 30th and 31st. Laura Rabb, a Certified Industrial Hygienist from the US Coast Guard also assisted in air sampling.

Both boats have a stern deck that extends a number of feet beyond the transom where the propulsion engine out drives are located. The decks' supporting structures above and below the water line frame the sides of the airspace beneath the decks. Both boats also have a lower swim platform that extends the full width of the boat and rests within inches of the water surface. Each boat has two inboard/outboard gasoline-powered propulsion engines exhausting into the airspace under the deck.

The two boats differ in one design aspect. The stern deck of the boat on which the recent fatality occurred (referred to in this report as Boat 2) is completely enclosed; the other boat (Boat 1) has side vents on either side of the supporting structure and access port openings near the swim platform.

Boat 1. The boat used on the first day of sampling is a 60' x 14' Stardust houseboat with twin Mercury 220 horsepower 5 liter inboard/outboard gasoline-powered propulsion engines, each with more than 800 hours of use. The volume of the airspace beneath the stern deck of this boat is approximately 63 cubic feet (14' x 3'2" x 17"). The swim platform attached to this deck rests approximately 4" above the water whether the boat floated freely or is beached. The stern deck of this boat has side louvers (2" by 16" in dimension) for venting this airspace and two access ports (8" by 19") above the swim platform parallel to the transom of the boat. Five cycles of sampling were conducted using different configurations of open and blocked louvers/ports to evaluate CO decay rates in the space as follows: Rounds 1 and 2 - louvers and access ports fully open; Rounds 3 and 4 - louvers and access ports blocked; Round 5 - louvers open and access ports blocked. During rounds 1, 2, and 3, the boat was floating freely in the water, and the swim step rested approximately 4" off the water. During rounds 4 and 5, the boat was nose up to the beach, and the swim step again was approximately 4" off the water.

On this boat, the access ports allowed placement of sampling devices or probes directly in the space. The sampling probe for a high-range direct-reading air sampling instrument (Bacharach Monoxor II H) and tygon tubing were secured under the stern deck prior to activation of the engines. Air from the airspace was pumped through the tygon tubing to a valved tevlar bag for analysis by high range detector tubes. Two datalogging lower-range direct-reading air sampling instruments (ToxiUltra CO monitors) were secured to a pole that was then inserted into the space as the concentrations reduced to below approximately 1,000 ppm. Evacuated glass vial sampling devices were secured to a pole, inserted into the space, and the tip broken for sample collection by lightly tapping it against the boat components while the vial was in the space.

Boat 2. The boat used on the second day of sampling is the one under which the recent fatality occurred. It is a 2001 65' x 16' Sharpe Marine, Inc. houseboat with twin Mercury 240 horsepower 5 liter inboard/outboard gasoline-powered propulsion engines with 340.5 hours of use when this work was begun. The extended stern deck (shown in Figure 1) is similar to Boat 1, except that it is completely enclosed, with no openings other than 2" diameter holes for the mounting bracket for personal water craft. The volume of the airspace beneath this deck is approximately 110 cubic feet (16' x 4' x 20"). Five cycles of sampling were conducted, with no changes in the deck configuration. The swim step rested within an inch of the water surface during each sampling cycle.

Safe access to the airspace on this boat was very difficult. Prior to engine activation, tubing and probes were fed through the 2" diameter holes into the airspace beneath the stern deck (shown in Figure 2). Air-sampling pumps were used to pass air from the airspace across the ToxiUltra air sampling device sensors at a flow rate of approximately 1 liter per minute, and to bring exhaust-contaminated air to the glass vial tubes. The sampling tip of the glass vial was placed in the tube after exhaust had been pumped from the airspace. The tip was broken while it was in the tube. Detector tubes attached to the piston pump were placed in these holes for sampling.

Air Sampling Methods

The propulsion engines on each boat were operated at approximately 1,200 revolutions per minute until a relatively stable concentration of CO accumulated under the stern deck (as measured by a high-range direct-reading instrument). Air samples were collected at this time using high range detector tubes and glass vial grab samples. The engines were then deactivated. Measurements from the high-range direct-reading instrument were recorded every minute and used to guide us in the placement of the lower range datalogging direct-reading instruments into the space. The latter instruments were used to determine when concentrations in the space were nominally 0 parts per million (ppm) ($\pm$ 2 ppm). Glass vial and detector tube samples were collected at 1-, 5-, and 10-minute intervals after the propulsion engines were deactivated.

The high-range direct-reading instrument used was a Bacharach Monoxor II H portable CO analyzer was also used to measure CO concentrations in the airspace beneath the stern deck. The analyzer was calibrated in the field using gas known to contain 4% (40,000 ppm) CO. According to the manufacturer, this analyzer uses an electrochemical sensor to detect CO concentrations between 0 and 80,000 ppm. The sensor response time is listed as 90% of the final value within 40 seconds. The stated accuracy of the device is as follows:

CO Concentration (ppm)	Accuracy
1-5000	±100 ppm or 5% of the reading (whichever is greater)
5001 - 40,000	±10% of the reading
>40,000	Not specified

Airborne CO concentrations on and under the boat were also measured using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. All ToxiUltra CO monitors were calibrated before and after each day's use according to the manufacturer's recommendations. These monitors are direct-reading instruments that record data that is then transferred to a computer through an optical interface. The instruments were operated as described earlier, set to log data in 15-second intervals. The instruments have an accurate detection range from 0 ppm to 1000 ppm, but will record data up to approximately 1,200 ppm, depending upon the sensor. If the sensor is exposed to CO concentrations above 1000 ppm for an extended period of time, the sensor can become overloaded (poisoned) which causes the cessation of data recording. It is important to remember that once the concentration exceeds approximately 1,200 ppm (as indicated by a flat-topped peak at that concentration), it is impossible to characterize the actual concentration with these instruments.

Grab samples for laboratory CO and oxygen analysis were collected in the airspace beneath the stern deck 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. This laboratory analysis is the most accurate of all methods used, and allows characterization of very high CO concentrations. The limitation of the method is that it allows only a limited number of instantaneous measurements.

CO concentrations in the airspace beneath the stern deck were also measured with detector tubes [GasTec CO, range 0.1 % (1,000 ppm) to 10 % (10,000 ppm), with a stated accuracy of ±15%]. The detector tubes are used by drawing air through the tube with a piston 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. These tubes are the least accurate of the methods used for sampling during this investigation. The stated accuracy differed from our calibration of these tubes. During this investigation, we exposed two tubes to a known concentration of calibration gas (40,000 ppm CO), and both tubes read 30,000 ppm, thus 25% lower than the actual concentration. An average concentration over the 3-minute period during which air is drawn through the tube is indicated by the color change.

Wind speed was measured using a vane anemometer.

Evaluation Criteria and Exposure Health Effects

Detailed information about evaluation criteria and health effects of exposure to CO can be found in Attachments 1 and 2. Table 1 provides summary information about CO exposure concentrations and related standards and health effects.

Oxygen content is reported in Tables 2 - 11 in regard to determination of oxygen deficient environments. An "oxygen-deficient environment" is defined by the Occupational Safety and Health Administration (OSHA) as an atmosphere with an oxygen content of less than 19.5% by volume. Oxygen deficient environments are considered to be immediately dangerous to life and health (IDLH). Employees cannot enter an oxygen-deficient environment without wearing pressure-demand self-contained breathing apparatus (SCBA) or other oxygen-providing escape apparatus.

Attachment 3 contains further discussion of confined space entry requirements.

Table 1. Concentrations of Airborne CO and Related Limits or Effects

Exposure Concentration (ppm*)	Relevant Environmental Limit or Impact of Exposure
26	World Health Organization (WHO) recommended limit for general population exposure -- maximum 1-hour averaged exposure concentration
87	WHO recommended limit for general population exposure -- 15-minute averaged exposure concentration
200	NIOSH Ceiling Limit for workers -- recommended never to be exceeded
1,200	NIOSH Immediately Dangerous to Life and Health (IDLH) concentration for workers
6,400	Danger of death in 10 - 15 minutes
12,800	Danger of death in 1 - 3 minutes

*ppm – parts of CO per million parts of air

Results

Computer-calculated exposure concentration:
Using the computer program provided by OSHA, we calculated that the average CO exposure concentration experienced by the victim was approximately 12,000 parts of CO per million parts of air (ppm) during his total 6-minute exposure in the airspace beneath the stern deck.

CO decay in the airspace beneath the stern decks

Data from all sampling methods used to characterize the rate of CO decay in the airspace beneath the stern deck of boats 1 and 2 are presented in Attachment 4. Figures 3 and 5 illustrate the accumulation and overall decay of CO in the airspace under the stern deck of each boat as measured by the Bacharach instrument. The final decay curves as measured by ToxiUltras are shown in Figures 4 and 6.

Detailed data from the 10 sampling periods (5 on each boat) and all sampling methods are shown in Attachment 4, Tables 2 through 11. Table 12 presents information relevant to CO clearance from the airspace of the two boats (including clearance times, wind speed, maximum CO concentration).

Although the Bacharach instrument was very accurate during field calibration with 40,000 ppm CO, it consistently indicated much higher CO concentrations in the airspace beneath the stern deck than other air sampling methods. This discrepancy between the Bacharach and other methods does not affect the results of this investigation. This instrument was used only to determine when CO concentrations reached a relatively stable maximum, and to guide us in placement of the other air sampling equipment and methods.

CO concentrations elsewhere on the boats

Inside the boat cabin: Average CO concentrations within the boat staterooms and in the galley areas of Boats 1 and 2 were very low, with averages ranging from 2 to 6 ppm during the sampling periods of several hours.

On the stern deck railing: Figures 7 and 8 show CO concentrations measured on the port and starboard sides of the stern deck during the entire sampling period on each boat. It is important to remember that wind speeds during sampling on Boat 2 were higher (5-14 mph) than during sampling on Boat 1 (mostly 0 mph), which would have affected these external CO measurements.

CO concentrations reached as high as 663 ppm on the stern deck of Boat 1, and 143 ppm on Boat 2. Average CO concentrations on the stern deck of each boat during each period of engine operation (approximately 10 minutes in duration) ranged from 55 ppm to 209 ppm on Boat 1, and from 3 to 38 ppm on Boat 2. These data show that when the wind is relatively calm, very high CO concentrations are present on the stern deck of these types of boats during engine operation.

On the swim platform attached to the stern deck: Figures 9 and 10 show CO concentrations measured on the port and starboard sides of the swim platform during the entire sampling period on each boat. It is important to remember that wind speeds during sampling on Boat 2 were higher than during sampling on Boat 1, which would have affected these external CO measurements.

On Boat 1, any time the engines operated, CO concentrations on the port and starboard sides of the swim platform exceeded the measuring capacity of the CO monitors (thus were greater than 1,000 ppm), as was indicated by the consistently flat peaks at that concentration. This means that anytime the engines operated, CO concentrations on the swim platform were always above the concentration classified by NIOSH as Immediately Dangerous to Life and Health (IDLH).

On Boat 2, when the engines operated, maximum CO concentrations ranged from approximately 200 to greater than 1,000 ppm. This means that CO concentrations on the swim platform were consistently greater than the NIOSH ceiling limit, and sometimes in excess of the IDLH value when the engines operated.

Discussion

Several previous investigations have documented the accumulation of CO in the airspace beneath the stern deck of boats of this design. Reports related to these investigations are available at the following internet website: http://safetynet.smis.doi.gov/COhouseboats.htm. One report focused on issues related to entry procedures for this space. In a letter dated November 21st, 2000 from Ron Hall and Jane McCammon of NIOSH to Joe Alston of Glen Canyon National Recreation Area[1], it was emphasized that when these houseboats are in the water, the area under the swim deck meets NIOSH and OSHA criteria for a permit-required confined space; therefore, permit-required confined space requirements must be followed before any workers enter this area. The report further pointed out that three CO poisonings (two fatal and one non-fatal) occurred on Lake Powell within the span of 12 days in August 1998 as a result of men entering the airspace beneath the swim deck for engine maintenance or clearing ropes from propellers. One of the recommendations in this report was that the cavity below and the area directly around the swim platform must be immediately addressed through design changes to help reduce CO hazards when the generator or propulsion engines are in operation.

Another NIOSH report[2] provides data related to CO accumulation from propulsion engine and generator exhaust in this space, as well as the rate of CO decay following deactivation of both engines. In this investigation, the CO concentration decayed to 0 ppm after a period of approximately 8 minutes. Wind speeds were relatively low during this sampling period, with an average wind speed of 181 feet per minute (2 miles per hour). This report recommended that the cavity beneath the swim platform should be modified by keeping the area under positive pressure to prevent the buildup of hazardous CO concentrations from the main engines.

Currently, 17 poisonings have been identified (10 on Lake Powell and 7 on other water bodies) in which adult were accessing the outdrive of houseboats to conduct maintenance activities or free propeller from entanglements. Nine of these adults died as a result of their exposure. Three of these adults were employees engaged in occupational activities, and thus covered by the OSHA confined space entry regulations. We know that 11 of these men (7 of which died, 2 others lost consciousness) entered the under deck airspace of houseboats designed similarly to Boat 1 and 2 in this investigation. The remaining records do not provide information about the specific design of the boat, but state that the victim had gone "under the houseboat" to access the engine outdrive

(5 cases) or "working on a houseboat that had a rope around the prop with his head down around the operating generator" (1 case).

Data presented in Tables 2 through 11 of this report illustrate some of the many variables that may affect clearance of CO from the airspace beneath the stern deck of boats of this design. These variables include wind speed, the presence or absence of openings in the structure of the stern deck, maximum concentrations accumulating beneath the deck, position of the boat (beached, floating, etc.), and volume of the airspace.

Several configurations were used for sampling during the five cycles of testing on Boat 1, and testing was repeated on only one of the four configurations (boat floating freely, access ports and louvers open, two rounds of testing of this configuration). Clearance times ranged from 10 to 30 minutes. Because of the numerous configurations, and limited opportunity to repeat sampling under each configuration, no conclusions could be drawn about the impact of any single change in configuration (i.e., did louvers or wind or boat position make a difference in clearance time). However, the data do support the fact that clearance times are unpredictable and range widely.

Conversely, 5 rounds of testing were conducted on Boat 2 with only one airspace configuration, and with very little difference in wind speed in each round of testing. The resulting data (clearance times ranging from 9 to 30 minutes in the 5 rounds of testing) indicate that even when sampling configurations are limited, clearance times vary widely and unpredictably.

Conclusions

We want to very clearly communicate that the measurements in this or previous investigations ***do not*** provide guidance for estimating clearance times for entry into this very hazardous confined space. In fact, the wide range of clearance times (from 8 minutes in a previous survey to as much as 30 minutes in this investigation) indicates that it is not possible for consumers or employees to accurately predict CO clearance times. Past incidents indicate that the risk of being wrong about those clearance times (given the wide range of boat configurations and environmental circumstances possible) is deadly.

The data collected here, as well as circumstances surrounding previous fatal and non-fatal poisonings indicate the following:

> Loss of directional control of the boat resulting from loss of propulsion thrust when the prop is fouled presents the boat occupant with an urgent need to correct the situation, especially if it is windy and the boat may be damaged due to the loss of directional control.
>
> It is not unusual for props to become fouled during attempts to anchor or otherwise moor boats, especially when it is windy and the boat is blown over the ropes. This requires entry into the under deck airspace to access the outdrive and alleviate the problems.

Clearance of CO from this space is likely to take longer than the boat occupant will wait under these urgent circumstances, especially if the occupant is not fully aware of the potential consequences of entering that space.

The continuing occurrence of CO poisonings under these circumstances (attempting to access the outdrive of the propulsion engines) and the absence of entry procedures for consumers indicates a need to improve boat and/or develop safe entry procedures for consumers.

Recommendations

1) Manufacturers should examine options for modifying these boats to prevent the buildup of hazardous CO concentrations from any engine exhausting into the airspace under the deck. Design changes could include modification of the structure of the stern deck and/or sufficient pressurization of the airspace to reduce CO concentrations to safe concentrations within 1 minute of engine deactivation.

2) Boat manufacturers should enhance their existing warning and/or educational materials for consumers to include guidelines for safe entry into the airspace beneath the stern deck when necessary.

3) Employers must require the use of confined space entry procedures described in Attachment 3 if workers enter the airspace beneath the stern decks of these boats when the boat is on the water.

References

1. Hall, R. M. and J. B. McCammon (2000). Letter of November 21, 2000 from Ronald M. Hall and Jane B. McCammon, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Public Health Service, U.S. Department of Health and Human Services and to Joe Alston, Park Superintendant, Glen Canyon National Recreation Area, Page, Arizona. Cincinnati, OH, NIOSH: Nov. 21, 2000.

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Attachment 1
Health Effects of Exposure to Carbon Monoxide

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

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

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

The altitude of Lake Powell 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.[8]

References

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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.

7. World Health Organization. Environmental Health Criteria 213 - Carbon Monoxide (Second Edition). WHO, Geneva, 1999; ISBN 92 4 157213 2 (NLM classification: QV 662). ISSN 0250-863X

8. American Gas Association [1988]. What you should know about carbon monoxide. American Gas Association 1985 Operating Section Proceedings. American Gas Association, Arlington, Virginia.

Attachment 2
Evaluation Criteria

Occupational criteria for CO exposure are applicable to National Park Service and concessionaire employees who have been shown to be at risk of boat-related CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities) because occupational standards do not provide the same degree of protection they do for the healthy worker population. 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)] Standards relevant to the general population take these factors into consideration, and are listed following the occupational criteria.

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

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[(2)] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®), [(3)] (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 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 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.

2. NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

3. ACGIH [2002]. 2002 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.

5. Public Law 91 – 596 Occupational safety and Health Act of 1970, Sec. 5.(a)(1).

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).

7. Code of Federal Regulations [1989]. 29 CFR 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register.

8. NIOSH [2000]. Immediately dangerous to life and health concentrations. DHHS (NIOSH) Publication NO. 2000-130, Pocket Guide to Chemical Hazards and other Databases, July.

9. ACGIH [2001]. Documentation of threshold limit values and biological exposure indices. 7th edition. 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.

12. World Health Organization [1999]. Environmental Health Criteria 213 - Carbon Monoxide (Second Edition). WHO, Geneva. ISBN 92 4 157213 2 (NLM classification: QV 662). ISSN 0250-863X..

Attachment 3
Confined Space Entry Procedure Summary

When houseboats of this design are in the water, the area under the swim deck meets NIOSH and OSHA criteria for a permit-required confined space; therefore, permit-required confined space requirements should be followed before any workers enter this area.

OSHA regulation 29 CFR 1910.146 defines a ***confined space*** as a space that meets three criteria: (1) is large enough and configured so that an employee can bodily enter and perform any assigned work; (2) is a space that has limited or restricted means for entry or exit (for example, tanks, vessels, storage bins, vaults, and pits that have limited means of entry); and (3) a space that is not designed for continuous employee occupancy. The standard then defines a ***permit–required confined space*** as a space that meets one or more of the following criteria: (1) a space that contains or has a potential to contain a hazardous atmosphere; (2) a space that contains a material that has the potential for engulfing (surrounding and capturing of a person by a liquid or finely divided solid substance that can be aspirated and cause death or that can exert enough pressure to cause death by strangulation, constriction, or crushing) the person entering the space; (3) the internal configuration of the space is designed in a way that the person entering the space could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross section; or (4) a space that contains any other recognized serious safety or health hazard.[0]

NIOSH defines a confined space as "an area which by design has limited openings for entry and exit, unfavorable natural ventilation which could contain (or produce) dangerous air contaminates, and which is not intended for continuous employee occupancy.[0] The NIOSH criteria for working in confined spaces further classifies confined spaces based upon the atmospheric characteristics such as oxygen level, flammability, and toxicity. As shown in the table below, if any of the hazards present a situation which is immediately dangerous to life or health (IDLH), the confined space is designated Class A. A Class B confined space has the potential for causing injury and/or illness, but is not an IDLH atmosphere. A Class C confined space is one in which the hazard potential would not require any special modification of the work procedure. The following table lists the confined space program elements which are recommended (or must be considered by a qualified person, as defined by the criteria) before entering and during work within confined spaces based on the established hazard classification.

References

1. Code of Federal Regulations [1997]. 29 CFR 1910.146. Washington, DC: U.S. Government Printing Office, Federal Register.

2. NIOSH [1979]. Criteria for a recommended standard: Working in Confined Spaces. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 80–106.

Confined Space Classification Table

Parameters	Class A	Class B	Class C
Characteristics	Immediately dangerous to life – rescue procedures require the entry of more than one individual fully equipped with life support equipment – maintenance of communication requires an additional standby person stationed within the confined space	Dangerous, but not immediately life threatening – rescue procedures require the entry of no more than one individual fully equipped with life support equipment – indirect visual or auditory communication with workers	Potential hazard – requires no modification of work procedures – standard rescue procedures – direct communication with workers, from outside the confined space
Oxygen	16% or less *(122 mm Hg) or greater than 25% *(190 mm HG)	16.1% to 19.4% *(122 – 147 mm Hg) or 21.5% to 25% (163 – 190 mm Hg)	19.5 % – 21.4% *(148 – 163 mm Hg)
Flammability Characteristics	20% or greater of LFL	10% – 19% LFL	10% LFL or less
Toxicity	**IDLH	greater than contamination level, referenced in 29 CFR Part 1910 Sub Part Z – less than **IDLH	less than contamination level referenced in 29 CFR Part 1910 Sub Part Z

* Based upon a total atmospheric pressure of 760 mm Hg (sea level)

** Immediately Dangerous to Life or Health – as referenced in NIOSH Registry of Toxic and Chemical Substances,
Manufacturing Chemists data sheets, industrial hygiene guides or other recognized authorities.

NIOSH [1979]. Criteria for a recommended standard: working in confined spaces. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 80–106.

Check List of Considerations for Entry, Working in and Exiting Confined Spaces

ITEM		CLASS A	CLASS B	CLASS C
1.	Permit	X	X	X
2.	Atmospheric Testing	X	X	X
3.	Monitoring	X	0	0
4.	Medical Surveillance	X	X	0
5.	Training of Personnel	X	X	X
6.	Labeling and Posting	X	X	X
7.	Preparation			
	Isolate/lockout/tag	X	X	0
	Purge and ventilate	X	X	0
	Cleaning Processes	0	0	0
	Requirements for special equipment/tools	X	X	0
8.	Procedures			
	Initial plan	X	X	X
	Standby	X	X	0
	Communications/observation	X	X	X
	Rescue	X	X	X
	Work	X	X	X
9.	Safety Equipment and Clothing			
	Head protection			
	Hearing protection	0	0	0
	Hand protection	0	0	0
	Foot protection	0	0	0
	Body protection	0	0	0
	Respiratory protection	0	0	0
	Safety belts	0	0	
	Life lines, harness	X	X	X
		X	0	
10.	Rescue Equipment	X	X	X
11.	Recordkeeping/Exposure	X	X	

X indicates requirement 0 indicates determination by the qualified person

NIOSH [1979]. Criteria for a recommended standard: working in confined spaces. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 80-106.

Attachment 4

Figures 1 – 10

Tables 2 - 11

Figure 1. Houseboat (Boat 2) with stern deck that extends beyond the transom. Propulsion engine outdrives are at the transom and in the airspace created by the structure of the extended deck. Hull vents to the right of the transom allow pressurization of the engine compartment. The under deck airspace is not vented on this boat.

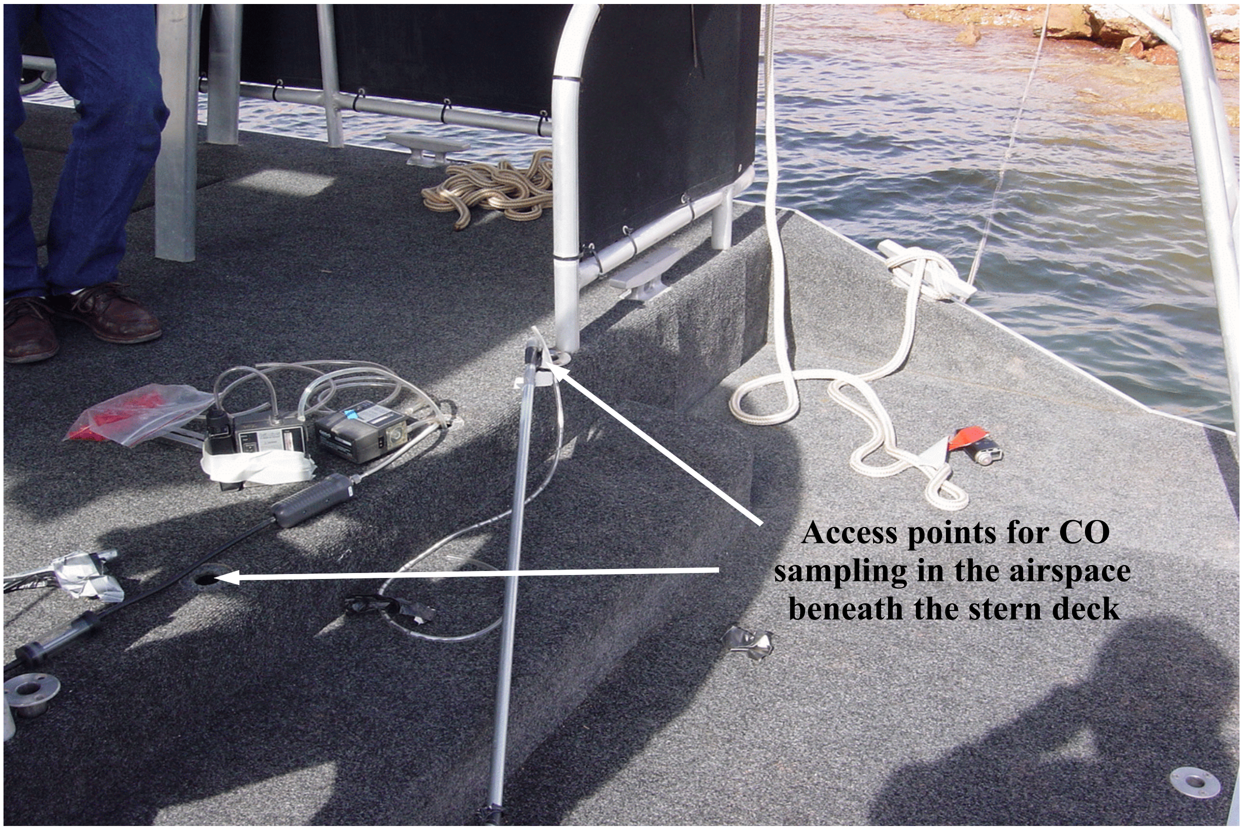

Figure 2. Access to the under deck airspace of Boat 2.

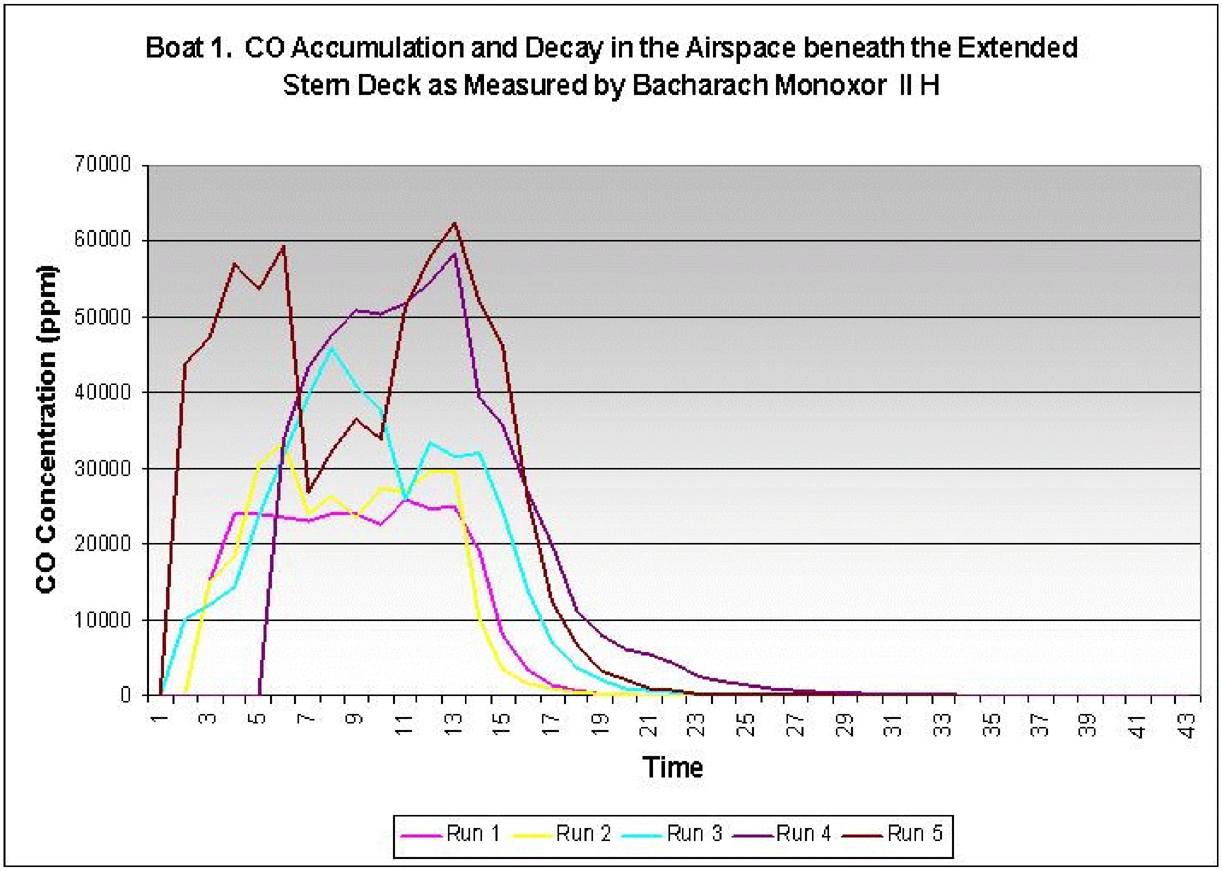
Boat 1. CO Accumulation and Decay in the Airspace beneath the Extended Stern Deck as Measured by Bacharach Monoxor II H
CO Concentration (ppm)
70000
60000
50000
40000
30000
20000
10000
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
Time
Run 1
Run 2
Run 3
Run 4
Run 5

Figure 3

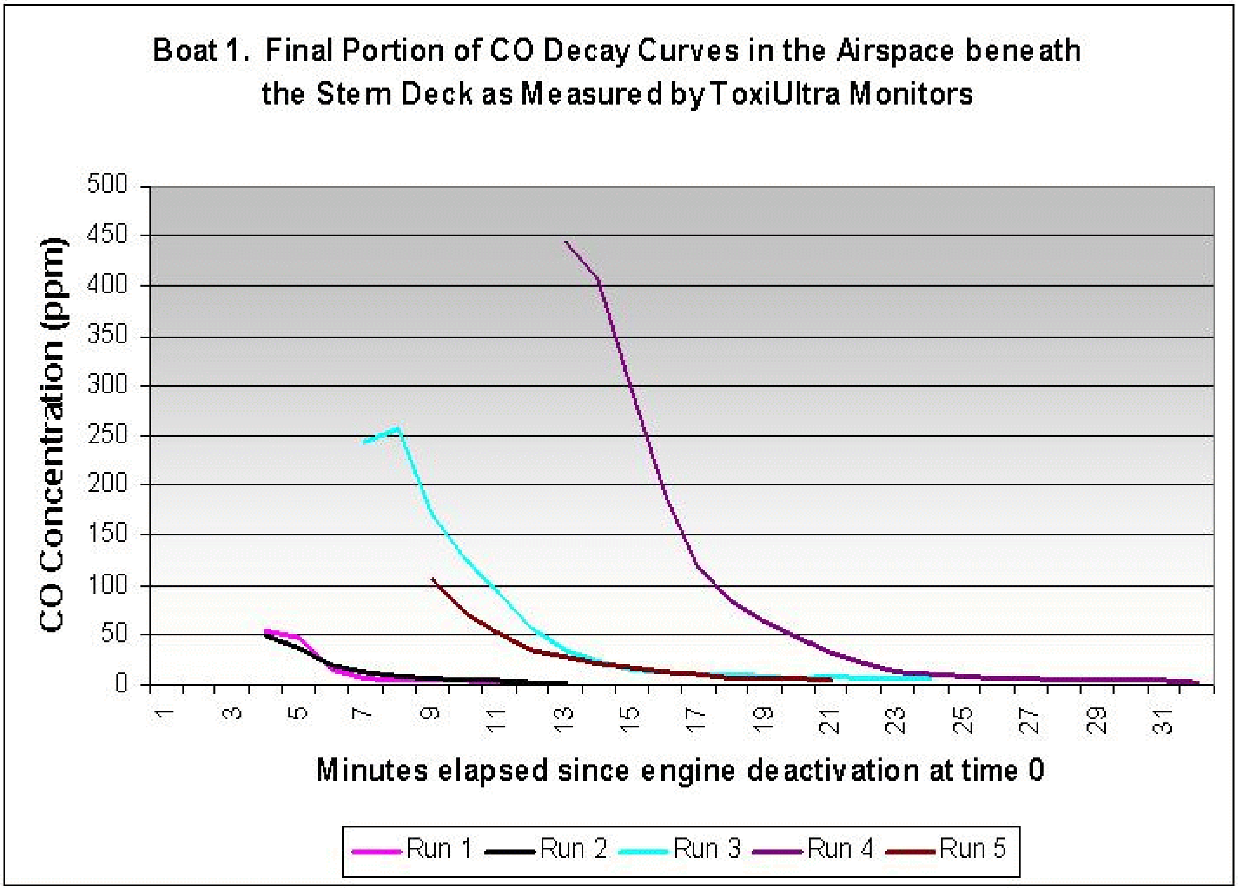
Boat 1. Final Portion of CO Decay Curves in the Airspace beneath the Stern Deck as Measured by ToxiUltra Monitors
CO Concentration (ppm)
500
450
400
350
300
250
200
150
100
50
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Minutes elapsed since engine deactivation at time 0
Run 1
Run 2
Run 3
Run 4
Run 5

Figure 4

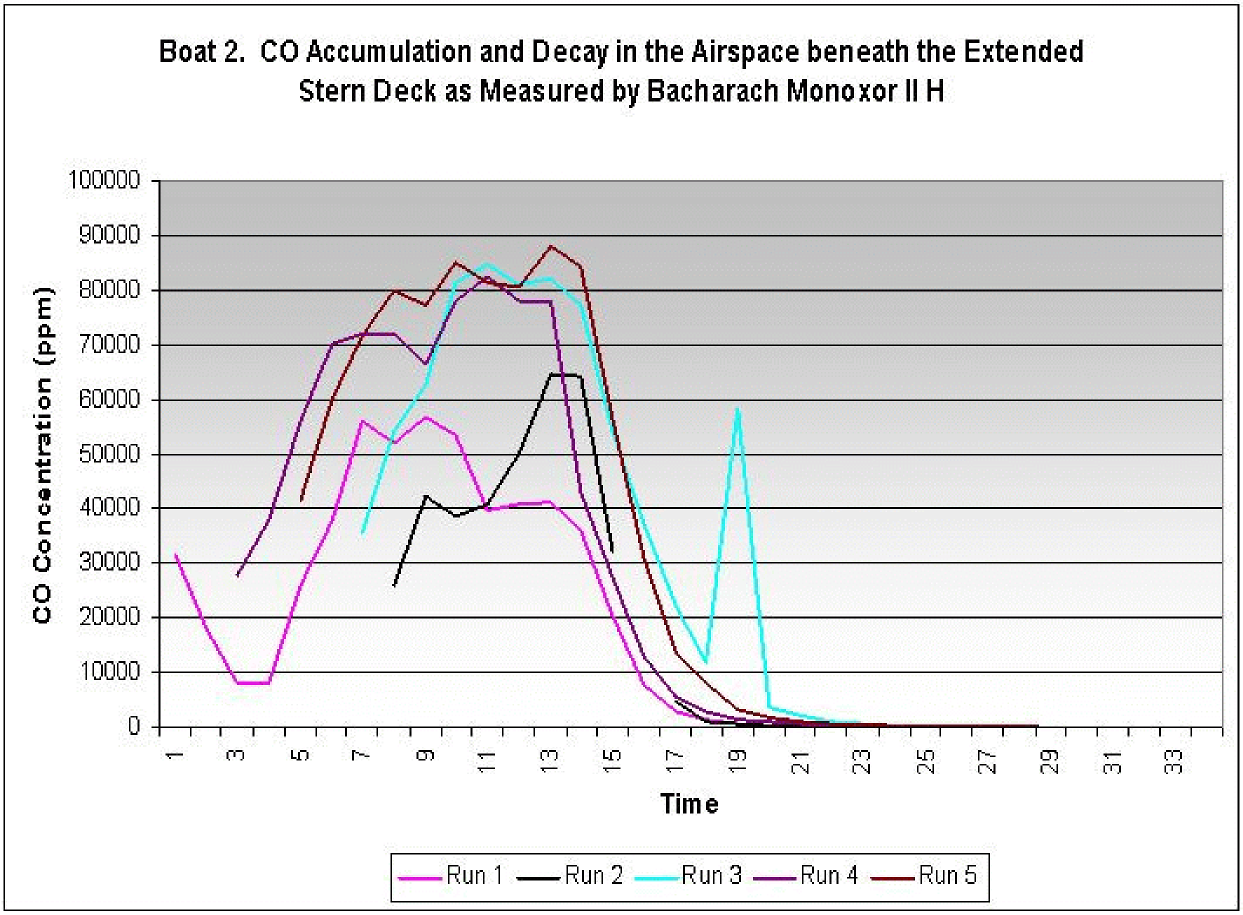
Boat 2. CO Accumulation and Decay in the Airspace beneath the Extended Stern Deck as Measured by Bacharach Monoxor II H
CO Concentration (ppm)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
Time
Run 1
Run 2
Run 3
Run 4
Run 5

Figure 5

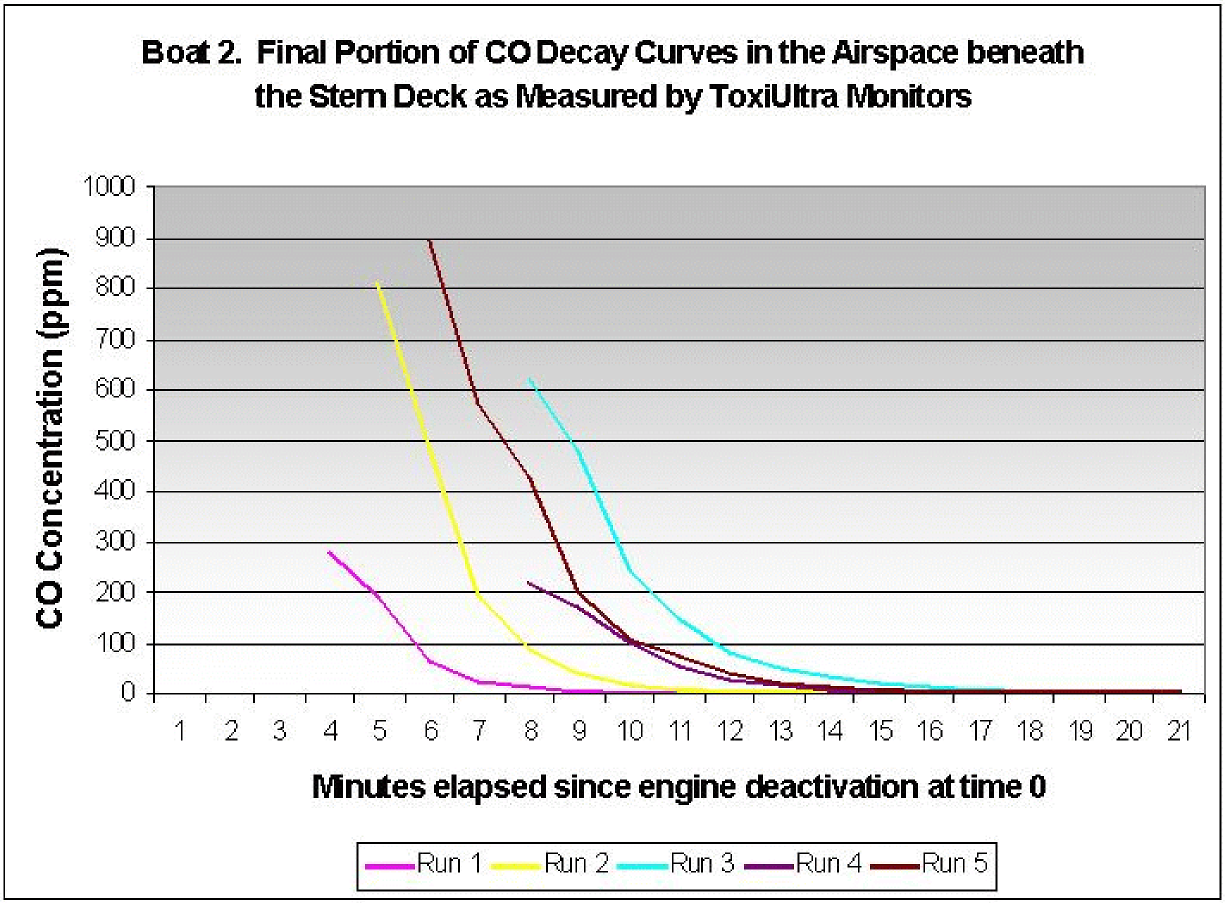
Boat 2. Final Portion of CO Decay Curves in the Airspace beneath the Stern Deck as Measured by ToxiUltra Monitors
CO Concentration (ppm)
1000
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Minutes elapsed since engine deactivation at time 0
Run 1
Run 2
Run 3
Run 4
Run 5

Figure 6

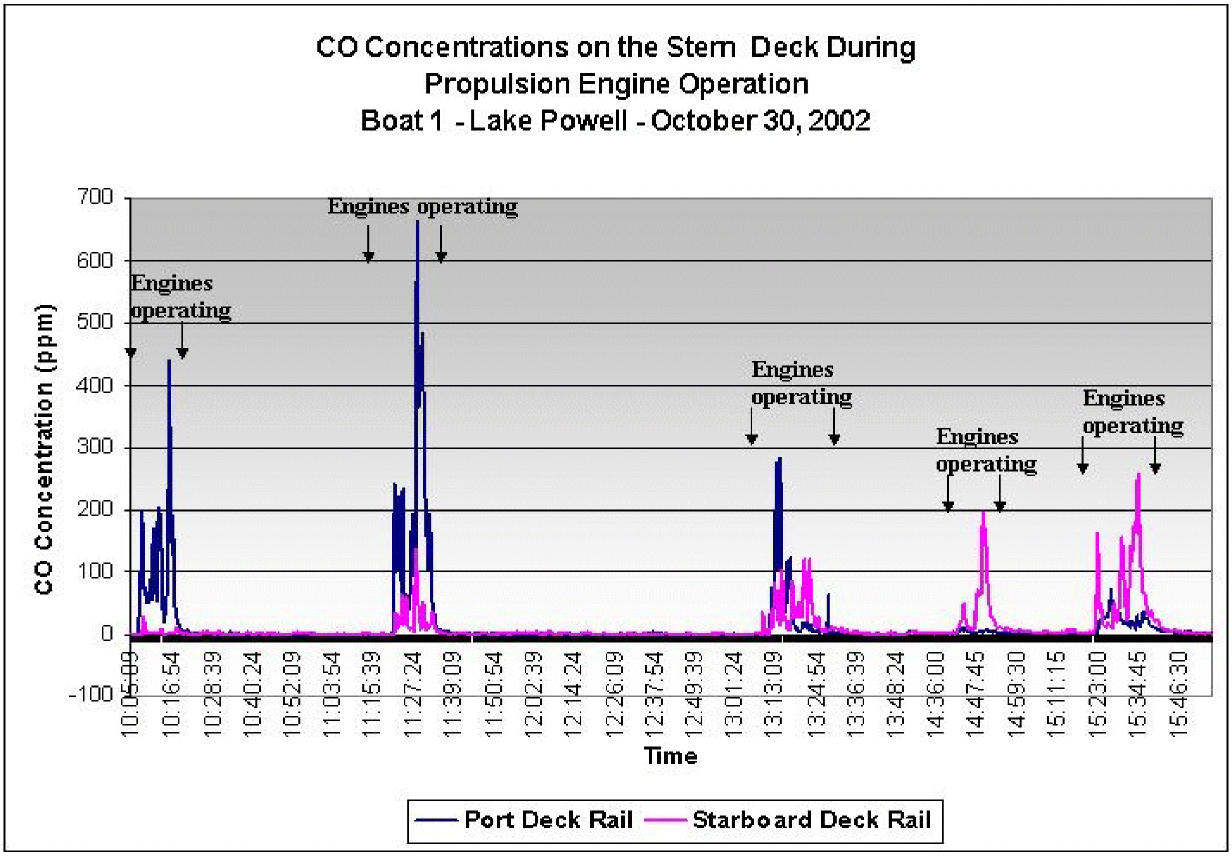
CO Concentrations on the Stern Deck During
Propulsion Engine Operation
Boat 1 - Lake Powell - October 30, 2002
CO Concentration (ppm)
700
600
500
400
300
200
100
0
-100
Engines operating
Engines operating
Engines operating
Engines operating
Engines operating
10:05:09
10:16:54
10:28:39
10:40:24
10:52:09
11:03:54
11:15:39
11:27:24
11:39:09
11:50:54
12:02:39
12:14:24
12:26:09
12:37:54
12:49:39
13:01:24
13:13:09
13:24:54
13:36:39
13:48:24
14:36:00
14:47:45
14:59:30
15:11:15
15:23:00
15:34:45
15:46:30
Time
Port Deck Rail
Starboard Deck Rail

Figure 7

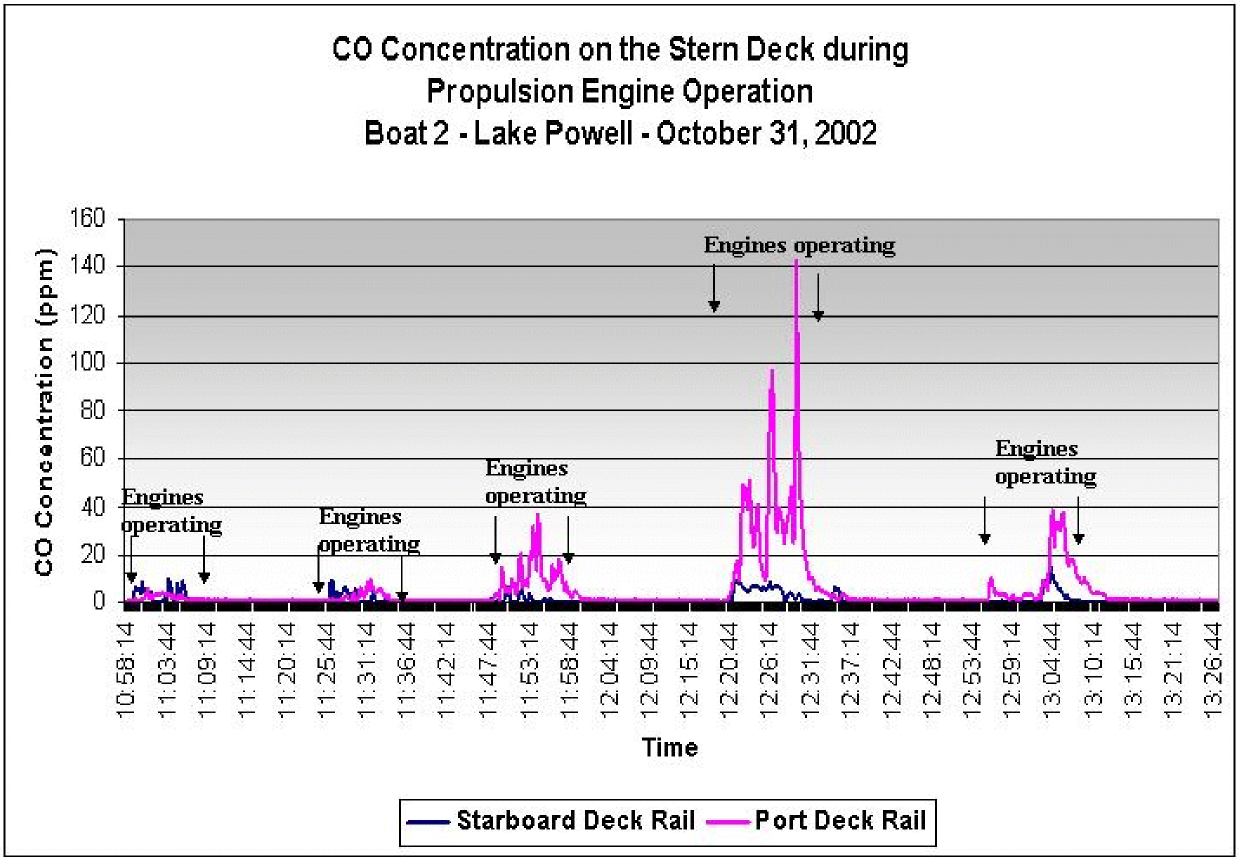
CO Concentration on the Stern Deck during
Propulsion Engine Operation
Boat 2 - Lake Powell - October 31, 2002
CO Concentration (ppm)
160
140
120
100
80
60
40
20
0
Engines operating
Engines operating
Engines operating
Engines operating
Engines operating
10:58:14
11:03:44
11:09:14
11:14:44
11:20:14
11:25:44
11:31:14
11:36:44
11:42:14
11:47:44
11:53:14
11:58:44
12:04:14
12:09:44
12:15:14
12:20:44
12:26:14
12:31:44
12:37:14
12:42:44
12:48:14
12:53:44
12:59:14
13:04:44
13:10:14
13:15:44
13:21:14
13:26:44
Time
Starboard Deck Rail
Port Deck Rail

Figure 8

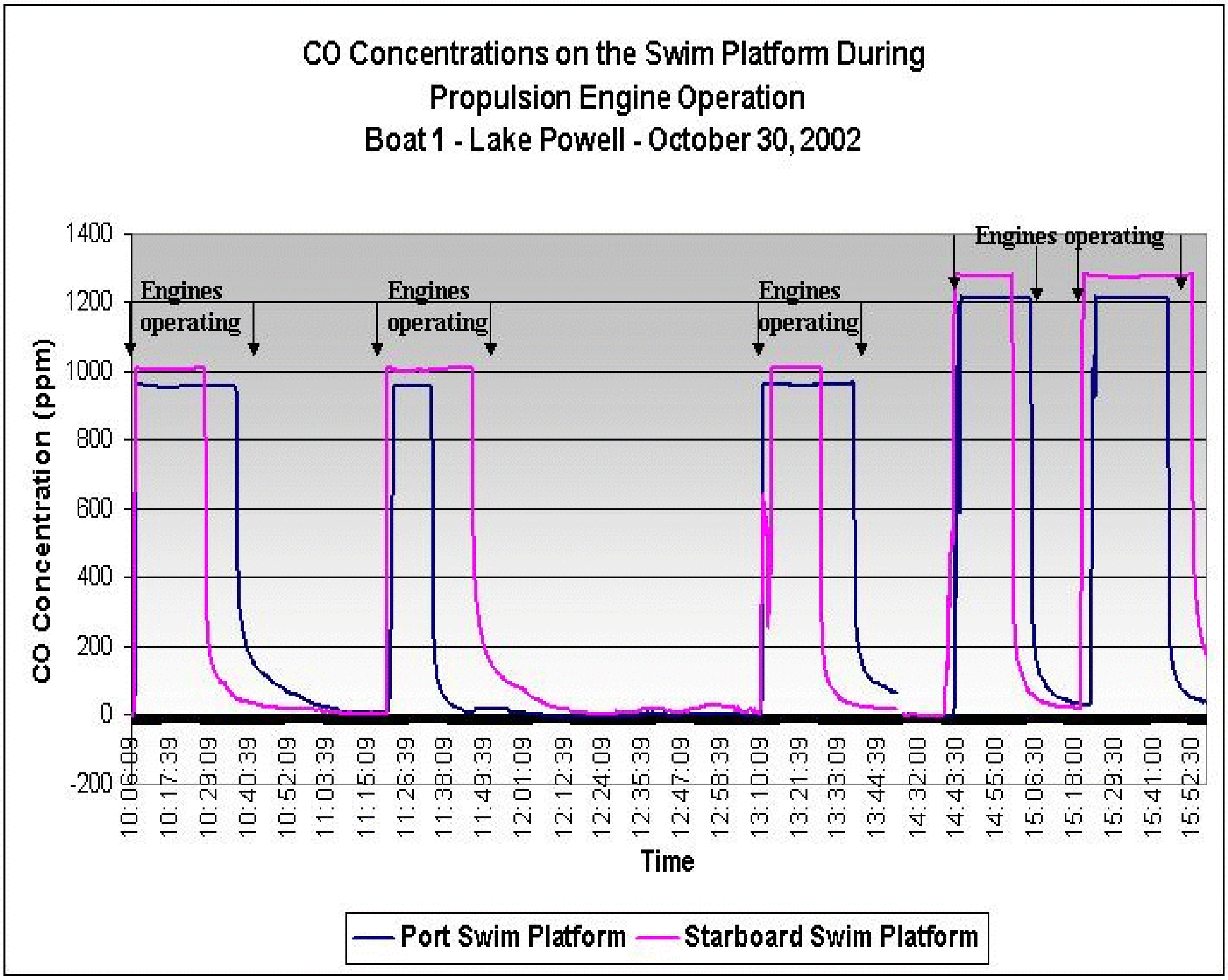
CO Concentrations on the Swim Platform During
Propulsion Engine Operation
Boat 1 - Lake Powell - October 30, 2002
CO Concentration (ppm)
1400
1200
1000
800
600
400
200
0
-200
Engines operating
Engines operating
Engines operating
Engines operating
10:06:09
10:17:39
10:29:09
10:40:39
10:52:09
11:03:39
11:15:09
11:26:39
11:38:09
11:49:39
12:01:09
12:12:39
12:24:09
12:35:39
12:47:09
12:58:39
13:10:09
13:21:39
13:33:09
13:44:39
14:32:00
14:43:30
14:55:00
15:06:30
15:18:00
15:29:30
15:41:00
15:52:30
Time
Port Swim Platform
Starboard Swim Platform

Figure 9

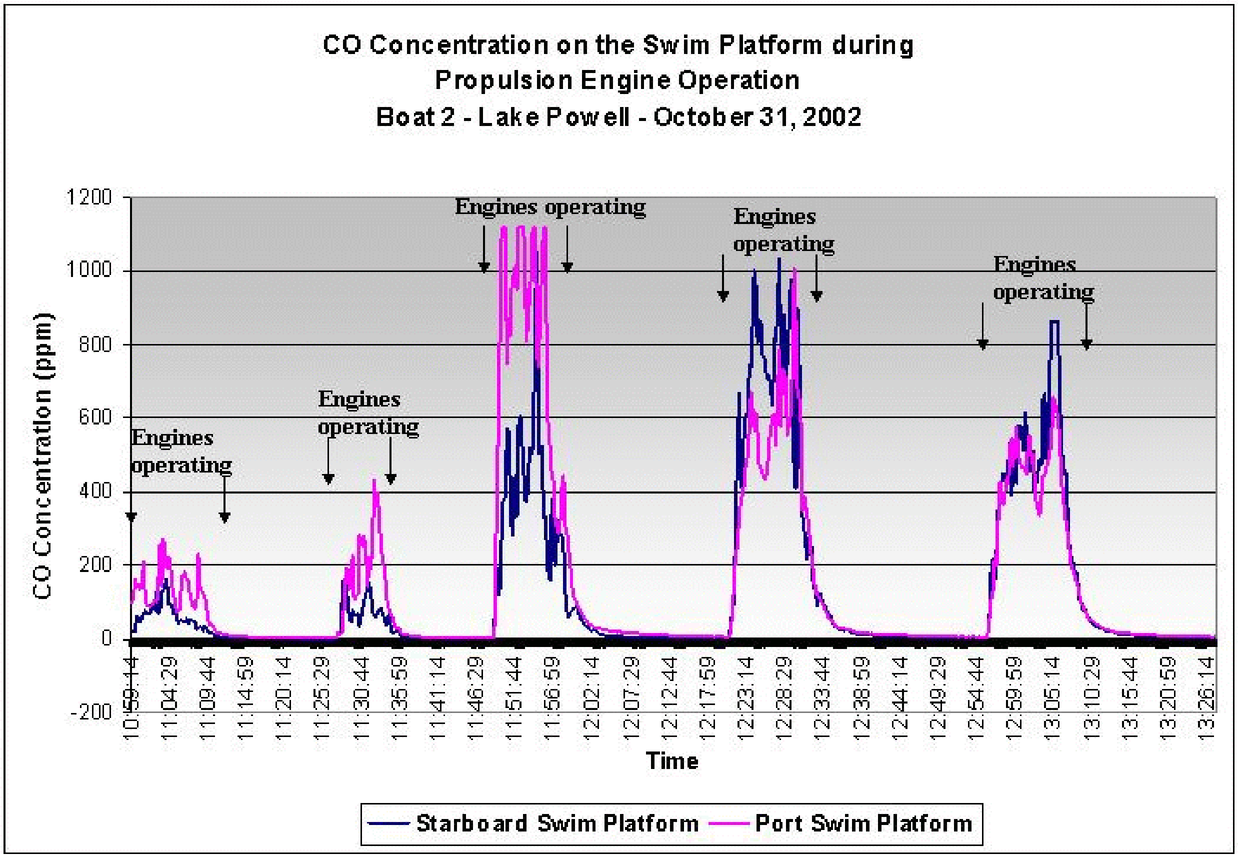
CO Concentration on the Swim Platform during
Propulsion Engine Operation
Boat 2 - Lake Powell - October 31, 2002
CO Concentration (ppm)
1200
1000
800
600
400
200
0
-200
Engines operating
Engines operating
Engines operating
Engines operating
Engines operating
10:59:44
11:04:29
11:09:44
11:14:59
11:20:14
11:25:29
11:30:44
11:35:59
11:41:14
11:46:29
11:51:44
11:56:59
12:02:14
12:07:29
12:12:44
12:17:59
12:23:14
12:28:29
12:33:44
12:38:59
12:44:14
12:49:29
12:54:44
12:59:59
13:05:14
13:10:29
13:15:44
13:20:59
13:26:14
Time
Starboard Swim Platform
Port Swim Platform

Figure 10

Table 2. CO decay beneath the stern deck - propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	**BOAT 1, RUN 1** **Configuration:** Boat floating freely: Access ports and louvers open
					NOTES
1006	0				
1007	0				engines started
1008	15000				
1009	24000				
1010	24000				
1011	23500				
1012	23000				
1013	24000				
1014	24100		not done	15,000	
1015	22700				
1016	26000				
1017	24700				
1018	25000				engines off
1019	19000			10,000	
1020	8000				
1021	3500	53			
1022	1300	47			
1023	700	15		1,000	
1024	340	7			
1025	160	4			
1026	70	5			
1027	30	4			
1028	0	3		not done	

Table 3. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Side-by-Side Toxi Ultras (ppm)		CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 1, RUN 2 Configuration: Boat floating freely Access ports and louvers vents open
		Monitor 1	Monitor 2				NOTES
1121							engines started
1122	15100						
1123	18300						
1124	30700						
1125	33400						
1126	24100						
1127	26500						
1128	23500			15100	15000	16.94	
1129	27300						
1130	27000						
1131	29600						stop engines
1132	29600			2300	2000	20.40	1 min
1133	10200						
1134	3500	50	50				
1135	1640	36	35				
1136	900	19	19	26	none detected	20.95	5 min
1137	490	12	14				
1138	280	8	9				
1139	160	6	7				
1140	110	4	6				
1141	60	4	5	14	none detected	20.95	10 min
1142	40	3	4				
1143	30	2	3				
1144	30	2	2				
1145	30	1	3				
1146	30	2	3				
1147	30	2	3				
1148	20	2	3				
1149	20	2	3				
1150	20	1	3				
1151	20	1	3				

Table 4. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Side-by-Side Toxi Ultras (ppm)		CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial	BOAT 1, RUN 3 Configuration: Boat floating freely Access ports and louvers blocked
		Monitor 1	Monitor 2				NOTES
1310							engines started
1311	10100						
1312	12000						
1313	14400						
1314	23800						
1315	31800						
1316	39700						
1317	45900						
1318	40900						
1319	37600						
1320	25900						
1321	33400						
1322	31500			21600	10000	15.09	engines off
1323	32000			12000	12000	18.04	1 min
1324	24600						
1325	14200						
1326	7040						
1327	3670			1000	3000	20.78	5 min
1328	2040	244	211				tox
1329	970	256	211				
1330	620	170	138				
1331	430	126	111				
1332	300	92	88	not done	not done	not done	10 min
1333	240	56	56				
1334	150	34	38				
1335	130	24	29				
1336	100	16	22				
1337	80	12	19				
1338	80	11	17				
1339	70	11	15				
1340	70	9	14				
1341	60	7	11				
1342	60	8	10				
1343	50	6	9				
1344	50	6	9				
1345	40	6	8				
1346	30						

Table 5. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Side-by-Side Toxi Ultras (ppm)		CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 1, RUN 4 **Configuration:** Boat beached Access ports and louvers blocked
		Monitor 1	**Monitor 2**				**NOTES**
1443							engines start
1444	34000						
1445	43300						
1446	47500						
1447	51000						
1448	50500			28,900	29000	11.21	
1449	51900						
1450	54600						engines off
1451	58400			33500	20000	11.68	1 min
1452	39400						
1453	35800						
1454	27100						
1455	20000			7600	5000	19.33	5 min
1456	11420						
1457	8020						
1458	6150						
1459	5330						
1500	4130			1800	not done	20.62	10 min
1501	2560						
1502	1870	302	445				
1503	1470	366	408				
1504	980	278	295				
1505	720	189	190				
1506	520	117	119				
1507	370	84	84				
1508	260	63	63				
1509	200	46	47				
1510	150	32	32				
1511	130	22	21				
1512	100	15	14				
1513	80	12	10				
1514	80	9	8				
1515	70	8	7				
1516	70	7	6				
1517	60	5	5				
1518	60	5	5				
1519	50	4	4				
1521	50	2	2				

Table 6. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Side-by-Side Toxi Ultras (ppm)		CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	**BOAT 1, RUN 5** **Configuration:** Boat beached Access ports blocked, louvers open
		Monitor 1	**Monitor 2**				**NOTES**
1524	43900						
1525	47400						
1526	57000						
1527	53700						
1528	59300						
1529	26800						
1530	32400						
1531	36500						
1532	33900						
1533	51300						
1534	58000			lab error	41000	11.77	
1535	62500						engines off
1536	52000			13600	30000	16.96	1 min
1537	46300						
1538	26500						
1539	12440						
1540	6940			620	2000	20.84	5 min
1541	3200						
1542	2080						
1543	1030	84	105				
1544	630	71	72				
1545	350	52	51	not done	not done	not done	10 min
1546	280	35	34				
1547	210	29	29				
1548	180	27	21				
1549	150	17	17				
1550	120	13	13				
1551	110	10	10				
1552	110	7	7				
1553	100	6	6				
1554	90	6	6				
1555	90	4	4				
1556	90						

Table 7. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 2, RUN 1
						NOTES
1045						engines started
1046						
1047	39300					
1048	42000					
1049	61900					
1050	46000					
1051	44200			20000		
1052	46800					
1053	51800					
1054	52400					
1055	48200					engine 1500 rpm forward gear
1056	31600					
1057	18000					
1058	8020					engine to idle, 1200 rpm
1059	8090					engine to idle and neutral, 1200 rpm
1100	26000					
1101	37900					
1102	56300					
1103	51900		38000	18000	14.45	
1104	57000					
1105	53700					
1106	39800					
1107	41000					
1108	41200					engines off
1109	36000		11700	4000	19.04	1 min
1110	20600					
1111	7730	276				
1112	3120	190				
1113	1490	66	120	0	20.95	5 min
1114	780	24				
1115	460	11				
1116	320	5				
1117	250	2				
1118	190	1	5	0	20.95	10 min
1119	180	0				
1120	160	0				
1121	140	0				
1125	100					

Table 8. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 2 RUN 2
						NOTES
1127						engines started
1128	26000					
1129	42500					
1130	38600					
1131	41000					
1132	50200					
1133	64500		27800	not done	16.13	engines off
1134	64300		9300	8000	19.42	1 min
1135	32300					
1136						
1137	4650	808				
1138	1190	482	120	0	20.95	5 min
1139	590	194				
1140	290	84				
1141	190	40				
1142	140	17				
1143	110	8	2	0	20.95	10 min
1144	100	5				
1145	90	4				
1146	90	4				
1147	80	3				

Table 9. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 2, RUN 3
						NOTES
1148	engine started					
1149	35600					
1150	54200					
1151	62800					
1152	81500					
1153	84800					
1154	81200		53000	40000	11.49	
1155	82000					engine off
1156	77500		35700	22000	14.61	1 min
1157	54300					
1158	37000					
1159	22300					
1200	11830		2800	3000	20.54	5 min
1201	58300					
1202	3870	622				
1203	2060	478				
1204	1210	244				
1205	700	146	58	trace	20.95	10 min
1206	470	82				
1207	340	48				
1208	260	31				
1209	220	20				
1210	200	12				
1211	160	7				
1212	150	5				
1213	130	5				
1214	120	4				
1215	120	4				
1216	110	3				

Table 10. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (ppm)	BOAT 2, RUN 4
						NOTES
1220						engines started
1221	27800					
1222	37800					
1223	56100					
1224	70200					
1225	72000					
1226	72000					
1227	66500					
1228	78100		63500	50000	9.98	
1229	82700					
1230	78000					engines off
1231	78100		30500	16000	15.52	1 min
1232	43300					
1233	27600					
1234	13070					
1235	5640		1300	1000	20.78	5 min
1236	2910					
1237	1450	216				
1238	1050	172				
1239	660	104				
1240	430	53	45	not recorded	20.95	10 min
1241	320	28				
1242	250	18				
1243	220	10				
1244	190	6				
1245	180	4				
1246	160	4				
1247	150	4				
1248	150	3				
1249	140	3				
1250	130	3				
1251	130	3				
1252	120	3				
1253	120	3				
1254	120	3				
1255	120	3				

Table 11. CO decay and corresponding oxygen concentrations within the airspace beneath the stern deck: propulsion engines operating at approximately 1,200 rpm.

Time	CO - Bacharach (ppm)	CO - Toxi Ultra (ppm)	CO - Evacuated Glass Vial (ppm)	CO - Detector Tube (ppm)	Oxygen - Evacuated Glass Vial (%)	BOAT 2, RUN 5
						NOTES
1256	engines on					
1257	41800					
1258	60100					
1259	71800					
1300	80100					
1301	77500		62400	5500	10.07	
1302	85200					
1303	81300					
1304	80700					
1305	88200					engines off
1306	84300		38600	2200	14.30	1 min
1307	56400					
1308	30800					
1309	13750					
1310	8050	891	1800	2000	20.70	5 min
1311	3250	572				
1312	2030	425				
1313	1230	201				
1314	860	106				
1315	600	74	140	0	20.95	10 min
1316	420	41				
1317	340	20				
1318	270	14				
1319	230	8				
1320	200	6				
1321	180	5				
1322	170	4				
1323	160	4				
1324	150	4				
1325	140	3				
1326	130	3				
1327	130	3				
1328	120	3				
1329	120	1				
1330	120	1				
1331	110	1				

Table 12. Relative CO Clearance Times for Boats 1 and 2, and Related Factors

	Clearance Time (minutes)	Maximum Concentration Reached - Measured by Bacharach Instrument (ppm)	Maximum Concentration Reached - Measured by Evac. Glass Container (ppm)	Wind Speed (mph)
Boat 1, Run 1 (boat floating freely, access ports and louvers open)	10	24,000	Not measured	not measured
Boat 1, Run 2 (boat floating freely, access ports and louvers open)	11-12	30,700	15,100	0
Boat 1, Run 3 (boat floating freely, access ports and louvers blocked)	>23	41,000	21,600	0
Boat 1, Run 4 (boat beached, access ports and louvers blocked)	30	58,400	28,900	0 - 2
Boat 1, Run 5 (boat beached, access ports blocked and louvers open)	>20	62,500	Laboratory error	0 - 3.5
Boat 2, Run 1	9	61,900	38,000	5.5 - 10 (gusts of 14)
Boat 2, Run 2	14	64,500	27,800	12
Boat 2, Run 3	21	84,800	53,000	4 - 8
Boat 2, Run 4	18	82,700	63,500	5 - 11 (gusts of 13)
Boat 2, Run 5	24	88,200	62,400	6 - 8