This Health Hazard Evaluation (HHE) report and any recommendations made herein are for the specific facility evaluated and may not be universally applicable. Any recommendations made are not to be considered as final statements of NIOSH policy or of any agency or individual involved. Additional HHE reports are available at http://www.cdc.gov/niosh/hhe/reports

December 18, 2000
HETA 2001-0026

Rice C. Leach, M.D., Commissioner
Cabinet for Health Services
Commonwealth of Kentucky
Department for Public Health
275 East Main Street
Frankfort, Kentucky 40621-0001

Dear Dr. Leach:

On October 13, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Cabinet for Health Services in the Commonwealth of Kentucky to evaluate carbon monoxide (CO) concentrations associated with the operation of houseboats on Lake Cumberland. On October 23 - 25, 2000, NIOSH investigators conducted a site visit at Lake Cumberland to investigate CO concentrations on houseboats located at the State dock, Jamestown dock, and Alligator II dock. This letter describes our evaluation methods, findings, and conclusions.

Background

Previous investigations were performed by NIOSH industrial hygienists and representatives from several agencies in September, 2000 and October, 2000 in response to CO related poisonings and deaths on houseboats at Lake Powell, AZ. These investigations characterized the circumstances of boat related CO poisonings through review of emergency medical service (EMS) transport records, and measured hazardous CO concentrations on houseboats.[1, 2] Incident reports provided by the National Park Service revealed 9 known boat-related CO poisoning deaths on Lake Powell since 1994. Some of these incidents involved multiple poisonings in addition to the deaths reported (total of 25 people poisoned in the 8 incidents involving fatalities). Information regarding the fatalities was provided in a previous report.[1]

Some of the severely hazardous situations identified during the September and October, 2000 evaluations at Lake Powell, AZ included:

- The open space under the swim platform could be lethal under certain circumstances (i.e., generator/motor exhaust discharging into this area) on some houseboats.
- Some CO concentrations above and around the swim platform were at or above the immediately dangerous to life and health (IDLH) level [greater than 1,200 parts of CO per million parts of air (ppm)].

- Measurements of personal CO exposure during boat maintenance activities indicated that employees may be exposed to hazardous concentrations of CO.

Please refer to Attachments 1 and 2 for discussions of health effects of CO exposure and relevant evaluation criteria.

Methods and Materials

During our investigation at Lake Cumberland, CO was measured in the space below the swim deck (on houseboats where the generator exhaust discharged into this area) and the area on the back of houseboats with only the generator operating, and with the generator and boat engines operating simultaneously.

CO concentrations were measured on the back of the houseboats using ToxiUltra Atmospheric Monitors (Biometrics, Inc., Middletown, CT) 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. The instruments were operated in the passive diffusion mode, with a 15 - 30 second sampling interval. The instruments have a nominal range from 0 ppm to 500 ppm with the highest instantaneous reading of 1000 ppm. Figure 1 illustrates a typical houseboat and where ToxiUltra CO monitors were placed. Some of the locations varied on different houseboats depending on the swim deck and swim platform designs.

CO measurements were also made with detector tubes [Drager CO, CH 29901– range 0.3% (3,000 ppm) to 7% (70,000 ppm)] in the areas below and around the swim deck. 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 using Mine Safety and Health Administration (MSHA) 50–mL glass evacuated containers. These samples were collected by snapping open the top of the evacuated glass container and allowing the air 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.

Results

Navigator Houseboat

During the early afternoon on October 23, 2000, CO samples were collected on a 2000 model Navigator houseboat with the specifications listed below. The diesel generator ran approximately 38 minutes and the diesel motors ran approximately 20 minutes during this evaluation.

Engines: Two 4 cylinder diesel Volvo Penta 150 HP engines
Generator: 20 Kw Onan, 4 cylinder diesel generator
Exhaust Configuration: Generator exhaust discharged out the back corner of swim platform (into the open area around the corner of swim platform).
Air speed above deck: air speed readings ranged between 108 - 268 feet per minute
Air speed below deck: air speed readings ranged between 2 - 17 feet per minute

Area around exhaust and off back of houseboat

Figure 2 shows a portion of the back deck of the Navigator houseboat, and also illustrates the generator exhaust discharging out the back corner of the swim platform. An evacuated glass container measurement in this area indicated a CO concentration of 13 ppm. A similar measurement collected in an exhaust cloud off the back of the swim platform, at the water when both the generator and motors were in operation, indicated a CO concentration of 27 ppm. A third evacuated container sample collected on the swim platform with only the generator in operation did not detect CO.

Area Above Swim Deck on Back of Boat

The prevailing air movement was toward the left back corner (when on back of boat and facing the water) and flowing across the back deck. Smoke tube tests indicated that eddy currents were being formed off the back of the swim platform. Table 1 lists the CO monitor results obtained on the back of the Navigator houseboat, with the generator and motors operating.

Table 1. Sample locations and CO results on the diesel powered Navigator houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
On the back of the left slide (the slide on the left of swim deck when on the boat and facing the water) at breathing zone height	1.5	29
On the back of the right slide (the slide on the right of swim deck when on the boat and facing the water) at breathing zone height	1	21
Left side of swim platform (at floor level)	11	218*
Right side of the swim platform (at floor level)	8	128*
On the stairs between the two slides on the back deck	1	24

Location	**CO average (ppm)**	**CO peak (ppm)**
Near the sliding glass door on the back deck	5	161
On the top deck of boat	0.5	18
Inside the boat	0.4	7

* CO monitors on the right and left sides of the swim platform were placed in exhaust cloud (see Figure 2) off the back of the swim platform resulting in the reported CO peak concentrations.

Jamestown Boat Works Houseboat
During the afternoon on October 23, 2000, CO samples were collected on a 1995 model Jamestown Boat Works houseboat with the specifications listed below. The diesel generator ran approximately 43 minutes and the motors ran approximately 23 minutes during this evaluation.

Engines: Two gasoline outboard Evinrude 88 HP engines
Generator: 10.5 Kw Lugger, 3 cylinder diesel generator
Exhaust Configuration: Generator exhaust out the back corner of swim platform. See Figure 3 for exhaust discharge.
Air speed above deck: air speed readings ranged between 144 - 247 feet per minute
Air speed below deck: air speed readings ranged between 13 - 55 feet per minute

Area around exhaust off back of houseboat

An evacuated glass container used in the area around the exhaust of the diesel generator did not detect the presence of CO.

Area Above Swim Deck on Back of Boat

The prevailing air movement was across the back right corner of the rear deck (when on back of boat and facing the water) and flowing toward the left corner of the swim platform (where the generator exhaust was located) at 144-247 fpm. Table 2 lists the CO monitor results.

Table 2. Sample locations and CO results on the Jamestown Boat Works houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Diesel Generator Running (ran for approximately 20 minutes without motors operating)		
On the back of the slide at breathing zone height	CO not detected	
Right side of the swim platform (at floor level)	1	6

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Diesel Generator Running (ran for approximately 20 minutes without motors operating)		
Left side of swim platform (at floor level)	1	10
On the ladder on swim platform	0.2	3
On stairs going up to top deck	CO not detected	
On the top deck of boat	CO not detected	
Inside the boat	CO not detected	
Diesel Generator and Gasoline powered Outboard Motors Running (ran together for approximately 23 minutes)		
On the back of the slide at breathing zone height	11	116
Right side of the swim platform (at floor level)	71	455
Left side of swim platform (at floor level)	56	200
On the ladder on swim platform	19	181
On stairs going up to top deck	6	53
On the top deck of boat	3	63
Inside the boat	9	60

Stardust Houseboat
During the morning on October 24, 2000, CO samples were collected on a 2000 model Stardust houseboat with the specifications listed below. This houseboat was equipped with a gasoline generator and motors. The generator ran approximately 65 minutes and the motors ran approximately 15 minutes during this evaluation.

Engines: Two 4 cylinder Mercury Mercruiser engines
Generator: 15.0 Kw Westerbeke, 4 cylinder gasoline generator
Exhaust Configuration: Generator exhaust ran under swim deck and platform and exhausted out the back of the boat.
Air speed above deck: air speed readings ranged between 180 - 605 feet per minute
Air speed below deck: air speed readings ranged between 5-50 feet per minute

Area around exhaust off back of houseboat and beneath swim deck

Two evacuated glass container samples and two detector tube samples were collected approximately 6 - 12 inches above the water (off the back of the swim platform in the vicinity of the generator exhaust) while the generator was in operation. This is an area where individuals could conceivably swim around, and enter and exit the water. The two evacuated container samples indicated CO concentrations of 426 and 4,662 ppm. A detector tube sample collected in this same area indicated a CO concentration of 0.3 % (3,000 ppm). Another detector tube collected in this area had a CO color change on the tube below the tube minimum scale reading of 3,000 ppm.

The ToxiUltra CO monitors have a nominal range from 0 ppm to 500 ppm with the highest instantaneous reading of 1000 ppm. Exposing the CO monitor to concentrations greater than 1,000 ppm for extended periods can damage the sensor. Therefore, the CO monitors were placed in the area off the back of the swim platform for only short periods of time to give brief indications of CO concentrations. The monitors placed in this area indicated CO concentrations greater than 1,000 ppm and therefore, were removed from the environment.

A CO monitor was placed in the access port to the area beneath the swim deck on the boat while the generator and motors were in operation. This monitor indicated CO concentrations greater than 1,000 ppm. An evacuated container sample collected in this area indicated a CO concentration of 818 ppm. A detector tube sample collected in this area had a CO color change on the tube below the tube minimum scale reading value of 3,000 ppm.

Area Above Swim Deck on Back of Boat

The air movement ranged between 180 - 605 fpm. The prevailing air movement was from the right side of the back deck (when on back of boat and facing the water) and flowing across the back deck toward the left side of the boat. Table 3 list the CO monitor results.

Table 3. Sample locations and CO results on the Stardust houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 65 minutes without motors operating)		
On the back of the slide at breathing zone height	16	139
On stairs going up to top deck	8	188
Left side of swim platform (at floor level)*	170	885
Right side of the swim platform (at floor level)*	100	1170
On the top deck of boat	2	72

Inside the boat	8	89
Generator and Motors Running (ran together for approximately 15 minutes)		
On the back of the slide at breathing zone height	5	46
On stairs going up to top deck	CO not detected in this area during this 15 minute period	
Left side of swim platform (at floor level)*	26	255
Right side of the swim platform (at floor level)*	14	198
On the top deck of boat	0.1	1
Inside the boat	0.1	1

* See Figure 4 and 5 for graphical displays of the data collected on the swim platform.

Jamestown Deluxe Houseboat
During the mid-afternoon on October 24, 2000, area CO samples were collected on a 1988 model Jamestown Deluxe houseboat with the specifications listed below. This houseboat was equipped with a gasoline generator and motor. CO concentration data were collected while the generator ran for approximately 57 minutes and while the motor and generator ran together for approximately 24 minutes during this evaluation.

Engine: 4 cylinder, 140 HP, Mercury Mercruiser engine
Generator: 12.0 Kw Westerbeke, 4 cylinder gasoline generator
Exhaust Configuration: Generator exhaust ran under back deck and exhausted out the back of the boat.
Air speed above deck: air speed readings ranged between 11 - 53 feet per minute
Air speed below deck: air speed readings ranged between 8 - 32 feet per minute

Area around back of houseboat and beneath swim deck

The Jamestown Deluxe houseboat did not have a swim platform that extended down to the water level like other boats evaluated (see Figure 6). The generator and motor exhaust discharged out the back of the boat into the area under the back deck. Evacuated glass container samples and detector tube samples were collected approximately 12 inches above the water level off the back deck when the generator was in operation. CO samples were also collected near the bottom of the stairs that lead down to the water off the back deck (see Figure 6) where individuals could conceivably swim around, and enter and exit the water.

The two evacuated container samples indicated CO concentrations of 1,157 and 663 ppm while the generator was running. Detector tubes collected in this area indicated CO color changes on the tube below the tube minimum scale reading value of 3,000 ppm. CO monitors placed in this area indicated CO concentrations of greater than 1,000 ppm.

A CO monitor was placed in the access port to the area beneath the swim deck while the generator and motors were in operation. This monitor indicated CO concentrations greater than 1,000 ppm. An evacuated container and a detector tube sample were collected in this area and indicated CO concentrations of 818 and 1000 ppm, respectively. Another evacuated container sample collected off the back of the boat while the motor and generator were in operation indicated a CO concentration of 265 ppm.

Area Above Swim Deck on Back of Boat

Table 4 lists the CO monitor results obtained on the back of the Jamestown Deluxe houseboat.

Table 4. Sample locations and CO results on the Jamestown Deluxe houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 57 minutes without motors operating)		
On the back of the slide at breathing zone height	68	210
On stairs going up to top deck	54	204
Left side of back deck (at floor level)*	326	1122
Right side of back deck (at floor level)*	274	961
On the top deck of boat	9	62
Inside the boat	59	109
On back deck at the sliding glass door	72	259
Generator and Motors Running (ran together for approximately 24 minutes)		
On the back of the slide at breathing zone height	48	188
On stairs going up to top deck	42	158
Left side of back deck (at floor level)*	300	1121
Right side of back deck (at floor level)*	288	862
On the top deck of boat	3	33
Inside the boat	40	166
On back deck at the sliding glass door	56	277

* See Figure 7 and 8 for graphical displays of the data collected at floor level on the back deck.

Stardust Presidential Houseboat
During the afternoon on October 24, 2000, area CO samples were collected on a 1998 model Stardust houseboat with the specifications listed below. This houseboat was equipped with a gasoline generator and two gasoline motors. CO concentration data was collected while the generator ran for approximately 71 minutes and while the motors and generator ran together for approximately 28 minutes during this evaluation.

> **Engine:** Twin 4 cylinder, Mercury Mercruiser engines
> **Generator:** 15.0 Kw Westerbeke, 4 cylinder gasoline generator
> **Exhaust Configuration:** Generator and motors exhausted under swim deck.
> **Air speed above deck:** air speed readings were mainly between 3 - 40 feet per minute. However, wind gust were measured up to 735 fpm
> **Air speed below deck:** air speed readings ranged between 21 - 43 feet per minute

Area under swim deck and around swim platform of houseboat

The generator and motor exhaust discharged out the back of the boat into the area under the swim deck. Evacuated glass container samples and detector tube samples were collected approximately 6-12 inches above the water level off the back of the swim platform. Evacuated container and detector tube samples were also collected in the view port into the area below the swim deck where the generator and motors exhaust (see Figure 9). Samples were collected when the generator was in operation and when the generator and motors were in operation simultaneously.

The evacuated container sample collected off the back of the swim platform (near water level) while only the generator was in operation indicated CO concentration of 4,078 ppm. An evacuated container sample, collected in the area off the back of the swim platform when the motors and generator were in operation, indicated a CO concentration of 10,224 ppm. This sample also indicated that the area where the sample was collected was oxygen deficient (17.2 % O_2). [During the analysis of this sample the evacuated container was damaged, which may have resulted in some loss of the sample. Thus, the result could be higher.] A detector tube sample also collected in the area off the back of the swim platform (near water level) indicated a CO concentration of 3,000 ppm when the generator and motors were in operation.

An evacuated container sample and a detector tube sample collected in the view port into the area below the swim deck while only the generator was in operation indicated CO concentrations of 7,985 ppm and 3,000 ppm, respectively. An evacuated container sample collected in this area when both the generator and motors were in operation indicated a CO concentration of 10,194 ppm. The two evacuated container samples collected below the swim deck with only the generator operating and with the generator and motors operating simultaneously also indicated that the area was oxygen deficient (18.5 % O_2 and 17.7 % O_2, respectively).

Area Above Swim Deck on Back of Boat

Table 5 list the CO monitor results obtained on the back of the Stardust Presidential houseboat.

Table 5. Sample locations and CO results on the Stardust houseboat (1998 model).

Location	CO average (ppm)	CO peak (ppm)
Only Generator Running (ran for approximately 71 minutes without motors operating)		
On the back of the slide at breathing zone height	13	213
On stairs going up to top deck	23	239
Left side of swim platform (at floor level)*	271	1121
Right side of swim platform (at floor level)*	280	1221
On the top deck of boat	5	68
Inside the boat	6	128
Generator and Motors Running (ran together for approximately 28 minutes)		
On the back of the slide at breathing zone height	41	364
On stairs going up to top deck	32	197
Left side of swim platform (at floor level)*	501	1120
Right side of swim platform (at floor level)*	542	1221
On the top deck of boat	12	78
Inside the boat	31	323

* See Figure 10 and 11 for graphical displays of the data collected on the swim platform. The upper limit of the CO monitors were exceeded at times and the graphs depict flat lines at the top of these peaks.

Lakeview Houseboat

During the morning on October 25, 2000, area CO samples were collected on a 1999 model Lakeview houseboat with the specifications listed below. This houseboat was equipped with a gasoline generator and two gasoline motors. The houseboat was taken out on the lake and anchored in a cove during the evaluation. CO concentration data was collected while the generator ran for approximately 25 minutes and while the motors and generator ran together for approximately 52 minutes. CO data was collected on the trip out to the cove, in the cove, and on the trip back to the dock.

Engine: Twin 4.3 liter V6 Mercury Mercruiser engines
Generator: 12.5 Kw Westerbeke, 4 cylinder gasoline generator
Exhaust Configuration: Generator exhausts to the side of the boat cabin
Air speed above deck: air speed readings ranged between 270 - 319 feet per minute
Air speed below deck: air speed readings ranged between 123 - 210 feet per minute

Area around swim platform of houseboat

The motors on this houseboat exhausted under the back of the swim deck and the generator exhausted out to the side of the boat. An evacuated glass container sample collected approximately 6-12 inches above the water off the back of the swim platform (with the motors and generator in operation after the boat had been stopped in a cove) indicated a CO concentration of 643 ppm. A CO monitor was briefly placed approximately 6-12 inches above the water level off the back of the houseboat with the generator and motors in operation and indicated a CO concentration greater than 1000 ppm.

The motors were shut off, and another evacuated container sample was collected off the back of the swim deck approximately 6-12 inches above the water level. CO was not detected in this sample. A CO monitor was briefly placed at the side of the boat in the vicinity where the generator exhaust is discharged. This monitor indicated a CO concentration of 500 ppm while only the generator was in operation.

Area Above Swim Deck on Back of Boat

Table 6 list the CO monitor results obtained on the back of the Lakeview houseboat.

Table 6. Sample locations and CO results on the Lakeview houseboat.

Location	**CO average (ppm)**	**CO peak (ppm)**
Only Generator Running (ran for approximately 25 minutes without motors operating)		
On stairs going up to top deck	0.5	5
Left side of swim platform (at floor level)*	78	503
Right side of swim platform (at floor level)*	35	234
On the top deck of boat	0.06	1
Inside the boat	4	46
Near sliding glass door on back deck	0.04	1

Generator and Motors Running (ran together for approximately 52 minutes)		
On stairs going up to top deck	6	115
Left side of swim platform (at floor level)*	208	968
Right side of swim platform (at floor level)*	121	787
On the top deck of boat	3	64
Inside the boat	5	55
Near sliding glass door on back deck	5	90

* See Figure 12 and 13 for graphical displays of the data collected on the swim platform.

Discussion and Recommendations

The CO concentrations measured on and around the houseboats with diesel generators were considerably less than CO concentrations on and around houseboats with gasoline powered generators and motors.

Diesel engines typically produce less CO than gasoline powered engines. The second houseboat evaluated (Jamestown Boat Works Houseboat) had a diesel generator with two outboard gasoline powered motors. When the generator was in operation, CO concentrations were low (0 - 10 ppm) around the generator exhaust and at the back of the boat. However, when the gasoline motors were in operation, CO concentrations increased considerably on the back of the boat and swim platform (CO concentrations measured up to 455 ppm on swim platform). The gasoline motors are used to power the boat and should not be in operation when the boat is stationary. The diesel generators evaluated in this study connect to an exhaust discharging out the back corner of the swim platform (see Figures 2 and 3). To date, a houseboat with the diesel generator exhausting under the back swim deck has not been evaluated. This type of design could conceivably allow a build-up of CO in the area beneath the back deck.

When gasoline generators are in operation, the area under the swim deck and around the back of the swim platform (near water level) on houseboats that exhaust the combustion gases in the space below the back deck, are extremely hazardous (CO concentrations well above IDLH levels were measured in this area at Lake Powell). These hazardous conditions also exist when the engines are in operation on the boats. During this survey, only one of the houseboats (Stardust 1998 model) exhausted the generator under the swim deck. The area under the swim deck and around the back of the swim platform (approximately 6-12 inches above the water where individuals could conceivably be swimming) indicated CO environments well above the NIOSH IDLH value of 1,200 ppm[3] (CO concentrations were measured up to 10,000 ppm in these areas). High CO concentrations and IDLH environments were also identified in the area off the back of the swim deck (where individuals could conceivably be swimming) on houseboats that discharge the generator exhaust out to the rear of the swim platform or deck.

The generator on the Lakeview houseboat exhausted to the side of the boat. Samples indicated CO concentrations up to 500 ppm around the generator exhaust and at the swim platform (left side at floor level). When the motors were operated, CO concentrations were higher (up to 1000 ppm off back of swim platform). This was also the case when the boat was in transit to and from the cove (see Figures 12 and 13). However, it is conceivable that if someone is in the vicinity of the exhaust under certain environmental conditions (i.e., stagnant air movement or slight air movement that allows the CO to migrate into occupied areas on the boat) CO poisonings could occur. Also, with this type of exhaust design (gasoline generator exhaust located on the side of the boat) CO poisonings could potentially occur if the exhaust is blocked such as tying two houseboats together and thus, allowing exhaust gases to drift into the boats.

This investigation reaffirms issues of concern regarding the potential for CO exposure on houseboats. Individuals swimming or working in the area under the swim platform, or around the area directly behind the swim platform (with the gasoline generator in operation on houseboats that exhaust the combustion gases in the space below the back deck, or out the back of the deck) could be exposed to extremely high CO concentrations resulting in CO poisoning or death within a short period of time. The area on the back deck of houseboats is also a concern. When the generator or motors are in operation, the area around the back deck of houseboats can be hazardous under certain conditions (i.e., lack of air movement).[1]

This evaluation was performed in October which is not in the prime operating season for houseboats. Activities at the dock were slow, due to the low number of houseboat rentals. Therefore, personal sampling was not conducted. However, general recommendations are provided to help control potential worker CO exposures. In addition, recommendations are provided to reduce the potential for CO exposure around and under the swim platform on houseboats.

1) Public education efforts must immediately inform and warn all individuals (including boat owners, renters, and dock workers) potentially exposed to these CO hazards. Public education programs should continue until engineering control solutions that eliminate the problem are in place.

An effort is being made to inform manufacturers of houseboats about the environmental data that has been collected, and the related design concerns. On September 1, 2000, the National Park Service (NPS) sent each of these manufacturers a letter informing them of the numerous deaths that may be attributed to CO poisoning from houseboat generator and/or engine exhaust. In these letters, the Park Service specifically pointed out that most of the deaths occurred when the victim was either on the back deck or in the water near or under the swim platform. In addition to this effort, the initial NIOSH letter describing the first evaluation of CO on houseboats at Lake Powell was also sent to 58 houseboat manufacturers.[1] This effort should be continued until all manufacturers are aware of the problem and solutions are formulated to redesign and correct the exhaust configuration. This should also include the redesigning of side-exhausting boats to help eliminate CO problems when boats are tied together, or when someone is in the area where the exhaust gases are expelled from the boat.

2) Previous investigations have indicated that boat mechanics can be exposed to high concentrations of CO.[1,2] Therefore, the feasibility and effectiveness of engineering controls should be investigated to help control CO exposures to boat maintenance mechanics. If repairs are conducted outside and at the boat dock (where electric power is easily available), the use of a high volume fan or other air-moving device may be effective in preventing worker short-term high-level exposures to CO. Research into potential engineering controls needs to be accomplished to make sure that the workers' breathing zone is protected from CO and that any exhaust from these controls is discharged into a well-ventilated area that is not occupied; therefore, eliminating the possibility of individuals breathing the exhaust from the control device.

3) Training about the severity of CO hazards in boating should be developed for marina personnel, EMS providers, and hospital emergency department staff so that symptoms experienced by either employees or other boat operators might be more easily associated with exposures. This training should include both environmental data, as well as information about the number and circumstances of CO poisonings on the lake.

4) The U.S. NPS has launched an awareness campaign to inform boaters on Lake Powell about boat-related CO hazards. This alert included press releases, flyers distributed to boat and dock-space renters, and verbal information included in the boat check-out training provided for users of concessionaire rental boats. In November, 2000, your cabinet issued a statewide news release regarding the hazards of CO behind houseboats.[4] Your cabinet should also distribute CO hazard flyers to boat and dock-space renters. Verbal information should be included in the boat check-out training provided for users of rental boats. Training about the specific boat-related CO hazards provided to houseboat renters, should include specific information about the circumstances and number of poisonings and deaths that have been documented in previous CO evaluations.[1] The training should include anecdotal information about deaths and near misses, and should specifically target warnings against entering air spaces under the boat (such as the cavity below the swim platform), or immediately behind the swim platform that may contain a lethal atmosphere.

5) When 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 should be followed before any workers enter this area. See Attachment 3 for a discussion regarding the basis for this recommendation.

Thank you for your cooperation with this investigation, and for providing important data related to this serious issue. Please contact me at (513) 841-4387 if you have any questions regarding this evaluation. Jane McCammon at (303) 236-6233 is an additional contact who can answer any questions or concerns you may have regarding CO fatalities and poisoning incident reports on houseboats.

Sincerely,

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2. Hall, RH, McCammon, JB [2000]. Letter of November 21, 2000, from R. Hall and J. 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, to Joe Alston, Park Superintendant, Glen Canyon National Recreation Area, Page, Arizona.

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

4. Cabinet of Health Services, Commonwealth of Kentucky [November, 2000]. Statewide News Release. Officials warn of Carbon Monoxide Levels Behind Houseboats and Tractors. Frankfort Kentucky.

Figure 1. Swim platform and back deck of houseboat with CO sample locations.

Figure 2. Back View of Navigator boat and generator exhaust discharge.

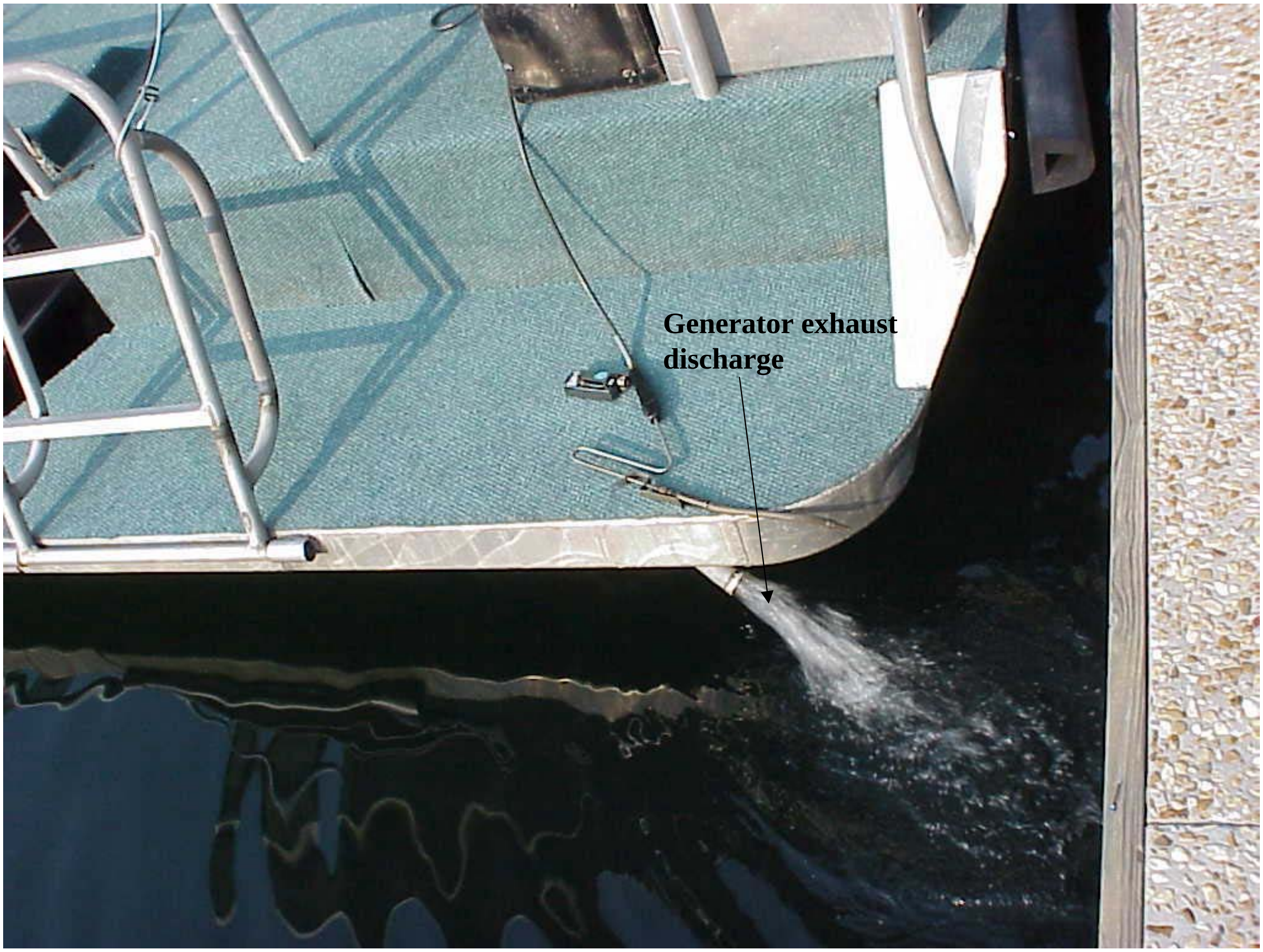

Figure 3. Generator exhaust discharge on the Jamestown Boat Works Houseboat.

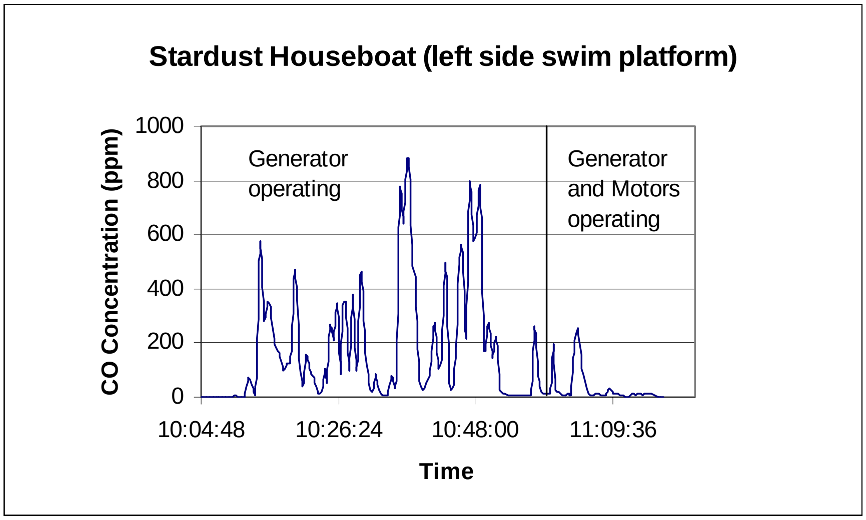

Figure 4. Graphical display of CO concentration data collected on the left side of swim platform. CO levels may have dropped when generator/engines where running because of wind shifts or an increase in wind speed.

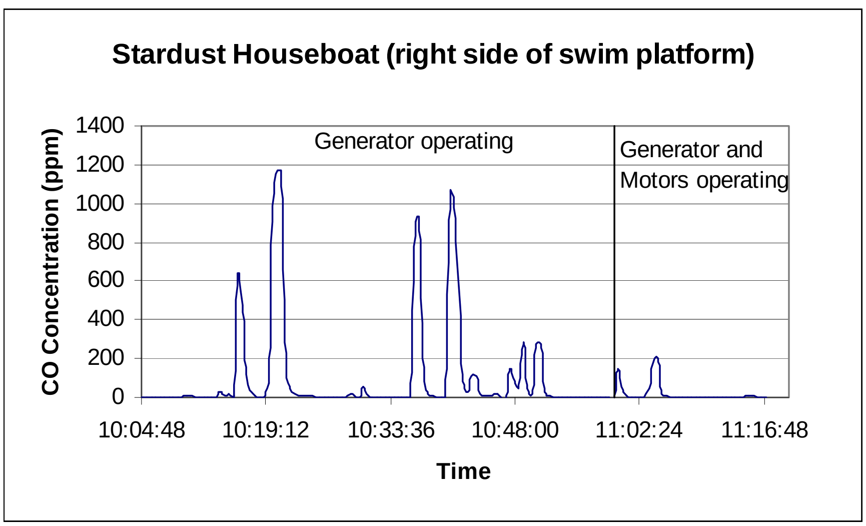

Figure 5. Graphical display of CO concentration data collected on the right side of swim platform. CO levels may have dropped when generator/engines where running because of wind shifts or an increase in wind speed.

Figure 6. Back deck of Jamestown Deluxe Houseboat

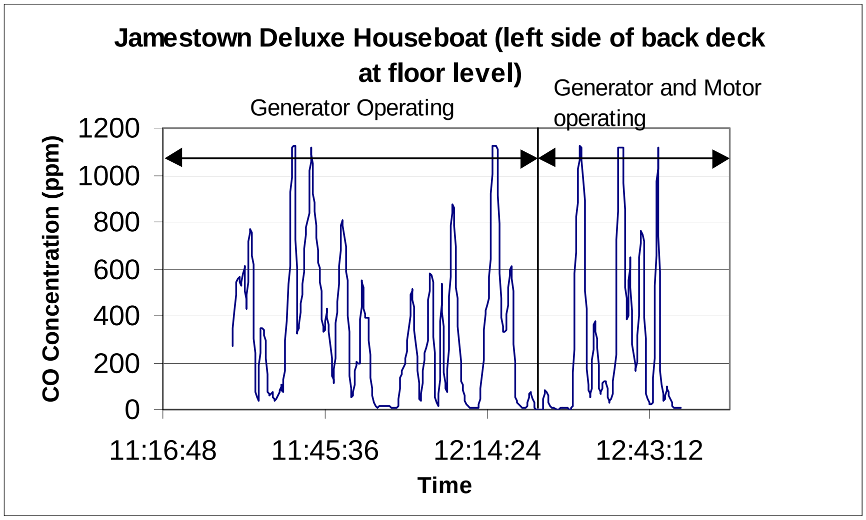

Figure 7. Graphical display of CO concentration data collected on the left side of back deck.

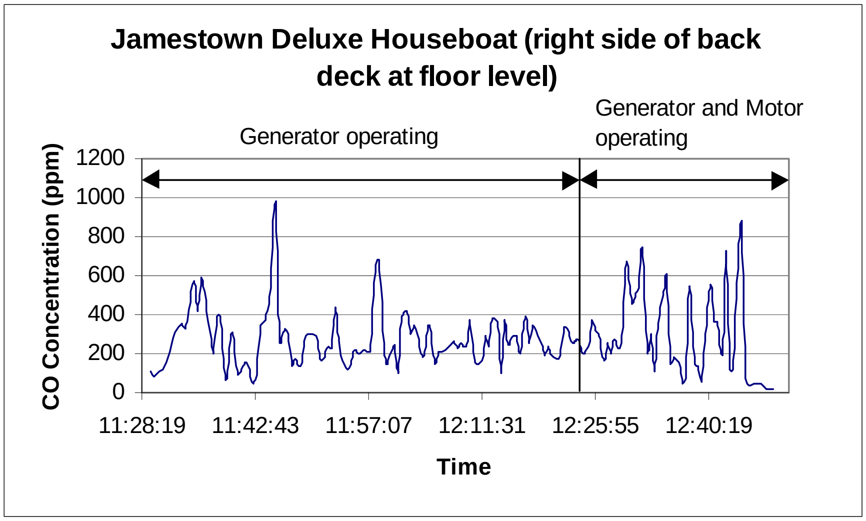

Figure 8. Graphical display of CO concentration data collected on the right side of back deck.

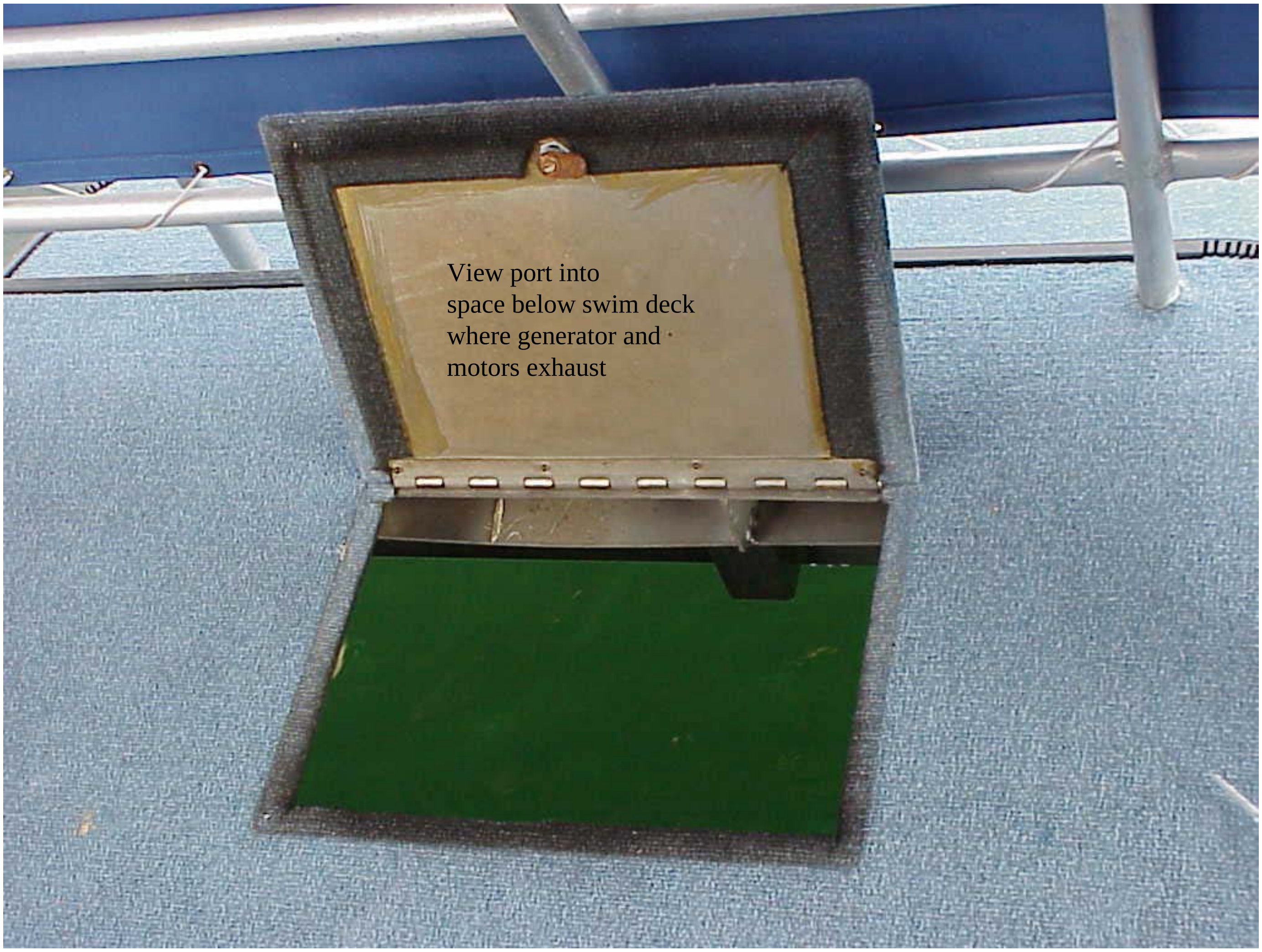

Figure 9. View port into area beneath the swim deck of the Stardust Houseboat (1998 model).

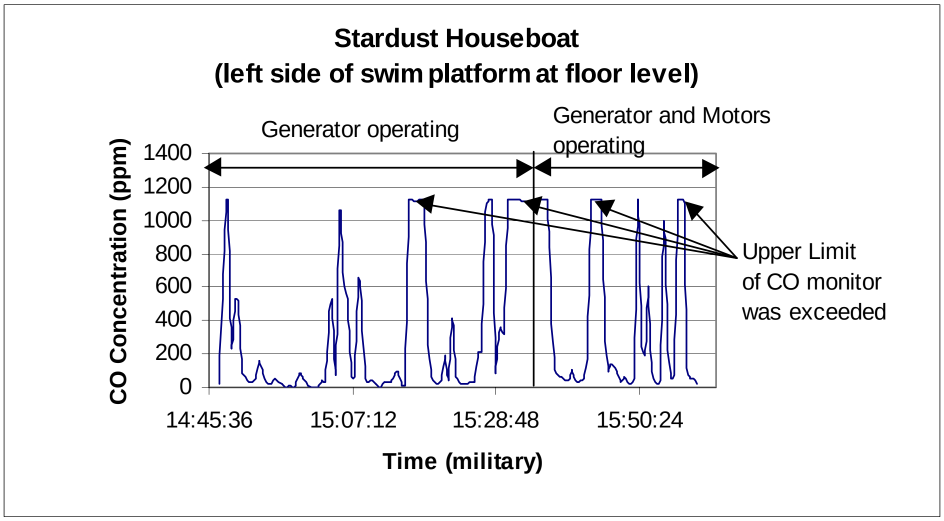

Figure 10. CO monitor results on the left side of swim platform (Stardust Houseboat 1998 model).

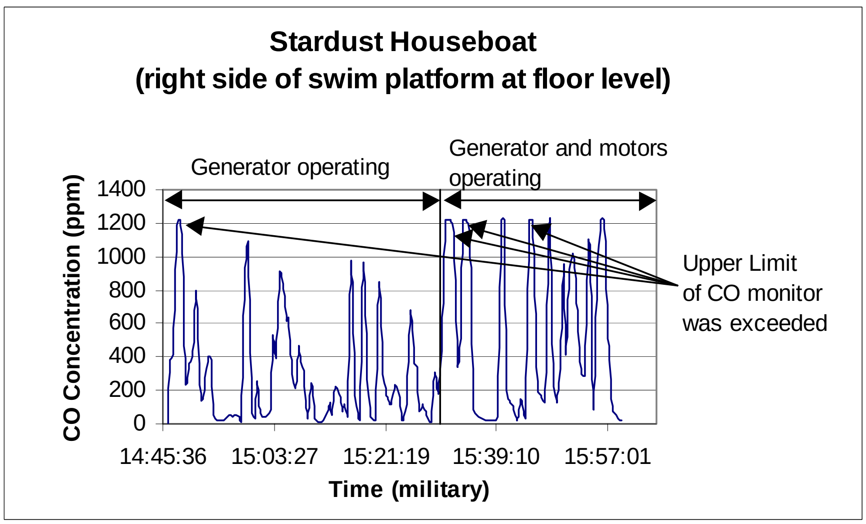

Figure 11. CO monitor results on the right side of swim platform (Stardust Houseboat 1998 model).

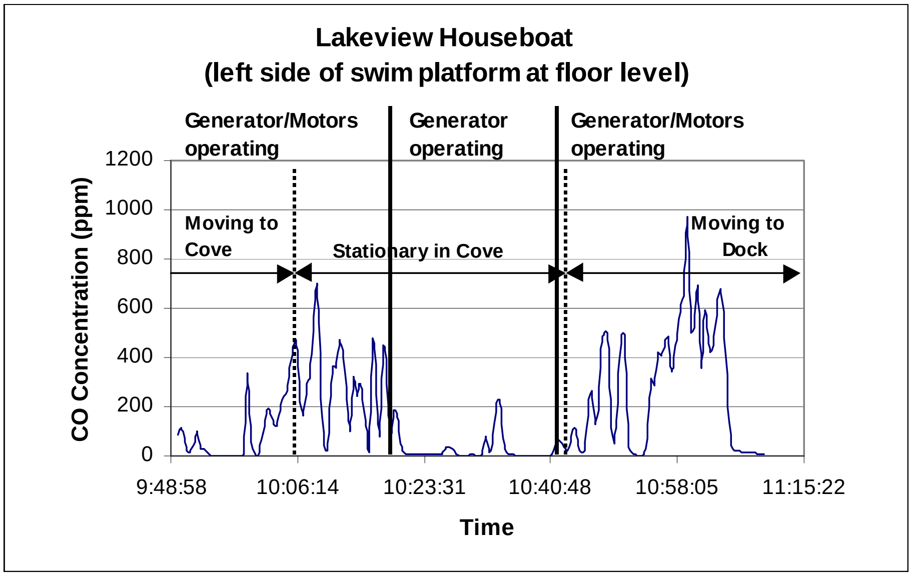

Figure 12. CO monitor results on the left side of swim platform (Lakeview Houseboat).

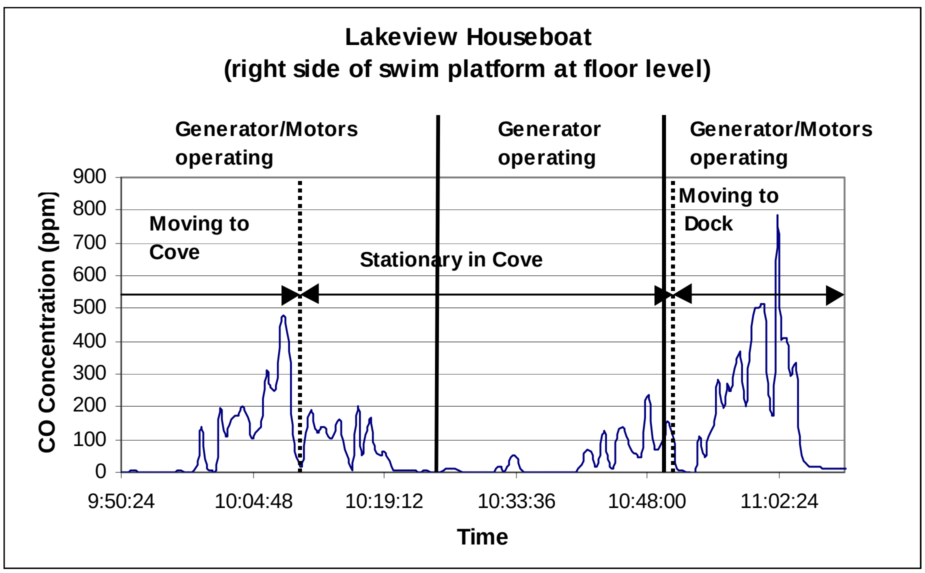

Figure 13. CO monitor results on the right side of swim platform (Lakeview Houseboat).

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.

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]

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. 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

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. Lake Cumberland employees should be in a state of health typical of any industrial worker. Thus, occupational criteria for CO exposure are applicable to that group. The general boating public, however, may range from infant to aged, be in various states of health and susceptibility, and be functioning at a higher rate of metabolism because of increased physical activity. The effects of CO are more pronounced in a shorter time if the person is physically active, very young, very old, or has preexisting health conditions such as lung or heart disease. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin.[(1)] The occupational exposure limits noted below should not be used for interpreting general population exposures because they would not provide the same degree of protection they do for the healthy worker population.

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

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[(2)] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®), [(3)] (3) the legal requirements of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs),[(4)] and (4) the American Society of Heating, Refrigerating, and Air-ConditioningEngineers (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)

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

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

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Attachment 3

Record reviews at Lake Powell indicated that three CO poisonings occurred within the span of 12 days in August, 1998, as a result of entering the airspace beneath the swim deck for engine maintenance or clearing ropes from propellers. In the first instance, a 56-year-old man died when he swam under the swim platform several times while the boat generator was operating. Ten days later, a 24-year-old employee was working under a houseboat changing the engine propeller while the boat generator was operating. He was found unconscious in the water and transported to a nearby medical clinic, where he was treated for carbon monoxide inhalation. Two days later, a 38-year-old man entered the airspace beneath the swim deck after deactivating the boat engines. Approximately 3 hours later, his body was located in approximately 8 feet of water.

One of these incidents involved an employee that worked at the marina at Lake Powell. 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.[1] 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. 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 Table 1, 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. Table 2 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.[2]

Table 1

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.

Table 2

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	0	0	0
Hearing protection	0	0	0
Hand protection	0	0	0
Foot protection	0	0	0
Body protection	0	0	0
Respiratory protection	0	0	
Safety belts	X	X	X
Life lines, harness	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 Welf
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