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HETA 20020325
Interim Report

December 3, 2002

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 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 industrial hygienists from the US Department of Interior and the Washington DC NPS office in the investigation of a fatal and a non-fatal carbon monoxide (CO) poisoning occurring behind a cabin cruiser on August 17th, 2002. The interagency investigation was supplemental to the NPS Glen Canyon investigation, and provided exposure information relevant to the poisoning of two 9-year-old girls on that date. This letter reports our evaluation methods, findings, and conclusions. For ease of understanding, summary information is provided in this cover letter. More extensive detail is included in the attached full report.

Background materials provided for the investigation included: the NPS GLCA Case Incident Record; the NPS GLCA Supplemental Incident Record; boat owner's manuals; and relevant medical/autopsy records. A detailed summary of events leading to these poisonings is included in the two NPS records.

Before initiating this investigation, NIOSH used a computer program to calculate estimated exposure concentrations experienced by a poisoned individual based upon COHb and elapsed time. Using this program, the calculated averaged CO exposure concentration experienced by the girls during the 10-minute exposure period would have been 3,800 parts of CO per million parts of air (ppm).

NPS made arrangements with the boat owner to facilitate measurement of CO on and near the boat. Sampling dates were August 28th and 29th. The team was joined in an opening conference by several representatives of the boat manufacturer, representatives of an engineering firm retained by the boat owner's law firm, and the boat distributor. Several of these representatives also observed and photographed the ensuing investigation.

Because it was very windy on the first day of sampling (in contrast to the reportedly calm day of the poisoning), sampling was repeated the following calm morning. Data from both days are discussed in the full report, but only the second day's sampling is discussed here.

Generator exhaust CO concentrations were measured within 2 - 6 inches of the exhaust terminus using laboratory-analyzed grab samples of air (instantaneous samples that can be used to measure any CO concentration), and high-range detector tubes (instantaneous samples capable of measuring as high as 70,000 ppm CO). CO monitors capable of continuously logging CO measurements as high as approximately 1,200 ppm were placed in stationary configurations at distances of approximately 1, 2, and 5 feet from the exhaust terminus, and also on the swim platform (starboard side), at the point of access to the seating area of the boat, on the boat transom, and in the rear starboard cup holder. A similar monitor was also used to measure CO concentrations at various locations approximately 10 feet from the exhaust terminus. (This monitor was hand-held and moved in a 10-foot radius of the exhaust terminus.)

On the relatively still morning of August 29th, NIOSH/DOI/NPS investigators found the following:

- CO concentrations ranging from 37 to 41,600 ppm were measured within 2 - 6 inches of the boat's generator exhaust terminus. Among these samples, those with 13,400 ppm and higher CO were accompanied by oxygen-deficient environments (measured as low as 12.29% oxygen).

- CO concentrations were consistently in excess of the maximum measurable value for the continuous CO monitors (>1,200 ppm) on the swim platform and in-line with the exhaust flow approximately one and two feet from the exhaust terminus. The CO concentration at these distances and locations was consistently in excess of 1,200 ppm (which is the NIOSH Immediately Dangerous to Life and Health concentration), meaning that the actual concentration there was between 1,200 ppm and the maximum value measured at the exhaust terminus (41,600 ppm).

- CO concentrations in-line with the exhaust flow approximately 5 feet from the terminus were often in excess of the capacity of the monitors (>1,200 ppm), as were CO concentrations at an angle to the exhaust flow one and two feet from the terminus. (See Figure 4 for monitor placement.)

- Peak CO concentrations at various locations 10 feet from the exhaust terminus ranged from 87 to 500 ppm.

These extremely high CO concentrations measured near the exhaust terminus and dispersing outward for distances as far as 10 feet would explain the acute, severe CO poisonings.

Information gathered in numerous interagency investigations conducted during the previous two years, leads us to make the following recommendations relevant to GLCA. The interagency investigative group will continue to work with manufacturers, boat users, standards setting organizations, and boat safety educators to develop further recommendations relevant to the broader scope of boat-related CO poisonings beyond this lake. Although many of the following recommendations deal with public awareness, such efforts at Lake Powell in the last two years have had limited impact on the occurrence of CO poisonings. The numerous poisonings that have occurred in 2001 and 2002 indicate that primary prevention in the form of boat design changes and emission control devices is equally crucial.

1) GLCA should reassess educational materials distributed as part of their public awareness program to include a broader spectrum of boat-related CO hazards. Due to the transient nature of the visitors the public awareness program should be continuous. The following items should be included in the awareness campaign at GLCA.

> Post additional permanent CO warning signs at locations boat users frequent, such as pump-outs, fuel docks, ramps, and other locations that presently don't have a sign;
>
> Personalize the notices on past fatalities and poisonings so that boaters will be able to relate more closely with the hazard;
>
> Continue handing out materials on CO Safety (brochures and park guide/newspaper) at entrance stations;
>
> Continue with CO articles in the spring/summer park guide/newspaper;
>
> Include CO Alert insert or news releases about CO poisonings with slip/mooring monthly billing statements;
>
> Ensure that all concessionaires include CO safety issues in boat operator orientation materials (video, written, and verbal orientation) as a condition of their permit;
>
> Print items such as "special attention" tent cards/wall notices that personalize the CO issue on past fatalities and near misses;
>
> Encourage dissemination of CO information during GLCA employee contacts with boat operators (ramp contacts, boat patrols, maintenance activities, etc.);
>
> Repeat Public Service Announcements in local media (radio, newspaper) during boating season.

2) NPS should ensure that similar educational programs are available for dissemination at other appropriate parks (those with water bodies that allow powered boats).

3) GLCA should assess additional active strategies that could be implemented to prevent CO poisonings at Lake Powell. Examples of possible GLCA active strategies are included in the minutes of the June 19, 2002 interagency meeting. Additionally, GLCA should consider dedicating more resources to CO poisoning prevention efforts within the Park by filling positions such as that of the vacant safety officer. If filled, that position could coordinate visitor safety issues within the Park, including CO poisoning.

4) GLCA/NPS should work with the U.S. Coast Guard to determine the best method to ensure that boat manufacturers, boat distributors, sales staff members, and consumers are made aware of the hazards of CO from generator and propulsion engine exhaust and options for hazard reduction. Hazard communication materials for these groups should include detailed information, including the fact that fatal poisonings are possible even if exposure occurs outside of any enclosure or obstruction of engine emissions.

5) GLCA/NPS should continue to encourage research into effective control technologies to control CO emissions and exposures. Examples of such technologies include labeling of through hull exhaust fittings on boats, emission control devices, rerouting of exhaust, use of alternate fuels such as diesel, etc.

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

Sincerely,

Jane Brown McCammon, CIH
Director, NIOSH Denver Field Office

Tim Radtke, CIH
US Department of Interior

David P. Bleicher, CIH
US National Park Service

Enclosure

Investigation of Two Carbon Monoxide (CO) Poisonings (One Fatal and One Non-fatal) Outside of a Sea Ray 2001 260 DA Cabin Cruiser Boat with an Operating Kohler 5 kW Generator

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 and nationwide. The interagency effort was triggered by the fatal CO poisoning of two brothers in August 2000.

Presently, 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 occupancy, 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, including cabin cruisers and ski boats.

Cabin cruisers were involved in 15 CO poisonings (including the 2 discussed in this report) at Lake Powell since 1990. In one incident, 6 people survived poisoning that occurred as a result of generator exhaust entering the boat cabin during the night. Four additional people (two incidents) survived poisoning as a result of exposure to propulsion engine exhaust while occupying the cabin area. Three additional people survived poisoning that occurred while they rode outside the cabin area of cabin cruiser boats, with the source of exposure being propulsion engine exhaust.

These CO poisonings at Lake Powell are among the nearly 400 boat-related poisonings across the United States that have been reported to the investigative team. Sixty-eight of the reported poisonings occurring on water bodies other than Lake Powell occurred on or near cabin cruisers. Four of these 68 poisonings occurred outside the cabin of the boat; 2 resulted in death. One of the deaths resulted when a child occupying the swim platform of a cabin cruiser was exposed to generator exhaust. The 3 remaining poisonings outside of cabin cruisers were the consequence of exposure to propulsion engine exhaust. Sixteen of the 64 people poisoned inside the cabin area of cabin cruisers died. Thirty-one of the 64 people were poisoned as a result of exposure to generator exhaust.

Incident Description
A detailed description of this incident is included in the NPS incident investigation report and related supplement which are included in Attachment 3.

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 and 3 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.

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

Exposure Concentration (ppm*)	Relevant Environmental Limit or Impact of ExposureRelevant Environmental Limit or Impact of ExposureRelevant 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

Methods and Materials

Interagency Team:
Data related to this incident (including an exposure time of 10 minutes, a measured COHb of 39%, an altitude of 3,630 feet; height and weight of the girl that died, an estimated effectiveness of blood circulation of 15% during CPR) were entered into a computer application to calculate an estimated CO exposure concentration of the person that died. This application developed by OSHA uses the Coburn-Forster-Kane relationship for modeling uptake and elimination of CO.[1]

CO measurements were taken on August 28th until the decision was made to defer further testing (because of the excessive wind) until the following morning. Winds were very calm on the morning of August 29th, which was more representative of the day on which the girls were poisoned. The boat was in the same location on both days (which was **not** where the boat was on the day the girls were poisoned). Figure 3 shows the location of the boat during testing. The boat was placed in this location because the incident site was no longer accessible (the water level had dropped significantly since the incident occurred, and the boat was in shallow water during the incident).

CO concentrations were measured during generator operation only. On August 28th, the generator was operated without loading. On August 29th, the generator was operated in two modes: with the air conditioner operating (generator operating under load), and with no electrical equipment in operation (no load).

We initially attempted to measure CO at the generator exhaust terminus using a KalEquip emissions analyzer, which is a direct-reading infrared four-gas analyzer that measures CO, CO_2, hydrocarbons, and oxygen content in the air. Unfortunately, this equipment was damaged in shipping, and did not function during this investigation. The advantage of using this equipment is that it allows accurate measurement of very high CO concentrations. Measurements on such emissions analyzers are expressed in percentages, ranging from 0-100%. One percent of CO is equivalent to 10,000 parts per million (ppm). The failure of this equipment meant we were limited to a small number of instantaneous grab samples to characterize the range of high CO concentrations near the boat.

Airborne CO concentrations on and near the boat were measured using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors placed at several locations on and near the boat (at the starboard rear cup holder; at the top center of the transom; at the access point to the rear seating area; on the port [on August 28 only] and starboard sides [on both August 28 and 29] of the swim platform. On both days the remaining monitors were placed on poles so that when the pole was placed in the mud at the bottom of the lake, the monitor would be in a fixed location relative to the anchored and secured boat, with the monitor being 1' above the water surface. On August 28th, these monitors were placed as follows (all measurements are approximate because the boat shifted a bit during the surveys): one monitor 2' from the terminus in the direction of the generator exhaust flow and three monitors on a 5' radius from the terminus (marked "left", "center" and "right" on the relevant figures showing results). On August 29th, the monitors were placed in an L-shaped configuration as follows: at 1 and 2 feet from the terminus perpendicular to the starboard side of the boat; at 1, 2, and 5 feet from the exhaust terminus, perpendicular to the starboard side of the transom. The direction of the exhaust flow was approximately 45 degrees to each sampling location. (See Figure 4 to better understand the placement of monitors relative to the boat and to the direction of the generator exhaust flow on August 29th.) In addition, on August 29th, CO was measured 10 feet away from the exhaust terminus using a hand-held monitor moved to various locations on a 10-foot radius. Monitors were configured in these patterns to assess the range of exhaust dispersal. 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 in the passive diffusion mode, 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 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 were also measured with detector tubes [Drager CO, CH 29901– range 0.3 % (3,000 ppm) to 7 % (7,000 ppm), with a stated accuracy of $\pm$15%]. 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. These tubes are the least accurate of the methods used for sampling during this investigation. If water was inadvertently drawn into the tube, the results were considered invalid.
Wind speed was measured using a TSI Velocicalc Model 8345 air velocity meter.

Boat Owner's Technical Representative:
CO data collected concurrently with that of the interagency team were provided by the representative of the engineering firm hired by the boat owner who used a Bacharach Monoxor II CO monoxide analyzer. This direct-reading instrument can quantify CO concentrations as high as 2,000 ppm. The engineer verbally reported the appropriate calibration methods for this analyzer, and also reported that it had been calibrated before use during this survey.

Results

Using the computer program provided by OSHA, we calculated that the average CO exposure concentration experienced by the girl that died was approximately 3,800 parts of CO per million parts of air (ppm) during her 10-minute exposure. Given the parameters listed in the methods section, the program calculated that her COHb would have been 47.5% when she sank into the water. The surviving girl's expired CO was measured after more than two half-lives (the amount of time it takes for the COHb concentration to be reduced by half, which varies depending upon a number of factors - see Attachment 1 for a more complete discussion) had passed based upon the duration of oxygen therapy and breathing of ambient air. Her COHb was 15.1% at that time, but could have been 60% or greater when she removed herself from exposure to go into the boat.

Figure 5 provides a map of the maximum CO concentrations measured at all sampling locations, regardless of sampling method or day of sampling. That map includes data collected by the interagency team and by the owner's representative (provided for this report). He measured greater than 2,000 ppm (the upper limit of the monitor) at various locations within the area labeled as "greater than 1,200 ppm and less than 41,600 ppm", and he also measured as high as 1,300 ppm in-line with the flow of exhaust 7 feet from the exhaust terminus.

August 28th, 2002

On the first day of sampling, wind speed at the sampling site ranged from 4 to 25 miles per hour (mph).

During this day of sampling, evacuated glass container and detector tube airborne CO samples were collected at various locations relative to the exhaust terminus. The two sampling methods were used as close to the same location as possible, and samples collected within 1 minute of each other are listed as "side-by-side" samples in Table 2.

Results of measurements collected on this day using the CO ToxiUltra datalogging monitors at various locations near the generator exhaust terminus are illustrated in Figures 6 and 7.

Table 2. CO and Oxygen Concentrations Measured using Detector Tubes and Evacuated Glass Tubes during Generator Operation only - Sea Ray 2001 260 DA Cabin Cruiser, Kohler 5 kW Generator - Lake Powell - August 28, 2002

Circumstances of Sample	Detector Tube CO Reading (ppm)	Evacuated Tube CO Concentration (ppm)	Evacuated Tube Oxygen Concentration (%)
Immediately after generator activation, approximately 2 inches from terminus	5,000 and 10,000 (2 samples)	15,500	17.34
6 minutes after generator activation, approximately 5 feet from terminus in the direction of the exhaust flow	0, 0, 0 (3 samples)	4	20.95
21 minutes after generator activation, approximately 6 inches from terminus	not done	36,500	13.55
29 minutes after generator activation, approximately 2 inches from terminus	20,000	20,400	17.02
32 minutes after generator activation, approximately 5 feet from terminus in the direction of the exhaust flow	0	2	20.95

August 29th, 2002

Weather on this morning of sampling was much calmer, with wind speeds at the sampling site ranging from 0 to 4 mph, with gusts up to 8 mph.

On this day of sampling, evacuated glass container and detector tube airborne CO samples were collected approximately 2 inches from the exhaust terminus. The two sampling methods were used as close to the same location as possible, and samples collected within 1 minute of each other are listed as "side-by-side" samples in Table 3.

Results of measurements collected on this day using the CO ToxiUltra datalogging monitors at various locations near the generator exhaust terminus are illustrated in Figures 8 - 14.

Table 3. CO and Oxygen Concentrations Measured approximately 2 inches from Generator Exhaust Terminus using Detector Tubes and Evacuated Glass Tubes during Generator Operation only - Sea Ray 2001 260 DA Cabin Cruiser, Kohler 5 kW Generator - Lake Powell - August 29, 2002

Circumstances of Sample	Detector Tube CO Reading (ppm)	Evacuated Tube CO Concentration (ppm)	Evacuated Tube Oxygen Concentration (%)
30 seconds after generator activation, air conditioner operating	3,000	37	20.95
4 minutes after generator activation, air conditioner operating	10,000	not done	not done
10 minutes after generator activation, air conditioner operating	3,000	13,400	18.49
22 minutes after generator activation, air conditioner operating	10,000	not done	not done
41 minutes after generator activation, no load on generator	10,000	41,600	12.29
50 minutes after generator activation, no load on generator	20,000	5,500	19.87
64 minutes after generator activation, air conditioner operating	5,000	not done	not done
72 minutes after generator activation, air conditioner operating	10,000	not done	not done

Discussion

The data collected here demonstrate that even a relatively small generator such as the 5 kilowatt one on this boat produces enough CO to result in rapid poisoning out in the open as far away as 5 to 10 feet when the weather is relatively calm. Unfortunately, these facts are neither well-known, nor well-understood. Outdoor CO poisonings have been poorly defined and likely poorly detected in the past. We are learning that acute, severe, and fatal poisonings outside of boats is not as rare as originally thought (see the listing of reported incidents at internet website http://safetynet.smis.doi.gov/COhouseboats.htm).

The data presented in this report, and the data from several others before it (also available at the above internet website http://safetynet.smis.doi.gov/COhouseboats.htm), document the very high CO concentrations emitted by gasoline-powered generators on boats (as high as 41,600 ppm here, and higher in other investigations). These concentrations are accompanied by an oxygen-deficient environment. Exposure to either of these asphyxiating situations is extremely hazardous when a person is standing on land or sitting in a boat. But when the person is immersed in water, the hazard is enhanced by the possibility of drowning.

As part of this investigation, we examined informational documents to see if there was room for improvement in educational materials being disseminated about CO poisonings on boats. First, we reviewed NPS materials distributed within Glen Canyon National Recreation Area. One flier that is widely distributed by the Park and is available on the NPS Glen Canyon website points out that houseboat generators and boat engines produce CO and have been the cause of fatalities on Lake Powell. The flier is accurate in describing the previous deaths at Lake Powell, but does not include information about the hazards related to generators on other boats. However, the flier specifically says "Don't swim or teak surf near exhaust ports!", and another instructs boaters to "Turn off generator and motor when there are swimmers in the water or on the rear swimming platform of your vessel." Public awareness programs (including fact sheet and brochure distribution, placarding, and production of educational programs and tools) have been in place at Lake Powell since August 2000. However, CO poisonings occurring on Lake Powell in 2002 (2 fatal outdoor and 25 non-fatal poisonings representing the second worst year) indicate that these efforts have limited impact, and that primary prevention (such as reduction of CO at the source) is crucial.

The other three documents examined during this investigation are sections related to CO poisoning in: 1) the boat owner's manual; 2) the manual for the generator; and 3) the propulsion engine manual. The boat owner's manual warns that CO is produced by engines, heaters, stoves or generators. The manual further states that "CO concentrations can occur when there are system leaks, inadequate ventilation or poor air circulation from the motion of the boat (also known as backdrafting)." The manual provides instruction to minimize the danger of CO accumulation, including to operate all combustion devices in well-ventilated areas, and to avoid idling (this referring to idling the propulsion engines) for long periods of time. Although it is difficult to define what a "well-ventilated area" is [2], few people would argue that outdoors seems to be a well-ventilated area. There is no mention in the manual about the hazardous environment created in the area surrounding the generator exhaust terminus in an unobstructed unenclosed setting.

The manual for the generator discusses CO poisoning, but again refers to situations involving obstructed or restricted flow of exhaust, accumulation of exhaust inside the cabin or other enclosed areas, and the use of CO detectors. There is no mention of avoiding the extended area around the exhaust terminus, or the possibility of outdoor poisoning. Neither this nor the boat owner's manual includes a diagram that specifically shows the location of the generator exhaust relative to the boat hull. This is a vital point, because many people do not know that generators on boats emit a stream of water with the exhaust, and when they see that water coming out of the boat, they don't realize that CO is expelled there as well. As is evident in Figure 2, there are several through-hull fittings on these boats. In previous investigations, boat distributors and owners have had difficulty showing us which is the generator exhaust fitting. At least one of the boat owners here was reportedly not familiar with the location of the generator exhaust on their boat.

Finally, the propulsion engine manual gives guidance about CO poisoning and good and bad ventilation practices. The manual states that "Although the occurrence is rare, on a very calm day, swimmers and passengers in an unclosed area of a stationary boat that contains or is near a running engine may be exposed to a hazardous level of carbon monoxide." It is not clear what is meant by the word "unclosed" which is likely a typographical error in that sentence, but could mean either unenclosed or enclosed. Two examples of poor ventilation while the boat is stationary follow this statement in the manual: 1) Running the engine when the boat is moored in a confined space; and 2) Mooring close to another boat that has its engine running. Neither applied in this situation.

Recommendations

Information gathered in numerous interagency investigations conducted during the previous two years, leads us to make the following recommendations relevant to GLCA. The interagency investigative group will continue to work with manufacturers, boat users, standards setting organizations, and boat safety educators to develop further recommendations relevant to the broader scope of boat-related CO poisonings beyond this lake. Although many of the following recommendations deal with public awareness, such efforts at Lake Powell in the last two years have had limited impact on the occurrence of CO poisonings. The numerous poisonings that have occurred in 2001 and 2002 indicate that primary prevention in the form of boat design changes and emission control devices is equally crucial.

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Continue handing out materials on CO Safety (brochures and park guide/newspaper) at entrance stations;

Continue with CO articles in the spring/summer park guide/newspaper;

Include CO Alert insert or news releases about CO poisonings with slip/mooring monthly billing statements;

Ensure that all concessionaires include CO safety issues in boat operator orientation materials (video, written, and verbal orientation) as a condition of their permit;

Print items such as "special attention" tent cards/wall notices that personalize the CO issue on past fatalities and near misses;

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2) NPS should ensure that similar educational programs are available for dissemination at other appropriate parks (those with waterbodies that allow powered boats).

3) GLCA should assess additional active strategies that could be implemented to prevent CO poisonings at Lake Powell. Examples of possible GLCA active strategies are included in the minutes of the June 19, 2002 interagency meeting. Additionally, GLCA should consider dedicating more resources to CO poisoning prevention efforts within the Park by filling positions such as that of the vacant safety officer. If filled, that position could coordinate visitor safety issues within the Park, including CO poisoning.

4) GLCA/NPS should work with the U.S. Coast Guard to determine the best method to ensure that boat manufacturers, boat distributors, sales staff members, and consumers are made aware of the hazards of CO from generator and propulsion engine exhaust and options for hazard reduction. Hazard communication materials for these groups should include detailed information, including the fact that fatal poisonings are possible even if exposure occurs outside of any enclosure or obstruction of engine emissions.

5) GLCA/NPS should continue to encourage research into effective control technologies to control CO emissions and exposures. Examples of such technologies include labeling of through hull exhaust fittings on boats, emission control devices, rerouting of exhaust, use of alternate fuels such as diesel, etc.

Figure 1. Incident scene

Figure 2. Closer detail

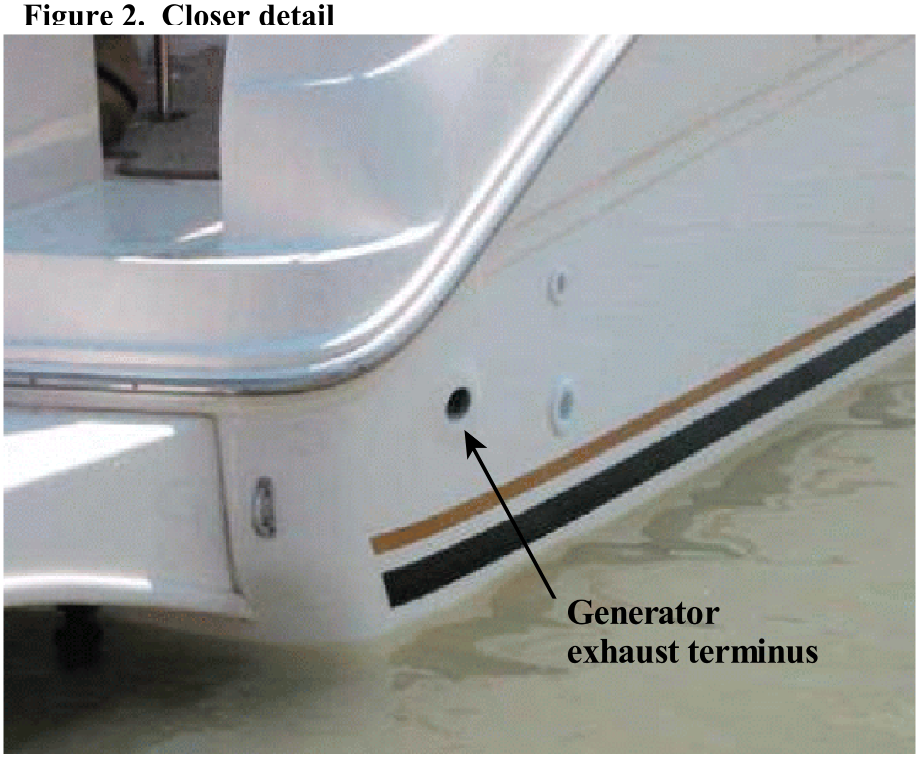


Figure 3. Placement of the boat during sampling on August 28th and 29th

Figure 4. Configuration of CO monitors on August 29, 2002, with red (largest) arrow denoting generator exhaust flow direction

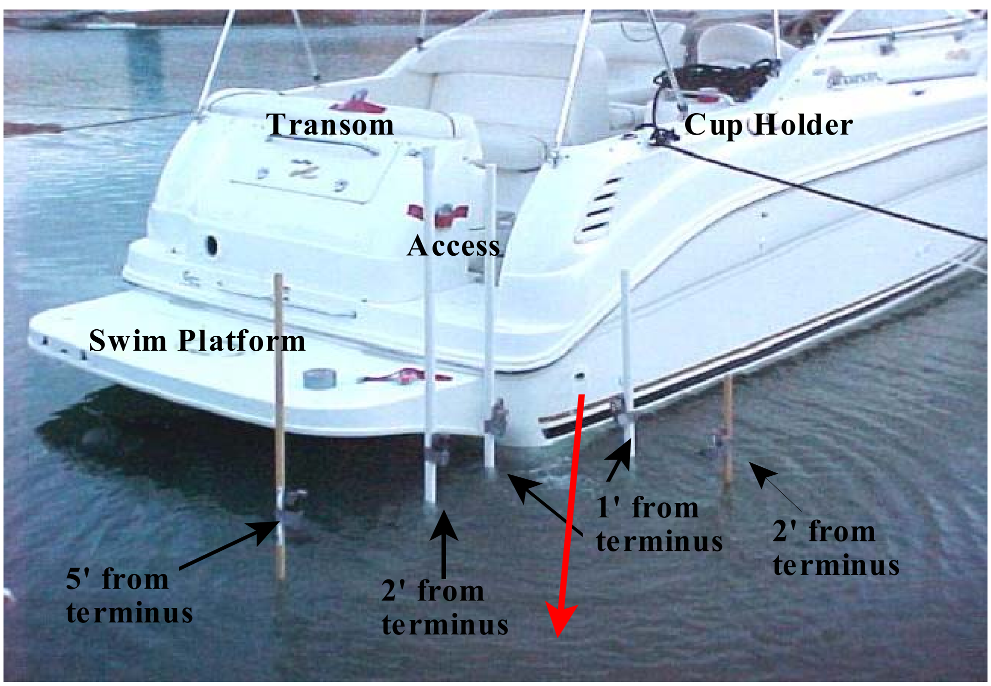
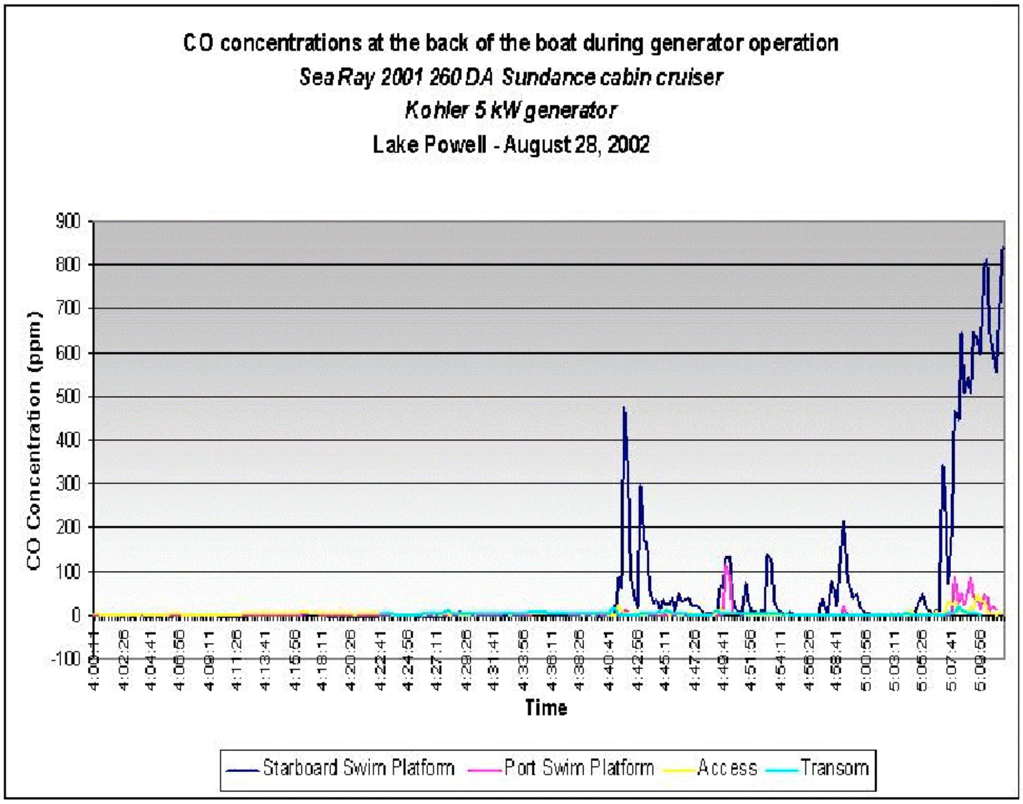


Figure 5. Maximum CO concentration measured at each location - August 29, 2002

Figure 6. Graph of CO concentrations measured concurrently using data recording monitors at four locations on the boat during high winds (prior to 4:40 on the x-axis) and a period of calmer winds (after 4:40 on the x-axis) on the first day of sampling



Please refer to Figure 4 for locations of these monitors. Figure 6 demonstrates the dramatic impact of wind on the accumulation of CO at the back of the boat. The generator was operating during this entire sampling period. The only difference was that winds calmed at 4:40, and the monitors began to detect much higher concentrations of CO, especially on the starboard side of the swim platform, where CO exceeded 800 ppm.

Figure 7. Graph of CO concentrations measured concurrently using data recording monitors at four locations relative to the generator exhaust terminus during high winds (prior to 4:40 on the x-axis) and a period of calmer winds (after 4:40 on the x-axis) on the first day of sampling

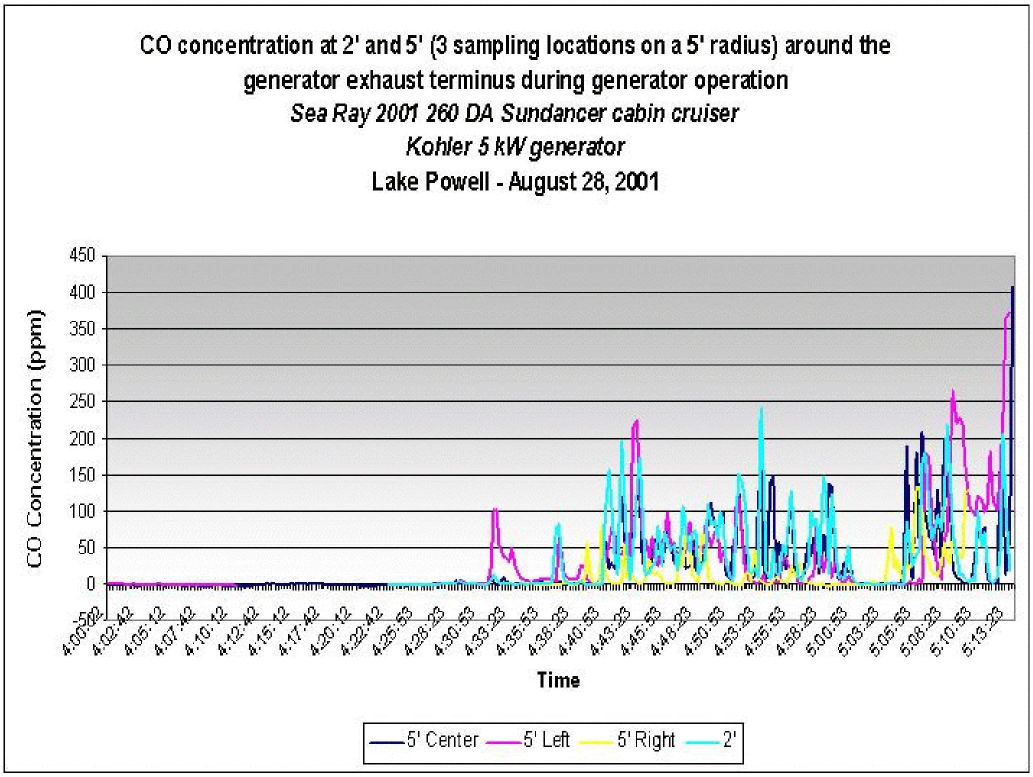


Figure 7 again demonstrates the dramatic impact of wind on accumulation of CO, even relatively close to the exhaust terminus. The generator was operating during this entire sampling period, with the only difference being that the wind died down a bit at approximately 4:30. The four line graphs are overlapped to show that CO concentrations rose concurrently, and that they were somewhat similar regardless of location.

Figure 8. Graph of CO concentrations measured concurrently using data recording monitors at three locations on the boat during the second day of sampling, during which wind speed ranged from 0 to 4 mph

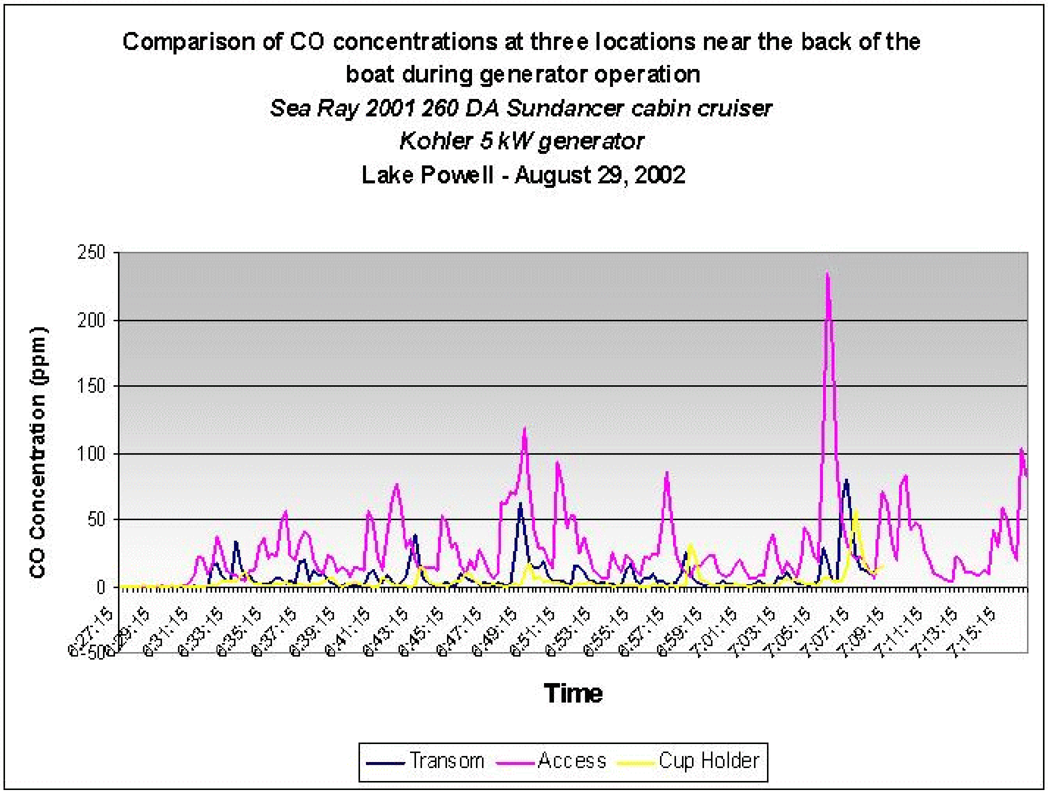


Figure 8 consolidates data from three locations on the boat, demonstrating relative consistency of patterns of CO dispersal, with one peak of short duration at the access point of the boat (this point is labeled in the photo of the boat presented in Figure 4) that exceeded the NIOSH ceiling limit of 200 ppm. The generator was activated at 6:30 at which point the air-conditioner was also activated to place a load on the generator. The air-conditioner was deactivated at 7:08, at which point two of these monitors were deactivated and relocated. The data from the remaining monitor indicates that CO concentrations at the access point to the boat were unaffected by the electrical load on the generator.

Figure 9. Graph of CO concentrations measured on the starboard side of the swim platform on August 29th, compared with those measured at the same location on August 28th

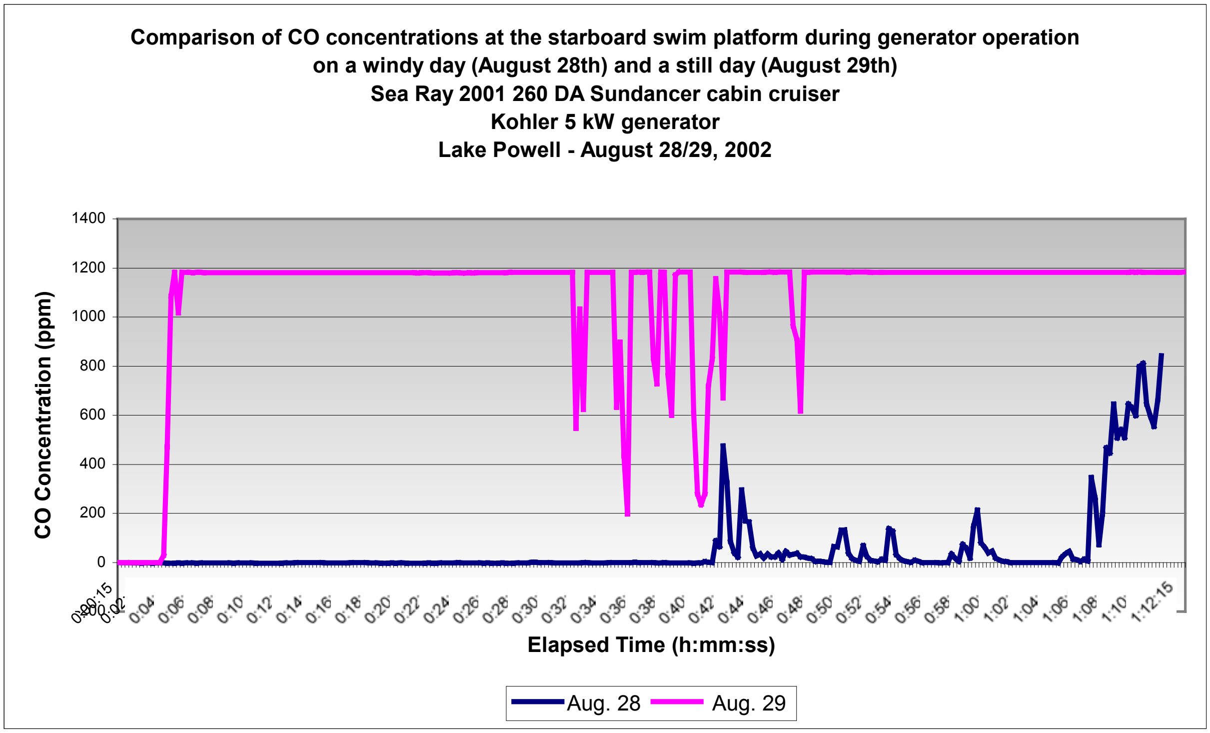


Figure 9 shows the dramatic impact of wind on CO accumulation on the rear swim platform during generator operation. On August 29th, CO concentrations were immediately in excess of the maximum concentration that could be quantified by the CO monitor (thus >1,200 ppm, which is the concentration considered to be immediately dangerous to life and health - IDLH) as soon as the generator was activated at 6:30 (marked by the immediate rise in CO concentration about 2 minutes into the sampling period). This consistent flat peak (indicating that concentrations were well in excess of this concentration) over the duration of sampling in combination with the CO measurements using another method with a higher range of detection capability (41,600 ppm measured 2" from the terminus and 36,500 ppm measured 6" from the terminus) indicate that CO concentrations on the swim platform during generator operation on a somewhat calm day were life threatening. In comparison, the data collected on August 28th, during high and variable winds, indicated that CO concentrations on the swim platform reached very high concentrations quickly as winds calmed late in the day. Changes in generator load on August 29th had no discernible impact on CO concentration at the swim platform.

Figure 10. Graph of CO concentrations measured concurrently using data recording monitors placed 1 foot from the exhaust terminus on the second day of sampling

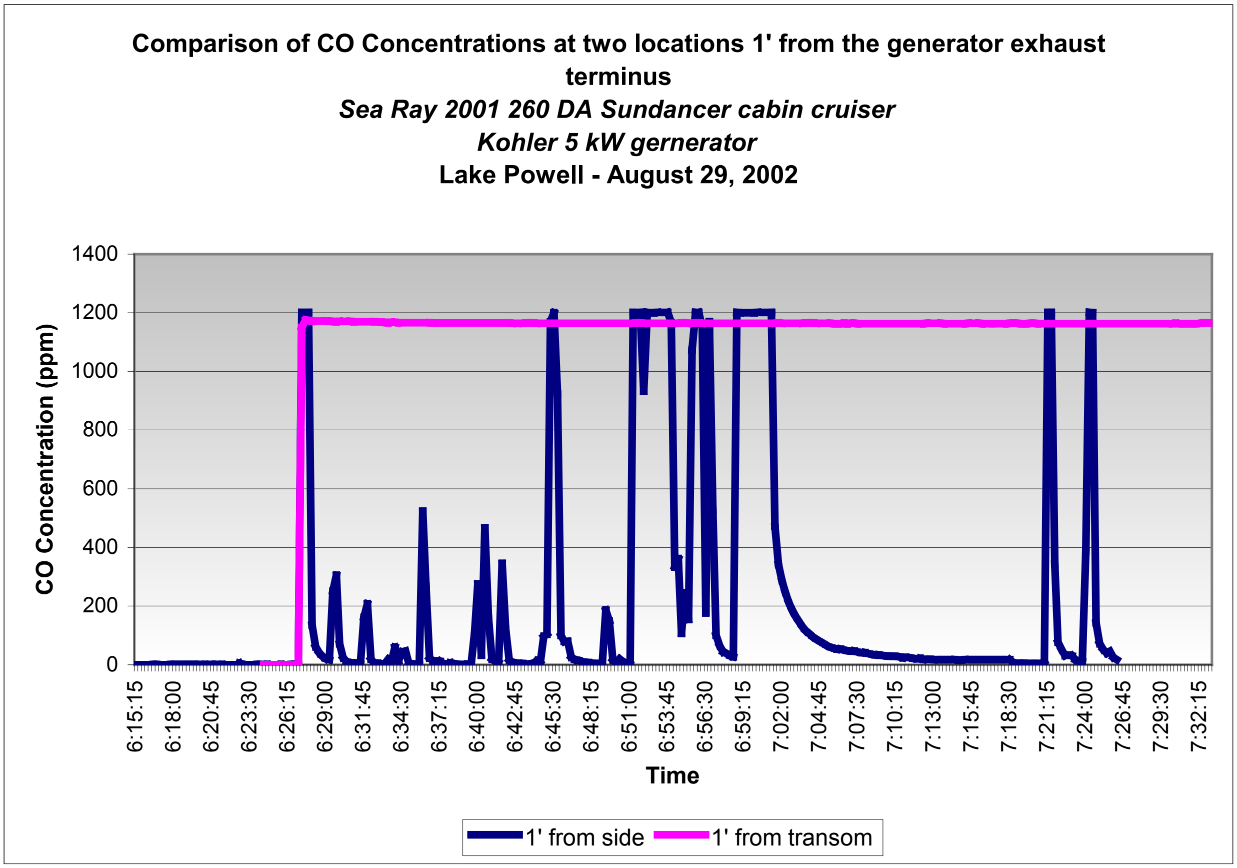


Figure 10 shows that the CO concentration 1 foot from the exhaust terminus perpendicular to the starboard transom was immediately in excess of the maximum concentration that could be quantified by the CO monitor (thus >1,200 ppm, which is the concentration considered to be immediately dangerous to life and health - IDLH) as soon as the generator was activated at approximately 06:30. This consistent flat peak in combination with the CO measurements using another method with a higher range of detection capability (41,600 ppm measured 2" from the terminus and 36,500 ppm measured 6" from the terminus) indicate that CO concentrations at this point were life threatening.

The generator operated under load (with the air-conditioner operating) from activation until 07:08, at which time the air-conditioner was deactivated. The air-conditioner was reactivated 20 minutes later (approximately 07:28 on the x-axis).

CO concentrations measured by the monitor placed 1 foot from the exhaust terminus perpendicular to the side of the boat also exceeded the maximum concentration that could be quantified with that method, although not as consistently as the one discussed above. Nevertheless, CO concentrations at this point exceeded the IDLH value for several minutes of the time the generator was in operation.

Figure 11. Graph of CO concentrations measured concurrently using data recording monitors placed 2 feet from the exhaust terminus on the second day of sampling

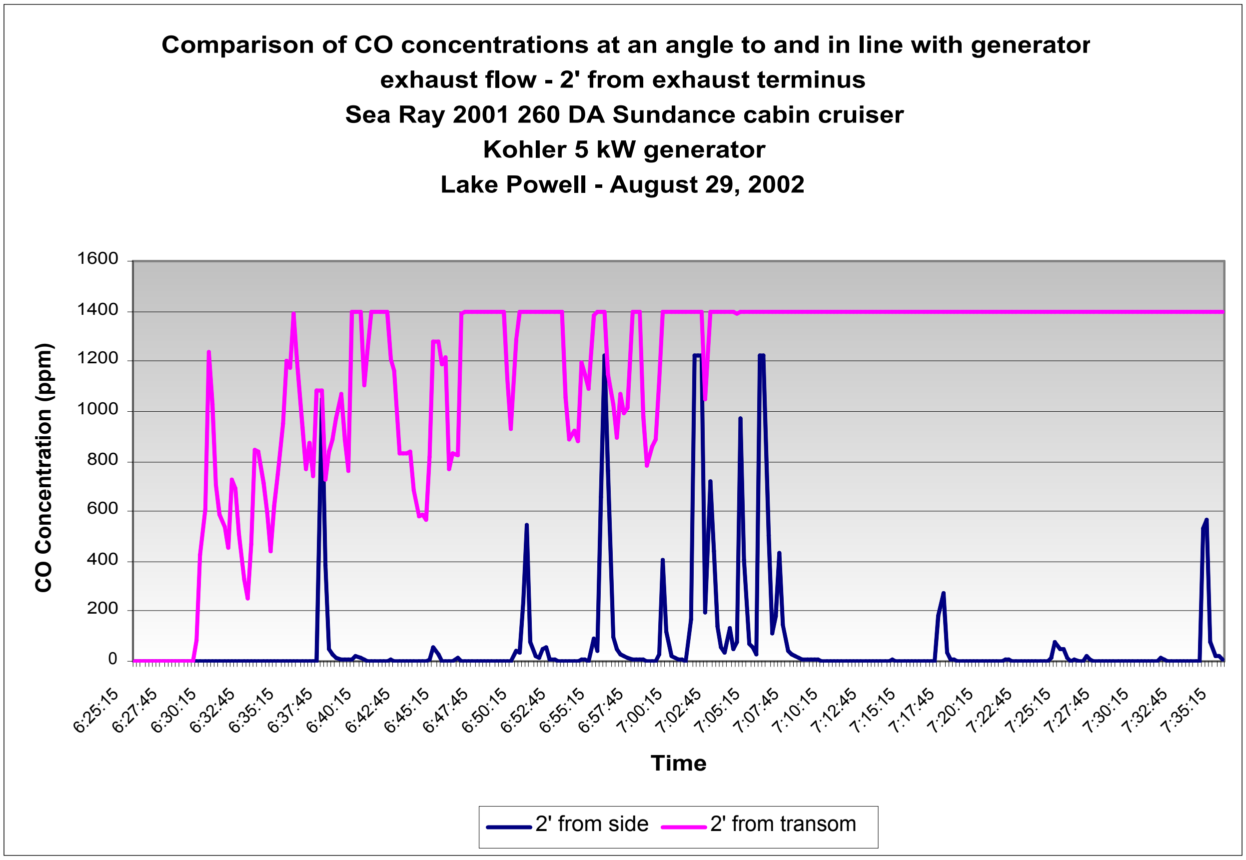


Figure 11 shows that CO exceeded immediately dangerous to life and health (IDLH) concentrations 2 feet from the generator exhaust terminus (in-line with the exhaust flow, perpendicular to the starboard transom) very quickly after the generator was activated, and soon exceeded the concentration quantifiable by these monitors (as indicated by the flat-topped peaks, and ultimately the flat line at 1400 ppm on the y-axis). This flat line in combination with the CO measurements using another method with a higher range of detection capability (41,600 ppm measured 2" from the terminus and 36,500 ppm measured 6" from the terminus) indicate that CO concentrations at this point were life threatening.

CO concentrations measured by the monitor placed 2 foot from the exhaust terminus perpendicular to the side of the boat also exceeded the maximum concentration that could be quantified with that method, although not as consistently as the one discussed above. Nevertheless, CO concentrations at this point exceeded the IDLH value for several minutes of generator operation.

Figure 12. Graph of CO concentrations measured concurrently using data recording monitors placed at the same location 5 feet from the exhaust terminus on the second day of sampling

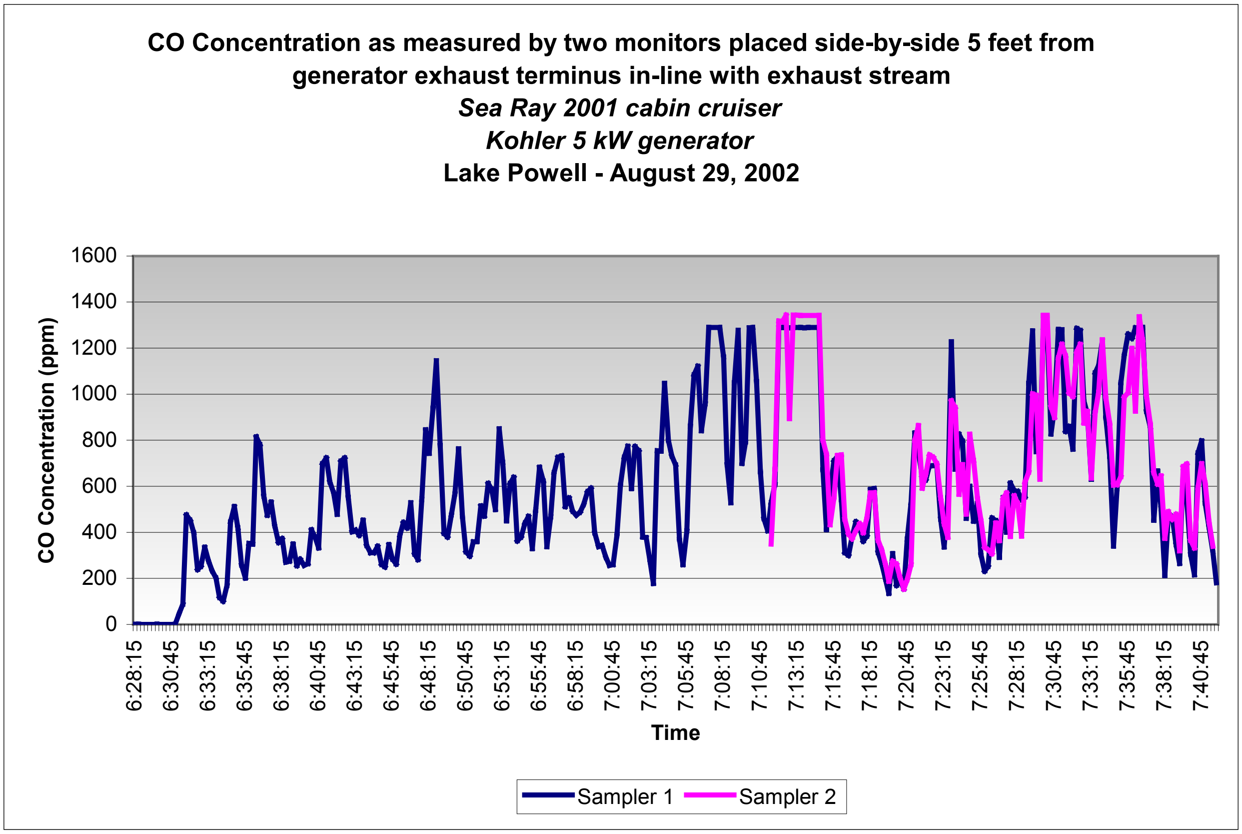


Figure 12 demonstrates excellent agreement between data recorded by two CO monitors at the same location (same day) 5 feet from the generator exhaust terminus perpendicular to the starboard transom. The second monitor was placed in this location about mid-way through the sampling period because the other monitor had peaked out, and we wanted to ensure that data were continuing to be recorded. CO concentrations at this distance were consistently in excess of the NIOSH CO exposure ceiling limit throughout the time of generator operation, exceeded the maximum concentration that could be quantified by the monitors (as demonstrated by the flat-topped peaks), and exceeded the immediately dangerous to life and health concentration many times during generator operation.

Figure 13. Graph comparing CO concentrations measured at the same location perpendicular to the starboard transom 5 feet from the generator exhaust terminus during a very windy day (August 28th) and a relatively calm day (August 29th)

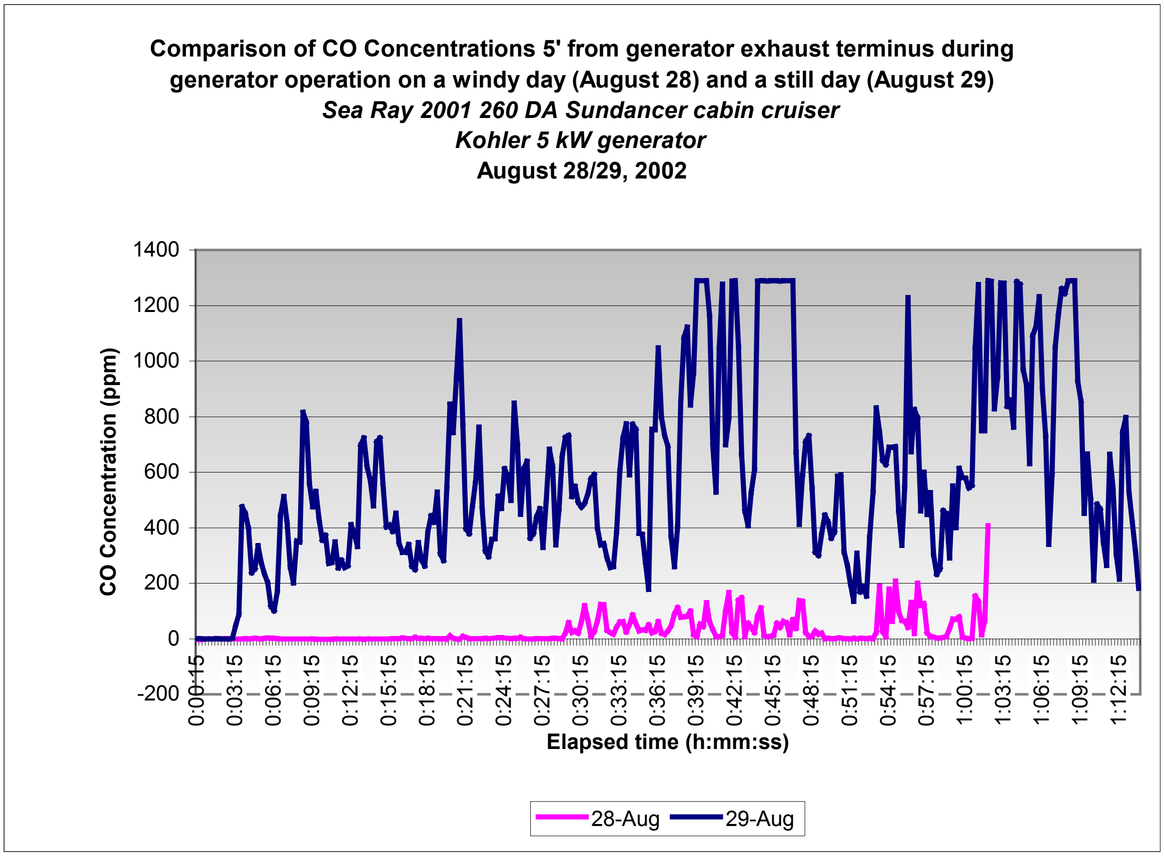


Figure 13 shows data from Figure 12 overlapped with data collected at the same location on the previous day during high and variable wind conditions. These data again illustrate the dramatic impact of wind on CO accumulation at distances behind the boat during generator operation.

Figure 14. Graph of CO concentrations measured using a data recording CO monitor while moving through different locations on a 10 foot distance from the generator exhaust terminus on the second day of sampling

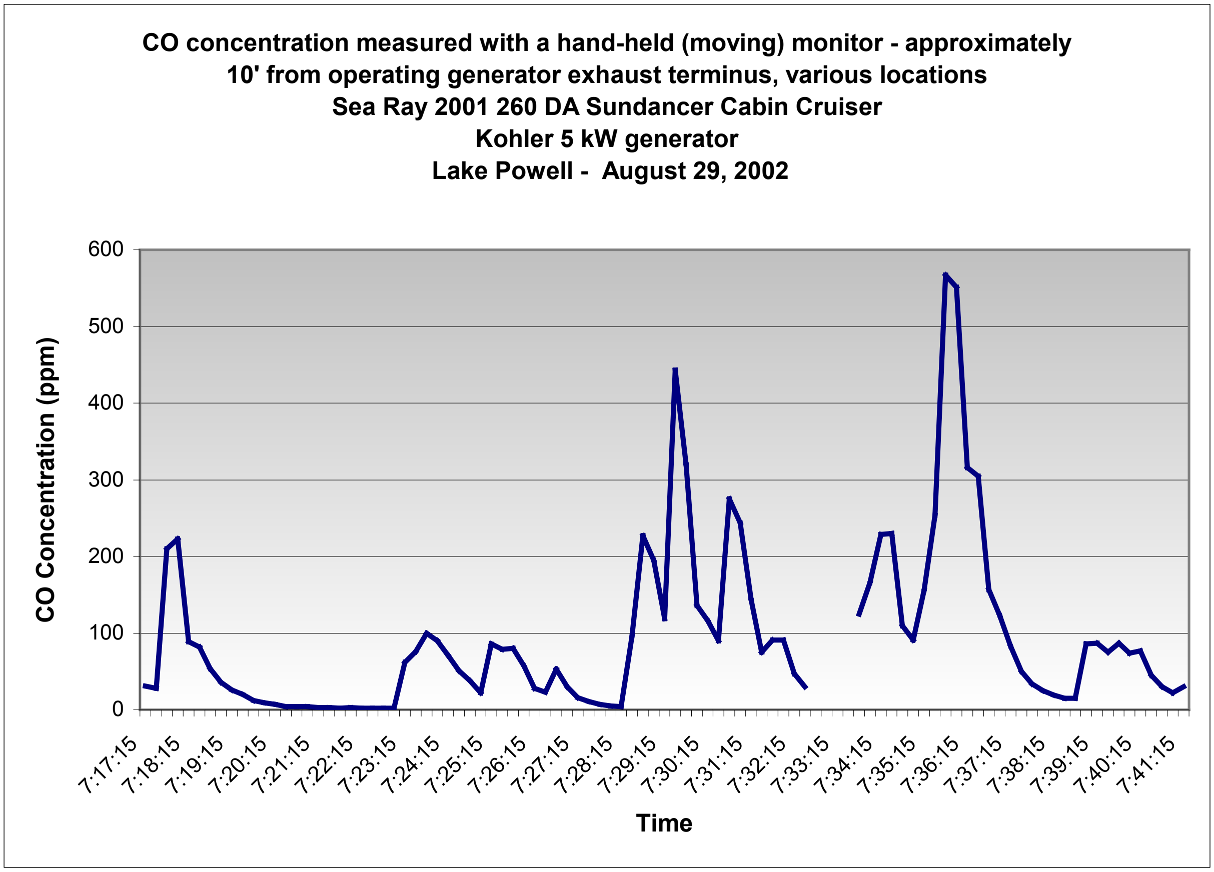


Figure 14 shows CO concentrations measured approximately 10 feet from the exhaust terminus during the last 25-minute period of generator operation.

Attachment 1
Health Effects of Exposure to Carbon Monoxide

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

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

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

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

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

Altitude 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]

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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

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Attachment 3

US NPS GLCA Incident Report