



National Institute for Occupational Safety & Health

Denver Field Office

Denver Federal Center
PO Box 25226
Denver, CO 80225-0226
(303) 236-6032
(303) 236-6072 FAX

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HETA 20000400
Interim

Kitty Roberts
Park Superintendent
US National Park Service Glen Canyon National Recreation Area
691 Scenic View Road
Page, Arizona 80604

Dear Ms. Roberts:

In July 2001, the National Institute for Occupational Safety and Health (NIOSH) monitored employee exposure to carbon monoxide (CO) at various locations within the US National Park Service (NPS) Glen Canyon National Recreation Area (GLCA). The purpose of this letter is to transmit the results of employee monitoring to you. Detailed results can be found in the enclosed report; a summary of the report follows.

Background

To date, NIOSH has measured GLCA employee CO exposures on three separate occasions. We have also assisted you in analyzing NPS Emergency Medical Service (EMS) response records from 1990-2001. In the previous exposure assessments, we characterized hazardous exposure zones near and under the rear deck and swim platforms of houseboats; measured employee CO exposures approaching the immediately dangerous to life and health (IDLH) concentration (1,200 parts per million [ppm]) during boat maintenance activities; and collected personal sampling results indicating that some workers were exposed to CO concentrations in excess of the NIOSH ceiling limit of 200 ppm.

Occupational CO Poisonings Reflected in NPS EMS Records

NPS EMS records indicate that 6 employees at GLCA have been poisoned as a result of CO exposure in 6 separate incidents since 1990. These records include both NPS and concessionaire employees. In all but one of these incidents, the employee experienced an acute exposure resulting in symptoms. Four of the 6 poisoned employees lost consciousness as a result of their exposure. Detailed information about the circumstances of these poisonings are provided within the report.

The most recent occupational exposure occurred in September 2001, when a concessionaire maintenance employee lost consciousness while tightening bolts on or under the swim platform of a houseboat (houseboat #1). This boat was tied to another houseboat (houseboat #2) on which the generator was operating. Houseboat #2's generator exhaust terminated on the side of the boat

directed toward houseboat #1, and consequently toward the employee. He was exposed in this position for approximately 2 minutes. His carboxyhemoglobin after 26 minutes of oxygen therapy was over 30%.

Synopsis of July 2001 Employee Exposure Monitoring

The outcome of the employee exposure monitoring conducted in July is summarized below. Please refer to the enclosed full text report for more detailed information.

Toll booth operator exposures at the North and South Entrance Stations and the Antelope Point Entrance station were consistently very low, with exposure concentrations averaged over the sampling period ranging from 0 to 2 ppm, and no peak exposure greater than 48 ppm at any time during the six days of sampling these employees.

Boat/Vehicle maintenance worker exposures measured during three days of sampling were also consistently very low, with average CO exposures during the sampling period ranging from 0 to 2 ppm, and peak exposures of 65 and 72 ppm. Unfortunately, we were not able to sample as many workers in this group as we had hoped, due to low participation by the concessionaire, and loss of one day's data (discussed more fully in the report).

Exposures of ***maintenance employees working at pump-out stations and collecting garbage*** (Lone Rock, State Line, Bullfrog) averaged over the sampling period ranged from 1 to 9 ppm. Peak exposures of these employees ranged from 13 to 685 ppm.

Maintenance employees conducting construction-related activities (operating a backhoe, installing water lines, working with a chainsaw) had exposures averaged during the sampling period ranging from 0 to 17 ppm. Peak exposures for this group ranged from 3 to 504 ppm.

Exposures of ***park rangers on boats*** conducting water quality patrol or other enforcement duties were monitored extensively. Exposures averaged over the sampling period measured during five days of workshifts for several employees in this group ranged from 0 to 16 ppm. Peak exposures during these same sampling periods ranged from 40 to 875 ppm.

Exposures of ***park rangers working on boat launch ramps*** were measured during three workshifts. Exposures averaged over the sampling period ranged from 0 to 3 ppm. Peak exposures ranged from 42 to 364 ppm.

The employee with the highest exposure measured during this survey was a ***fuel dock worker*** on the North lake who was exposed to 28 ppm averaged over an 8-hour workshift, with peak exposures greater than the reliable sampling range of our instruments (which is approximately 1,000 ppm).

Conclusions

The data above combined with environmental data from previous surveys at Lake Powell (and other similar workplaces) and occupational poisonings described in the enclosed report indicate

that, with one exception, peak CO exposures are the primary risk for the employee groups surveyed. The exception to this is the fuel dock worker whose average and peak exposures were in excess of recommended standards.

Data collected by NIOSH indicate the need for changes in work-practices and avoidance of specific situations. These are discussed in detail in the enclosed report, along with detailed recommendations to reduce the hazard of CO poisoning for employees.

We appreciated the chance to assist you in this effort. Please call me if you have any questions about the data we have provided.

Sincerely,

Jane Brown McCammon, CIH
NIOSH Denver Field Office Director

cc: Tim Radtke, DOI
Lloyd Olson, NPS Intermountain Region
Dr. Robert Baron
Richard Hartle, NIOSH/HETAB, Cincinnati OH

Interim Report

**Employee Exposure Assessments at
US National Park Service
Glen Canyon National Recreation Area**

July 2001

Background

Initial Request - This work is part of the ongoing interagency investigation of boat-related carbon monoxide (CO) poisonings at GLCA on Lake Powell, and elsewhere in the United States. In the initial request for NIOSH assistance, the National Park Service (NPS) and Department of Interior (DOI) expressed concern about employee exposures related to a number of fatal and non-fatal poisonings that had occurred on boats at Lake Powell. The agencies pointed out that NPS and concessionaire employees occupy privately-owned, company-owned, and government-owned boats for reasons including maintenance, boat transfer, lake patrol, provision of Emergency Medical Services, etc., and as such, employee exposures were of concern.

Previous investigations - An initial investigation was conducted in September 2000 involving representatives from NIOSH, US Coast Guard, US National Park Service, and Utah Parks and Recreation in response to CO related poisonings and deaths on houseboats at Lake Powell. This investigation identified the severity of the CO poisonings through epidemiologic data gathering, and the potential for acute carbon monoxide exposures on houseboats at Lake Powell. A record search revealed 9 known boat-related CO poisoning deaths (8 incidents) on the lake since 1994. Some of these incidents involved numerous poisonings in addition to the deaths reported. Information regarding these poisonings was summarized in the December 15th, 2000 edition of the Centers for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Report (MMWR).

To determine employee CO exposure concentrations, NIOSH conducted limited employee exposure assessments at Lake Powell in September 2000. As discussed in our September 28, 2000 letter to Mr. Joe Alston, Park Superintendent at that time, we documented three severely hazardous situations:

- 1) The environment in the open space under the swim platform was identified as being lethal under certain circumstances on some houseboats and should not be entered by anyone for any reason as was demonstrated by measurements as high as 30,000 parts of CO per million parts of air (ppm) in that space, and a concurrent oxygen deficiency of 12% in the space;
- 2) The environment above and around the swim platform was identified as being hazardous when CO measurements indicated concentrations in the immediately dangerous to life and health (IDLH) category (IDLH for CO is defined as greater than 1,200 ppm);
- 3) Employees exposures to CO during boat maintenance activities indicated that employees may be exposed to hazardous concentrations of CO as was evidenced by the short-term, near the IDLH concentrations measured on one maintenance employee.

Among our many recommendations in that report, we pointed out that the concessionaire should immediately investigate engineering controls to reduce exposures of boat maintenance mechanics. We also recommended that training about the severity of CO hazards in boating be developed for NPS employees, to include both environmental data and information about the number and

circumstances of CO poisonings on the lake. We outlined future directions of the interagency investigation of CO poisonings, to include monitoring of NPS and concessionaire employee exposures to CO and noise during boat operation and maintenance.

In a second investigation at Lake Powell (conducted in October 2000), we confirmed our earlier findings regarding potential excessive CO exposures near and under the swim platform of houseboats of a certain design. This work has now been repeated at several locations. In our November 8th, 2000 letter to Mr. Joe Alston, we summarized employee monitoring results. Personal sampling results during that survey indicated that some workers were exposed to CO concentrations that exceed the NIOSH ceiling limit of 200 ppm. One Park Service maintenance worker was exposed to a peak CO concentration of 780 ppm.

We repeated our earlier recommendations, provided guidelines for proper entry into this space, and added the following to help reduce worker exposures:

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. This recommendation is based on the following discussion.

Record reviews indicate 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.

NIOSH has warned of the hazard of “rafting” boats (tying two or more boats together) while engines of any kind are operating, especially if the generator is operating. In the September 28, 2000 report to Mr. Alston, we pointed out that:

Although none of the fatalities or poisonings reviewed during this investigation occurred on concessionaire boats, side-exhausting of generator exhaust will present hazards under certain circumstances. If two such boats are aligned, exhaust is directed into the neighboring boat and along the channel created between the two boats. During this investigation, IDLH concentrations of CO (greater than 1,000 ppm) were directed along this channel.

The hazardous effect of mooring boats closely together while CO is being produced has also been demonstrated and discussed by the American Boat and Yacht Council (ABYC) in educational

materials presented in ABYC TH-22, Educational Information about Carbon Monoxide.

Employee CO poisonings - NPS EMS records indicate that there have been two government and five concessionaire employees poisoned since 1990. Six of these poisonings occurred outside of the cabin or canopy-enclosed area of the boat. Five of these poisonings occurred on houseboats and two occurred on pleasurecraft. Four of the seven employees poisoned lost consciousness as a result of their exposure.

The outdoor poisonings occurred when the individual employee was:

- 1) working on fuel leak with the houseboat generator operating (the victim's carboxyhemoglobin [COHb] concentration was 27.2% after 70 minutes on oxygen - which is approximately one half-life - indicating that the initial concentration could have been as high as 54%)
- 2) repairing a propeller under the houseboat
- 3) changing a propeller under the houseboat
- 4) working at rear of a moving boat
- 5) riding on boat all day
- 6) tightening bolts while lying on a houseboat swim deck

The most recent occupational poisoning (September 2001) reinforces our concerns about side-exhausted generators on houseboats, and the potential for acutely hazardous employee exposure in certain circumstances. This concessionaire employee lost consciousness while lying on the swim deck of a houseboat. According to the NPS record of this incident, his head was within two feet of the generator exhaust terminus of the next houseboat. The generator was operating. While lying on the deck, he leaned his head over to tighten bolts under the deck. He was in that position for about two minutes when he lost consciousness. His COHb concentration measured after 26 minutes on oxygen was over 30%.

Environmental Sampling Methods and Materials

The size, remoteness, and logistics involved with assessing employee exposures throughout the entire lake necessitated that two NIOSH teams conduct the sampling described in this report. One team began sampling on Thursday, July 12th. They placed CO monitors with two Park Rangers who were assigned to a three-day Water Quality Patrol on the North part of the lake. This NIOSH team then traveled to Page (the South part of the lake) to continue employee exposure monitoring. The second NIOSH team began sampling on July 17th, and were based exclusively at Bullfrog (North part of the lake).

Personal breathing zone (PBZ) CO concentrations were measured on NPS and concessionaire employees using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. All ToxiUltra CO monitors used on the North lake were calibrated before the site visit and zeroed after each use according to the manufacturer's recommendations. ToxiUltra monitors used on the South lake were calibrated before and after each use. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode, with a 15 second, 30 second, and 1-minute sampling intervals, depending on the

instrument. The instruments have a nominal range from 0 to 500 ppm with the highest instantaneous reading of 1000 ppm. The instruments were also used to measure general area CO concentrations in various locations on NPS and Utah State boats on the North lake.

Fee booth operators rotated individual CO monitors when they rotated shifts. So, for example, data listed for Fee Booth 1 may have represented personal sampling of exposures for as many as three different operators during the period. Thus, data collected represented a “worse case” situation of exposure during the entire sampling period, rather than the exposure of one individual.

Grab samples were collected on boats on the North lake using Mine Safety and Health Administration (MSHA) 50–milliliter (mL) evacuated glass containers. These instantaneous samples were collected by snapping open the top of the 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.

Health Effects and Evaluation Criteria

Information about health effects and evaluation criteria for CO are included as Attachments 1 and 2.

Personal and Area Sampling Results - North Lake NIOSH Team

July 17, 2001

Personal samples were collected on NPS and Aramark employees on July 17, 2001. The Utah State Patrol boat was evaluated in the morning hours during routine activities. The boat was equipped with two Yamaha, 115 horsepower (hp), four stroke fuel–injected engines. A personal CO monitor was placed on the boat operator and area CO monitors were placed at the back of the boat, in the general vicinity of the boat operator, and at the front of the boat. Three evacuated container samples (near the engines, near the boat operator, and at the front of the boat) were also collected. Table 1 lists the results of personal and area sampling on this day.

Figures 1 and 2 illustrate the real–time CO concentration data for two CO monitors. Figure 1 displays the CO concentration data of the maintenance worker who worked at Hall’s Crossing pumping out sewage and collecting garbage. At approximately 11:45 AM, the worker was exposed to a peak CO concentration of 685 ppm while filling the vacuum pump with oil while the truck was still running. Figure 2 displays the CO concentrations in the back of the Utah State Patrol boat during routine operations on the lake. Peaks are indicative of the combination of the patrol boat and other boats that were stopped while performing patrol activities on the lake.

Three evacuated cylinder samples were collected on the Utah State Patrol boat in Forgotten Canyon while the engines were idling. Samples were collected at the back of the boat near the engines, near the boat operator, and at the front of the boat. The CO concentrations were

585 ppm, 28 ppm, and 11 ppm, respectively.

July 18, 2001

Personal samples were collected on NPS and Aramark employees on July 18, 2001. NPS Patrol boat (#262) was evaluated underway during the morning hours. The boat was equipped with two Mercury, 200 hp, outboard fuel-injected engines. A personal CO monitor was placed on the boat operator, and area CO monitors were placed at the back and front of the boat. Three evacuated container samples (near the engines, near the boat operator, and at the front of the boat) were also collected.

Three evacuated cylinder samples were collected on the NPS Patrol boat (262) while the engines were idling in a canyon. The air movement in the canyon was blowing the engine exhaust to the side of the boat. Samples were collected at the back of the boat near the engines, near the boat operator, and at the front of the boat. The CO concentrations were 246 ppm, 10 ppm, and not detected above the method detection limit, respectively.

During this evaluation, the boat operator responded to an emergency call on the lake. Figure 3 indicates CO concentrations during this time period during which the patrol boat with operating propulsion engines was next to a houseboat on which the generator was operating.

Figure 4 illustrates the real-time CO concentration data for the fuel dock worker during normal daily operations.

Another NPS boat was evaluated underway during the afternoon hours. This boat is a 24 foot Gulfstream Cabin cruiser. The boat was equipped with a 350 Mercruiser, 5.7 liter, V-8 engine with 1,912 hours. A personal CO monitor was placed on the boat operator and area CO monitors were placed at the back and front of the boat. Table 2 lists the results of personal and area sampling on this day.

July 19, 2001

Personal samples were collected on NPS employees on July 19, 2001. NPS Patrol boat (#261) was evaluated underway during the morning hours. The boat was equipped with a 454 Magnum Bravoone (Mercruiser) engine. A personal CO monitor was placed on the boat operator and area CO monitors were placed at the back and front of the boat. Table 3 lists the results of personal and area sampling on this day. Figures 5 and 6 illustrate the real-time CO concentration data for two CO monitors.

Personal and Area Sampling Results - South Lake

All monitoring conducted on the South lake was personal (i.e., no area sampling was done). In order to measure exposures of as many employees as possible, the NIOSH team distributed monitors and sheets for logging handwritten information to a wide variety of employees. Employees were asked to note activities occurring when the alarm sounded, as well as any other information they thought might be relevant to interpretation of the data. Some employees

provided very detailed information, while others provided very little.

Graphs depicting detailed information about data collected during workshifts are included as Figures 7 - 52. Each graph is accompanied with information about the average CO concentration measured, as well as the highest short-term average exposure concentration and the peak exposure measured during the sampling period. Other pertinent information noted by the employee is also listed.

Toll booth operator exposures at the South Entrance Station and the Antelope Point Entrance station were consistently very low, with CO exposures ranging from 0 to 2 ppm, and no peak exposure greater than 48 ppm.

Boat/vehicle maintenance worker exposures were also consistently low, with CO exposures ranging from 0 to 2 ppm, and peak exposures of 65 and 72 ppm. Unfortunately, we were not able to sample as many workers in this group as we had hoped, because some of their sampling data were lost, and there was low participation by the concessionaire.

Exposures of **maintenance employees working at pump-out stations** (Lone Rock and State Line) ranged from 1 to 9 ppm. Peak exposures of these employees ranged from 13 to 685 ppm.

Park rangers exposure while conducting water quality patrol or other boat patrol enforcement duties 0 to 16 ppm. Peak exposures ranged from 40 to 875 ppm.

Exposures of **park rangers working on boat launch ramps** ranged from 0 to 3 ppm. Peaks exposures ranged from 42 to 364 ppm.

Five sets of data were lost. Three data sets were collected on monitors placed with Park Rangers and a maintenance employee at Dangling Rope marina. Because the NIOSH team was not able to make contact with these employees before the end of the survey, the monitors were shipped to NIOSH in Denver. Unfortunately, the monitors arrived several days after the survey, still operating. As such, the data storage capacity of the monitors had been exceeded, and data from the days of employee monitoring had been overwritten. A fourth data set (monitoring of a boat/vehicle maintenance employee's exposure) was destroyed during data transfer. The fifth set of data (Park Ranger on ramp duty) was lost along with the monitor itself when it fell into the lake.

Discussion

NPS maintenance personnel may be exposed to high CO concentrations through various tasks involving the use of uncontrolled gasoline-powered engines that produce massive quantities of CO. These exposures are greatly impacted by variations of air movement during work conducted outdoors and location of the employee relative to the engine on which they are working.

The most recent occupational CO poisoning (discussed earlier, occurring in September 2001)

demonstrates the importance of ensuring that all employees understand the severity of the hazard posed by placing themselves near the exhaust of any operating engine (generator or propulsion).

NPS and Utah State Patrol personnel stationed on boats have potential exposure to CO above the NIOSH ceiling limit. The potential increases as the employee nears the back of the boat during engine operation. When patrol officers detain another boat, rafting to the boat increases the potential for high CO exposures if any engines are operating at the time. Table 2 and Figure 3 provide CO concentration data when a patrol boat responded to a call concerning a potential heart attack victim. The patrol boat tied off to the back of the houseboat with the houseboat generator running. Even though the patrol officer boarded the houseboat and was away from the exhaust of both boats, CO accumulated reaching very high concentrations on the back of the patrol boat. Figure 32 (July 13th, Water Patrol North Lake) similarly shows that when two boats raft together, employees experience high peak CO exposures.

Recommendations

Although employee CO exposures measured during this survey were generally low (with the exception of the fuel dock worker), peak CO exposures exceeding the NIOSH ceiling limit, and several past CO poisonings indicate the need for the following recommendations.

1. Employees on boat patrol duties should be made aware of CO hazards and be careful to stay away from boat engine and generator exhaust as much as possible.
2. Employees should avoid rafting boats together as much as possible. If boats must be rafted (as is the case for EMS responses, etc.), employees should ensure that all engines (including auxiliary engines, such as generators) are deactivated. Employees should avoid occupancy of the rear of the boat until engines are deactivated and exhaust has dissipated.
3. Results from previous sampling indicate that employers (NPS and concessionaire) of boat/vehicle engine maintenance staff should conduct further CO monitoring on these employees. NIOSH was unable to conduct extensive sampling of these employees during this survey.
4. NPS should ensure that further full-shift CO exposure monitoring is conducted for fuel dock workers. Sampling results indicate that these employees experience exposures over existing NIOSH and ACGIH recommended limits, including peak exposures greater than 1,000 ppm, above the NIOSH IDLH concentration. Significant exposure reduction may be accomplished through improved employee training and awareness of risk, as well as improved work practices such as ensuring that all engines, including generators, are deactivated before boats are refueled.
5. Maintenance employees should never work anywhere on or near the rear deck of houseboats when the generator or propulsion engines are operating. Employees should never place themselves in close proximity to the exhaust terminus of a generator.
6. NPS and their concessionaires should ensure that recommendations in previous NIOSH

reports related to CO exposures and potential CO poisonings are evaluated and implemented.

Attachment 1

Health Effects of Exposure to Carbon Monoxide

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

Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb). Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body. Once absorbed into the bloodstream, the half-life of bloodborne CO at sea level and standard pressure is approximately five hours. This means that an initial COHb level of 10% could be expected to drop to 5% in five hours, and then 2.5% in another five hours. If oxygen is administered to the exposed person, as happens in emergency treatment, the COHb concentration drops more quickly. Once exposed, the body compensates for the reduced bloodborne oxygen by increasing cardiac output, thereby increasing blood flow to specific oxygen-demanding organs such as the brain and heart. This ability may be limited by preexisting heart or lung diseases that inhibit increased cardiac output.

The altitude of this lake is 3,500 feet. Altitude effects the toxicity of CO. With 50 ppm CO in the air, the COHb level in the blood is approximately 1% higher at an altitude of 4,000 feet than at sea level. This occurs because the partial pressure of oxygen (the gas pressure causing the oxygen to pass into the blood) at higher altitudes is less than the partial pressure of CO. Furthermore, the effects of CO poisoning at higher altitudes are more pronounced. For example, at an altitude of 14,000 feet, a 3% COHb level in the blood has the same effect as a 20% COHb at sea level.⁽⁷⁾

References

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Attachment 2 Evaluation Criteria

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency, and cannot ignore the overlapping exposure concerns in this type of setting. National Park Service and concessionaire 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-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's guidelines are intended to ensure that carboxyhemoglobin levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

- 100 mg/m³ (87 ppm) for 15 minutes
- 60 mg/m³ (52 ppm) for 30 minutes
- 30 mg/m³ (26 ppm) for 1 hour
- 10 mg/m³ (9 ppm) for 8 hours

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Table 1. Area and PBZ CO Concentrations on July 17, 2001 at Bullfrog Marina, Lake Powell

Worker/Location	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Maintenance – sewage pumper/garbage pick-up	482	9	685
Maintenance – installing water lines	514	0	3
Backhoe operator	492	0	76
Area – toll booth	443	0	6
Fuel dock worker	415	4	116
Worker collecting water samples on lake	382	1	33
Utah State Patrol Boat			
State Patrol Officer – boat operator	289	2	56
Area – on back of boat	206	15	313
Area – near boat operator's area	205	6	161
Area – front of boat	204	3	88
NIOSH ceiling limit for CO exposure is 200 ppm.			

Table 2. Area and PBZ CO Concentrations on July 18, 2001 at Bullfrog Marina, Lake Powell

Worker/Location	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Maintenance – sewage pumper/garbage pick-up	487	1	63
Maintenance – various activities	535	3	146
Backhoe operator	509	1	98
Area – toll booth	553	0	31
Fuel dock worker	501	28	1150
Worker collecting water samples on lake	335	2	375
NPS Patrol Boat (262)			
NPS Patrol Officer – boat operator	95	7	134
Area – back of boat	83	108	623
Area – front of boat	83	5	127
NPS 24' Gulfstream			
NPS Ranger – boat operator	493	1	64
Area – back of boat	87	4	77
Area – front of boat	87	2	63
NIOSH ceiling limit for CO exposure is 200 ppm.			

Table 3. Area and PBZ CO Concentrations on July 19, 2001 at Bullfrog Marina, Lake Powell

Worker/Location	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Maintenance – working with chainsaw	254	17	504
Maintenance – boats and pump-out	244	4	225
NPS Boat (261)			
State Patrol Officer – boat operator	104	16	356
Area – on back of boat	106	22	335
Area – front of boat	105	10	136
NIOSH ceiling limit for CO exposure is 200 ppm.			

Table 4. CO Concentrations using Evacuated Cylinders at Bullfrog Marina, Lake Powell

Location	Date	Sample Time	CO Concentration (ppm)
State Patrol Boat – Forgotten Canyon – idling engines – near engines	July 17, 2001	11:43 AM	585
State Patrol Boat – Forgotten Canyon – idling engines – near boat operator		11:43 AM	28
State Patrol Boat – Forgotten Canyon – idling engines – front of boat		11:43 AM	11
NPS Patrol Boat – in canyon – idling engines – front of boat	July 18, 2001	10:10 AM	246
NPS Patrol Boat – in canyon – idling engines – near engines		10:11 AM	10
NPS Patrol Boat – in canyon – idling engines – near boat operator		10:12 AM	ND

ND = not detected above the method detection limit

Table 5. PBZ CO Concentrations - Park Rangers

Worker Location, Date	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Water Quality Patrol, S Lake, Boat 234, July 13	359	5	100
Water Quality Patrol, S Lake, Boat 234, July 13	354	6	90
Park Ranger, Dangling Rope, July 14	184	2	100
Park Ranger, Dangling Rope, July 15	603	1	122
Launch Ramps/Roving S Lake, July 14	571	0*	86
Water Quality Patrol, S Lake, Boat 284, July 14	524	2	68
Enforcement Patrol, S Lake, July 14	466	8	220
Water Quality Patrol, S Lake, Boat 234, July 14	519	3	187
Launch Ramp and Water Quality Patrol, S Lake, July 14	571	1	40
Enforcement Patrol, S Lake, July 14	480	11	158
Water Quality Patrol, S Lake, July 15	538	2	73
Launch Ramp, Lone Rock/Antelope Point, July 15	552	3	364
Water Quality Patrol, S Lake, July 16	468	6	261
Roving (launch ramp, hiking), S Lake, July 16	530	1	42
Enforcement activities, S Lake, July 16	476	2	56
Water Quality Patrol, S Lake, July 17	561	2	48
Water Quality Patrol, S Lake, July 17	550	2	124
Boat Patrol, S Lake, July 17	556	1	9
Water Quality Patrol, N Lake, July 12	235	3	119
Water Quality Patrol, N Lake, July 12-13 (evening hours)	720	1	5
Water Quality Patrol, N Lake, July 13	719	6	168
Water Quality Patrol, N Lake, July 13-14 (evening hours)	719	0*	5
Water Quality Patrol, N Lake, July 14	169	14	875
Water Quality Patrol, N Lake, July 14	445	2	49

Table 5 (continued). PBZ CO Concentrations - Park Rangers

Worker Location, Date	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Water Quality Patrol, N Lake, July 12-13 (evening hours)	560	1	8
Water Quality Patrol, N Lake, July 13	719	8	264
Water Quality Patrol, N Lake, July 13-14 (evening hours)	719	0*	5
Water Quality Patrol, N Lake, July 14	616	6	494
NIOSH ceiling limit for CO exposure is 200 ppm.			

*This value represents rounding of data averaged over the sampling period. As can be seen in the column representing peak exposure concentrations, CO was detected during the period.

Table 6. PBZ CO Concentrations - Maintenance Workers, S Lake

Worker/Location	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
Boat/Vehicle Maintenance Shop, S Lake, July 13	534	2	72
Dock Maintenance, Main/State Line Pump- Out Dock, July 13	550	7	326
Dock Maintenance, State Line Pump-Out Dock, July 14	493	1	13
Dock Maintenance, Lone Rock Pump-Out Dock, July 14	539	1	29
Dock Maintenance, Lone Rock Pump-Out Dock, July 15	499	1	53
Dock Maintenance, Pump-Out Dock, July 15	573	2	78
Boat/Vehicle Maintenance Shop, S Lake, July 17	519	0*	65
NIOSH ceiling limit for CO exposure is 200 ppm.			

*This value represents rounding of data averaged over the sampling period. As can be seen in the column representing peak exposure concentrations, CO was detected during the period.

Table 7. PBZ CO Concentrations - Fee Booth Operators, S Lake

Worker/Location	Sample Time (# of minutes)	Average CO Concentration During Sampling Period (ppm)	Peak CO Concentration During Sampling Period (ppm)
South Entrance Station, Fee Booth 1, July 13	325	2	9
South Entrance Station, Fee Booth 2, July 13	456	1	11
South Entrance Station, Fee Booth 3, July 13	200	1	8
Antelope Point Fee Booth, July 14	497	1	47
South Entrance Station, Fee Booth 1, July 14	566	0*	40
South Entrance Station, Fee Booth 2, July 14	573	1	23
Antelope Point Fee Booth, July 15	521	2	38**
South Entrance Station, Fee Booth 2, July 15	581	1	10
South Entrance Station, Fee Booth 3, July 15	580	1	48
NIOSH ceiling limit for CO exposure is 200 ppm.			

*This value represents rounding of data averaged over the sampling period. As can be seen in the column representing peak exposure concentrations, CO was detected during the period.

**This value may represent interference from ammonia used during this sampling period. Please see Figure 49 for further detail.

Figures 1 and 2. Real-time CO Concentrations on July 17, 2001 at Bullfrog Marina, Lake Powell

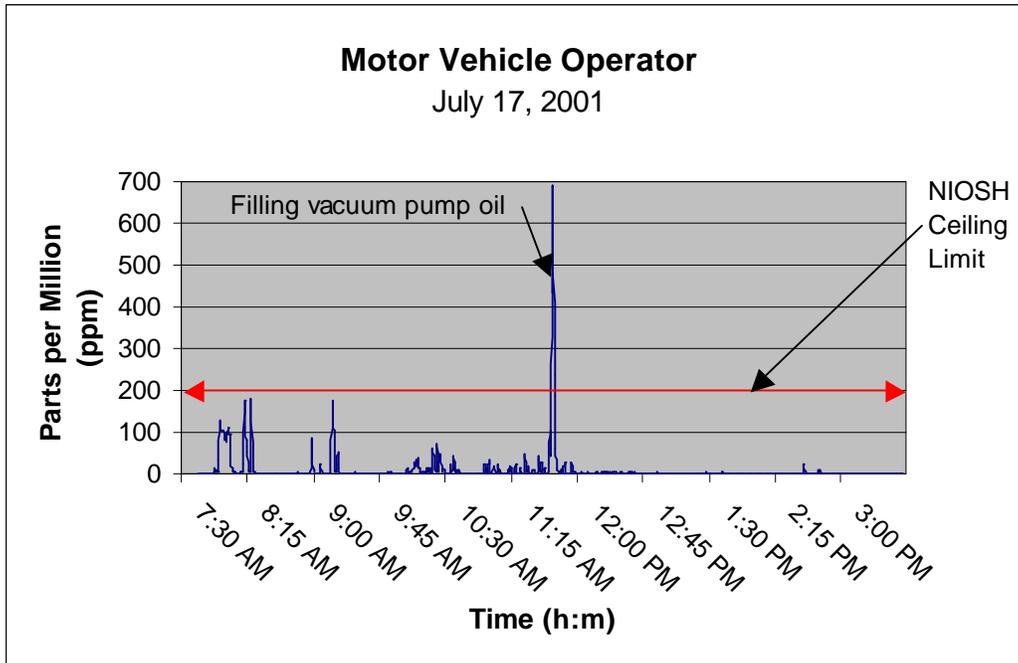


Figure 1. Hall's Crossing – sewage pumper and garbage pick-up.

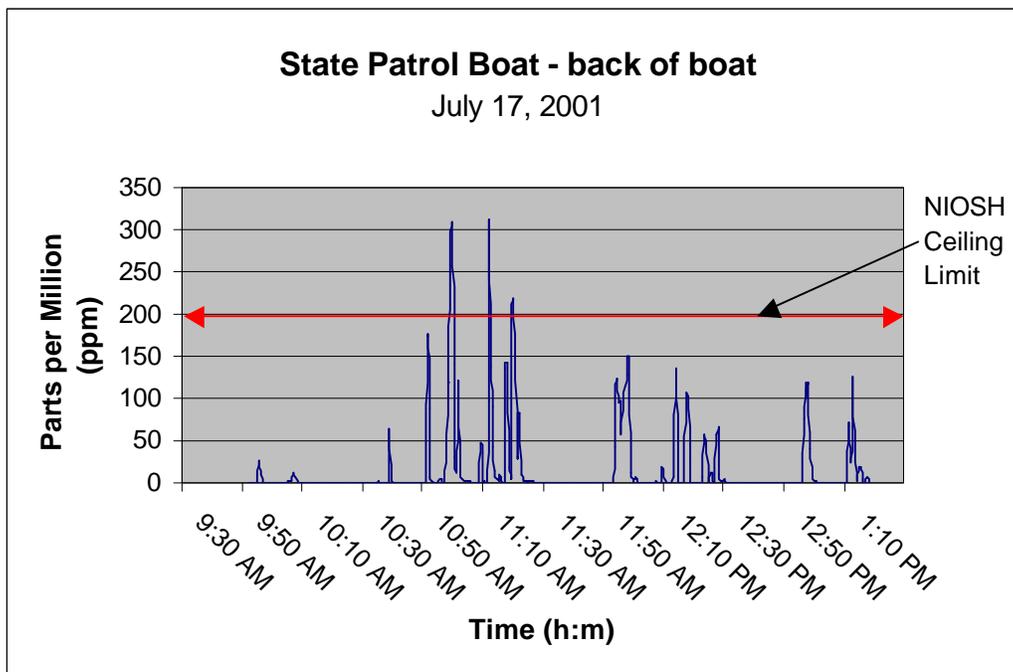


Figure 2. Area sample on back of underway State Patrol Boat.

Figures 3 and 4. Real-time CO Concentrations on July 18, 2001 at Bullfrog Marina, Lake Powell

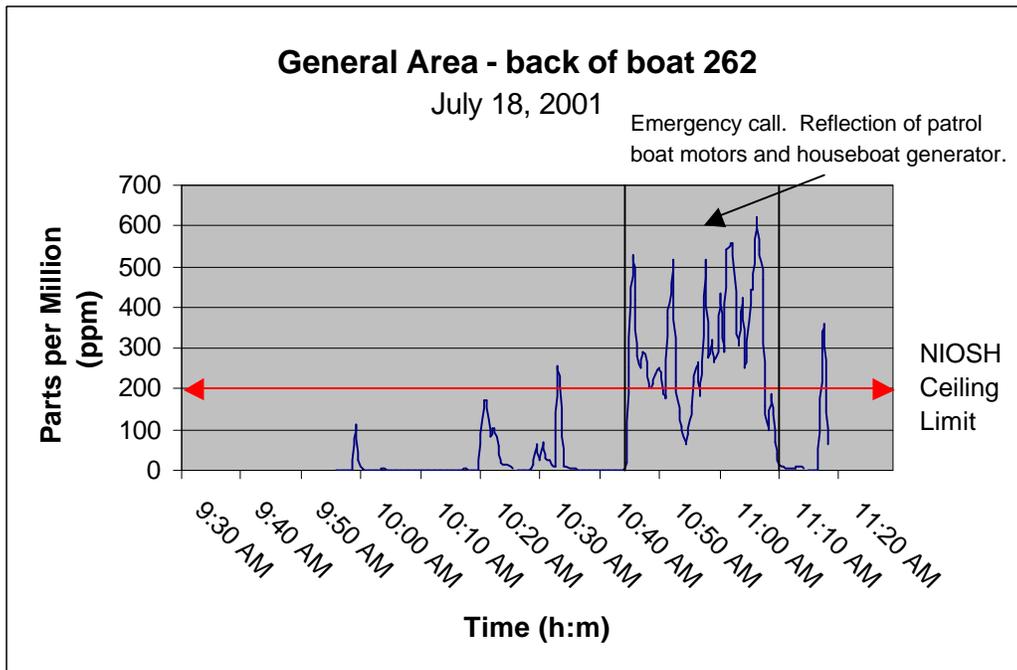


Figure 3. NPS Patrol Boat underway.

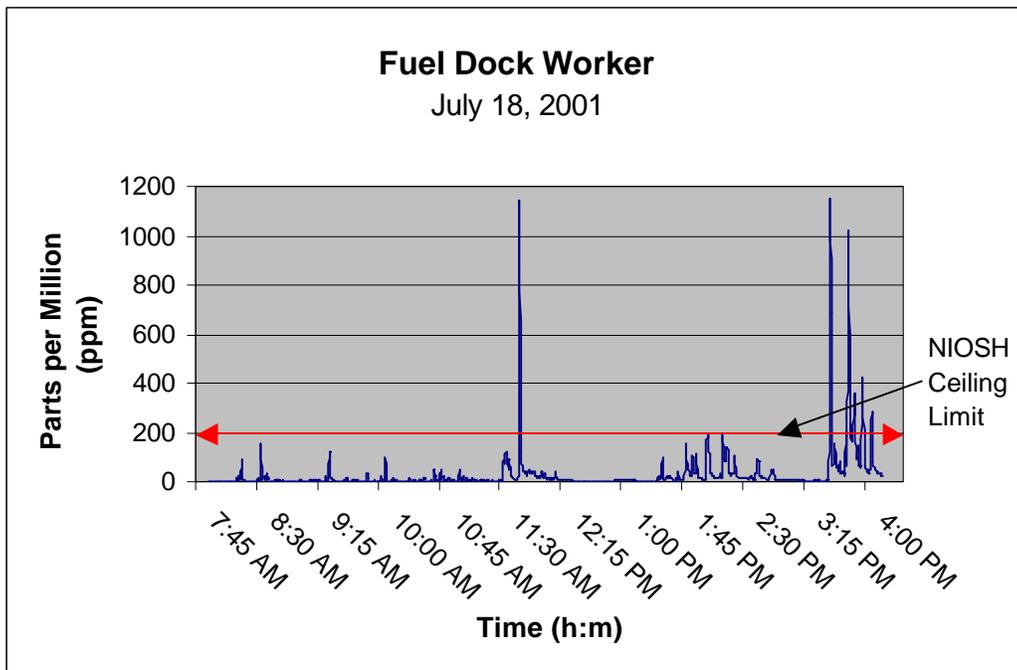


Figure 4. Fuel dock worker refueling boats.

Figures 5 and 6. Real-time CO Concentrations on July 19, 2001 at Bullfrog Marina, Lake Powell

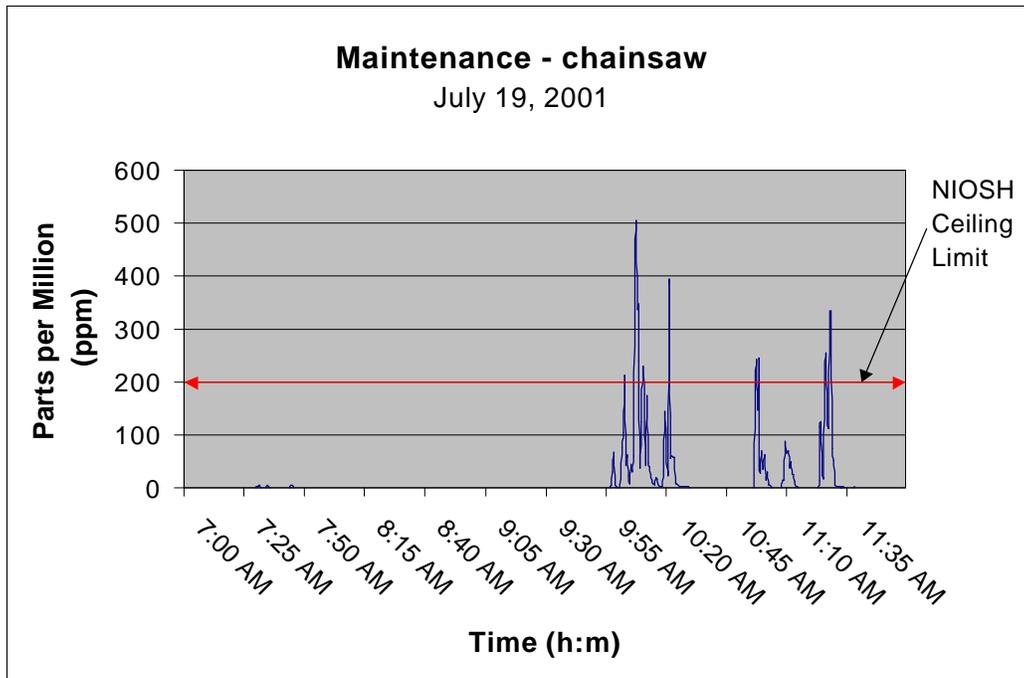


Figure 5. Maintenance worker using chainsaw for most of day.

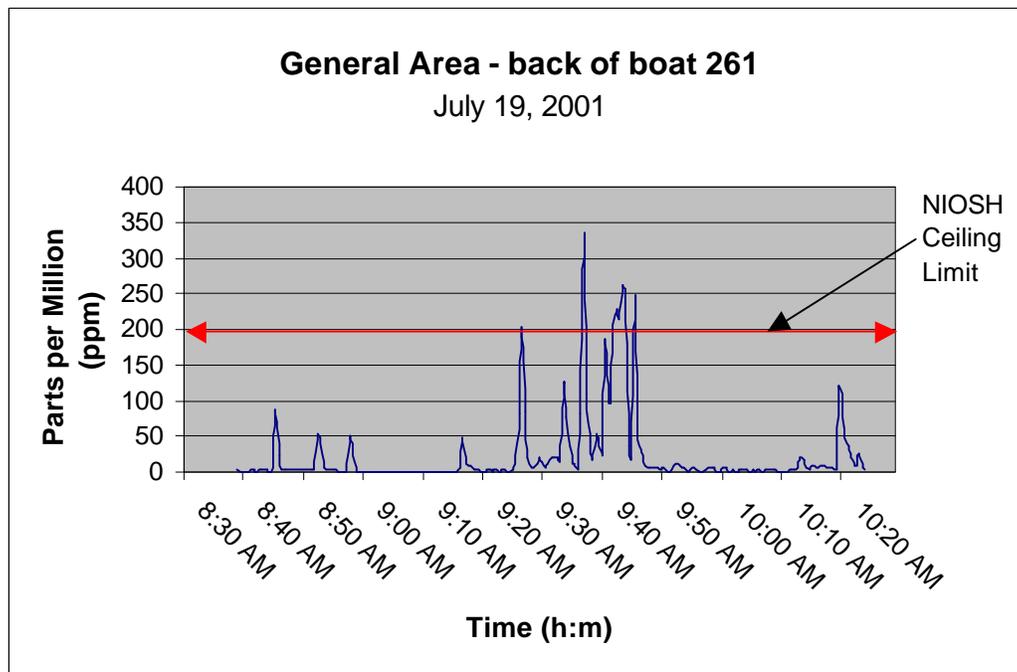


Figure 6. Area sample positioned at back of the boat underway.

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Park Rangers

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Maintenance Employees

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Fee Booth Employees

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Figure 52

**CO Exposure Monitoring during Patient Transfer Simulation
Dock to Helipad**

**Lake Powell
July 2001**