NIOSH HEALTH HAZARD EVALUATION REPORT

HETA #2000-0400-2956
HETA #2002-0325-2956
Glen Canyon National Recreation Area
Arizona and Utah

January 2005

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluation and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employers or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Jane McCammon, MS, CIH, NIOSH Denver Field Office, HETAB, Division of Surveillance, Hazard Evaluation, and Field Studies. Field assistance was provided by Ron Hall, Rob McCleery, and Eric Esswein (NIOSH). Additional field assistance was provided by representatives of the US Department of Interior, National Park Service, US Coast Guard, and individual boat owners. Analytical support was provided by Ardith Grote, Division of Applied Research and Technology (DART). Desktop publishing was performed by Lisa Maestas. Ellen Galloway provided editorial assistance.

Copies of this report have been sent to employee and management representatives at Glen Canyon National Recreation Area, the US Department of the Interior, the US Coast Guard Office of Boating Safety, and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed from the following internet address: www.cdc.gov/niosh/hhe/hhesearch.html. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your written request to:

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Highlights of the NIOSH Health Hazard Evaluation

Identification of Boat-Related Carbon Monoxide (CO) Poisonings and Related Risk Factors in Glen Canyon National Recreation Area (GCNRA), Arizona/Utah

What NIOSH Did

Worked with Department of Interior and National Park Service representatives in searching law enforcement, emergency medical services, and hospital records to identify diagnosed boat-related CO poisonings on Lake Powell within GCNRA.

Led investigations to measure CO on and near houseboats and other types of recreational boats.

What NIOSH Found

Between 1990 and 2004, 176 acute boat-related CO poisonings occurred on Lake Powell within GCNRA, 14 of which resulted in death.

Many of these poisonings were related to:

- CO from generators and/or propulsion engines contained within the airspace formed by an extended rear houseboat deck
- Water-level exhaust of generators on houseboats or cabin cruisers
- Features on pleasurecraft that encourage occupancy in proximity to CO sources
- Failure of CO detectors inside living quarters of houseboats

CO concentrations measured in the airspace under the extended rear deck of houseboats were as high as 30,000 ppm.

Operation of propulsion engines alone resulted in CO concentrations as high as 88,200 ppm in this airspace.

CO concentrations measured near water-level generator exhaust reached as high as 41,600 ppm at the exhaust terminus, and were consistently greater than 1,200 ppm as far away as 5 feet from the terminus.

CO measured on other recreational watercraft indicated that CO exposures as high as 26,700 ppm could be experienced during "teak surfing" on ski boat platforms.

On-board CO detectors sounded in only 1 of 15 poisoning incidents occurring inside houseboat cabins.

What National Park Service Managers Can Do

Ensure that Safety Officers use visitor and employee injury and exposure data to develop effective prevention programs to reduce the number and severity of boat-related CO poisonings.

What Other Agencies and Boat Manufacturers Can Do

Continue to support effective engineering changes to control CO at the source.

Develop educational programs and warning labels aimed at preventing poisonings on boats.

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for HETA Report #2000-0400-2956 and 2002-0325-2956

Health Hazard Evaluation Report 2000-0400-2956 & 2002-0325-2956
Glen Canyon National Recreation Area (GCNRA), Utah and Arizona

January 2005
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SUMMARY

After the August 2000 death of two young brothers swimming near their family houseboat, the US Department of Interior (DOI) and the National Park Service (NPS) requested assistance from the National Institute for Occupational Safety and Health (NIOSH) to evaluate potential boat-related exposures to carbon monoxide (CO) on Lake Powell, within Glen Canyon National Recreational Area (GCNRA). DOI and NPS also asked for assistance in identification of boat-related CO poisonings. NIOSH led the identification of 176 boat-related acute CO poisonings occurring on Lake Powell within GCNRA between 1990 and 2004. All poisonings were medically assessed as such by EMS or emergency department personnel. Fourteen poisonings resulted in death due either to drowning or from CO intoxication, and 59 of the 162 people that survived poisonings lost consciousness during their exposure. Factors related to these poisonings included: 1) lethal concentrations of CO from generators and/or propulsion engines contained within the airspace formed by an extended rear houseboat deck; 2) water-level exhaust of generators on houseboats or cabin cruisers creating a direct route of exposure to CO in the exhaust gases; 3) features on pleasurecraft that encourage occupancy in proximity to CO sources (such as water-level swim platforms, padded rear bench seats also referred to as sunning decks, and shower devices using warm water from the operating propulsion engine); 4) CO detectors inside living quarters of houseboats that failed to sound during the poisoning event. During operation of on-board generators (without operation of propulsion engines), concentrations of CO in the airspace under the extended rear deck of houseboats were measured in excess of 30,000 ppm (parts per million); this environment was also determined to be oxygen-deficient (as low as 12% oxygen). Operation of propulsion engines alone resulted in CO concentrations as high as 88,200 ppm in this airspace, with an accompanying oxygen-deficient environment. CO concentrations measured near water-level generator exhaust reached as high as 41,600 ppm at the exhaust terminus, and consistently greater than 1,200 ppm as far away as 5 feet from the terminus. CO measured on other recreational watercraft indicated that exposures as high as 26,700 ppm could be experienced during "teak surfing" on ski boat platforms. On-board CO detectors sounded in only 1 of 15 CO poisoning events occurring inside houseboat cabins (in which a total of 80 people were poisoned).

CO in uncontrolled exhaust from boat generators or propulsion engines presents a risk of acute, possibly fatal CO poisoning and CO-related drowning.

Keywords: SIC 9229 (Public Order and Safety). Carbon monoxide, CO, boat, houseboat, CO poisoning, COHb, exhaust, teak surfing, CO detectors, EMS, Emergency Medical Services

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INTRODUCTION

In August 2000, after the death of two young brothers swimming near their family houseboat, the US Department of Interior (DOI) requested assistance from the National Institute for Occupational Safety and Health (NIOSH) to determine the potential exposures to carbon monoxide (CO) from generators on houseboats on Lake Powell, within Glen Canyon National Recreational Area (GCNRA). DOI expressed interest in evaluating the exposure to employees who work on or around houseboats while the generators operated, and also to the public who operate the boats. In their request, DOI stated:

> "The National Park Service [NPS] is very concerned about this issue considering the two recent fatalities where kids swimming around the boat were overcome. The exhaust ports for the generators are located on the stern of the boats and the exhaust accumulates in this area on days with little air movement. It also collects under the diving platform on the stern and creates a hazard to swimmers. If possible, we would like you to work with boat manufacturers, the concessionaire, and NPS staff to develop solutions to the CO problem in order to protect our employees and the public."

DOI attached three letters to the request: two were from NPS to the Commandant of the US Coast Guard (dated 1994 and 1999). The third was a letter of response from the Coast Guard (1999). In the first letter, NPS expressed concern about CO exposure hazards related to a houseboat design and asked for help in effecting a design change to relocate onboard generator exhaust ports. The letter referred to a recent death on such a boat and two prior non-fatal incidents. The design of these boats is shown in Figures 1–3.

The second letter referred to two deaths in 1998 that occurred within 12 days of each other, and 10 CO-related deaths and injuries investigated by NPS occurring on boats designed as discussed above. NPS again recommended redesigning these types of boats by relocating the generator exhaust terminus and increasing air exchange in the stern cavity.

The third attachment, the letter of response from the Coast Guard, stated that regulations affecting the routing of exhaust lines or the installation of swim platforms did not exist. The letter referred NPS to the American Boat and Yacht Council's (ABYC) voluntary standards related to the exit location of exhaust piping. The Coast Guard letter also referred to positioning of the swim platform relative to exhaust openings and platform design as recent ABYC technical committee topics.

Subsequent to NIOSH receipt of the request for assistance, DOI asked the NPS to provide listings of fatalities within the GCNRA and NPS emergency medical services (EMS) responses for CO poisonings. DOI also asked NPS to gather investigative records related to the recent fatalities and all others for which CO exposure was a contributing factor.

NIOSH and DOI investigators traveled to GCNRA on September 18, 2000, to join an investigative team assembled by GCNRA NPS. Following an administrative meeting, NIOSH and DOI directed environmental investigations on three houseboats designed similarly to those on which fatal and non-fatal CO poisonings had occurred. Concern arising from the very high CO concentrations measured on and around these boats combined with the deaths of the victims led NIOSH investigators and DOI to ask participants to reconvene at Park headquarters on September 21, 2000. The group was briefed about the need for immediate action in a number of areas, including notifying boat manufacturers again about the extent of the problem under investigation at Lake Powell and notifying the owners of the boats on which the environmental investigations had been conducted.

The first interim report of results, dated September 28, 2000, provided preliminary information about investigative record review; environmental investigation of exposures on and near the boats, recommendations related to the immediate severe concerns, and plans for the future direction of the interagency investigation.

Because of the alarming nature of the hazard revealed by the initial investigative results, NIOSH investigators and other participants took the following additional steps to warn others of the identified hazards. These included:

On October 3, 2000, the interim report was sent to 65 houseboat manufacturers. The cover letter warned the manufacturers of the hazard related to swimming near or standing on the rear swim platform of houseboats, identified CO concentrations measured in these areas as a significant threat to public health, and asked for response related to design changes the manufacturers may have made specifically related to CO exposures. Of the 65 manufacturers, four responded, detailing changes or original design features on their boats related to this issue.

On December 12, 2000, NIOSH investigators, DOI, and the Medical Director for Prehospital Medical Care at GCNRA forwarded the interim report to 12 national boating safety organizations. The cover letter warned the organizations of the hazard and requested their assistance in a public awareness campaign by informing their membership of the GCNRA findings.

On December 28, 2000, NIOSH investigators forwarded a second letter to each of the 65 houseboat manufacturers, enclosing three items: 1) a one-page summary of further environmental sampling results from boats on Lake Powell and Lake Cumberland; 2) a publication of preliminary results of the review of CO poisoning records at Lake Powell[1], and 3) a DOI-prepared summary of the overall continuing investigation (dated December 7, 2000).

On June 1, 2001, NIOSH, DOI, and the Medical Director for Prehospital Care at GCNRA sent individually addressed letters to 263 boat rental companies warning them of the CO hazard on houseboats of this design. The letters asked the rental companies to urge boat owners at their facilities to retrofit generator exhaust to move the exhaust terminus out of the airspace beneath the rear houseboat deck (noting the February 23, 2001 Coast Guard houseboat recall that approved venting the generator exhaust through the vessel's side as a solution to the design problem). Rental companies were also advised that regardless of the boat's design, boaters should still be aware of the hazard of CO in engine or generator exhaust and avoid exposure. Recipients also were provided with the DOI website address related to this issue for further information and copies of technical reports.

Over the 4-year course of this investigation, there were six extensive NIOSH interim investigative reports covered under project number HETA 2000-0400, each with information related to record reviews, CO air sampling on various boats, investigations of new CO-related fatalities, and recommendations related to each issue under investigation. On May 8, 2002, the GCNRA Park Superintendent requested an extension of NIOSH assistance to continue monitoring employee and visitor CO-related incidents to ascertain the effectiveness of NPS education efforts. This request (covered under a new project number – HETA 2002-0325) resulted in two additional extensive interim reports. Because of the similarity of intent and focus of HETA 2000-0400 and 2002-0325, results of both projects are summarized in this final report.

All interim reports listed below are available at the internet website http://safetynet.smis.doi.gov/COhouseboats.htm.

Investigation Dates	Interim Report Date	Interim Report Subject
September 19, 2000	September 28, 2000	Preliminary CO air sampling on houseboats
October 10–13, 2000	November 21, 2000	Further investigation of CO on GCNRA houseboats
January 23–25, 2001	June 4, 2001	Review of EMS records–Lake Mead
June 30, 2004; July 1, 2001; July 11, 2001	July 31, 2001	Investigation of a "teak surfing" fatality at Lake Powell
July 11, 2001	April 1, 2002	Fire boat investigation
July 12–19, 2001	April 23, 2002	Boat-related occupational CO exposures at Lake Powell
August 28–29, 2002	December 3, 2002	Investigation of a fatality near a cabin cruiser
October 30–31, 2002	March 17, 2003	Investigation of propulsion engine exhaust clearance from airspace under the stern deck of a houseboat

The initial GCNRA Health Hazard Evaluation request led to six additional requests for assistance related to boats and CO at other lakes.[2,3,4,5,6,7]

The combined investigations led to extensive engineering control evaluations by NIOSH's Division of Applied Research and Technology (DART) Environmental and Physical Hazards Branch (EPHB). Two of these control technology evaluations were conducted in GCNRA. Most of the EPHB studies were conducted as interagency projects through funding provided by the US Coast Guard. Although the EPHB work is continuing, a number of reports have been finalized.[8,9,10,11,12,13,14,15,16]

As of this writing, NIOSH has authored or coauthored five peer-reviewed journal articles related to boat-related CO poisonings and control technology,[1,17,18,19,20] presented related technical information at over 80 venues, and participated in extensive national and local print and broadcast media coverage. Many of these articles, presentations, media items, and final reports for completed NIOSH HETA and EPHB projects and a plethora of related materials are available at the DOI website at http://safetynet.smis.doi.gov/COhouseboats.htm.

This report summarizes NIOSH efforts conducted at GCNRA from 2000–2004 related to the two Health Hazard Evaluations (HETA 2000-0400 and 2002-0325) and highlights of the interim results already transferred to the NPS. Refer to the interim reports and related publications for detailed data about each field investigation. The amount of data related to each investigation in those interim reports is too vast to be repeated here.

BACKGROUND

GCNRA covers a 1,236,800 acre area crossing the Arizona-Utah border, and hosts approximately 3,000,000 international and domestic visitors a year. Lake Powell, contained within GCNRA, was formed in 1963 with the construction of the Glen Canyon Dam on the Colorado River in Page, Arizona. The second largest man-made lake in the United States, it covers approximately 13% of the total land area of the GCNRA. The lake is 187 miles long, and has nearly 2,000 miles of shore line comprised of 96 major side canyons with huge sheer cliffs of sandstone rock formations rising straight up from the water. The surface of the lake is approximately 3,700 feet above sea level, and the deepest part of the lake is more than 500 feet.

Houseboaters are drawn to this lake due to the canyons that afford privacy, protection from wind, and striking scenic beauty. NPS estimates that there are between 2,000 and 3,000 houseboats on Lake Powell, and that this probably represents two thirds of the boat traffic on the lake. Many of the privately-owned houseboats moored on Lake Powell are shared ownership partnerships between numerous families or individuals.

As the agency with proprietary legal jurisdiction, NPS responds to the vast majority of law enforcement and emergency service incidents occurring within GCNRA. This response is coordinated through NPS dispatch. Medical direction for NPS EMS services has been provided primarily by one physician since 1983, through Banner Good Samaritan Regional Medical Center in Phoenix, Arizona. NPS holds sole jurisdiction for EMS response on the lake.

The lake is difficult to access, with paved roads leading to only four locations along its length. Although 90% of the lake is in Utah, the only hospital near the lake is in Page, AZ. That hospital operates a satellite clinic in Bullfrog, Utah, staffed by physician assistants. Emergency medical transport is conducted by NPS by boat or airplane, or by the contracted flight service also dispatched through NPS. The isolation of the lake and the dearth of nearby medical facilities results in few "self-transports" (people transported by private vehicle to the hospital). Thus, most medical emergencies occurring on the lake are managed by NPS.

Patients requiring more extensive care than can be provided at Page Hospital or the Bullfrog Clinic are flown to hospitals more than 400 miles away (primarily located in Salt Lake City UT, Phoenix AZ, or Grand Junction CO).

The isolation of the lake, and the central authority for law enforcement and medical activities, contributed to recognizing that CO poisonings were occurring on or near a variety of boats on Lake Powell beginning in the early 1990s. However, in 1994 with the first documented CO-related drowning, a particular houseboat design drew concern. A child exposed to CO drowned while swimming near a houseboat with a design similar to the one on which the double fatality occurred in 2000. Both vessels had an onboard generator used to supply electricity for appliances, and the generator exhaust terminus was under the extended rear deck of the boat. NPS stated in its letter to the Coast Guard that the area under the aft deck is inviting for children to explore because it resembles a small cave. The child who died in 1994 was exposed to generator exhaust for approximately 3 minutes before drowning. (A second juvenile was also swimming in the area, but was able to get out of the water before losing consciousness.)

Between 1994 and the beginning of this investigation in September 2002, a total of nine deaths were documented as CO-related on or near boats on Lake Powell. Of these nine deaths, seven occurred on houseboats of similar design. NPS made two attempts to gain assistance in dealing with this problem, but none became available until the deaths in August 2000.

METHODS

Medical/Epidemiologic Methods

During the course of these two NIOSH health hazard evaluations, boat-related CO poisonings occurring within GCNRA were identified to determine the number and distribution of cases, and risk factors related to the poisoning. All drownings that occurred in the GCNRA were also identified to allow assessment of the total number of drownings and the proportion of drownings related to recreational boating and carbon monoxide.

Boat-related carbon monoxide poisoning case-finding

An analysis of preliminary data abstracted from GCNRA EMS response records was published in December 2000. At that time, 111 boat-related CO poisonings occurring between 1990 and 2000 had been identified at GCNRA. Identification of such poisonings has continued since that publication as described below.

Retrospective CO Poisoning Case-Finding

Review of three listings initially provided to the investigative team was the starting point for identifying boat-related CO poisonings. These lists contained information related to dispatch events from 1991 (when such records were first computerized) through the death of the two brothers in August 2000, and had been created through queries of the GCNRA NPS law enforcement dispatch database. The dispatch database contains information about the date, time, and location of the dispatch; officer responding; the type of incident (EMS versus a traffic violation, for example); and a brief narrative field for details about the call for assistance. About 5%–10% of the EMS dispatch entries contain no information in the narrative field. NPS staff involved with the CO poisoning issue at GCNRA had also collected EMS run sheets from 1990, and these records were also included in this study.

List 1 identified deaths occurring within GCNRA. List 2 identified EMS dispatches for which CO poisoning was recorded as the cause for the response. List 3 identified GCRNA EMS dispatches for which symptoms recorded in the dispatch database were consistent with CO poisoning (but CO poisoning was not directly recorded). Investigative records related to the medical events identified in the lists were requested for review. Investigative records varied from very complex (usually for events involving a fatality) to very simple, but consistently contained EMS run sheets and some level of description of the event. Review of these records allowed differentiation between an unrelated medical event (such as a broken arm) and an event medically assessed as a boat-related CO poisoning. If the patient was transported to Page Hospital, the related hospital record was also requested.

A database was developed to allow organization, abstraction, and analysis of records. The database included approximately 90 variables related to the victim, extent of available records, circumstances of poisoning, the boat, medical findings, and a lengthy narrative field describing the incident.

As this study moved forward, the NPS provided a listing of all dispatch events for 2001. A review of that listing indicated that a request for all EMS dispatch entries for 1991–2000 was warranted to ensure that all CO poisoning cases had been identified through the computer query. The narrative field for each EMS entry was reviewed, and further investigative records were requested. An additional source of information, known as the "death book," was also reviewed to identify fatal CO poisonings. The death book, begun in 1959, contains information about fatal incidents occurring within GCNRA, including a one-paragraph description of the circumstances of each death. Investigative records related to these fatalities were requested and reviewed. Boat-related CO poisonings identified through these additional reviews were abstracted into the database.

In addition, Page Hospital carboxyhemoglobin (COHb) analysis records were requested to ensure that CO poisoned patients transported to the hospital by other emergency responders or private individuals were identified. Page Hospital began conducting in-house COHb analyses in 1997, with cumulative records of all results hand-recorded by a staff member in the Respiratory Therapy department. Hospital records related to treatment of patients identified through this listing were requested to determine if the poisoning occurred on a boat within GCNRA, and data were abstracted as appropriate.

Finally, the Arizona Department of Health Services analyzed hospital discharge data for 1995–1999 to identify boat-related CO poisoning cases admitted for treatment at any Arizona nonfederal hospital, including Page Hospital, using the ICD-9-CM nature of injury diagnosis code for CO poisoning (N986) and external cause codes E830 – E838.

Prospective CO Poisoning Case-Finding

Under the terms of the contract between GCNRA and the Banner Health System, all EMS "run sheets" (records documenting EMS procedures in a given medical response) are forwarded to the GCNRA EMS Medical Director for review. Beginning in 2001, all GCNRA CO-related medical events were identified through this mechanism, as well as through direct communication between NIOSH investigators, DOI, and NPS GCNRA staff members. Investigative reports related to CO-related EMS events were provided to NIOSH as they were completed and data from these records were abstracted. Self-transports were identified for 2001–2004 through annual requests for COHb analysis records from Page Hospital.

Drowning Case-Finding

To assess the proportion of all drownings and reportable boat-related drownings for which CO poisoning was a contributing or primary cause of death, drownings that occurred within GCNRA from 1994–2004 were identified. The 1994 starting point was chosen because that was the year for which the first CO-related drowning was identified.

Three sources were used to identify possible drownings, including: List 1 (described above, and covering 1991–2000); the death book (described above, and covering all years); and updated queries of dispatch log records for EMS and Search and Rescue response activity related to fatal events occurring from 1994–2004.

Investigative records related to identified drownings were requested. The investigative records ranged in scope, but most contained a lengthy narrative of events, documented timelines backed by dispatch information, Medical Examiner (ME) records or verbatim accounts of ME findings, EMS run sheets (when applicable), information about the location of the incident, records related to body search and recovery, and chain of custody information related to transport of the body.

For those incidents where official cause of death was not documented in the NPS record, either the Utah or Arizona State Health Departments were contacted for verification that drowning was listed in cause of death information on the death certificate.

Data from these drowning records were abstracted into a database grouped under the following categories: extent of records available; cause of death; chronological information about the incident (onset time, time of body recovery, where within the park the drowning occurred, etc.); victim demographics and activity of the victim when the drowning occurred; medical information (COHb concentrations, blood alcohol concentration, etc.); information about the boat; and a lengthy narrative field for describing the incident.

Case Definition

Boat-Related CO Poisoning

All identified boat-related CO poisonings were medically assessed as such by EMS responders, hospital emergency department staff, or medical examiners. Medical assessments of patients with adequate documentation of the following were accepted as cases: either death or sudden onset of signs and symptoms consistent with CO poisoning (i.e., loss of consciousness, seizures, headache, nausea, confusion, weakness, and/or altered state of consciousness) that improved upon removal from exposure or autopsies; and adequate documentation of exposure to CO.

Two types of exposure documentation were accepted:

1) a laboratory-confirmed elevated carboxyhemoglobin level (>2% in either children or nonsmoking adults or >9% in smoking adults or adults for whom smoking status was unknown);

2) details in the record documenting that the person was either near the emissions of an operating source of CO (i.e., a generator or a propulsion engine) when symptom onset occurred, or that the person was with a group of similarly symptomatic people on a boat with an operating source of CO.

COHb concentrations measured 3 or more half-lives after cessation of exposure were considered irrelevant.

Drownings

A drowning case was defined as a person who unintentionally drowned within the boundaries of GCNRA as documented by circumstances of death detailed in GCNRA records and by designation of drowning as primary or contributing cause of death in Medical Examiner reports or on the death certificate. Drownings were classified as CO-related based on the incident's circumstances and a COHb concentration indicating that CO exposure was a contributing factor in the incident (again >2% in either children or nonsmoking adults or >9% in smoking adults or adults for whom smoking status was unknown).

Identified drowning cases were classified as: 1) unrelated to boating activities (i.e., drownings associated with cliff jumping, swimming from shore, or other activities where no boat was involved); 2) related to boating activities, but *not meeting* Coast Guard Boating Accident Report Database (BARD) Reporting Criteria and Guidelines for Recreational Vessel Accidents (and thus not reportable); and 3) drownings *reportable* to the Coast Guard BARD.

Industrial Hygiene Methods

Overall, NIOSH investigators assisted DOI and NPS at GCNRA by leading seven extensive field investigations in which CO concentrations on and around boats on Lake Powell were measured. DOI and NPS industrial hygienists also participated in four of the seven surveys. Included in these seven surveys are NIOSH-led supplemental field investigations of three of the five CO-related fatalities that occurred at GCNRA from 2001–2004.

Industrial hygiene methods used in these seven surveys are detailed in previous interim reports, and thus will not be repeated in detail here. Overall, measurements were made using a number of direct reading instruments equipped to measure CO in differing ranges of concentrations. Low range direct-reading instruments were useful in characterizing CO concentrations at or below 1,000 ppm. High-range direct-reading instruments were capable of measuring CO in percentages, with 1% being equivalent to 10,000 ppm. The measurements that used direct-reading analytical instruments were confirmed by direct-reading high-range detector tubes, and by collecting air samples in evacuated glass containers that were then shipped to Mine Safety and Health Administration for analysis.

HEALTH EFFECTS

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.[21, 22, 23, 24, 25, 26] 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 blood's ability to carry oxygen to tissues by binding with the hemoglobin to form 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, so 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. This means that if the initial COHb level was 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.

Carboxyhemoglogin measurements are typically made when a patient arrives at the hospital or a body arrives at the morgue. The time elapsing between CO exposure and COHb analysis may explain the poor clinical correlation between symptoms of carbon monoxide poisoning and COHb level. This complicates any discussion of "normal" COHb concentrations and COHb concentrations associated with symptoms. Carboxyhemoglobin concentrations among unexposed non-smokers are typically between 1%–2%, and between 3%–8% for smokers.[27] Exposures resulting in COHb concentrations less than 10% usually cause no appreciable symptoms; exposures resulting in COHb greater than 50% are often fatal. However, COHb levels as low as 1%–10% have been associated with severe symptoms (including prolonged loss of consciousness), and COHb levels as high as 47% resulted in no associated loss of consciousness.[28] Thus, elevated COHb concentration can only be used to confirm exposure, not to confirm poisoning severity.

EVALUATION CRITERIA

Carbon Monoxide Occupational Exposure Criteria

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessing 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, a pre-existing medical condition, and/or hypersensitivity (allergy). 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. Also, some substances are absorbed by direct contact with the skin and mucous membranes, which potentially increases the overall exposure. 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)[29], (2) the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®)[30], and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[31] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever is the more protective criterion.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm.[32] Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

Occupational criteria for CO exposure apply to employees who may be at risk for CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures because occupational standards are intended for healthy worker populations. 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 COHb.[33]

The NIOSH REL for CO is 35 ppm for full shift TWA exposure, with a ceiling limit of 200 ppm that should never be exceeded. The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%. NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm. An IDLH value is defined as a concentration at which an immediate or delayed threat to life exists or at which an individual's ability to escape unaided from a space would be compromised.

The ACGIH recommends an 8-hour TWA TLV of 25 ppm based upon limiting shifts in COHb levels to less than 3.5% to minimize adverse neurobehavioral changes such as headache, dizziness, etc., and to maintain cardiovascular exercise capacity. ACGIH also recommends that exposures never exceed five times the TLV (i.e., 125 ppm). ACGIH recommends a Biological Exposure Index (BEI) for end of shift exhaled breath analysis in nonsmoking workers exposed to CO of 3.5% COHb (or 20 ppm). The BEI generally indicates a concentration below which nearly all workers should not experience adverse health effects.

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.[31]

Carbon Monoxide Exposure Criteria Relevant to the General Public

The 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 1-hour average.[34] The NAAQS for CO was established to protect "the most sensitive members of the general population" by maintaining increases in COHb to less than 2.1%.

The World Health Organization has recommended guideline values and periods of TWA exposures related to CO exposure in the general population. WHO guidelines are intended to ensure that COHb levels do 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, and 10 mg/m^3 (9 ppm) for 8 hours.

Confined Space Entry Criteria

The airspace under the rear deck of houseboats of the design related to the CO-poisoning and drowning deaths at GCNRA meets the definition of a confined space, therefore confined space entry procedures must be followed if the airspace must be entered.

OSHA regulation 29 CFR 1910.146 defines a ***confined space*** as a space that meets three criteria: (1) is large enough and configured so that an employee can bodily enter and perform any assigned work; (2) is a space that has limited or restricted means for entry or exit (for example, tanks, vessels, storage bins, vaults, and pits with limited means of entry); and (3) is a space not designed for continuous employee occupancy. The standard then defines a ***permit–required confined space*** as a space that meets one or more of the following additional criteria: (1) a space that contains or has a potential to contain a hazardous atmosphere; (2) a space that contains a material that has the potential for engulfing (surrounding and capturing a person by a liquid or finely divided solid substance that can be aspirated and cause death or that can exert enough pressure to cause death by strangulation, constriction, or crushing) the person entering the space; (3) a space whose internal configuration is designed in a way that the person entering the space could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section; or (4) a space that contains any other recognized serious safety or health hazard.[35]

NIOSH defines a confined space as "an area which by design has limited openings for entry and exit, unfavorable natural ventilation which could contain (or produce) dangerous air contaminates, and which is not intended for continuous employee occupancy.[36] The NIOSH criteria for working in confined spaces further classify confined spaces based upon the atmospheric characteristics such as oxygen level, flammability, and toxicity. As shown in the confined space classification in Table 1, if any of the hazards present a situation immediately dangerous to life or health, the confined space is designated Class A. A Class B confined space has the potential for causing injury and/or illness, but is not an IDLH atmosphere. A Class C confined space is one in which the hazard potential would not require any special modification of the work procedure.

The checklist in Table 2 lists the confined space program elements that are recommended (or must be considered by a qualified person, as defined by the criteria) before entering and during work within confined spaces based on the established hazard classification.

RESULTS

Medical/Epidemiologic Results

Boat-Related Carbon Monoxide Poisoning Case-Finding

Records related to 327 patients treated at GCNRA and/or in Page Hospital from 1990–2004 were reviewed. Of these, 176 were CO poisonings on boats, and 14 of the poisonings resulted in death. Fifty-nine of the 162 surviving cases lost consciousness as a result of their exposure. Six of the surviving cases were noted as having seizures at some point during exposure. The numbers of fatal and non-fatal cases by year and boat type are listed in Table 3.

Figures 5–8 show the following information: Boat-related CO poisonings by month of the year; by age of victim; by source of CO exposure; by location of the victim when exposed.

COHb concentration was available for all fatal cases, and for 78 of the 162 surviving cases. COHb concentrations for fatal cases ranged from 1.9% (after 7 hours of oxygen by intubation) to 59%; COHb for surviving cases ranged from 2.2% (after 4 hours of oxygen therapy) to 38.5% (50 minutes after exposure ended). COHb concentrations were measured at the treating hospital (primarily Page Hospital) by blood analysis and/or by estimation based upon expired breath CO measurement. In 2003, NPS also began analyzing expired breath CO in the field, allowing more efficient triage and identification of CO poisoning cases.

Glasgow Coma Scale (GCS) determination was available for 115 of the surviving cases, and ranged from 3 to 15. (GCS is a medical rating system that was developed to quantify observations of unconsciousness by applying a numeric scale to arousability and eye opening, whether spontaneous or as response to verbal or pain stimulus, with 15 being the highest score possible.)

Cause of death for the 14 fatalities listed on the medical examiner or autopsy report was either drowning secondary to CO intoxication (11), CO intoxication (2), or drowning with no secondary cause listed (1).

Seven of the people poisoned were employees (either concessionaire or NPS employees), and five of these employees were engaged in work tasks at the time of poisoning. Four of the 5 poisoned employees lost consciousness as a result of their exposure, indicating the severity of their exposure.

One of these poisonings occurred in September 2001, when a concessionaire maintenance employee lost consciousness while tightening bolts on or under the swim platform of a houseboat. 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 the houseboat where the employee was working. He was exposed in this position for approximately 2 minutes. His COHb concentration, after 26 minutes of oxygen therapy, was over 30%. This poisoning reinforced the need to reassess employee training and education at the Park, as well reinforcing the hazard presented by rafting boats with side-exhausting generators. ("Rafting" is the practice of lashing boats together, side-by-side.)

<u>Houseboat poisonings:</u>
Fourteen people (five children and nine adults) were known to have been poisoned as a result of CO exposure within the airspace beneath the outdoor rear deck of houseboats of the design shown in Figures 1–3. Seven of the 14 died and two survivors lost consciousness.

Additionally, six people (two children, four adults) were poisoned near the rear deck boats of this design, but the poisoning was either an unwitnessed fatality (thus unknown if they entered the space) or the record of the incident did not document entry into the space. Two of these six people died as a result of their exposure.

The estimated duration of exposure for the 14 people known to have entered the airspace ranged from 1 minute to several hours as follows: nine were exposed less than 10 minutes; two were exposed between 10 and 20 minutes; two were exposed for 30 minutes or more; there was no estimated exposure duration for one case.

Nine of the 14 people who entered the airspace were adults accessing the outdrive of houseboats to conduct maintenance activities or free propellers from entanglements, and three of these adults died as a result of their exposure. Three children died after entering this airspace while playing.

Overall, 80 people survived poisonings inside houseboats in 15 incidents. COHb concentrations were available for 37 of these people, and ranged from 2.2% to 47.8%. Fifty of the 80 people were poisoned in boats that were documented to have CO detectors in the living quarters. However, in only one incident (four people poisoned) did the alarm sound alerting the occupants to their exposure. Twenty were poisoned in three separate instances involving disarmed or "broken" detectors. Twenty-two people were poisoned in four instances involving functional detectors that failed to sound during the poisoning incident. Ten people were poisoned in a houseboat that was not equipped with CO detectors. Twenty people were poisoned in houseboats in which the record failed to document absence or presence of detectors.

<u>Other recreational boats</u>

Six people, all 21 years of age or younger, were poisoned as a result of occupancy of the water-level swim platform of a recreational boat other than a houseboat (referred to as a ski boat in the record). One of the six died, and three of the survivors lost consciousness. Four people (including one that died) were poisoned during an activity referred to as "teak surfing" or "platform dragging", shown in Figure 4. Two others lost consciousness while sitting on the platform of a stationary ski boat, either pausing while accessing the boat or playing with a shower device that uses warm water from the operating boat engine. COHb concentrations, available for three of the six, were as follows: 18% after 50 minutes of oxygen therapy; 32% after 37 minutes of oxygen therapy; 56% on autopsy.

Four people, aged 14 to 28, survived poisoning while occupying the cushioned rear bench seat on the transom of a recreational boat referred to in the record as a "ski boat." In all incidents, the boat was moving slowly through the water. Three of these people lost consciousness as a result of their exposure. COHb concentrations were available for all 4, and were as follows: 25% and 31% measured before oxygen therapy; 31% after 48 minutes of oxygen therapy; and 35% after 10 minutes of oxygen therapy.

Ten people were poisoned in three incidents inside the cabin of boats described as cabin cruisers. None of these records included information about the presence or functionality of CO detectors in the living quarters of these boats.

Drowning Case-Finding

Seventy-two people died of unintentional drowning within GCNRA from 1994–2004. Nearly half (46%) of the drownings in GCNRA (33/72) occurred with no boat involved (i.e., hikers washed away in a flash flood, cliff jumpers, people swimming from shore). Twelve (17%) of 72 people who drowned at GCNRA were first poisoned by CO from marine generators or propulsion engines of houseboats or other recreational boats.

Thirteen (18%) of the 72 identified drownings were related to boating activities but in circumstances that did not meet BARD reporting criteria (i.e., wandering on land or in the water near their moored boat; swimming from shore to retrieve a boat that was drifting or being blown from shore). Twenty-five (35%) of the 72 identified drownings met

Coast Guard BARD reporting requirements for boating accidents, and 12 (48%) of the 25 were first poisoned by CO.

Industrial Hygiene Results

Complete data from the seven NIOSH field investigations involving air sampling for CO are contained in the interim reports listed in the introduction, and found at the DOI website. Major findings of each investigation are listed chronologically below by the date of investigation.

September 19, 2000 (sample date); September 28, 2001 (report date)

This initial air sampling investigation related to houseboats with extended rear decks and gas-powered generators with exhaust terminus exiting the boat transom under the deck (shown in pictures and diagram in Figures 1–3). The generators supply the boat with electrical power to operate on-board appliances (i.e., air-conditioner, refrigerator, lights, charging batteries, etc.

GCNRA NPS and concessionaire staff had measured CO concentrations on three houseboats of this design on August 25, 2000. They measured CO concentrations of 1,393 ppm, 1,451 ppm, and greater than 2,000 ppm (the maximum concentration their instruments could measure) at water level below the swim deck of the three boats, each measurement taken approximately 10 minutes after generator activation. CO measurements collected on the swim platforms were 800 ppm, 100 ppm, and 1156 ppm. During the first test, two of the people conducting the test began to experience headache, mild nausea, and weakness.

NIOSH sampling on September 19, 2000 documented three severely hazardous situations requiring immediate attention. The environment in the open space under the swim platform of houseboats with an extended rear deck can be lethal under certain circumstances and should not be entered by anyone for any reason as demonstrated by measurements as high as 30,000 ppm in that space, and a concurrent oxygen deficiency of 12% in the space. The environment above and around the swim platform may be hazardous as was demonstrated when immediately dangerous to life and health (IDLH for CO is defined as greater than 1,200 ppm) concentrations of CO were measured on the rear deck of a houseboat during startup of one of the two engines. Employees may be exposed to hazardous concentrations of CO during boat maintenance activities as evidenced by the short-term, near the IDLH concentrations measured on one maintenance employee.

October 10–13, 2000 (sample dates); November 21, 2000 (report date)

This investigation confirmed the issues of concern regarding CO on houseboats expressed in the first report, again documenting that when generators are in operation, the area beneath the rear deck and around the back of the swim platform (near water level) contains extremely hazardous CO concentrations. These hazardous conditions also exist when the engines are in operation on the boats. CO concentrations measured with three separate methods (i.e., real time instruments, evacuated containers, and detector tubes) indicated concentrations well above the NIOSH established IDLH value of 1,200 ppm. Individuals swimming or working in the area under the swim platform, or around the area directly behind the swim platform (near the water level), with the generator or motors in operation could experience CO poisoning or death within a short period of time.

The area on the swim deck of the houseboats was also documented as an area of concern. During this second NIOSH evaluation, CO concentrations in this area reached 1000 ppm (the upper limit for the CO monitors used in this evaluation). Investigators stated that when generator or motors were in operation, the area around the back deck of the houseboats could be hazardous under certain environmental conditions (i.e., lack of air movement), as substantiated by the CO poisonings and deaths reported in this area of the boat. CO measurements obtained on the top deck of the boats did not indicate a CO hazard during this evaluation.

Personal sampling results indicated that some workers were exposed to CO concentrations that exceed the NIOSH ceiling limit of 200 ppm. One Park Service maintenance worker received a peak CO concentration of 780 ppm.

June 30, 2004, July 1, and July 11, 2001 (sample dates); July 31, 2001 (report date)

This letter reported NIOSH evaluation methods, findings, and conclusions related to the death of an 18-year-old boy. In summary, this person succumbed to exposure to extremely high concentrations of CO within 5 minutes of beginning an activity that the family referred to as "teak surfing." This activity, shown in Figure 4, is made possible by specific design features of ski boats with an extended water-level teakwood swim platform and recessed propeller. The boy's measured COHb was reported by the coroner as 56%. At the time of this report, NIOSH was aware of four other similar fatal poisonings nationwide, and at least two non-fatal CO poisonings resulting in loss of consciousness also associated with similar activities and boats.

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

July 11 ,2001 (sample date); April 1, 2002 (report date)

On this day, NIOSH monitored CO concentrations on the fire boat recently purchased by the GCNRA. The fire boat (an Almar 30' X 11') is used by NPS employees for fire suppression and other rescue operations. The CO sampling was conducted based upon employee concerns about the location of the boat's gasoline-powered generator and related possible CO exposure hazards. The generator, which powered lights and other equipment during rescue/fire operations, was located in the staging area for these operations. The generator also served as a passenger seat. The exhaust terminus on the generator was directed toward the port deck side of the generator.

Maximum CO concentrations at the generator exhaust ranged from 22,000 to 28,000 ppm when the generator operated with no load. When the microwave was operating, the range was 30,000 to 32,700 ppm, indicating that area concentrations could be expected to be significantly higher when the generator was under full load as would be the case during a rescue operation. In summary, very high CO concentrations were reached within minutes of activating the generator. The location and configuration of the exhaust resulted in rapid dispersal of CO throughout the areas of the boat that would be occupied during a rescue/fire operation. NIOSH investigators recommended that GCNRA NPS immediately suspend use of the generator until it, or its exhaust terminus, could be relocated. GCNRA removed the generator from the boat.

July 12–19, 2001 (sample dates); April 23, 2002 (report date)

In this investigation, NIOSH monitored employee exposure to CO at various locations within GCNRA. NIOSH had previously measured GCNRA employee CO exposures on three separate occasions and had also provided assistance in analyzing NPS EMS response records from 1990–2001. In the previous exposure assessments, NIOSH characterized hazardous exposure zones near and under the rear deck and swim platforms of houseboats; measured employee CO exposures approaching the IDLH concentration (1,200 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.

The outcome of the employee exposure monitoring conducted in July 2001 is summarized below.

•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 6 days of sampling these employees.

•Boat/vehicle maintenance worker exposures measured during 3 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 average exposures 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 5 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 work shift, with peak exposures greater than the reliable sampling range of our instruments, approximately 1,000 ppm.

August 28– 29, 2002 (sample dates); December 3, 2002 (report date)

In this investigation, NIOSH assisted industrial hygienists from the DOI and the Washington DC NPS office in the investigation of a fatal and a non-fatal CO poisoning occurring behind a cabin cruiser on August 17, 2002. The interagency investigation was supplemental to the GCNRA NPS investigation, and provided exposure information relevant to the poisoning of two 9-year-old girls on that date.

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, as it was more indicative of what was happening on the day the girls were poisoned.

On the relatively still morning of August 29, 2002, 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 the NIOSH IDLH concentration, indicating that the actual concentration 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 1 and 2 feet from the terminus.

October 30–31, 2002 (sample dates); March 17, 2003 (report date)

In this investigation, NIOSH assisted industrial hygienists from DOI, the Washington DC NPS office, and the US Coast Guard in gathering data related to a fatal poisoning that occurred in GCNRA on September 28, 2002. This death occurred when a man entered the airspace beneath the extended rear deck of a houseboat to free anchor ropes fouling the propellers. The boat's generator was not involved in this poisoning, as it exhausted out the side of the boat's hull, outside the airspace beneath the rear deck. He was exposed to propulsion engine exhaust only, and the propulsion engines were not operating at the time he entered the airspace.

The purpose of this interagency investigation was to provide data about clearance of propulsion engine exhaust CO from the airspace beneath the extended stern deck of boats associated with deaths at GCNRA. A previous NIOSH report provided data related to CO accumulation from propulsion engine and generator exhaust in this space, and documented that it took approximately 8 minutes for the CO concentration to decay to 0 ppm following deactivation of both engines.[15]

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

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

During this day of sampling, the boat's CO detector located inside the rear sleeping quarters sounded on more than one occasion. NIOSH air sampling equipment housed in this room (which was used as an equipment staging area) indicated only sporadic low (less than 10 ppm) CO concentrations, indicating that there was no cause for it to sound.

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

Because the detector on the previous boat had sounded on several occasions for no reason, the detector on Boat 2 was tested for performance. The alarm sounded when the test button was pressed, indicating that the detector was powered and capable of sounding. Three 2-liter mylar sampling bags were filled with air collected from the airspace beneath the swim platform. The concentration of CO in the bags (as indicated by high range detector tube measurement) was in excess of 40,000 ppm. The contents of the bags were released near the sensor of the detector in the rear bedroom of the houseboat. The detector never sounded, neither when the exhaust was released, nor in the 2 hours that passed before the boat was vacated.

CONCLUSIONS/ DISCUSSION

The body of work represented in this report relates to a number of boat-related issues, each addressed through epidemiologic and environmental investigations. Conclusions below are grouped according to primary issues researched and addressed over the period of HETA 2000-0400 and 2002-0325.

Acute, fatal boat-related CO poisonings occurring outside the cabins of boats are not unique to GCNRA. The 176 CO-related deaths and nonfatal poisonings (near misses) identified at GCNRA differ little from the 395 fatal and non-fatal poisonings identified on other U.S. bodies of water.[37]

Without doubt, the cavity below the swim platform of houseboats with an extended rear deck presents a severe, sometimes fatal hazard that must be immediately addressed through design changes and public education. In all, we know of 21 people nationwide who have been poisoned by entering this airspace (14 on Lake Powell and 7 on other bodies of water), 13 of whom died (7 on Lake Powell, 6 on other bodies of water). This hazard is present during the operation of on-board generators housed in the engine compartment and exhausting into the cavity, as well during the operation of propulsion engines. Exhaust lingers in this airspace for an extended period following deactivation of either type of engine.

Initial recommendations contained in interim reports for this project were that the airspace beneath the extended rear deck of houseboats should never be entered for any reason. Unfortunately, the current design of this type of houseboat necessitates entry into the airspace to access the propulsion engine outdrives (to conduct maintenance and repair) or propellers that often get fouled by anchor ropes. CO concentrations measured in the airspace of these types of boats, and related fatalities associated with this airspace, confirmed the need: 1) for manufacturers to immediately address the placement of the generator exhaust terminus (get it out of that space and up to an location that is not accessible by swimmers or boat occupants); 2) for manufacturers to develop safe entry procedures for boaters until this space can be redesigned; and 3) to educate boaters about exercising extreme caution when entering this airspace.

Changing the generator exhaust terminus location from the transom to the side of the boat (as was required by the US Coast Guard as part of their recall in 2001) improved the situation, but did not eliminate CO poisonings. The two reasons for this are that fatal and nonfatal poisonings related to water-level generator exhaust outside the confined airspace have also been identified (see the GCNRA incident involving the death of a young girl outside a cabin cruiser in 2002) and fatal and nonfatal poisonings related to propulsion engine exhaust in the airspace have also been identified (see the GCNRA death of a 42-year-old man entering the airspace in 2002). Data collected at GCNRA demonstrated that even a relatively small generator (5 kilowatts) produces enough CO to result in rapid and fatal poisoning out in the open as far away as 5 to 10 feet from the terminus when the weather is relatively calm.

Another equally emergent issue arose during the course of the GCNRA investigations – deaths and severe poisonings related to ski boat and cabin cruiser features that attract occupancy at the rear of the boat. Most prominently covered in news media and subsequent legislative measures in Pennsylvania, California, and Nevada was occupancy of the water-level swim platforms of ski boats during an activity called "teak surfing" or "platform dragging," or during other activities while the boat moves slowly in the water, or is stationary. The six poisonings identified at GCNRA related to occupancy of the swim platform of recreational speed boats were strikingly similar to 43 severe (17 resulting in death and 19 others resulting in loss of consciousness) poisonings occurring on swim platforms of recreational speed boats identified randomly in other states (http://safetynet.smis.doi.gov/COhouseboats.htm).

Four GCNRA poisonings were related to occupancy of padded bench seats (also referred to as "sunning decks" or "tanning decks") on the transom of ski boats. This feature also encourages occupancy of an area rich in CO when the boat engine is operating. These poisonings occurred in 2001 and 2004, and reinforce concern about poisonings on ski boats that occur outside of any enclosure. A similar poisoning occurred on Lake Minnetonka, Minnesota in July 2000, when a 15-year-old girl survived CO poisoning while she was lying on the rear padded sunning deck of a ski boat.

Boat occupants were waiting for a fireworks display, with the engine operating to power the on-board music system. Other occupants thought the girl was sleeping until they tried unsuccessfully to awaken her. She had stopped breathing. Her COHb concentration (measured at an unspecified time after her removal from exposure) was 30%.

In addition, during the course of this work, a feature described as a shower that operates using warm water from the operating propulsion engine arose as a serious concern. This device draws heated water from the propulsion engine, meaning that the engine has to be operating for the device to work. In the GCNRA incident, a 4-year-old girl was poisoned. She had been playing with a shower hose that was fed hot water by the engine. While sitting on the swim platform she clenched her arms, started crying, and her eyes rolled to the top of her head. She appeared to stop breathing. She survived. However, in a 1995 incident occurring in Flaming Gorge, Utah, three boys were hospitalized and another died in connection with the use of a similar device. In the Flaming Gorge incident, the boat had been completely covered because of rain. When the boat was occupied, a panel was unzipped and a door to the rear of the boat was opened to allow access to the ski platform. All four boys were discovered unconscious; the COHb of the boy who died was 46.6%.

Finally, the failure of on-board CO detectors in the living quarters of houseboats on Lake Powell raises concern about the impact of such devices in CO poisoning prevention. Improving the effectiveness of these devices is complex, as there were four types of problems identified, each indicating a different corrective strategy. (Identified problems included: failure to alarm; alarming when they shouldn't; disarmed or dysfunctional detector; absence of detectors.) Failure of functional detectors to warn occupants of high CO concentrations and the sounding of alarms for no discernable cause are related to detector sensor technology. A likely explanation of disabling of detectors by boaters is that the detectors are sounding frequently and the boater either cannot identify a cause for the alarm (also a detector technology issue) or cannot resolve the issue that is causing CO to enter the cabin (an issue related to boat design, technology, and boater education).

Data gathered at GCNRA point to the need for improved national data collection to identify the scope of the problem of boat-related CO poisonings. Better data collection hinges on both improved case identification and improved case reporting.

RECOMMENDATIONS

The following recommendations, listed by subject category, are a consolidation of those found in all the interim reports, and are still relevant, despite the Coast Guard recall and all prevention efforts conducted to-date.

Engineering Controls

1. GCNRA should investigate engineering controls to reduce exposures of boat maintenance mechanics. If repairs are conducted outside and at the boat dock (where electric power is easily available), using a high volume fan or other air-moving device may help to prevent short-term IDLH exposures as measured during at least one investigation.

2. Employers (NPS and concessionaire) of boat/vehicle engine maintenance staff should conduct further CO monitoring on these employees to characterize their extent of exposure and determine if engineering controls are warranted and feasible to control exposures.

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

4. GCNRA, NPS, and DOI should continue to encourage research into effective technologies to control CO exposure through emission control devices on generators and propulsion engines.

5. Manufacturers should change boat design features that encourage passengers to occupy environments rich in CO. Examples of such changes might include: removal of the swim platform, thus removing the opportunity to teak surf; changing the direction/location of the exhaust; working with engine manufacturers to add or develop emission control devices for marine engines.

6. The location of generators and the configuration of generator exhaust should be taken into consideration for any future NPS equipment purchases. This recommendation is based on sampling conducted on the newly purchased GCNRA Fire Boat on which the auxiliary power generator was located in the staging area for emergency responders. The generator exhaust terminus should be located in an area that is neither accessible nor occupied.

Medical

1. To improve boat-related CO poisoning case identification, the following are needed:

- Training for EMS providers to help them recognize CO as a possible contributor and to give them guidance in collecting needed information about CO sources;

- Information materials for the medical community (EMS, Emergency Department, and Coroners/Medical Examiners) that stress the need for immediate COHb measurements anytime a drowning occurs near a boat or boat passengers experience symptoms consistent with CO poisoning;

2. Emergency medical services on bodies of water with large concentrations of boaters should consider using expired CO monitors when responding to medical emergencies. This equipment allows improved case identification as well as improved case management. The practicality and cost-effectiveness of using this equipment has been demonstrated during the past two years in GCNRA. Symptoms of CO poisoning are similar to those of dehydration, excessive alcohol consumption, and many other illnesses. The use of expired CO monitors allows medics to clearly assess CO poisonings and assists them in convincing patients to accept appropriate medical care.

Record Keeping / Reporting CO Poisonings

1. Awareness among EMS personnel is critical to accurate diagnosis and treatment of CO poisonings, as is developing related records for EMS personnel to use to thoroughly document CO poisoning. NPS should encourage the use of a standard data collection form when boat occupants requesting assistance present with or report symptoms consistent with CO poisoning (headache, nausea, dizziness, loss of consciousness, convulsions, etc.). An example of this type of form for use by EMS or other park rangers investigating the incident can be found on the Internet at: http://safetynet.smis.doi.gov/COhouseboats.htm.

2. EMS personnel should ensure that the information collected above is transferred to the receiving medical facility to aid the treating physician in treatment and diagnosis decisions. In addition, this information should be shared with coroners/medical examiners who receive the bodies of drowning victims (particularly if the drowning was unwitnessed or nontraumatic in nature) or people who died of natural causes. The goal of this recommendation is to encourage the collection of blood and/or breath samples for COHb analysis at the hospital emergency department or other medical facility receiving the patient.

3. NPS EMS Medical Directors' tasks should include monitoring trends reflected in data from EMS records on a periodic basis. Frequency of this review of data should be based upon such things as size of the park, number of incidents, and available resources.

4. NPS and other agencies responsible for responding to emergencies on bodies of water should work with the appropriate US Coast Guard, national NPS, and DOI staff to develop a systematic method of reporting and tracking severe medical events.

5. GCNRA should ensure that all boating accidents (including CO-related boating accidents) are reported through appropriate State Reporting

Authority to the U. S. Coast Guard Boating Accident Report Database.

Regulatory / Guidelines / Procedural

1. When houseboats with a confined airspace beneath the extended rear deck are on the water, the area under the swim deck meets NIOSH and OSHA criteria for a permit-required confined space. Therefore, permit-required confined space procedures must be followed before any workers enter this airspace.

2. The similar hazard for boat occupants is no less important. Boat manufacturers should develop similar safe entry procedure guidelines for boaters that many also have to enter this space. Boaters should be cautioned that entry into this airspace has resulted in at least 13 deaths, and several more severe poisonings as well. Boaters should contact the boat manufacturer for guidance about safe entry procedures.

3. Employees should avoid rafting boats (lashing two or more boats together side-by-side) as much as possible. If boats must be rafted (as is the case for EMS responses, etc.), employees should deactivate all engines including auxiliary engines, such as generators. Employees should avoid occupying the rear of the boat until engines are deactivated and exhaust has dissipated.

4. Legislators should consider rules prohibiting occupancy of swim platforms and transom-mounted padded seats when the propulsion engines are operating. NPS should similarly prohibit such activities on bodies of water under their jurisdiction.

5. Manufacturers should immediately place warning labels on all boats with design features that encourage or allow occupancy of areas that are rich in CO. These labels should warn of the hazardous circumstances and specifically tell passengers to stay away from the rear of the boat when the engines are operating. Information about the hazard of indoor and outdoor CO poisonings on boats should also be prominently placed in owner's manuals.

6. GCNRAA should assess additional active strategies that could be implemented to prevent CO poisonings at Lake Powell. Examples of possible GCNRA active strategies were discussed during an interagency meeting at a June 19, 2002 interagency meeting. Additionally, GCNRA should consider dedicating more resources to CO poisoning prevention efforts within the Park by filling vacant positions such as that of the safety officer. If filled, that position could coordinate visitor safety issues within the Park, including CO poisoning.

7. Portable shower devices that operate using hot water from an operating propulsion engine should be evaluated for potential recall.

CO Detectors in Boat Living Quarters

1. The U.S. Coast Guard should extend laboratory testing of marine-rated CO detectors (conducted under Contract Number DTCG39-00-D-R0009, Task Order 01-F-00016, August 17, 2004) to include comprehensive field testing of detector efficiency and effectiveness.

2. Even though alarms may sound in the absence of high CO levels, boat owners and operators should never disable CO detectors and should always heed the warning alarm when it sounds.

3. Boat owners should report detector failures to the manufacturer.

4. Boat owners should comply with owner's manual instructions to ensure that they understand the proper functioning of the onboard CO detector.

5. Boat owners should routinely check alarm function.

6. Boat rental companies should check the proper function of CO detectors before each new rental.

7. Boating accident investigators should gather detailed information about CO detector failure, including reasons for detectors being disabled. This information should be communicated to the appropriate state boating accident reporting authority. Detectors that fail to alarm during a poisoning incident should be tested.

Training / Sharing Information

1. Training about the severity of CO hazards in boating should be reviewed and continued for Park Service personnel, especially EMS providers, so that symptoms experienced by employees or other boat operators might be more easily associated with exposures. This training should include both environmental data and information about the number and circumstances of CO poisonings on the lake.

2. Awareness campaigns to inform boaters of boat-related CO hazards on NPS and other lakes should be continued and enhanced. Training about the specific boat-related CO hazards provided for boat renters should be enhanced to include specific information about the circumstances and number of poisonings and deaths. The training (including videotaped training) should include anecdotal information about deaths and near misses, and should specifically warn against entering air spaces under the boat (such as the cavity below the swim platform) that may contain a lethal atmosphere.

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

4. NPS should work with receiving medical facilities and medical examiners/coroners to increase awareness of CO exposure and poisonings on boats. The goal of this recommendation is to encourage improved identification of CO-related fatalities through regular measurement of COHb when victims die of unwitnessed non-traumatic drownings.

5. NPS and their concessionaires should educate all boat users about CO hazards (both symptoms of poisoning, and what circumstances lead to poisoning). Examples of educational materials developed for this purpose can be found on the Internet at http://safetynet.smis.doi.gov/COhouseboats.htm. NPS should ensure that this training and information is provided for all boat owners and users, regardless of the type of boat ownership or management.

6. 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.

7. 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.

8. Manufacturers of houseboats must continue to be informed of the environmental data that has been collected, and the related design concerns. This relates most critically to the issue of side-exhausting generators. NIOSH sampling and deaths occurring near houseboats and cabin cruisers with water-level generator exhaust configuration, regardless of direction, has repeatedly demonstrated a CO poisoning hazard. This hazard is enhanced when boats are rafted (aligned boats moored to each other), as is very often the case with houseboat use. NIOSH control technology studies have demonstrated that rerouting generator exhaust through a properly designed “stack” terminating well above the upper deck effectively reduces CO concentrations in potentially occupied areas around houseboats

9. Boat manufacturers should continue to be informed that the presence of design features that encourage occupancy at the rear of the boat (i.e., extended easy-to-access swim platforms in combination with a recessed propeller, padded transom-mounted “sunning decks”, and showers that operate using hot water from the engine) are in an environment that is very hazardous when the engines operate.

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

11. GCNRA 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 GCNRA.

- Post additional permanent CO warning signs at locations boat users frequent, such as pumpouts, 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 distributing materials on CO safety (brochures and park guide/newspaper) at entrance stations.

- Continue printing 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 GCNRA employee contacts with boat operators (ramp contacts, boat patrols, maintenance activities, etc.)

- Repeat Public Service Announcements in local media (radio, newspaper) during boating season.

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

13. GCNRA/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 possibility of fatal poisoning even if exposure occurs outside of any enclosure or obstruction of engine emissions.

Further Testing

1. NPS should ensure that further full-shift CO exposure monitoring is conducted for fuel dock workers. Sampling results indicated that these employees experience exposures over existing NIOSH and ACGIH recommended limits, including peak exposures greater than 1,000 ppm. 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.

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TABLES

Table 1. Confined Space Classification

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

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

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

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Table 2. Checklist of Considerations for Entry, Working In and Exiting Confined Spaces

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

X = indicates requirement Q = indicates determination by the qualified person

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Table 3. Number of Boat-Related CO Poisonings by Year – Glen Canyon National Recreation Area*

Year	Fatal Poisonings				Non-Fatal Poisonings			
	Inside the Cabin		Outside the Cabin		Inside the Cabin		Outside the Cabin	
	Houseboat	Motorboat	Houseboat	Motorboat	Houseboat	Motorboat	Houseboat	Motorboat
1990	0	0	0	0	3 boat type not listed		1	0
1991	0	0	0	0	0	0	3	0
1992	0	0	0	0	0	0	2	0
1993	0	0	0	0	12	0	1	0
1994	0	0	1	0	1	6	2	0
1995	0	1	0	1	14	6	3	7
1996	0	0	1	0	0	0	3	0
1997	0	0	0	0	0	0	2	3
1998	0	0	2	0	9	1	3	3
							1 boat type not listed	
1999	0	0	1	0	0	0	1	1
2000	0	0	2	0	0	6	8	2
2001	0	0	1	1	11	0	2	9
2002	0	0	1	1	23	0	1	1
2003	0	0	1	0	0	0	0	0
2004	0	0	0	0	10	0	0	1
Total	**0**	**1**	**10**	**3**	**80**	**19**	**32**	**27**
					3		**1**	

*Source of data – GCNRA law enforcement and emergency medical services records; Page Hospital emergency department records

FIGURES

Figure 1. Example of the Houseboat Extended Rear Deck Related to Seven Deaths at Lake Powell

Figure 2. Airspace Beneath the Houseboat Extended Rear Deck

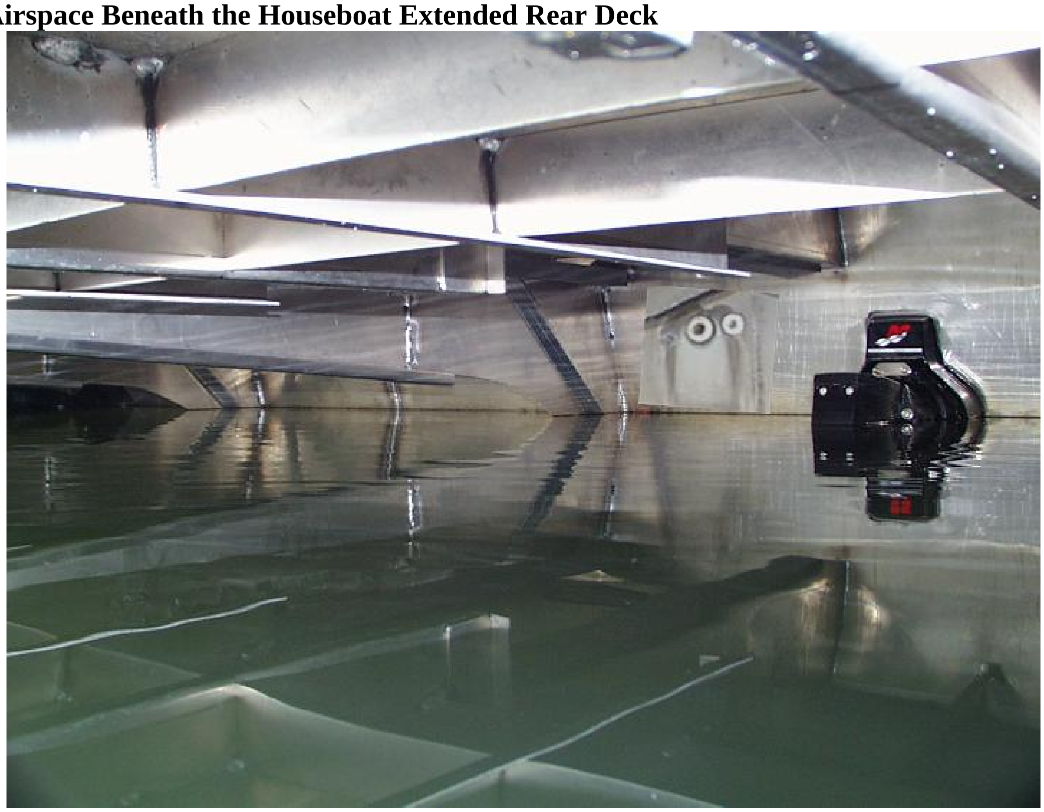


Figure 3. Overhead Diagrammatic View Illustrating Generator and Generator Exhaust Terminus Location on Houseboats of the Design Associated with Seven GCNRA Deaths

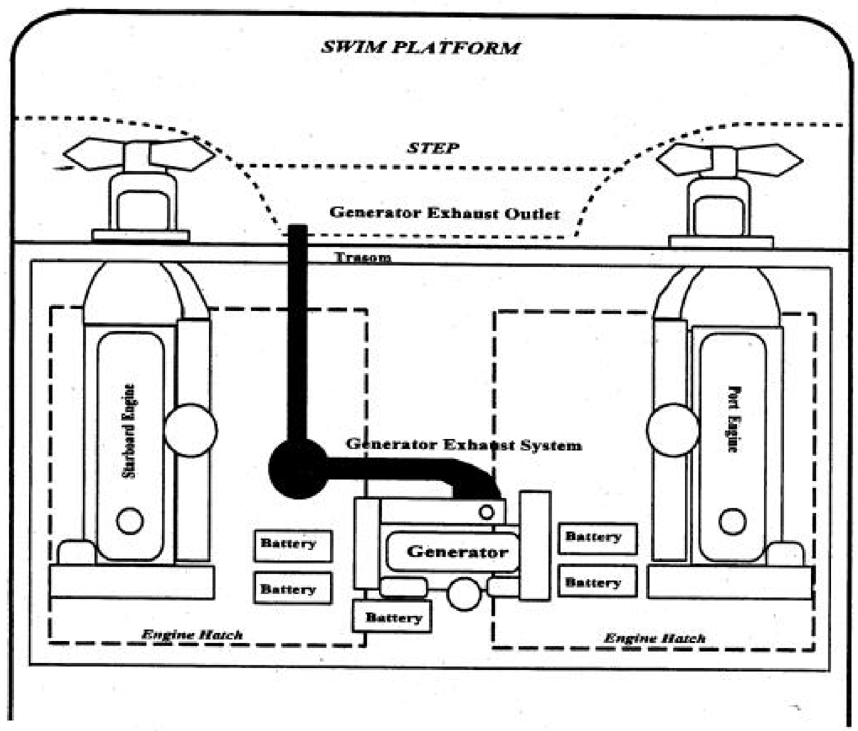
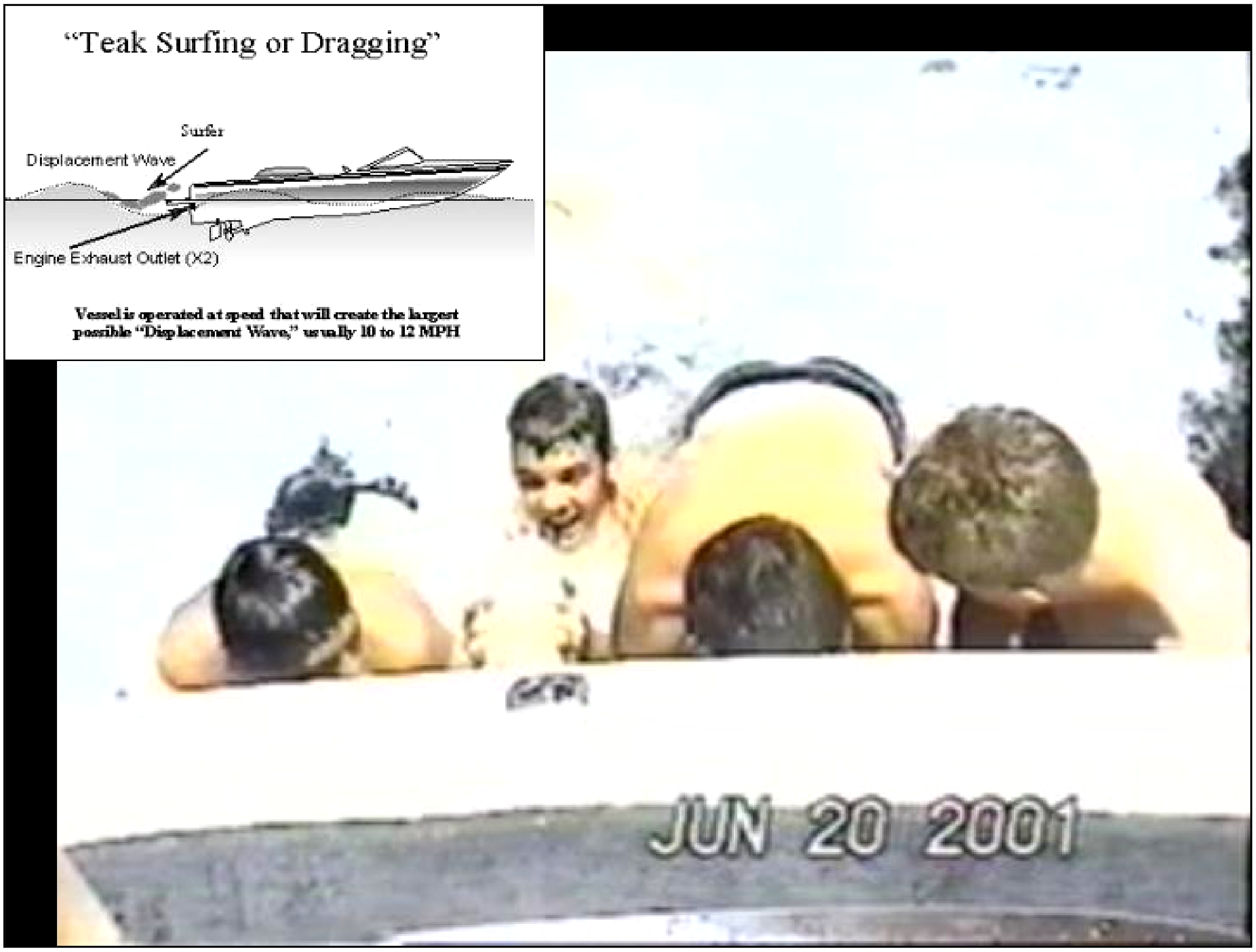


Figure 4. Teak Surfing or Platform Dragging



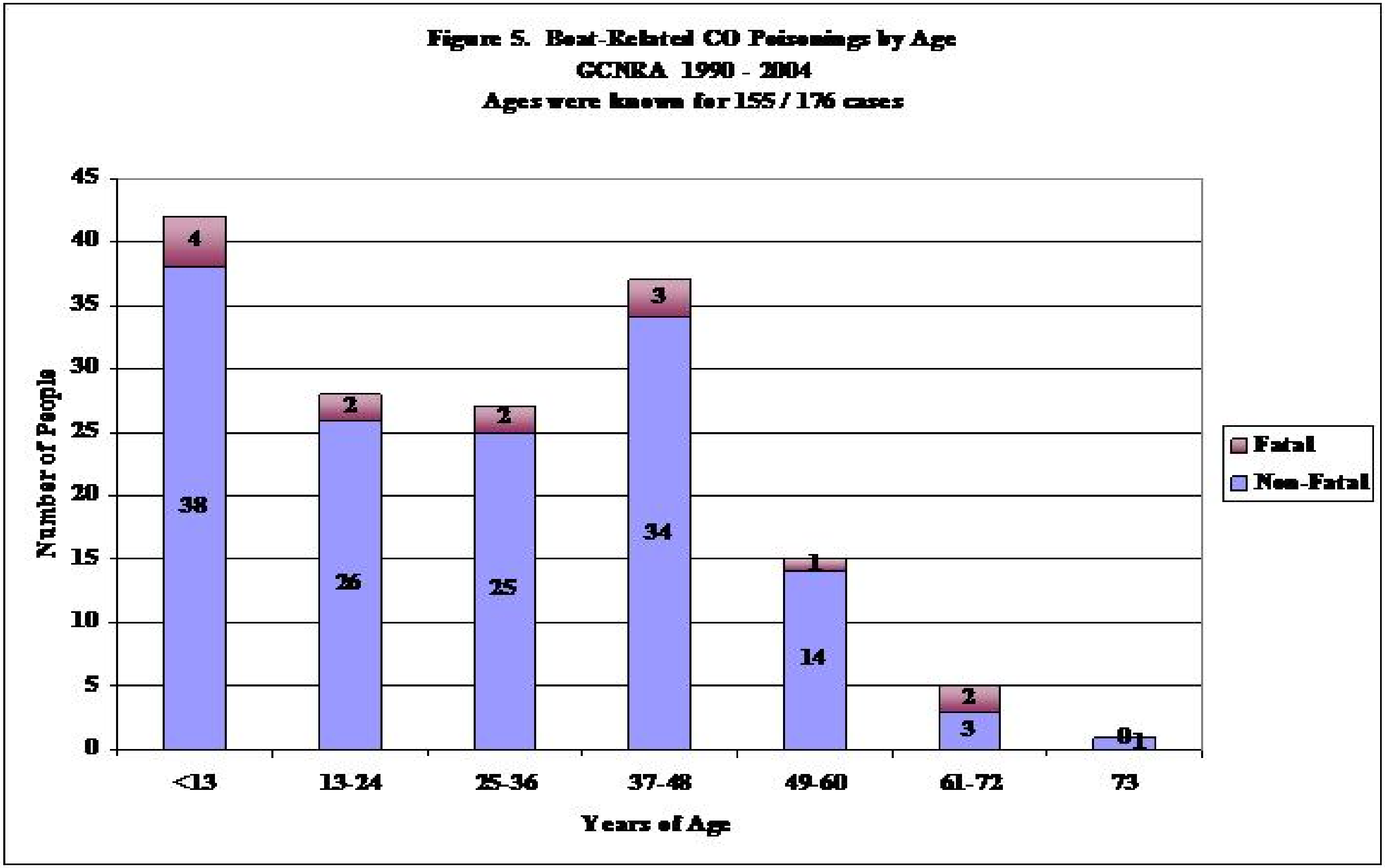


Figure 5. Boat-Related CO Poisonings by Age
GCNRA 1990 - 2004
Ages were known for 155 / 176 cases
Number of People
45
40
35
30
25
20
15
10
5
0
4
38
2
26
2
25
3
34
1
14
2
3
0
1
<13
13-24
25-36
37-48
49-60
61-72
73
Years of Age
Fatal
Non-Fatal

Figure 6. Boat-Related CO Poisonings by Source of CO
GCNRA 1990 - 2004
(n = 176)

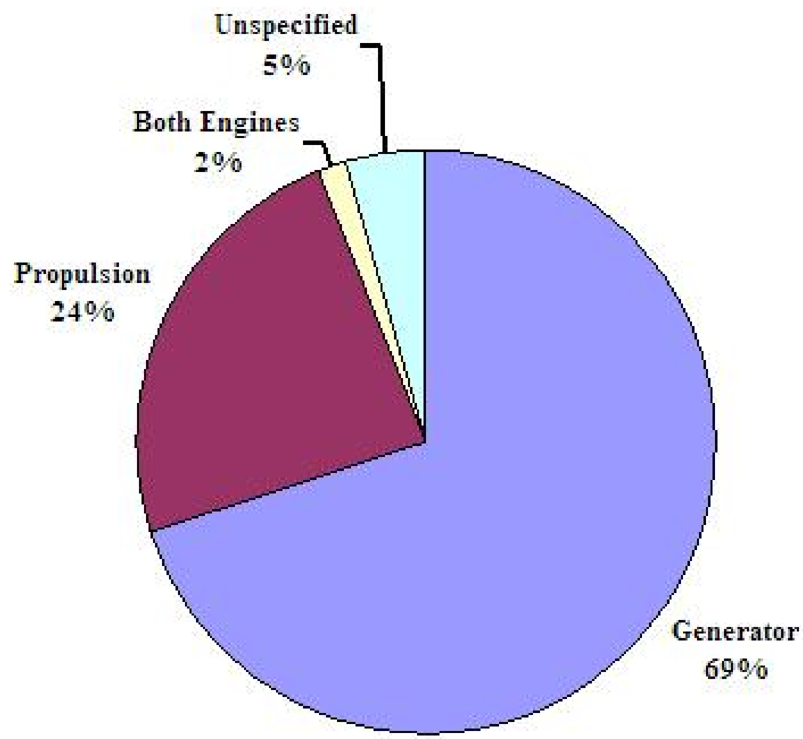


Figure 7. Boat-Related CO Poisoning by Location of Victim
GCNRA 1990 - 2004
(n = 176)

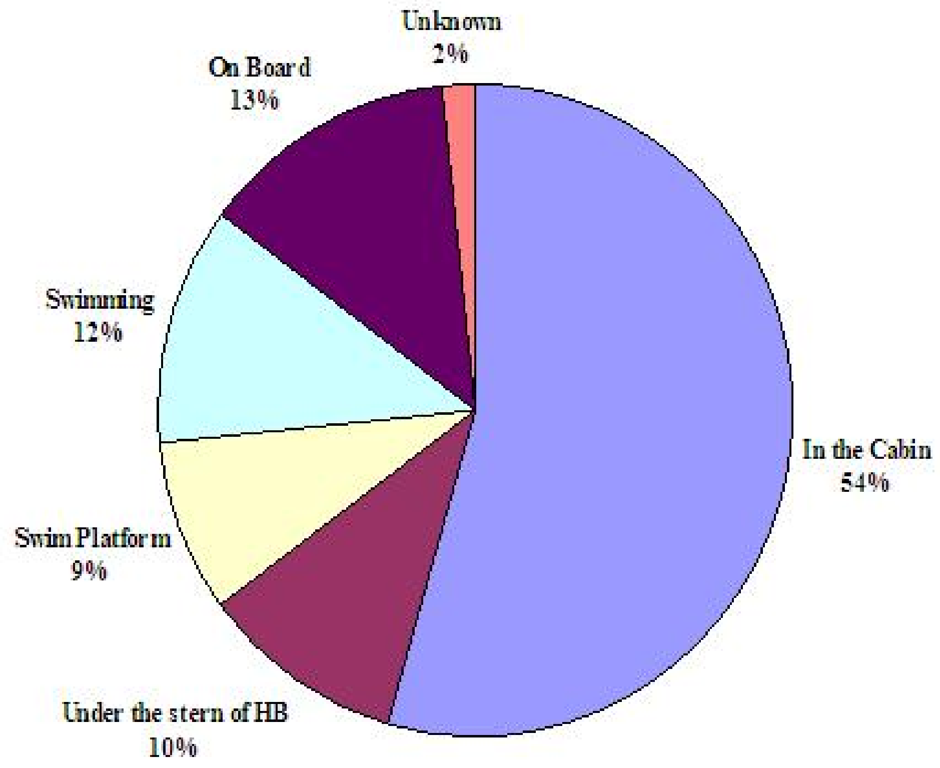
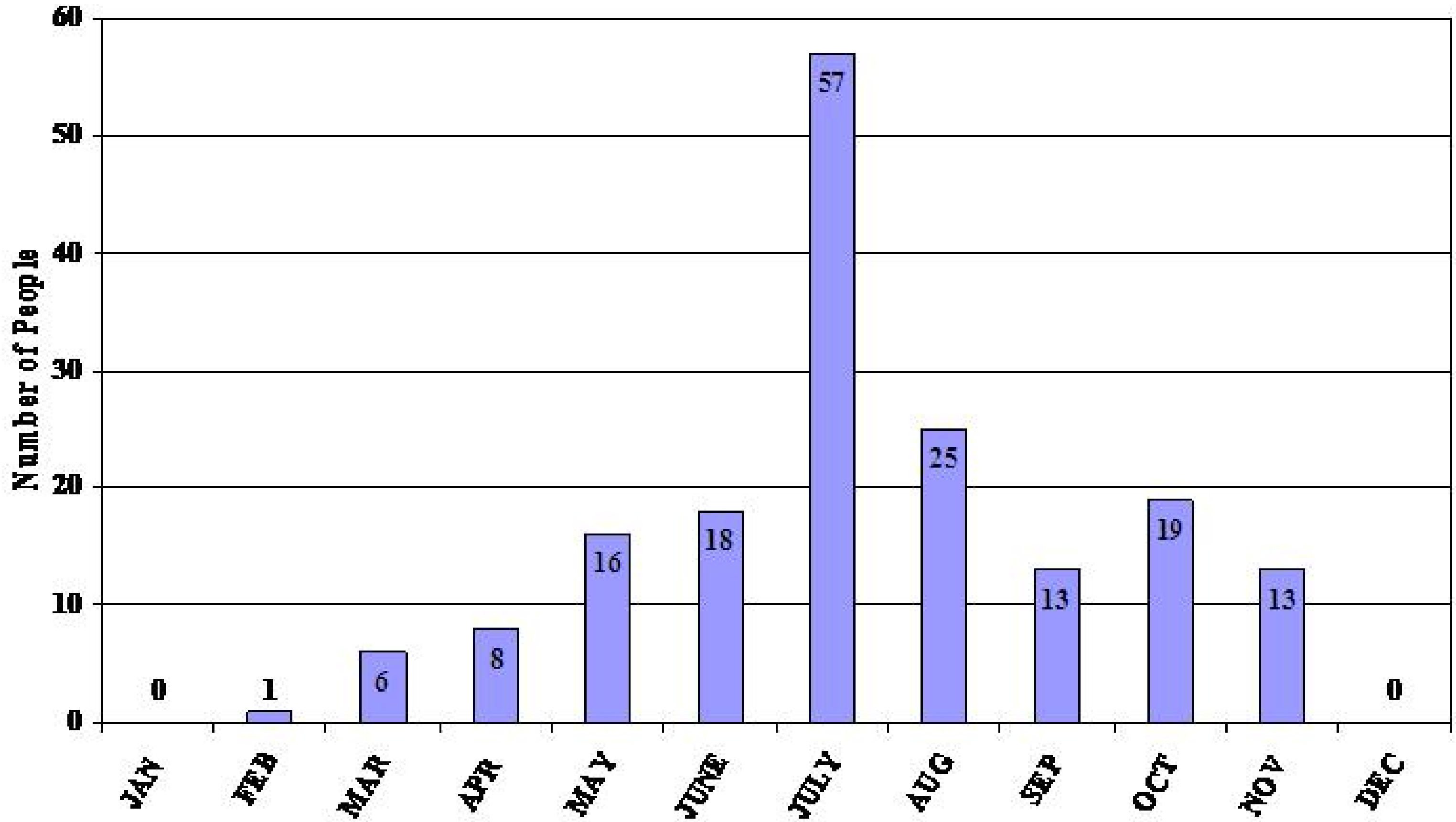


Figure 8. Boat-Related CO Poisonings by Month
GCNRA 1990 - 2004



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