NIOSH HEALTH HAZARD EVALUATION REPORT

HETA #2002-0393-2928
Lake Havasu Municipal Employees
Lake Havasu City, Arizona

February 2004

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 Robert E. McCleery, MSPH; Loren Tapp, MD, MS; and Jane McCammon, MS, CIH, of HETAB; and Kevin L. Dunn of Industrywide Studies Branch (IWSB), Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Analytical support was provided by Ardith Grote, Division of Applied Research and Technology (DART); and Data Chem Laboratories, Salt Lake City, Utah. Desktop publishing was performed by Robin Smith. Review and preparation for printing were performed by Penny Arthur.

Copies of this report have been sent to employee and management representatives at Lake Havasu City (LHC) 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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For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Carbon Monoxide Exposures in the Bridgewater Channel in Lake Havasu, Arizona

In August 2002, NIOSH received a health hazard evaluation request for assistance in evaluating carbon monoxide (CO) exposures in the Bridgewater Channel (BC) in Lake Havasu, Arizona. The request expressed concern about police and fire department personnel who patrol the BC on holiday weekends and their exposures to CO. In response to this request, NIOSH conducted an initial evaluation in August 2002 and a follow-up evaluation in May 2003.

What NIOSH Did

- We evaluated Lake Havasu City (LHC) employee exposures by measuring CO in air and in exhaled breath.
- We measured area concentrations of airborne CO, formaldehyde, acrolein, and VOCs (volatile organic compounds).
- We surveyed LHC employees about job duties, work locations, and possible CO-related symptoms.

What NIOSH Found

- We found that over half of LHC employees working in the BC were overexposed to CO during the 2003 Memorial Day weekend.
- More than half of all LHC employees reported post-shift symptoms on days with highest CO exposures.
- Airborne formaldehyde in two of four samples collected at the back of boats was below irritant levels, but above the NIOSH recommended exposure limit. Acrolein in air was not detectable.

What LHC Managers Can Do

- Determine actions to reduce overall CO concentrations in the BC area during high boat-traffic days.
- Develop an LHC employee exposure monitoring program to determine patterns of employee overexposure.
- Until CO concentrations are reduced within the BC, reduce the number of hours LHC employees are exposed to high CO concentrations by rotating assignment locations.
- Assure the effectiveness of control measures through continued LHC employee exposure monitoring.

What LHC Employees Can Do

- Report symptoms of CO poisoning to designated health and safety personnel.
- Stay as far away from the CO source as possible.
- Deactivate engines whenever possible.
- Ask visitors to deactivate their boat engines when you pull alongside them for your work.

CDC Workplace Safety and Health

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 #2002-0393-2928

NIOSH

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SUMMARY

In August 2002, the National Institute for Occupational Safety and Health (NIOSH) was asked for assistance in evaluating carbon monoxide (CO) at the Bridgewater Channel (BC) in Lake Havasu City (LHC), Arizona. The request, from the Medical Director for Emergency Medical Services at Lake Havasu (also a physician at the Havasu Regional Medical Center), expressed concern about police and fire department personnel who patrol the BC on holiday weekends, and also about visitors in the BC who had been treated for CO poisoning in the Havasu Regional Medical Center Emergency Department (ED). These visitors had carboxyhemoglobin (COHb) concentrations greater than 30%, indicating severe poisoning. LHC Police officers (POs) and Emergency Medical Service/Firefighter (EMS/Fire) personnel patrol the waterway for as much as 10 hours per workshift on holiday weekends, when the boat traffic is excessive. In response to this request, subsequently supported by a letter from an LHC spokesperson (Chief of the Fire Department), NIOSH investigators conducted an initial investigation in the BC during the 2002 Labor Day weekend and a follow-up investigation during the 2003 Memorial Day weekend.

Real-time CO monitoring was conducted on POs and EMS/Fire personnel with additional general area air sampling in and around the BC. Daily pre-shift, mid-shift, and post-shift questionnaires were administered in conjunction with exhaled breath CO measurements. Questionnaires included information on work duties and location, tobacco use, and potential CO exposure symptoms.

There were 78 total workshifts where real-time CO monitoring was performed. Of those 78 workshifts, 54 exceeded the NIOSH ceiling limit of 200 parts per million (ppm), 64 exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) excursion limit of 125 ppm, 7 exceeded the Occupational Safety and Health (OSHA) Permissible Exposure Limit (PEL) of 50 ppm, 17 exceeded the NIOSH Recommended Exposure Limit (REL) of 35 ppm, and 33 exceeded the ACGIH Threshold Limit Value (TLV) of 25 ppm.

Exhaled breath CO analyses and symptom questionnaires were conducted for 81 workshifts. Forty of the 81 workshifts had cross-shift COHb increases of at least 3.5%. Nonsmoking participants made up 63 of the 81 workshifts. Among the 63 nonsmoker workshifts, 42 had a post-shift %COHb at or above the ACGIH Biological Exposure Index (BEI) of 3.5%, with some levels approaching 15%. Questionnaire

responses indicated that the most frequent symptom was headache, followed by fatigue or weakness, visual disturbances, and dizziness.

NIOSH investigators conclude that a health hazard related to CO exposure generated from boat exhaust exists for Lake Havasu City municipal employees and visitors of Lake Havasu, Arizona. Real-time CO monitoring indicates that Lake Havasu City POs and EMS/Fire personnel working in the canal over the 2002 Labor Day weekend and the 2003 Memorial Day weekend were exposed to CO concentrations approaching and/or exceeding relevant evaluation criteria. Exhaled breath CO analyses over the 2003 Memorial Day weekend revealed estimated %COHb levels above established occupational biological exposure criteria. These elevated %COHb levels indicate employee overexposure to CO and a potential for adverse health effects. Suggested improvements for Lake Havasu municipal employees are presented in the Recommendations section of this report.

Keywords: SIC 9221 (Police Protection), carbon monoxide, CO, carboxyhemoglobin, COHb, police, emergency medical services, firefighter, EMS/Fire, boats, exhaust

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INTRODUCTION

In August 2002, the National Institute for Occupational Safety and Health (NIOSH) was asked for assistance in evaluating carbon monoxide (CO) at the Bridgewater Channel (BC) in Lake Havasu City (LHC), Arizona. The request, from the Medical Director for Emergency Medical Services at Lake Havasu (also a physician at the Havasu Regional Medical Center), expressed concern about police and fire department personnel who patrol the BC on holiday weekends, and also about visitors in the BC who had been treated for CO poisoning in the Havasu Regional Medical Center Emergency Department (ED). These visitors had carboxyhemoglobin (COHb) concentrations greater than 30%, indicating severe poisoning. LHC Police officers (POs) and Emergency Medical Service/Firefighter (EMS/Fire) personnel patrol the waterway for as much as 10 hours per workshift on holiday weekends when the boat traffic is excessive.

In response to this request, which was subsequently supported by a letter from a LHC spokesperson (Chief of the Fire Department), NIOSH investigators conducted an initial investigation in the BC during the 2002 Labor Day weekend (August 31 and September 1, 2002) and a follow-up investigation during the 2003 Memorial Day weekend (May 23-26, 2003).

The initial investigation included preliminary CO exposure assessments to determine the necessary scope of a more comprehensive evaluation. The follow-up investigation included (1) full workshift CO exposure monitoring of LHC municipal employees working in the BC, and (2) measuring CO in exhaled breath and conducting symptom questionnaires with LHC municipal employees in cooperation with Mohave County Department of Public Health (MCDPH) personnel. This report summarizes the NIOSH evaluations and provides recommendations for improving the occupational health of LHC municipal employees.

BACKGROUND

LHC, Arizona, borders the Colorado River and is located south of Lake Mead and Las Vegas, Nevada. The name "Havasu" came from a Mojave Indian and means "blue water".[1] Lake Havasu is a 45-mile long body of water created by Parker Dam.[2] The city is most famous for the London Bridge, which crosses the BC. The LHC area has extensive outdoor activities for tourists, many of which revolve around the lake itself.

Lake Havasu and the BC are popular weekend destinations. For this reason, NIOSH and hospital ED staff gathered preliminary range-finding data regarding airborne CO concentrations in the BC on August 31st and September 1st of the 2002 Labor Day weekend to determine if there was need for a more extensive evaluation. Results of this preliminary effort are included as Appendix A. In addition, hospital ED staff measured CO in exhaled breath of symptomatic people reporting to the ED on these days.

The data collected during the 2002 Labor Day weekend indicated that employees and vacationers spending lengthy periods within the BC during days of high traffic may be experiencing CO poisoning. This was based upon the following:

1. Two BC visitors reporting to the hospital ED during the second day of air sampling had lost consciousness in the water, and both were non-smokers and had elevated COHb measurements (9.4% and 28.3%). The latter patient had received oxygen therapy for approximately 30 minutes prior to the measurement of COHb level, and thus the COHb at the time consciousness was lost would have been even higher. If the hospital the patient was treated at had not been conducting exhaled CO measurements as part of this research, this patient's loss of consciousness may well have been attributed to other factors, such as heat stress, dehydration, or alcohol consumption.

2. Four of twelve (33%) patients tested by ED staff after boating activities had estimated COHb

concentrations that substantially exceeded guidelines of 2.5% (World Health Organization [WHO]) or 2.1% (Environmental Protection Agency [EPA]).[3,4] These four patients had COHb concentrations 4 to 11 times these criteria, and two were transported to the hospital after being pulled unconscious from the water. All patients tested were non-smokers.

3. Spot checks of CO concentrations near vacationers on and near moored boats in the BC were in excess of every recognized short-term exposure limit.

4. Average CO concentrations measured for 20-40 minute periods ranged from 77 to 131 parts per million (ppm), and indicated that employees who spend lengthy periods patrolling the BC or responding to incidents may be overexposed to CO.

These data, in combination with information subsequently obtained regarding BC visitor CO-associated poisonings (two drownings and four cases of lost consciousness in 2001-2002), indicated the need for more complete characterization.

Recommendations in the NIOSH report from the 2002 Labor Day study included the following:

1. Conduct full workshift CO exposure monitoring for LHC municipal employees working in the BC to determine if they are overexposed to CO during high traffic days, and measure pre- and post-shift exhaled CO accompanied by employee surveys to determine if they experience symptoms of CO overexposure during their duties within the BC.

2. Collect further data related to visitor CO exposures within the BC area, to possibly include measurement of CO in exhaled breath of visitors and/or placement of stationary CO air sampling monitors at fixed locations among the moored boats where visitors linger during high traffic days.

3. Measure COHb concentrations among ED patients who have been boating in the BC during high traffic days.

4. Develop a more comprehensive research and intervention program related to the issue of boat-related CO exposures.

The following actions addressed the recommendations contained in the 2002 Labor Day report.

1. LHC hired a contractor to place stationary CO air sampling monitors and gather additional environmental data in and near the BC through the summer of 2003. The contractor conducted further characterization of CO concentrations and meteorologic conditions within the BC through placement of stationary and mobile air sampling equipment prior to the 2003 Memorial Day weekend.

2. At the request of the MCDPH, the Arizona Department of Health Services conducted exhaled CO measurements among visitors to the BC during the 2003 Memorial Day weekend (May 25-26). Appendix B presents the results of these measurements.

3. NIOSH provided two exhaled breath CO monitors for use by hospital ED staff during the 2003 Memorial Day weekend. Hospital staff used these monitors to measure CO in exhaled breath of ED patients who had been in the BC when they experienced symptoms.

4. NIOSH assisted LHC and Mohave County in obtaining educational brochures which were distributed by the City during the 2003 Memorial Day weekend. LHC also developed and distributed other educational materials warning visitors and employees about the dangers of exposure to CO in boat engine exhaust.

5. LHC responded to the intervention portion of recommendation #4 by developing warning signs to be posted at the BC entry.

METHODS

Logistics

LHC municipal employees who were scheduled to work in the BC area during the 2003 Memorial Day weekend were asked to participate in the NIOSH study. Special unit POs were assigned to work one of the following locations: the East or West bank booking station, the East or West bank police patrol (on either electric-powered or gas-powered golf carts, or gas-powered quads), or on the police boats that patrolled the BC. EMS/Fire personnel were assigned to work one of the following locations: the East or West bank (each bank had an EMS/Fire station with electric golf carts) or on one of the fire boats that would respond to emergencies on Lake Havasu, including the BC area. Each morning of the four day study, LHC employees received their CO monitor and provided exhaled breath for the pre-shift %COHb reading. Every 3-4 hours throughout the day (a "session" in Tables 1-4), if available, LHC employees went to East or West bank locations where NIOSH and MCDPH personnel were stationed for a midshift %COHb reading. After their workshift, LHC employees went to the NIOSH/MCDPH stations to drop off their CO monitors and provide their post-shift %COHb reading. In addition to the personal air samples collected for CO, general area (GA) air samples for formaldehyde, acrolein, and volatile organic compounds (VOCs) were collected in the BC area because these substances are known components of vehicle exhaust due to incomplete combustion.[5]

Industrial Hygiene

Carbon Monoxide

CO concentrations were measured on LHC municipal employees (POs and EMS/Fire personnel) and at GA work locations using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. All ToxiUltra CO monitors were zeroed and calibrated before each use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode, with a one-minute sampling interval. The instruments have a nominal range from 0 to 500 ppm with the highest instantaneous reading of 1000 ppm.

Formaldehyde

Four GA air samples were collected for formaldehyde. Samples were collected on silica gel sorbent tubes (containing a cartridge coated with 2,4-dinitrophenylhydrazine), at a calibrated flow rate of 0.2 liters per minute (lpm). The tubes were analyzed by high pressure liquid chromatography (HPLC) according to NIOSH Method 2016.[6] The analytical limit of detection (LOD) was 0.1 micrograms per sample (µg/sample), which is equivalent to a minimum detectable concentration (MDC) of 0.0007 ppm, assuming a sample volume of 118 liters. The limit of quantitation (LOQ) was 0.4 µg/sample, which is equivalent to a minimum quantifiable concentration (MQC) of 0.0028 ppm, assuming a sample volume of 118 liters.

Acrolein

Four GA air samples were collected for acrolein. Samples were collected on sorbent tubes (10% 2-(hydroxymethyl)piperidine on XAD-2, 120 milligrams (mg)/60 mg), at a calibrated flow rate of 0.05 lpm. The tubes were analyzed by gas chromatography (GC) according to NIOSH Method 2539.[6] The analytical LOD was 0.7 µg/sample, which is equivalent to a MDC of 0.01 ppm, assuming a sample volume of 30 liters. The LOQ was 2.0 µg/sample, which is equivalent to a MQC of 0.03 ppm, assuming a sample volume of 30 liters.

Volatile Organic Compounds

Eight thermal desorption tube area air samples were collected for qualitative analysis of VOCs in accordance with NIOSH Method 2549.[6] Samples were collected on three beds of sorbent material enclosed in a stainless steel tube using personal sampling pumps at a calibrated flow rate of 0.05 lpm. The thermal desorption tubes were purged with helium to remove any water and then analyzed using gas chromatography/ mass spectrometry (GC/MS).

Medical

LHC POs and EMS/Fire personnel, who worked in the BC area during the 2003 Memorial Day weekend, were included in the evaluation. Daily pre-shift, mid-shift, and post-shift questionnaires were conducted in conjunction with exhaled breath CO measurements on May 23-26, 2003. Questionnaires included information on work duties and location, tobacco use, and CO exposure symptoms. Mid-shift questionnaires and exhaled breath CO measurements were performed at varying times (typically at 3-4 hours and 6-7 hours) during the shift.

The breath analysis for CO was performed by using a Breath Analyzer Module which attaches to the top of a Toxi-Ultra monitor. Participants were asked to inhale, then exhale completely, and then inhale deeply and hold their breath for 20 seconds. At the end of 20 seconds the individual exhaled a small amount of air into the atmosphere, then blew the remainder of their exhalation into a balloon. The one-way valve on the Module forced the participant's exhaled air from the balloon through the CO monitor, which read the CO concentration of the breath in ppm. This concentration was converted from ppm into an estimate of the %COHb level in the body using the following formula from the American Conference of Governmental Industrial Hygienists (ACGIH):[7]

$$\%COHb = (CO\ [in\ ppm]/5) - 0.5$$

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, 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),[8] (2) ACGIH® Threshold Limit Values (TLVs®),[9] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[10] 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 [Occupational Safety and Health Act of 1970, Public Law 91-596, sec. 5(a)(1)]. 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 their 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.

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.[7,11,12,13,14,15] The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes.

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

Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body. Once absorbed into the bloodstream, the half-time of CO disappearance from blood (referred to as the "half-life") varies widely by individual and circumstance (i.e., removal from exposure, initial COHb concentration, partial pressure of oxygen after exposure, etc.). Under normal recovery conditions breathing ambient air, the half-life can be expected to range from 2 to 6.5 hours.[3] This means that if the initial COHb level were 10%, it could be expected to drop to 5% in 2 or more hours, and then 2.5% in another 2 or more hours. If the exposed person is treated with oxygen, as happens in emergency treatment, the half-life time is decreased again by as much as 75% (or to as low as approximately 40 minutes). Delivery of oxygen under pressure (hyperbaric treatment) reduces the half-life to approximately 20 minutes.

Occupational Exposure Criteria

Occupational criteria for CO exposure are applicable to employees who may be at risk of CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities) because occupational standards 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.[16] Standards relevant to the general population take these factors into consideration, and are listed following the evaluation criteria to aid in understanding information presented in the discussion section of this report, as well as Appendix B.

The NIOSH REL for CO is 35 ppm for full shift TWA exposure, with a ceiling limit of 200 ppm which should never be exceeded.[8] The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[11] NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm.[17] An IDLH value is defined as a concentration at which an immediate or delayed threat to life exists or that would interfere with an individual's ability to escape unaided from a space.

The ACGIH recommends an 8-hour TWA TLV of 25 ppm based upon limiting shifts in COHb levels to less than 3.5%, thus minimizing adverse neurobehavioral changes such as headache, dizziness, etc., and to maintain cardiovascular exercise capacity.[7] ACGIH also recommends that exposures never exceed five times the TLV (thus, never to exceed 125 ppm).[9] 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).[9] The BEI generally indicates a concentration below which nearly all workers should not experience adverse health effects. The BEI cannot be applied to current smokers since smokers have been shown to have %COHb levels between 4% and 10%,[7,18] and can exceed 15% in heavy smokers.[19]

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.[10]

Health Criteria Relevant to the General Public

The US EPA has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a one-hour average.[4] 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 WHO has recommended guideline values and periods of TWA exposures related to CO exposure in the general population.[3] WHO guidelines are intended to ensure that COHb levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are: 100 mg/m^3 (87 ppm) for 15 minutes, 60 mg/m^3 (52 ppm) for 30 minutes, 30 mg/m^3 (26 ppm) for 1 hour, and 10 mg/m^3 (9 ppm) for 8 hours.

Formaldehyde

Formaldehyde is a colorless gas with a strong odor. Exposure can occur through inhalation and skin absorption. The acute effects associated with formaldehyde are irritation of the eyes and respiratory tract and sensitization of the skin. The first symptoms associated with formaldehyde exposure, at concentrations ranging from 0.1 to 5 ppm, are burning of the eyes, tearing, and general irritation of the upper respiratory tract. There is variation among individuals, in terms of their tolerance and susceptibility to acute exposures of the compound.[20]

In two separate studies, formaldehyde has induced a rare form of nasal cancer in rodents. Formaldehyde exposure has been identified as a possible causative factor in cancer of the upper respiratory tract in a proportionate mortality study of workers in the garment industry.[21] NIOSH has identified formaldehyde as a suspected human carcinogen and recommends that exposures be reduced to the lowest feasible concentration. The OSHA PEL is 0.75 ppm as an 8-hour TWA and 2.0 ppm as a STEL.[22] ACGIH has designated formaldehyde to be a suspected human carcinogen and therefore, recommends that worker exposure by all routes should be carefully controlled to levels "as low as reasonably achievable" below the TLV.[9] ACGIH has set a ceiling limit of 0.3 ppm.[9]

Note: NIOSH testimony to DOL on May 5, 1986, stated the following: "Since NIOSH is not aware of any data that describe a safe exposure concentration to a carcinogen NIOSH recommends that occupational exposure to formaldehyde be controlled to the lowest feasible concentration; 0.1 ppm in air by collection of an air sample for any 15-minute period as described in NIOSH analytical method 3500 which is the lowest reliably quantifiable concentration at the present time." NIOSH also lists a REL for formaldehyde of 0.016 ppm for up to a 10-hour TWA exposure (again using NIOSH analytical method 3500 and indicating that this is the lowest reliably quantifiable concentration at the present time). Investigators should be aware that formaldehyde levels can currently be measured below 0.016 ppm. It may be appropriate to refrain from using numerical limits and instead state that concentrations should be the lowest feasible (in some situations, this may be limited by the ambient background concentration.)[23]

RESULTS

Tables 1-4 present the individual daily results for those employees who participated in the real-time CO monitoring during the four days of sampling over the 2003 Memorial Day weekend. The tables also provide the COHb information if the individual participated during the four days of sampling. Each table provides the location(s) and times worked by the employee, the pre-shift COHb reading and each COHb reading thereafter. Each subsequent COHb reading has the average and peak CO concentration for the time period between COHb readings. Additionally, a cumulative average CO concentration from the beginning of the workshift to each additional COHb reading is provided. Figures 1-85 present the graphical representations of (1) the real-time CO monitoring and (2) the COHb readings if the employees participated.

Industrial Hygiene

Carbon monoxide

May 23, 2003

Fourteen LHC municipal employees wore CO monitors during their workshift (Table 1). Additionally, three GA CO monitors were used in the following locations: one near pumpstation #3, which was moved near the Westside booking station; one used as a exhaled breath monitor, then moved close to the Westside booking station; and one at the restroom located near pumpstation #3 (along with instruments from Sanoma Technologies Inc. - picked-up on May 24).

Eleven of the fourteen employees exceeded the NIOSH ceiling limit of 200 ppm at some point during the day. All employees had peak exposures exceeding the ACGIH excursion limit of 125 ppm. The average CO concentration of each monitor indicated that there was the potential to exceed 8-hour TWA limits. One employee's average readings exceeded and two employee's approached (within 5 ppm) the OSHA PEL of 50 ppm. Three employee's average readings exceeded and three employee's approached (within 5 ppm) the NIOSH REL of 35 ppm. Eight employee's average readings equaled or exceeded and two employee's approached (within 5 ppm) the ACGIH TLV of 25 ppm. The GA monitor near the Westside booking station indicated an average CO concentration of 15 ppm with a peak reading of 188 ppm. The GA monitor near the Westside booking station indicated an average CO concentration of 20 ppm with a peak reading of 197 ppm. The GA monitor at the restroom (collected readings until the morning of May 24) indicated an average CO concentration of 19 ppm with a peak reading of 437 ppm.

May 24, 2003

Twenty-four LHC municipal employees wore CO monitors during their workshift (Table 2). Additionally, two GA CO monitors were used in the following locations: one on police boat #1297 and one near the trailer used by NIOSH personnel on the West side.

All employees exceeded the NIOSH ceiling limit of 200 ppm and the ACGIH excursion limit of 125 ppm at some point during the day. The average CO concentration of each monitor indicated that there was the potential to exceed 8-hour TWA limits. Six employee's average readings exceeded and three employee's approached (within 5 ppm) the OSHA PEL of 50 ppm. Ten employee's average readings exceeded and two employee's approached (within 5 ppm) the NIOSH REL of 35 ppm. Sixteen employee's average readings exceeded and six employee's approached (within 5 ppm) the ACGIH TLV of 25 ppm. The GA monitor on the police boat indicated an average CO concentration of 180 ppm with a peak reading of 1179 ppm. The GA monitor near the trailer used by NIOSH personnel indicated an average CO concentration of 17 ppm with a peak reading of 116 ppm.

May 25, 2003

Twenty-four LHC municipal employees wore CO monitors during their workshift (Table 3). Additionally, two GA CO monitors were used in the following locations: one on police boat

#2196 and one near the trailer used by NIOSH personnel on the West side.

Eighteen of the twenty-four employees exceeded the NIOSH ceiling limit of 200 ppm at some point during the day. Twenty-two of the twenty-four employees had peak exposures exceeding the ACGIH excursion limit of 125 ppm. The average CO concentration of each monitor indicated that there was the potential to exceed 8-hour TWA limits. Three employee's average readings exceeded the OSHA PEL of 50 ppm. Six employee's average readings exceeded and three employee's approached (within 5 ppm) the NIOSH REL of 35 ppm. Eleven employee's average readings exceeded and one employee approached (within 5 ppm) the ACGIH TLV of 25 ppm. The GA monitor on the police boat indicated an average CO concentration of 111 ppm with a peak reading of 1053 ppm. The GA monitor near the trailer used by NIOSH personnel indicated an average CO concentration of 12 ppm with a peak reading of 135 ppm.

May 26, 2003

Fifteen LHC municipal employees wore CO monitors during their workshift (Table 4). Additionally, two GA CO monitors were used in the following locations: one by the Eastside booking station and one by the Westside booking station. All employees' monitoring times were less than 8-hours due in part to employees being released for the day from work early.

One of the fifteen employees exceeded the NIOSH ceiling limit of 200 ppm at some point during the day. Four of fifteen employees had peak exposures exceeding the ACGIH excursion limit of 125 ppm. No employee's average reading exceeded the OSHA PEL of 50 ppm, the NIOSH REL of 35 ppm, or the ACGIH TLV of 25 ppm. The GA monitor at the Eastside booking station indicated an average CO concentration of 22 ppm with a peak reading of 75 ppm. The GA monitor at the Westside booking station indicated an average CO concentration of 24 ppm with a peak reading of 137 ppm.

Formaldehyde

Four GA air samples for formaldehyde were collected and results are presented in Table 5. Sample concentrations ranged from 0.004 to 0.047 ppm. The highest formaldehyde concentration (0.047 ppm) was located on the backseat of the police boat in the BC on May 24, 2003. Calculated GA, 8-hour TWA concentrations are intended as representations of potential exposure. Two of four formaldehyde concentrations were above the NIOSH REL of 0.016 ppm.

Acrolein

All four GA air samples for acrolein were below the analytical LOD.

Volatile Organic Compounds

Eight thermal tube GA air samples were collected and results are presented in Table 6. Chromatographs are provided in Appendix C. The major peaks detected were various aliphatic and aromatic hydrocarbons. Aliphatic hydrocarbons included hexane, isooctane, butane, pentane, and other alkanes primarily in the C_4-C_9 range. Aromatics included benzene, toluene, ethyl benzene, xylenes, and higher alkyl benzenes. Other compounds detected included methyl tert-butyl ether (MTBE), acetone, acetonitrile, naphthalene, methyl naphthalenes, methanol, and ethanol. Based on the peak shapes of the early eluting compounds, sample A39694 (from the police boat) appeared to be saturated and may have still contained some moisture even after the initial helium purge. This sample also contained acetonitrile as a major component.

Medical

Thirty-six of forty available LHC municipal employees participated in the exhaled breath analysis for CO and questionnaires over the 2003 Memorial Day weekend (four of the forty workers did not complete one full day of testing and were excluded from the data analysis). Of the 36 employees who participated, 23 were POs and 13 were EMS/Fire personnel. These participants worked from one to four days during the evaluation period of May 23-26, 2003. Seven of the thirty-six were smokers; three smoked between 1½ to 2½ packs of cigarettes per day; four smoked 2 to 5 cigarettes per day. The average age among the 36 participants was 34 years (ranging from 25 to 46). Two reported a history of respiratory disorder. There was one female participant.

Exhaled Breath CO Monitoring

Exhaled breath CO measurements were analyzed in two ways: (1) for the greatest cross-shift difference observed for all participating employees on each day of testing, and (2) comparing the daily post-shift estimated %COHb levels with the ACGIH BEI criteria.

Cross-shift Change in %COHb

Table 7 presents the change (increase) in %COHb levels from pre-shift to post-shift (cross-shift difference) by date. For example, if the employee's pre-shift level was 1.0% COHb and his/her post-shift level was 8.0%, then the level increased by 7% COHb. The cross-shift difference was used to minimize the effect of smoking and capture the effects of CO exposure from the work environment. To date, there are no specific cross-shift levels of %COHb that have been recommended as criteria or guidelines for workplace exposures. We chose to use an increase of 3.5% COHb or greater as an indication of potential occupational CO over-exposure based on the ACGIH BEI recommendation for end-of-shift %COHb.

Among the 18 participating employees on May 23, 9 (50%) had a cross-shift increase of %COHb at or above 3.5% COHb. Of the 24 employees participating on May 24, 17 (71%) had a cross-shift increase at or above 3.5%. Thirteen of the twenty-five (52%) participants on May 25 had a cross-shift increase %COHb level at or above 3.5%. One of fourteen employees participating on May 26 had a cross-shift increase in %COHb level at or above 3.5%.

Looking at the three heaviest boating days, May 23, 24, and 25, the average %COHb among nonsmoking employees increased from 1% to 6% between initial testing hours (8-10 a.m.) and final testing hours (6-8 p.m.). The average %COHb in smoking employees increased from 3% to 7% between the same testing periods. The maximum %COHb level observed among nonsmoking employees was 13%; among smoking employees, the maximum was 11%.

Comparing post-shift %COHb to the BEI

Table 8 presents the post-shift %COHb levels by day among the 29 nonsmoking participants in relation to the ACGIH BEI. We found that on May 23, 24, and 25, more than 60% of these employees had post-shift %COHb levels at or above the BEI (64%, 100%, and 67%, respectively). On May 24 and 25, two (11%) and four (19%) nonsmoking participants, respectively, had post-shift % COHb levels above 10%. On the least crowded day, May 26, 2 out of 12 nonsmoking workers (17%) had levels that were at or above the BEI.

Questionnaire

Pre-shift questionnaires included questions concerning possible CO exposure symptoms ever experienced while working in the BC. Twenty-four of thirty-six (67%) reported that they had previously experienced at least one symptom while working in this area. All 24 reported experiencing headache; 7 (19%) reported fatigue or weakness, 6 (17%) drowsiness, 6 (17%) dizziness, 3 (8%) nausea or vomiting, and 1 (3%) vision disturbances.

Table 9 describes the post-shift symptoms reported by participants during the 2003 Memorial Day weekend by date. The most frequently reported symptom was headache, followed by fatigue or weakness, visual disturbances, and dizziness. Of the 17 employees completing the post-shift symptom survey on May 23, 12 (71%) reported having one or more symptom at the end of the shift. On May 24, 25, and 26, 16 of 24 (67%), 13 of 25 (52%), and three of 14 (21%), respectively, reported having one or more symptom post-shift.

Level of post-shift %COHb and nonsmoking employee reporting of symptoms

Table 10 shows the number of nonsmoking city employees reporting symptoms in relation to their post-shift %COHb. As seen in Table 10, when summary data are evaluated, reported symptoms consistent with excessive exposure to CO appeared to increase with increasing %COHb.

DISCUSSION

The integrated multiagency study conducted during the 2003 Memorial Day weekend combined information related to visitors and employees in the BC of Lake Havasu. BC visitor poisonings and exhaled CO data (presented in Appendix B) collected concurrent with the NIOSH data are relevant to the risk of poisoning among EMS/Fire responders and law enforcement officers who are in the same environment.

The Arizona State Health Department concluded that the COHb levels observed among BC visitors late in the day demonstrated a public health hazard during the 2003 Memorial Day weekend. They found that the average %COHb among non-smoking BC visitors participating in CO breath tests rose dramatically after 4:00 p.m. on the days of their study. This finding was temporally consistent with data collected among those occupationally exposed.

Three clinically evident CO poisonings occurred among BC visitors during the 2003 Memorial Day weekend - while the various aspects of the study reported here (and related information dissemination) were underway. First, on May 28, a 31-year-old man lost consciousness in the BC, drowned, and was found to have a COHb of 40.6% by the Medical Examiner. Second, on May 29, a 21-year-old woman who was transported to the hospital ED after losing consciousness in the BC was found to have a COHb of 47% measured in blood. Finally, her 22-year-old companion was found to have a COHb of 19% measured by exhaled CO. During the subsequent Labor Day weekend, August 2003, a 23-year-old female standing in waist deep water behind two idling boats in the BC lost consciousness. Her COHb from a blood specimen drawn at the site was determined to be 42.7%.

Industrial Hygiene

The real-time CO monitoring over the 2003 Memorial Day weekend indicated that there was potential for POs and EMS/Fire personnel to be exposed to elevated CO concentrations resulting in an average CO concentration during the workshift in excess of OSHA, NIOSH, and ACGIH evaluation criteria. Overall, there were 78 total workshifts where real-time CO monitoring was performed. Of those 78 workshifts, 54 exceeded the NIOSH ceiling limit of 200 ppm, 64 exceeded the ACGIH excursion limit of 125 ppm, 7 exceeded the OSHA PEL of 50 ppm, 17 exceeded the NIOSH REL of 35 ppm, and 33 exceeded the ACGIH TLV of 25 ppm.

In general, POs and EMS/Fire personnel on boats working in the BC had the highest exposures to CO; some were exposed to peak CO concentrations in excess of 1000 ppm. However, all jobs had exposures to elevated CO concentrations. It is difficult to say whether the elevated CO concentrations were a reflection of the job for the day (working at the booking station, operating a gas-powered quad, etc.) and/or where a PO or EMS/Fire employee was located in the BC and what he/she was doing at the time. However, it stands to reason that as one approaches the area where the CO is being generated (the BC), the greater opportunity there is to be exposed to higher CO concentrations. It was not possible for detailed information to be collected about every PO's or EMS/Fire employee's whereabouts during the day to be able to correlate an activity with a particular CO concentration.

Although we did not characterize exhaust emissions from the carts or quads, we did find that employees on both gas- and electric-powered land vehicles experienced elevated estimated COHb levels. This fact combined with the overall exposure and COHb data indicate that the carts and quads themselves had little impact on the employees' exposures.

NIOSH investigators observing the BC noticed a haze above the water beginning in the late afternoon, and the real-time CO monitoring indicated that the CO concentrations became elevated late in the afternoon through the early evening. This suggests that as the day progresses, the boat exhaust possibly increases due to insufficient natural removal (wind), temperatures over 100ºF, and/or increased boat traffic. This information was also in agreement with findings of the Arizona State Health Department report discussed above.

Air sampling results (VOC air samples) indicated chemicals consistent with what is typically found in boat exhaust. Formaldehyde air sampling results compared to relevant evaluation criteria, revealed concentrations above the NIOSH REL in the back of the boats in the BC. As stated in the Evaluation Criteria section in this report, formaldehyde concentrations ranging from 0.12-6.15 mg/m^3 (0.1-5 ppm) have resulted in symptoms of burning eyes, tearing, and general irritation of the upper respiratory tract. Formaldehyde levels found during the 2003 Memorial Day weekend did not fall within the aforementioned range. However, formaldehyde in combination with other contaminants found in boat exhaust may possibly result in the above listed symptoms.

Medical

Results of the employee exhaled breath analyses for CO are consistent with the results of the real-time CO monitoring, with %COHb levels rising throughout the day to peak at post-shift. The majority of non-smoking post-shift breath measurements had estimated %COHb levels at or above the BEI of 3.5%, representing a hazardous occupational exposure to CO. Using a more stringent criteria (cross-shift increase in %COHb), over half of all cross-shift exhaled breath measurements had elevations of COHb greater than 3.5%. In general, LHC municipal employees working on boats in the BC had the highest %COHb levels. Symptom questionnaires found that more than half of all employees reported post-shift symptoms consistent with CO exposure on the three days with the highest CO exposures. When summary data are evaluated, reported symptoms appeared to increase with increasing %COHb. However, due to the non-specific nature of these symptoms and other factors (including the cross sectional nature of our evaluation), conclusions regarding CO exposure as the only potential etiology of these symptoms cannot be made. The *NIOSH Criteria for a Recommended Standard: Occupational Exposure to Carbon Monoxide* document finds that studies "concerning the effect of CO on behaviors ranging from vigilance to cognitive function are sufficient to suggest possible safety hazards for the worker exposed to CO. A review of the above studies indicates that a value of 5% COHb should not be exceeded if these behavioral effects are to be avoided."[11] Elevated COHb levels in employees responsible for public safety are an even greater concern.

Based on data from the Arizona Department of Health Services, 2003 Memorial Day weekend survey, BC visitors had COHb levels twice as high as the LHC municipal employees, likely due to extended lengths of time on boats or wading in the BC. Elevated COHb levels are especially dangerous for susceptible individuals such as children, pregnant women and their fetuses, and persons with cardiovascular or respiratory disease. The safety of individuals is also compromised when wading or swimming in the water near congested boat areas, operating watercraft, or recreating in the rear area of boats.

CONCLUSIONS

- During periods of increased public recreational activities in the BC area, LHC municipal employees working in this area (and BC visitors) have the potential to be exposed to elevated CO concentrations.

- PO and EMS/Fire personnel working on boats in the BC have the potential to be exposed to CO approaching and/or exceeding IDLH concentrations. Additionally, these personnel also have the potential to have COHb levels approaching or in excess of 15%.

- The CO concentrations tend to become more elevated as the day progresses, which results in the potential for PO and EMS/Fire personnel to be exposed to elevated CO concentrations.

- LHC municipal employees with occupational CO exposures resulting in elevated COHb levels may develop symptoms of CO poisoning which could affect their health and safety and the safety of the public they serve.

RECOMMENDATIONS

The following recommendations are based on the findings of this investigation and are intended to reduce the health hazard for employees. Similar measures should be considered related to visitor exposures.

- LHC should determine what actions to take to bring about a reduction of overall CO concentrations within the BC area during high boat-traffic days, thus reducing the potential for employee over-exposure.

- Employees assigned to duty within the BC or on boats elsewhere should receive training about the health effects of CO, how to recognize symptoms of CO poisoning in themselves and co-workers, and work-practices that can reduce exposure to vehicle and boat exhaust.

- Until CO concentrations are reduced within the BC, LHC should periodically rotate employee assignments to areas where CO exposure does not occur, particularly in the late afternoon and early evening hours when CO concentrations elevate in the BC.

- LHC should develop an employee exposure monitoring program to determine patterns of overexposure for employees (i.e., are they overexposed only on warm-weather holiday weekends, or at other times or during certain job tasks) and to ensure that control measures such as assignment rotation, or reduction of CO concentrations within the BC, are effective.

- Employees should be encouraged to report symptoms of CO poisoning to designated health and safety personnel and should be provided with appropriate medical evaluation of symptoms.

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TABLES

Industrial Hygiene

Abbreviations and Symbols Used in the Following Tables

COHb	=	carboxyhemoglobin
CO	=	carbon monoxide
Avg.	=	average
Cumul.	=	cumulative
*	=	light smokers (five or less cigarettes per day)
**	=	moderate to heavy smokers (over 15 cigarettes per day)
PO	=	police officer
EMS/Fire	=	emergency medical service
Chan	=	channel
E	=	East
W	=	West
GG	=	gas-powered golf cart
GQ	=	gas-powered quad
EG	=	electric-powered golf cart
F	=	foot patrol
BS	=	booking station
ppm	=	parts per million
C	=	ceiling concentration - a concentration which should not be exceeded at any time
LFC	=	lowest feasible concentration - see formaldehyde in Evaluation Criteria section
STEL	=	short-term exposure limit - a 15-minute exposure limit that should not be exceeded at any time during the day
A2	=	suspected human carcinogen
NIOSH REL	=	National Institute for Occupational Safety and Health, Recommended Exposure Limit
OSHA PEL	=	Occupational Safety and Health Administration, Permissible Exposure Limit
ACGIH TLV	=	American Conference of Governmental Industrial Hygienists, Threshold Limit Value

Table 1. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 23, 2003 at Lake Havasu, Arizona

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	Session CO Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg. (Peak)	Cumul. CO Avg.
101	PO, chan, boat	1046-1846	0.5%	1.7%	13 (99)	2.3%	26 (131)	20				5.9%	119 (849)	47
102*	PO, chan, boat	1052-1847	0.3%	1.5%	13 (102)	3.9%	27 (138)	20				7.1%	117 (997)	48
103**	PO, E/W, GG, GQ, F	1056-1939	5.5%	5.7%	4 (34)	5.9%	17 (124)	12				9.1%	64 (317)	31
104	PO, E, GG	1101-1927	0.3%	0.9%	8 (64)	1.5%	16 (130)	13	1.9%	26 (474)	17	3.5%	123 (357)	26
105	PO, E, GG	1053-1932	0.5%	1.3%	4 (54)	2.7%	10 (100)	8	3.3%	31 (490)	15	3.5%	101 (382)	23
106*	EMS/Fire, E, GG	1102-1901	2.5%	2.5%	7 (55)							3.5%	23 (197)	12
107**	PO, W, GQ	1107-1900	2.1%	6.7%	12 (88)	4.3%	16 (65)	14				10.9%	39 (252)	25
108*	PO, W, EG	1107-1908	0.7%	2.1%	15 (34)	2.3%	25 (63)	20				7.1%	50 (306)	33
109**	PO, E, BS	1113-1949	4.5%									8.3%	12 (278)	12
110	EMS/Fire, W, EG	1117-1848	0.3%	1.9%	10 (40)	2.1%	10 (60)	10				6.3%	52 (342)	19
111*	PO, E, GQ	1108-1936	1.3%	2.1%	5 (19)	1.3%	11 (78)	9				3.3%	47 (448)	23
112	EMS/Fire, E, EG	1114-1901	1.1%	2.1%	10 (79)							1.9%	21 (197)	13
114	PO, W, BS	1404-1959	2.7%	2.3%	17 (90)							5.5%	45 (197)	32
115	PO, chan, boat	1314-1953	0.7%	2.3%	32 (157)	4.7%	87 (590)	61				5.1%	89 (506)	67

Table 2. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 24, 2003 at Lake Havasu, Arizona

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	CO Monitor Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg.	Cumul. CO Avg.
101	PO, chan, boat	1037-2058	1.9%	5.3%	36 (175)	4.1%	49 (260)	41	11.7%	270 (1090)	101	11.3%	36 (180)	87
103**	PO, E/W, GG, GQ, EG	1048-1954	3.7%	4.1%	11 (56)							9.5%	44 (514)	28
104	PO, E, GG	123 min.	0.5%	0.5%		3.7%						3.9%	65 (487)	65
105	PO, E, GG	1051-1913	0.7%	2.7%	8 (157)							3.5%	54 (453)	27
106*	EMS/Fire, bay/chan, boat	1345-1924	1.5%	2.9%								6.9%	66 (1055)	66
107**	PO, E, GG, GQ, EG, F	0955-1745	4.1%	3.9%	8(73)	3.7%	21 (118)	12				6.5%	52 (597)	21
108*	PO, W, EG	0950-2008	1.3%	1.5%	3 (16)	2.9%	20 (132)	9				3.3%	36 (311)	20
109**	PO, E, BS	1009-1934	5.3%	7.1%	5 (44)	8.9%	22 (203)	14				7.5%	22 (165)	15
114	PO, W, BS, boat	1001-2117	3.9%	4.1%	6 (41)	4.3%	10 (89)	8				8.3%	54 (213)	17
120	PO, W, GG	0941-2031	0.1%	0.7%	9 (78)	3.9%	49 (460)	27				7.1%	31 (226)	28
121	PO, W, GQ	0957-2048	0.3%	1.9%	17 (127)	2.5%	35 (288)	25				7.3%	73 (282)	33
122	PO, W, GQ, boat	1033-2117	0.5%	1.9%	16 (90)	3.3%	31 (222)	22				8.1%	76 (274)	34

Table 2. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 24, 2003 at Lake Havasu, Arizona (cont.)

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	Session CO Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg.	Cumul. CO Avg.
123	PO, W, GG	1008-2044	0.7%	1.9%	11 (56)	4.7%	16 (121)	14				5.1%	38 (257)	20
124	PO, W, EG	1036-2025	0.9%	2.3%	23 (322)							10.3%	62 (504)	48
126	PO, W, GG	1039-2051	0.5%	1.5%	11 (164)							6.1%	32 (247)	23
127	PO, chan, boat	0912-1908	0.9%	2.3%	28 (194)								118 (1118)	64
128	PO, chan, boat	0910-1859											66 (1146)	66
129	PO, E, GQ	1042-1922	1.1%	2.3%	10 (98)	1.3%	15 (168)	13				3.9%	77 (480)	26
130	PO, chan, boat, W, BS	1043-2038	1.5%	4.3%	43 (185)	2.7%	58 (480)	48	10.1%	290 (1109)	114	9.7%	33 (167)	98
131	EMS/Fire, W, EG	0940-2001	0.9%	4.9%	12 (167)	5.5%	20 (229)	16				7.9%	43 (265)	22
132	EMS/Fire, W, EG	0957-2005	0.9%	1.3%	14 (82)	3.3%	21 (191)	17				5.5%	45 (242)	24
133	EMS/Fire, chan, boat	1004-1921	1.1%	4.3%	15 (206)							7.9%	82 (1224)	49
134	EMS/Fire, E, EG	1014-2053	0.5%	5.5%	36 (580)							7.3%	82 (335)	45
137	EMS/Fire, chan, boat	1018-1931	0.5%	1.3%	13 (214)							5.5%	61 (1084)	43

Table 3. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 25, 2003 at Lake Havasu, Arizona

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	Session CO Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg. (Peak)	Cumul. CO Avg.
101	PO, chan, boat	0934-2054	2.7%	2.5%	15 (119)	2.3%	14 (111)	14				12.9%	139 (662)	57
103**	PO, E/W, GG, GQ, EG	0912-2002	5.9%	5.5%	4 (33)	7.1%	13 (179)	8				9.3%	28 (236)	14
104	PO, E, GG	0957-1936	1.5%	1.5%	7 (260)							2.9%	27 (227)	17
105	PO, E, GG	1018-1935	0.9%	3.9%	4 (44)							2.1%	16 (100)	10
107**	PO, E, GG, GQ, EG, F	0939-2023	3.3%	3.5%	5 (12)	5.9%	16 (93)	10				8.1%	32 (378)	17
109**	PO, E, BS	0900-2042	5.3%									8.1%	13 (64)	13
114	PO, W, BS, boat, F	0946-2041	1.5%	3.5%	4 (12)	3.7%	41 (294)	24				8.5%	51 (258)	31
118	EMS/Fire, W, EG	0943-1926	2.5%	2.3%	4 (16)	5.7%	25 (175)	15				6.5%	22 (72)	16
120	PO, W, GG	1622-1919	0.5%	0.9%		0.9%		53 (327)				10.9%	85 (546)	63
121	PO, W, GQ	0949-2038	0.9%	2.5%	11 (82)	2.7%	28 (101)	17				7.3%	63 (351)	29
122	PO, W, GQ, boat	0940-2039	1.9%	4.1%	10 (175)	4.5%	56 (221)	24				8.9%	76 (318)	39
123	PO, W, GG	0930-2019	2.1%	1.7%	12 (81)	1.1%	15 (53)	14				1.5%	62 (321)	24

Table 3. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 25, 2003 at Lake Havasu, Arizona (cont.)

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	Session CO Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg. (Peak)	Cumul. CO Avg.
124	PO, W, EG	0954-2029	1.1%	2.3%	15 (86)	2.9%	36 (204)	22				11.5%	89 (665)	37
125	PO, E, GG, GQ	0936-1949	1.5%	3.3%	6 (46)	4.5%	18 (88)	10				2.7%	21 (157)	13
126	PO, W, GG, chan, boat	1003-2044	1.1%	1.5%	10 (71)	3.1%	29 (261)	20				7.5%	63 (409)	30
127	PO, chan, boat	0909-1834	1.3%	2.1%	16 (168)	5.9%	23 (242)	20				5.3%	51 (513)	30
128	PO, chan, boat	0907-1833											26 (411)	26
129	PO, E, GQ, chan, boat	0929-1953	1.1%	0.7%	15 (62)	4.5%	66 (365)	38				4.7%	33 (219)	37
130	PO, chan, boat, W, BS	0944-2045	2.3%	2.5%	15 (122)	2.9%	14 (63)	15				13.1%	187 (779)	73
131	EMS/Fire, W, EG	1005-1927	0.9%	1.9%	2 (20)	2.3%	5 (38)	3				3.7%	14 (64)	7
133	EMS/Fire, lake, boat	0923-1941	2.5%	2.7%	8 (109)							4.3%	21 (195)	16
137	EMS/Fire, W, EG	1012-1921	1.5%	1.5%	4 (13)	3.3%	26 (221)	17				3.3%	24 (90)	18
140	EMS/Fire, lake, boat	0917-2013	0.0%	0.7%	10 (98)							3.1%	18 (229)	15
141	EMS/Fire, lake, boat	0917-2010	0.3%	1.3%	13 (570)							2.5%	11 (100)	12
142	EMS/Fire, E, EG	0954-1931	0.9%	1.3%	3 (46)	3.7%	5 (38)	4				3.5%	17 (139)	8

Table 4. COHb Readings & Coinciding CO Monitor Averages and Peaks (in parts per million) on May 26, 2003 at Lake Havasu, Arizona

ID	Location	Sample Time (military)	Pre-shift COHb	2nd COHb	Session CO Avg. (Peak)	3rd COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	4th COHb	Session CO Avg. (Peak)	Cumul. CO Avg.	Post-shift COHb	Session CO Avg. (Peak)	Cumul. CO Avg.
104	PO, E, GG	0932-1411	0.9%									0.5%	13 (170)	13
105	PO, E, GG	0949-1411	1.1%									1.5%	10 (67)	10
107**	PO, chan, boat	0921-1639	3.1%									4.9%	9 (105)	9
109**	PO, E, BS	0923-1503	4.1%									5.1%	8 (99)	8
114	PO, W, BS, boat	0930-1537	3.9%	7.1%	15 (120)							3.7%	18 (104)	16
120	PO, W, other vehicle	0948-1425	0.5%									0.9%	5 (43)	5
121	PO, W, GQ	0953-1524	1.1%									0.9%	7 (70)	7
122	PO, chan, boat	0951-1538	1.1%	5.7%	16 (602)							2.9%	25 (127)	19
123	PO, W, GG	0926-1518	1.1%	1.9%	7 (128)							2.7%	13 (106)	9
124	PO, W, GQ	0945-1513	1.1%	2.1%	6 (54)							1.7%	10 (62)	7
125	PO, E, GQ	0916-1408	1.3%									2.3%	8 (49)	8
126	PO, W, GG	1002-1532	1.5%	1.9%	4 (52)							4.5%	13 (94)	7
127	PO, chan, boat	0910-1446	0.9%	1.9%	17 (117)							2.3%	24 (119)	19
128	PO, chan, boat	0903-1449											12 (130)	12
129	PO, E, GQ	0936-1411	1.9%									0.7%	6 (46)	6

Table 5. General Area Air Sampling for Formaldehyde on May 24 & 25, 2003

Date	Location	Sample Time (military)	Sample Volume (liters)	8-hour TWA concentration (ppm)
5/24/03	Backseat, police boat # 1297	1227 - 2110	106	0.047
	Park Host sign by W-side Booking Station	1250 - 2051	96.5	0.008
5/25/03	Backseat, police boat # 2196	1054 - 2046	118	0.034
	Park Host sign by W-side Booking Station	1126 - 2054	113	0.004
Minimum Detectable Concentration (MDC)				0.0007
Minimum Quantifiable Concentration (MQC)				0.0028
Evaluation Criteria			NIOSH REL	0.016, C 0.1, LFC
			OSHA PEL	0.75, STEL 2.0
			ACGIH TLV	C 0.3, A2

Table 6. General Area Air Sampling for Volatile Organic Compounds on May 24, 2003

Location	Sample #	Sample Time (military)	Major Compounds
Backseat, police boat # 1297	A41198	1227 - 1421	Acetone Isooctane Toluene Xylenes Alkyl benzenes
"	AO5370	1421 - 1624	Acetone Isooctane Toluene Xylenes Alkyl benzenes
"	A39694	1624 - 1845	Acetonitrile Isooctane Toluene
"	AO3998	1845 - 2110	Butane Isopentane Isooctane Toluene Xylenes Alkyl benzenes
Park Host sign by W-side Booking Station	A39892	1250 - 1451	Acetone Toluene
"	AO4085	1451 - 1645	Acetone Toluene
"	A40989	1645 - 1900	Acetonitrile Isooctane Toluene
"	AO5036	1900 - 2051	Acetone Isooctane Toluene Ethyl benzene/ xylene isomers Alkyl benzenes

Medical

Table 7. Exhaled Breath CO Monitoring: Estimated Cross-shift Increase in %COHb by Date

Estimated Cross-shift %COHb* (postshift minus preshift)	5/23/2003 N=18	5/24/2003 N=24	5/25/2003 N=25	5/26/2003 N=14
< 3.5	9 (50%)	7 (29%)	12 (48%)	13 (93%)
3.5 - 5	3 (17%)	5 (21%)	4 (16%)	1 (7%)
> 5 - 10	6 (33%)	12 (50%)	5 (20%)	0
> 10 - 15	0	0	4 (16%)	0
Total ≥ 3.5% COHb	9 (50%)	17 (71%)	13 (52%)	1 (7%)
Mean increase over day	3.82	5.33	4.77	1.39
Mean increase (of those reporting symptoms)	4.27	5.33	5.51	2.53

* = The cross-shift difference is the change (increase) in %COHb levels from pre-shift to post-shift. For example, if an employee's pre-shift level was 1% COHb and his/her post-shift level was 8%, then the employee had a cross-shift increase of 7% COHb.

Table 8. Exhaled Breath CO Monitoring: Post-shift %COHb in **Non-smoking** Lake Havasu City, Arizona Municipal Employees by Date

Post-shift %COHb	5/23/2003 N=11	5/24/2003 N=19	5/25/2003 N=21	5/26/2003 N=12
< 3.5	4 (36%)	0	7 (33%)	10 (83%)
3.5 - 5	2 (18%)	5 (26%)	4 (19%)	2 (17%)
> 5 - 10	5 (45%)	12 (63%)	6 (29%)	0
> 10 - 15	0	2 (11%)	4 (19%)	0
Total ≥ BEI (3.5% COHb)	7 (64%)	19 (100%)	14 (67%)	2 (17%)
Mean post-shift %COHb - non-smokers	4.23	6.67	6.03	2.05
Mean post-shift %COHb - smokers	7.04	6.74	8.15	5.0

Table 9. Reported Post-shift Symptoms by Lake Havasu City, Arizona Municipal Employees

Symptoms reported post-shift	5/23/2003 N=17	5/24/2003 N=24	5/25/2003 N=25	5/26/2003 N=14
Headache	11 (65%)	15 (63%)	11 (44%)	3 (21%)
Fatigue or weakness	2 (12%)	5 (21%)	3 (12%)	0
Visual disturbances	3 (18%)	3 (13%)	3 (12%)	0
Dizziness	3 (18%)	2 (8%)	3 (12%)	0
Nausea or vomiting	0	0	1 (4%)	1 (7%)
Drowsiness	1 (6%)	0	0	0
Chest pain	1 (6%)	0	0	0
Loss of muscle coordination	0	0	0	0
# reporting 1 or more symptom	12 (71%)	16 (67%)	13 (52%)	3 (21%)
# reporting 2 or more symptoms	4 (24%)	5 (21%)	5 (20%)	1 (7%)
# with symptoms of moderate or greater severity*	5 (29%)	10 (42%)	6 (24%)	0

* = Severity of post-shift symptoms was assessed by participant choosing either mild, moderate, or a lot for each symptom reported.

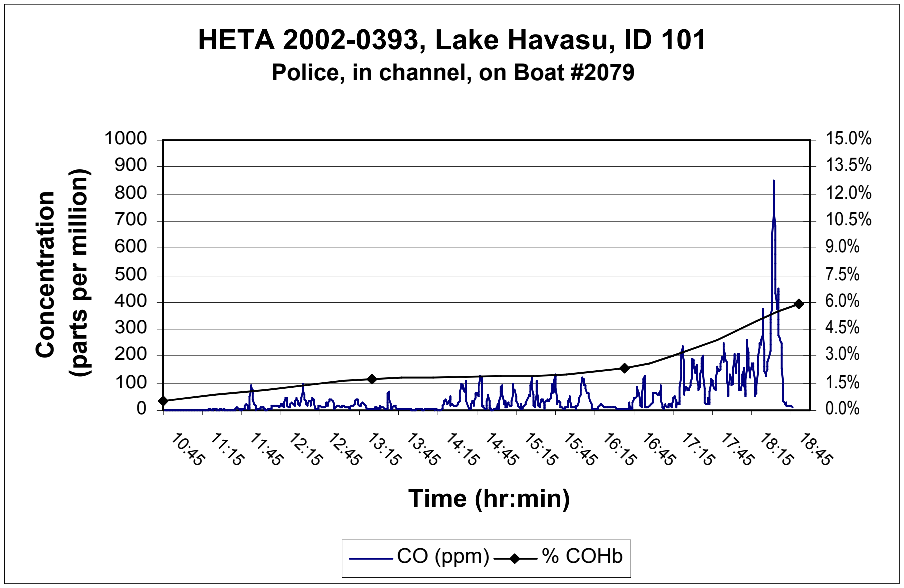
Table 10. Post-shift %COHb and Symptoms Among **Non-smoking** Lake Havasu City, Arizona Municipal Employees

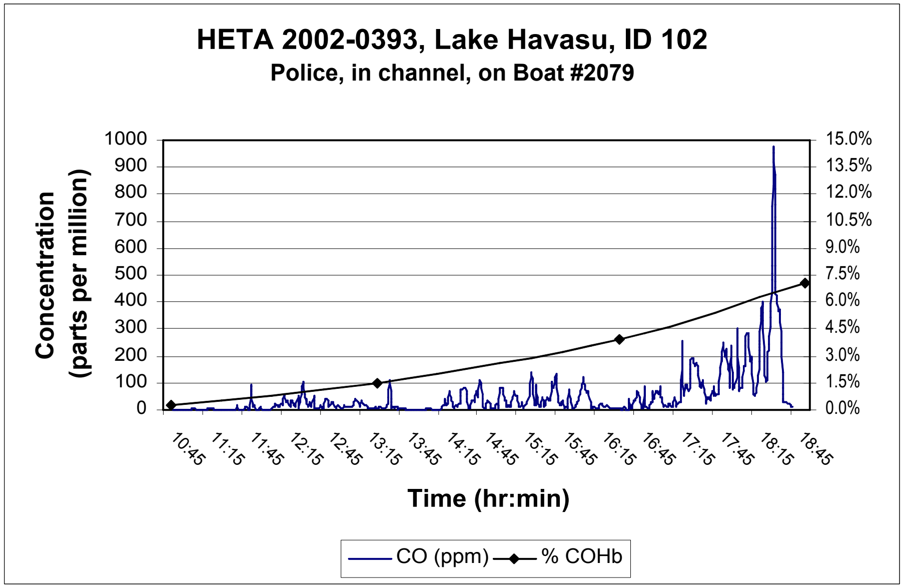
Non-smoking employees reporting one or more symptom by date:	Post-shift %COHb			
	< 3.5%	≥ 3.5-5%	> 5-10%	> 10%
5/23/2003 7 of 11 non-smokers reported symptoms	3 of 4 (75%)	1 of 2 (50%)	3 of 5 (60%)	0
5/24/2003 14 of 19 non-smokers reported symptoms	0	4 of 5 (80%)	9 of 12 (75%)	1 of 2 (50%)
5/25/2003 11 of 21 non-smokers reported symptoms	4 of 7 (57%)	1 of 4 (25%)	3 of 6 (50%)	3 of 4 (75%)
5/26/2003 3 of 12 non-smokers reported symptoms	2 of 10 (20%)	1 of 2 (50%)	0	0
Total non-smoker post-shift %COHb measurements over weekend = 63	9 of 21 (43%)	7 of 13 (54%)	15 of 23 (65%)	4 of 6 (67%)

FIGURES

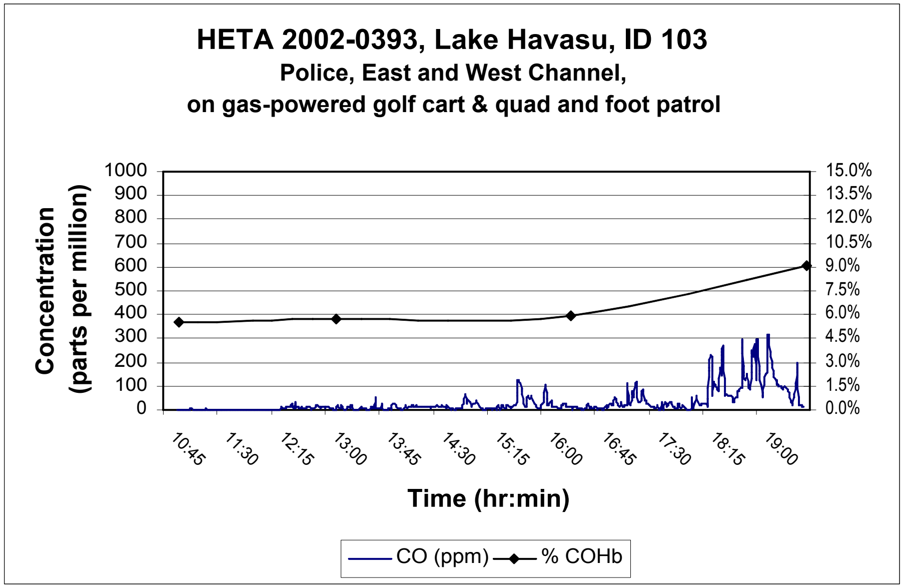
May 23, 2003

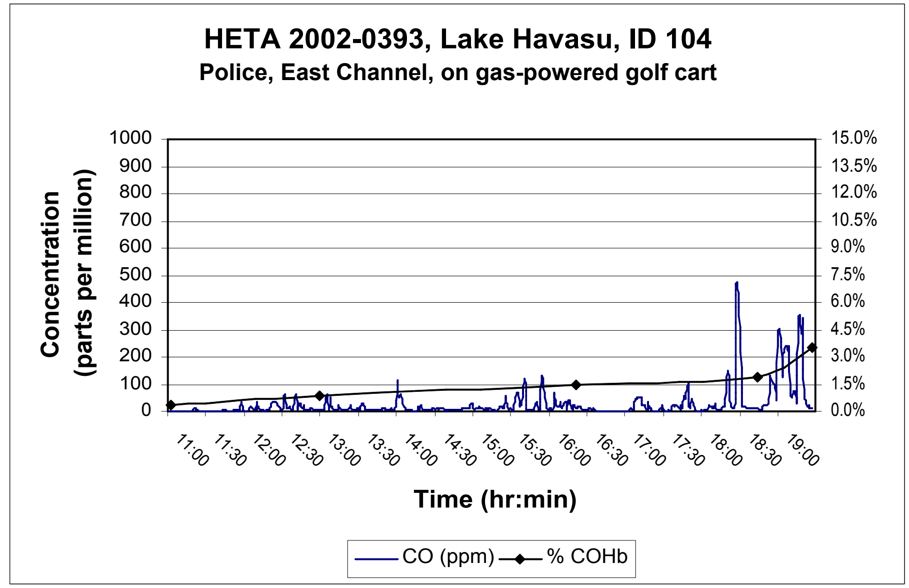
Figures 1-2 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 23, 2003 at Lake Havasu, Arizona

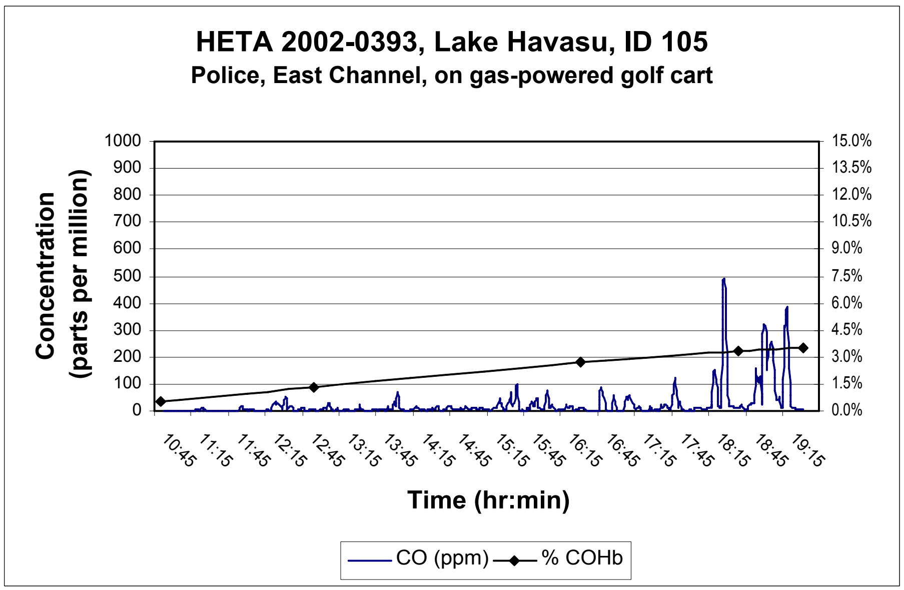


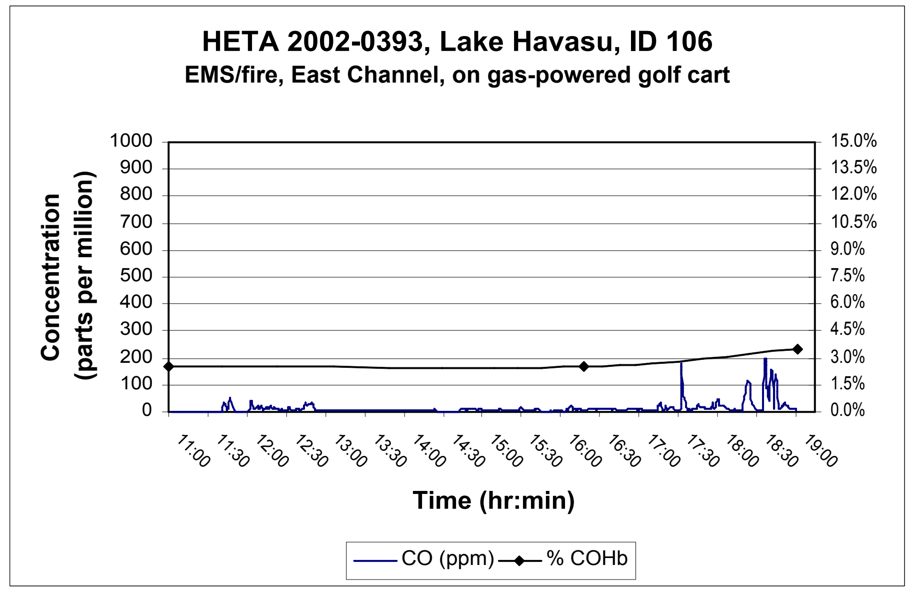


Figures 3-6 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 23, 2003 at Lake Havasu, Arizona

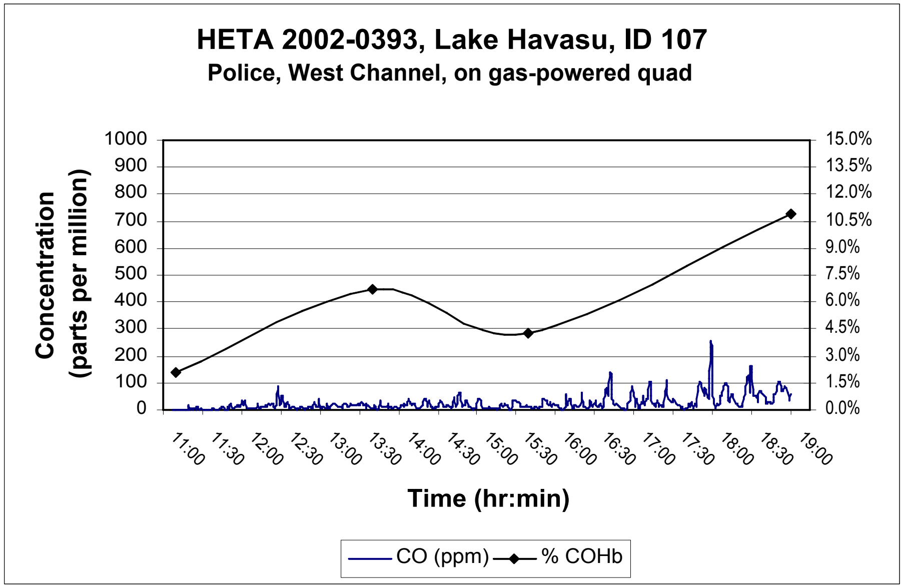


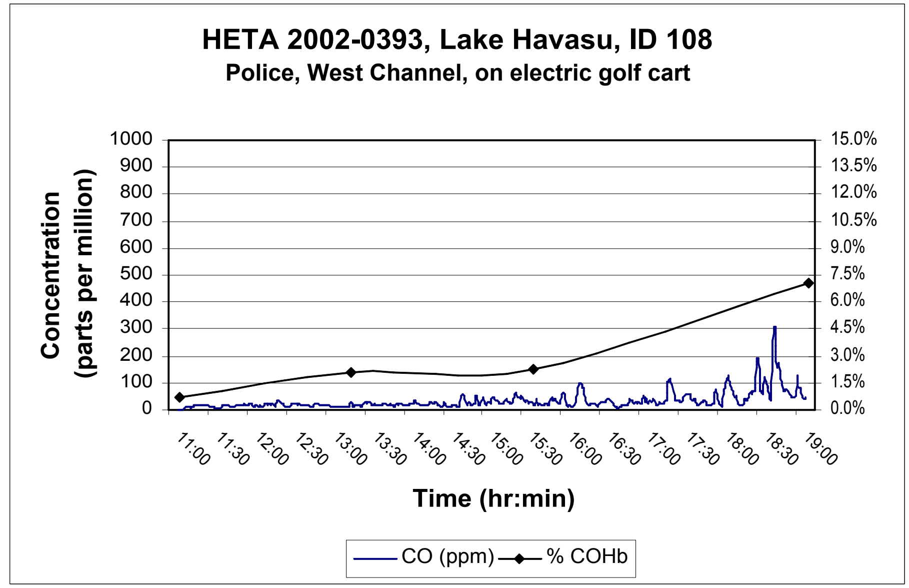


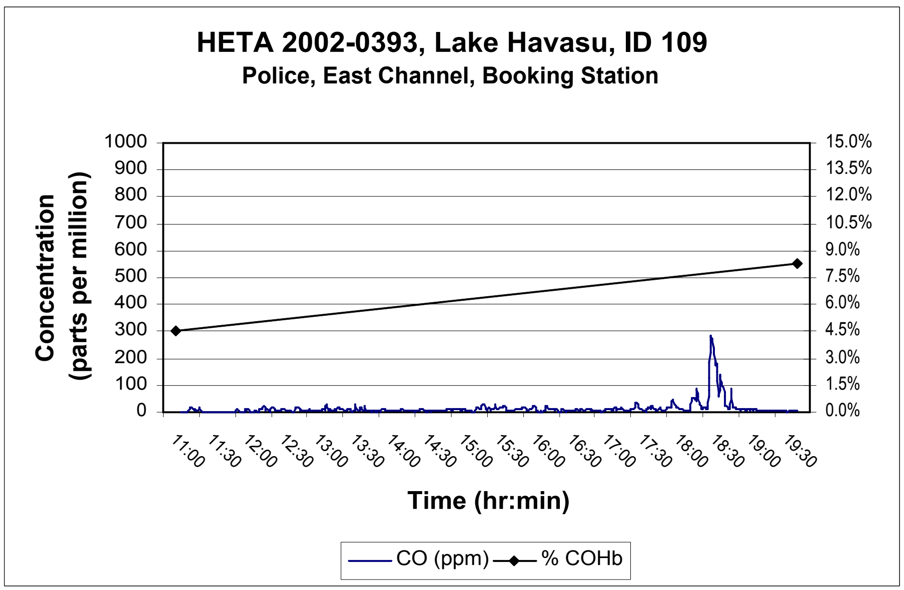


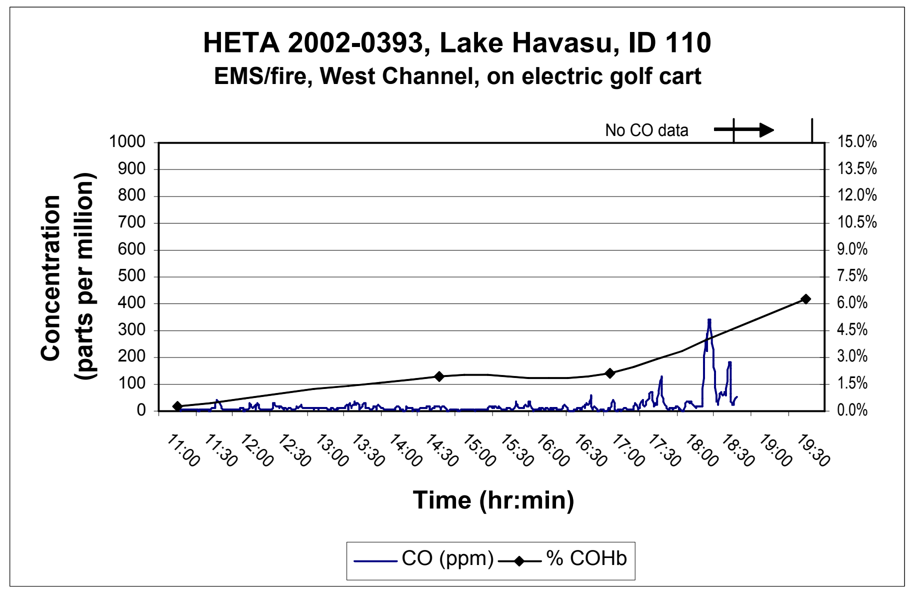


Figures 7-10 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 23, 2003 at Lake Havasu, Arizona

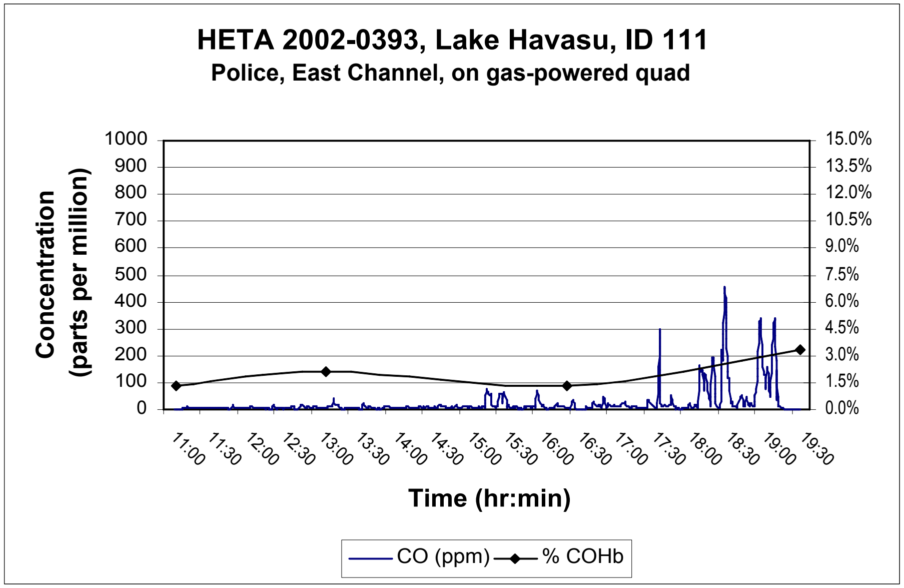


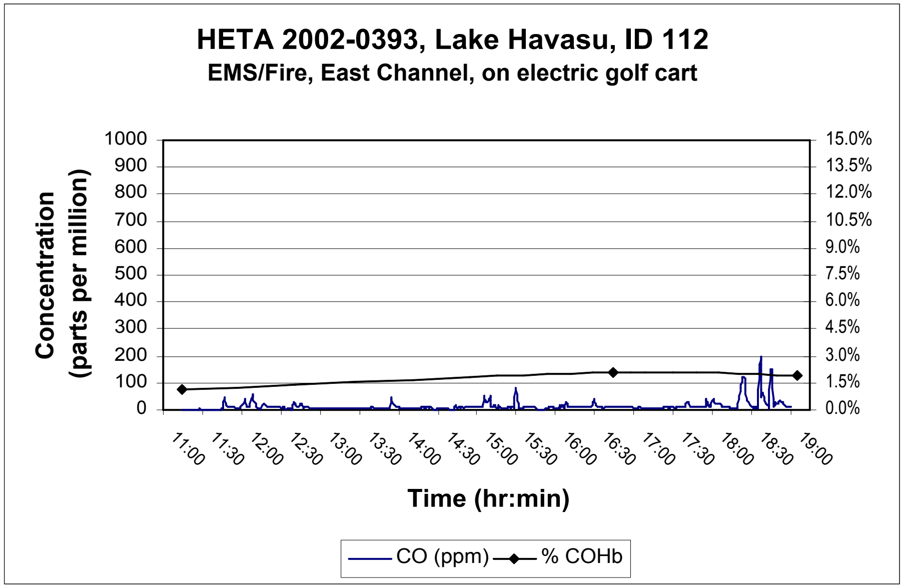


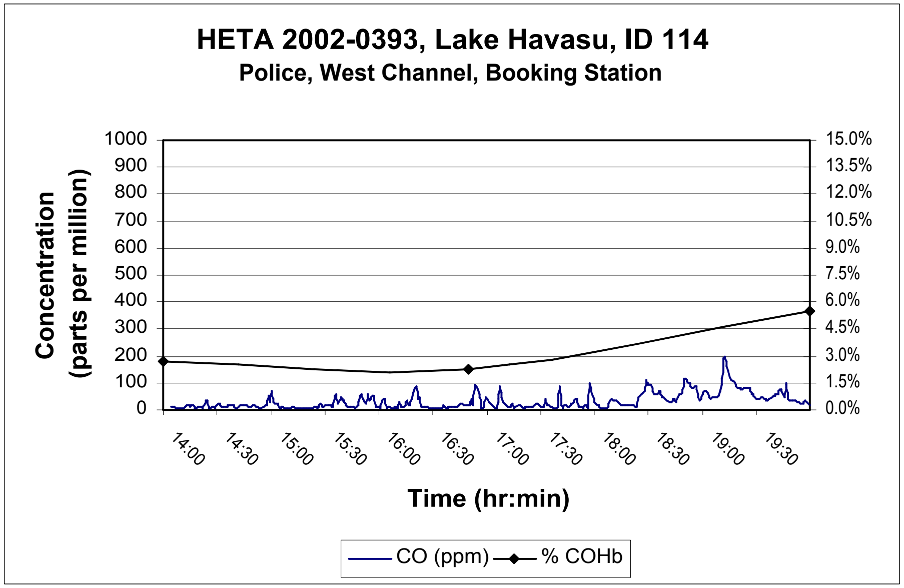


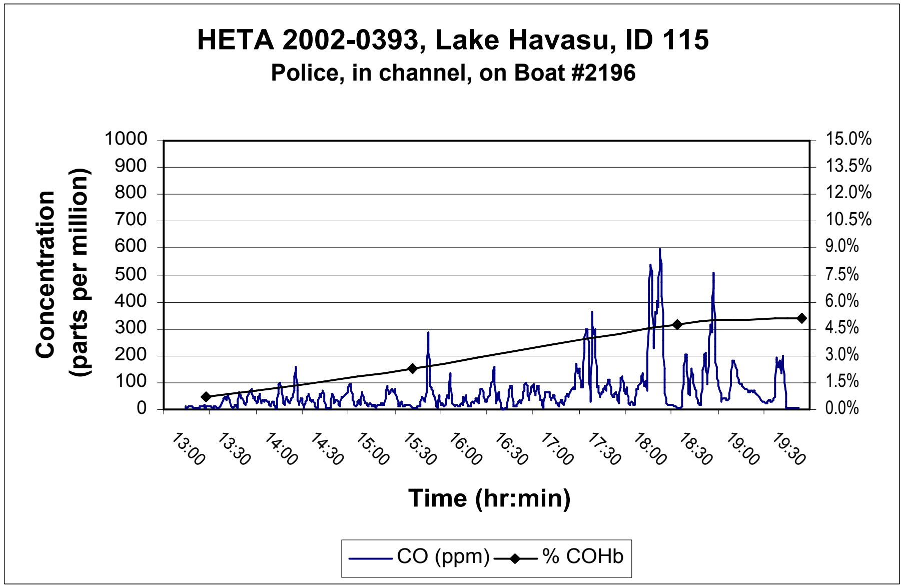


Figures 11-14 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 23, 2003 at Lake Havasu, Arizona

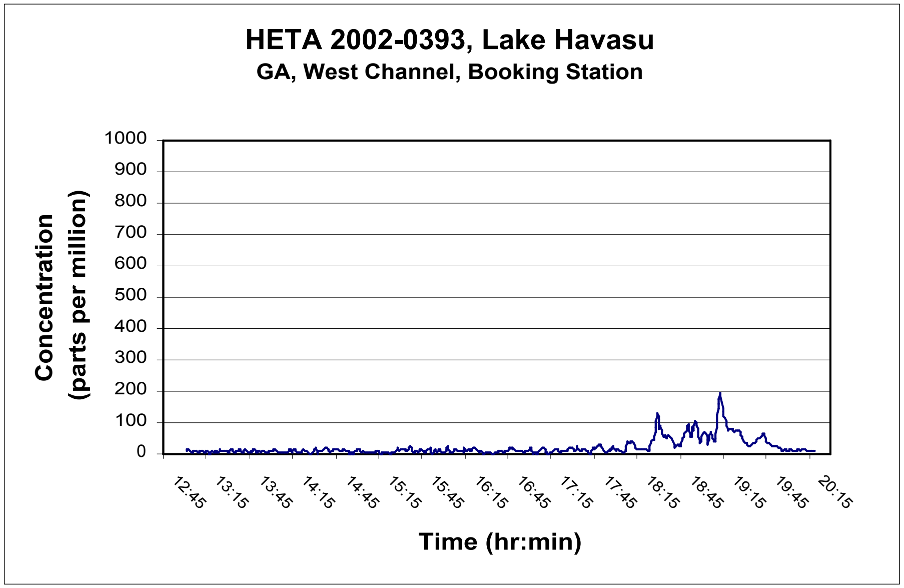


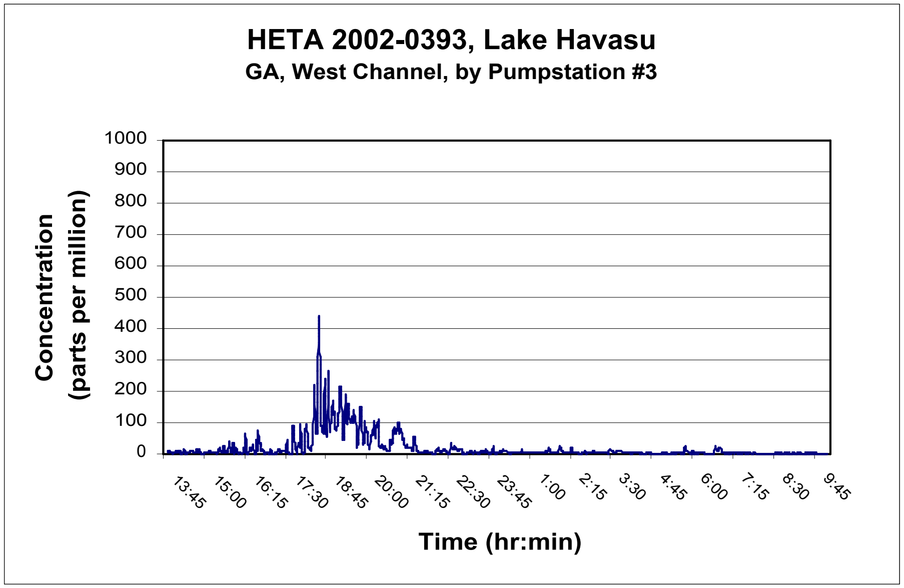






Figures 15-16 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 23, 2003 at Lake Havasu, Arizona





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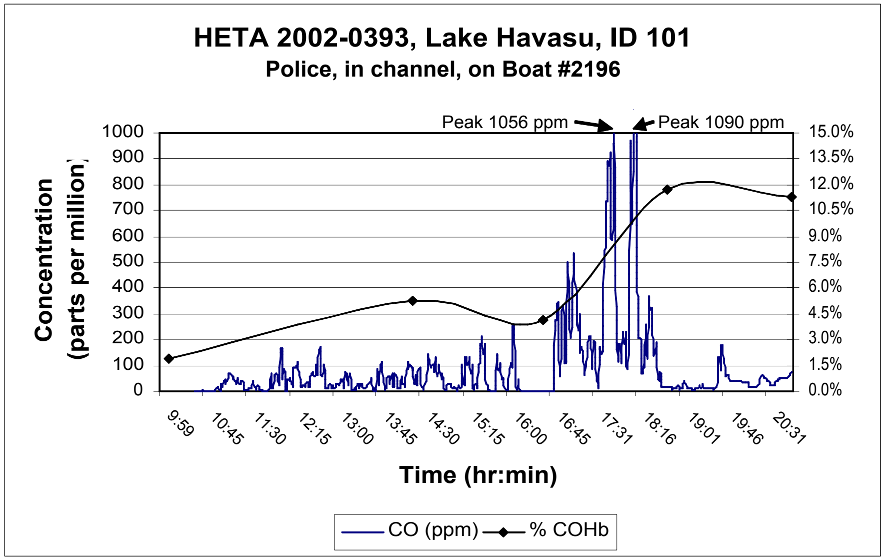
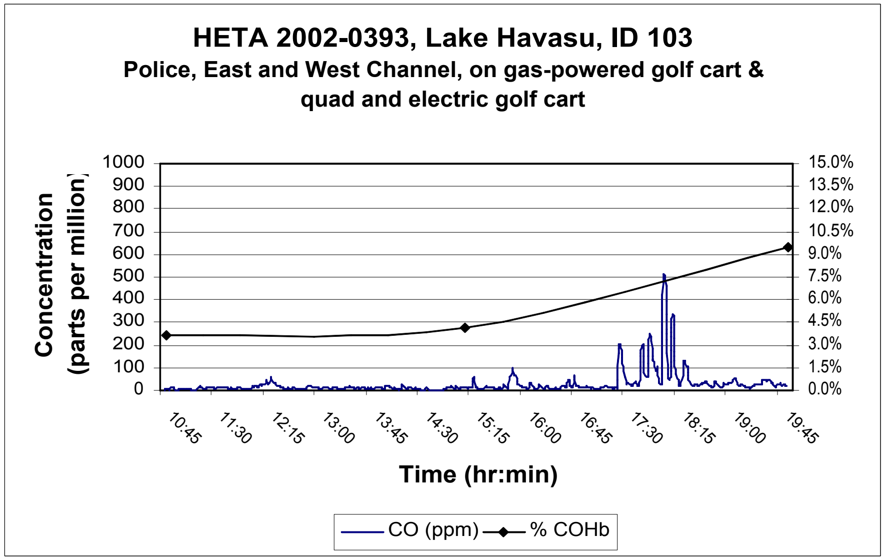
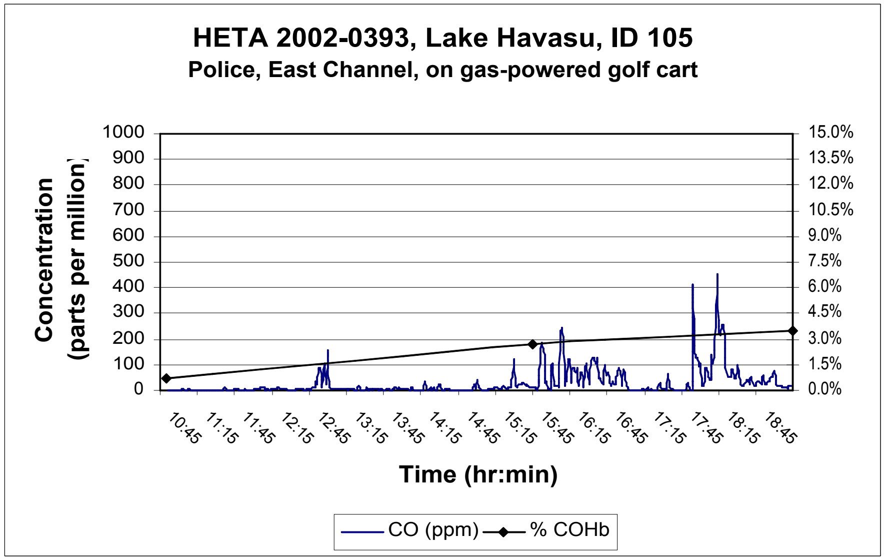
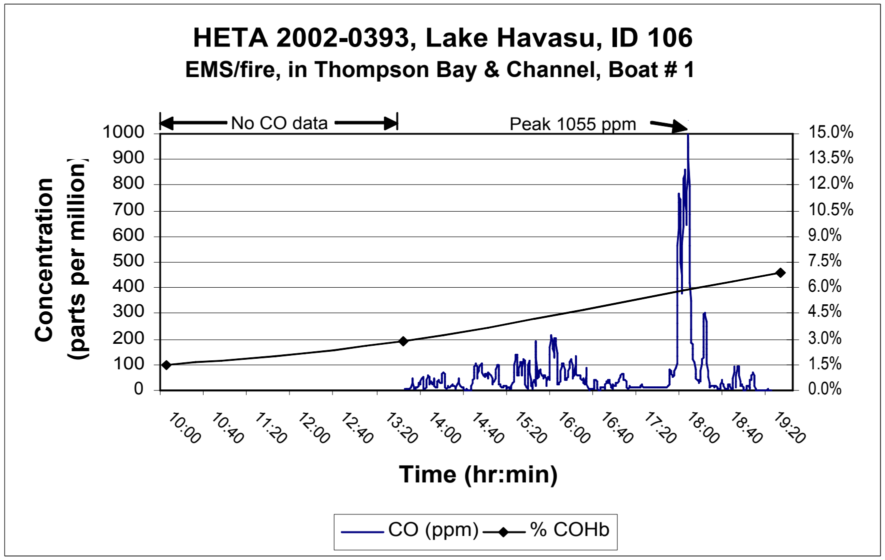
Figures 17-20 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

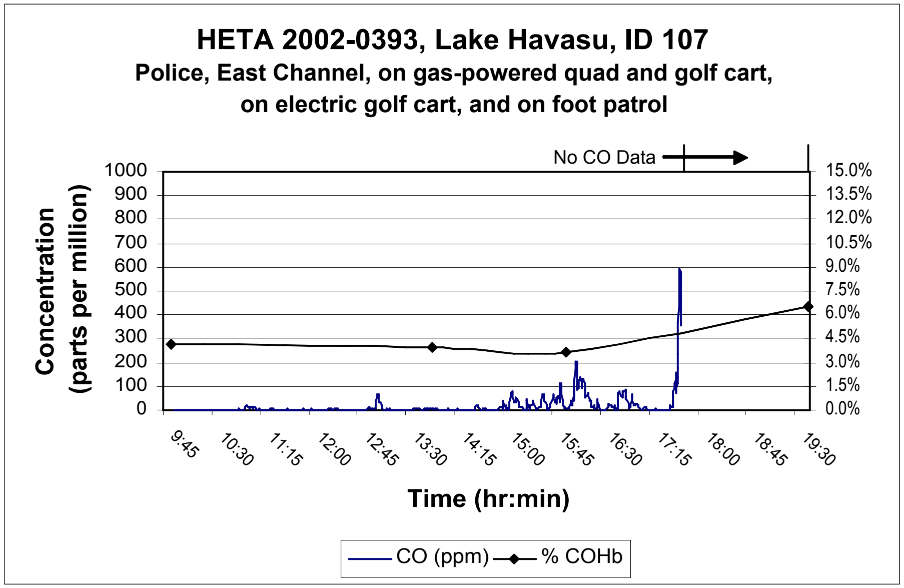


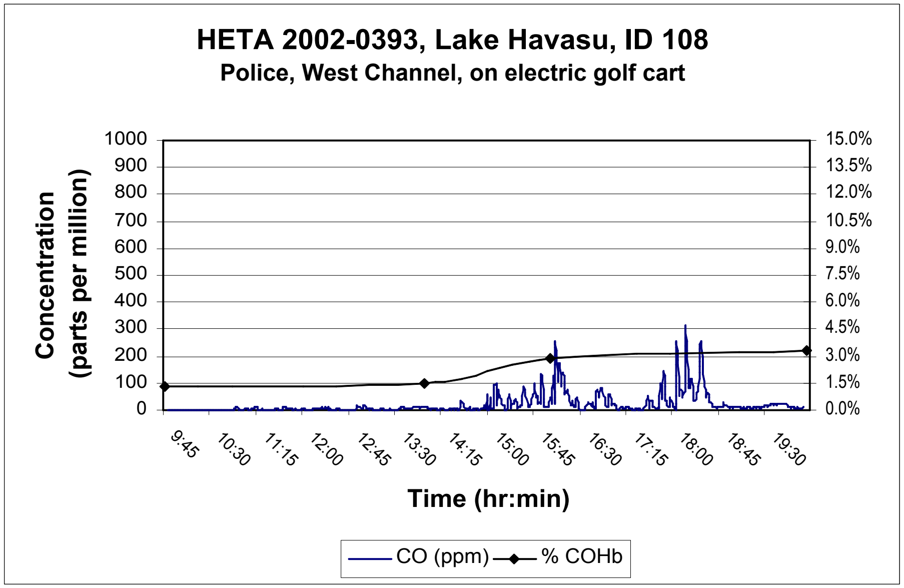


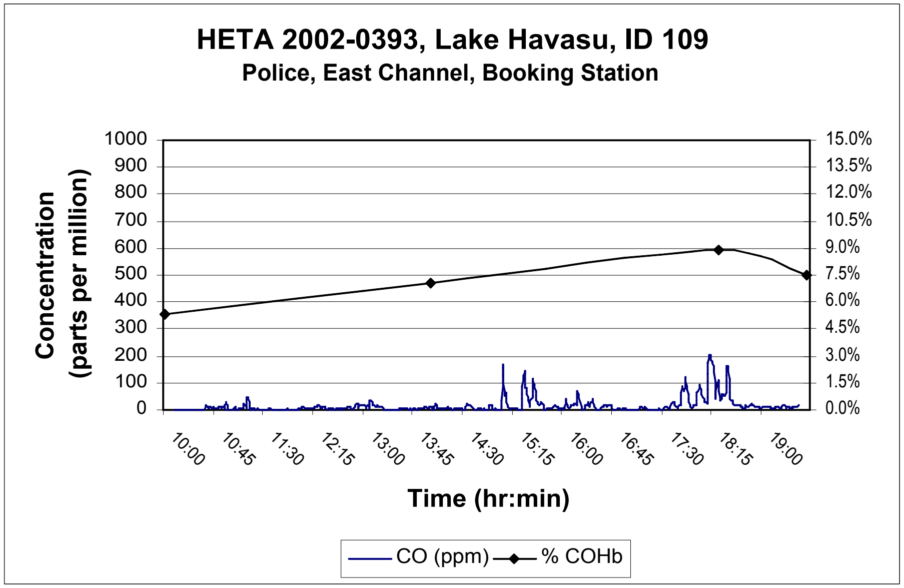


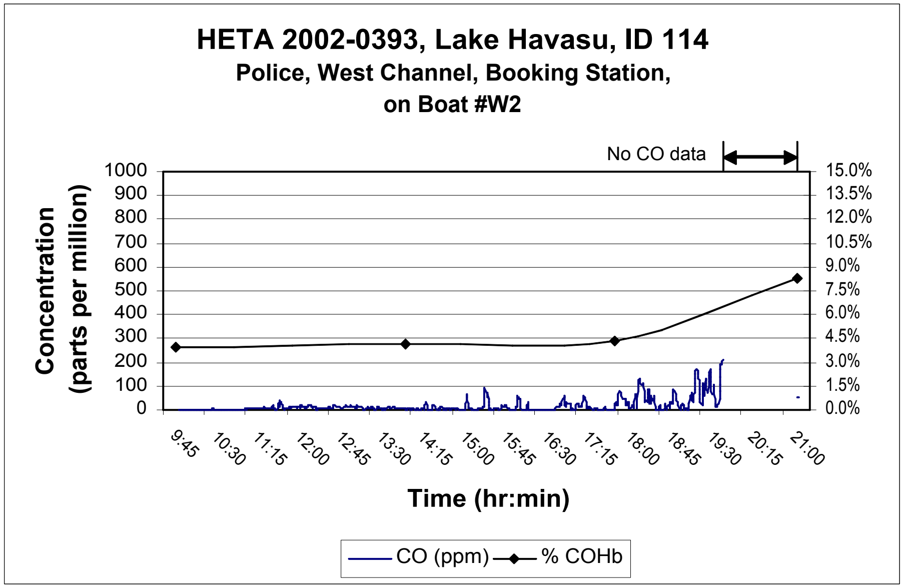


Figures 21-24 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

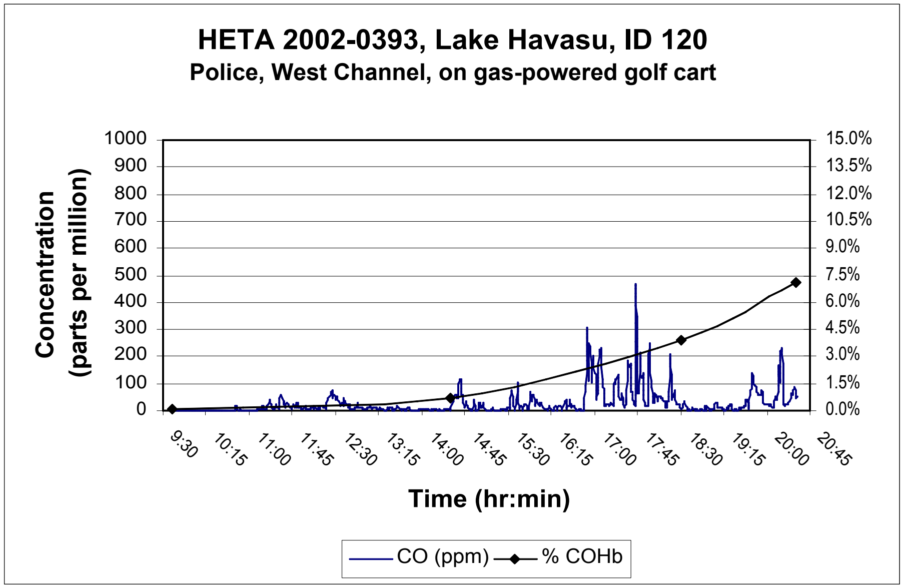


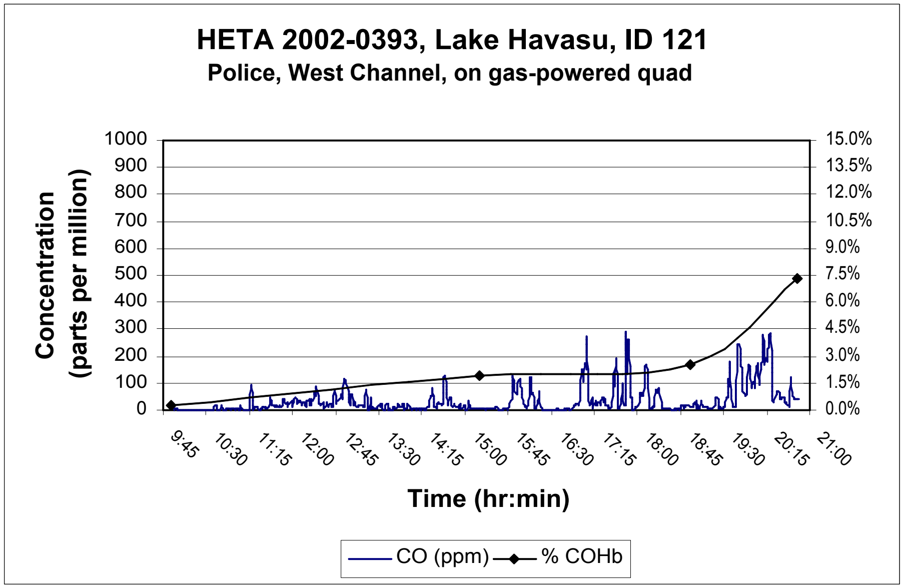


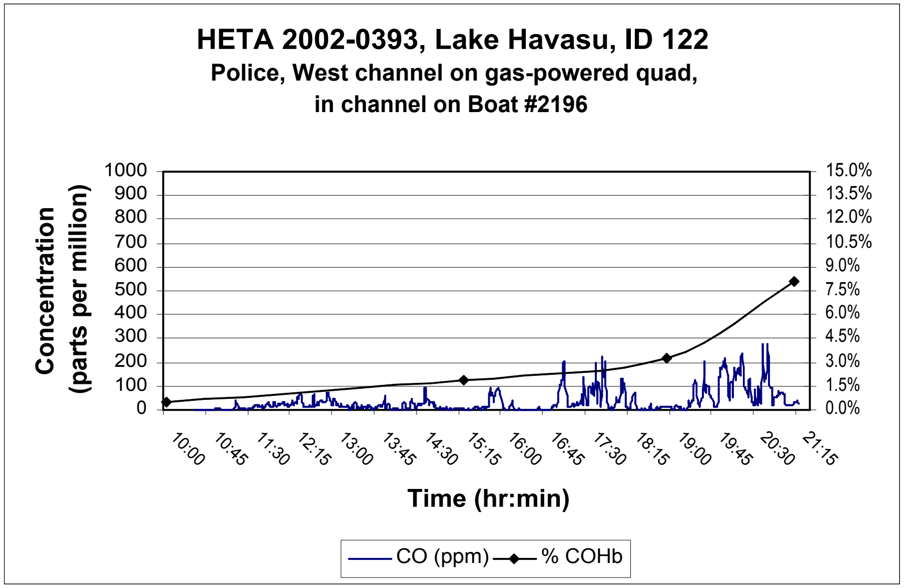


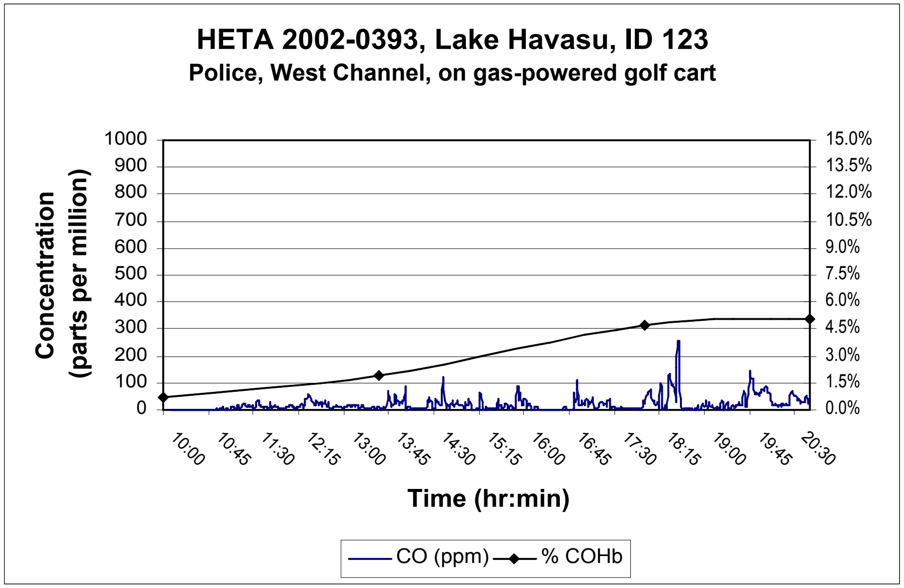


Figures 25-28 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

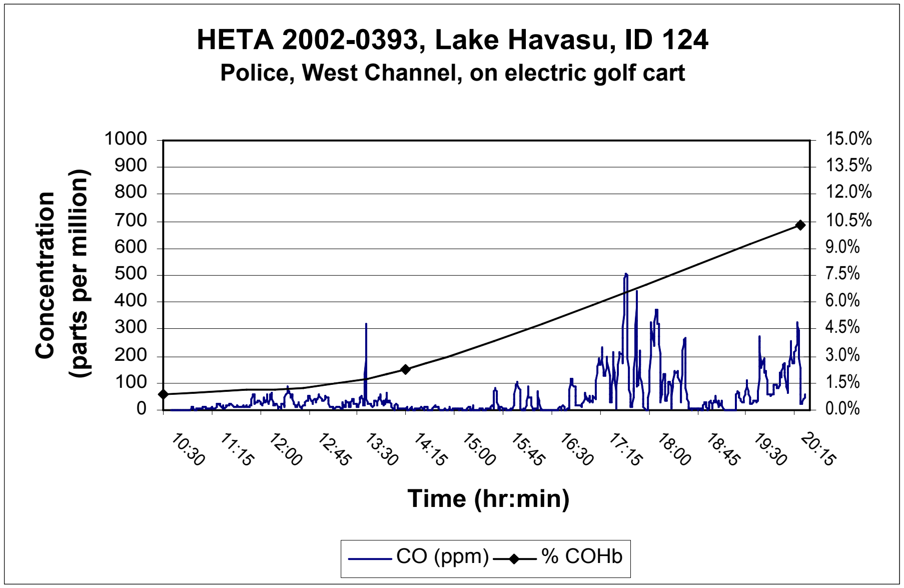


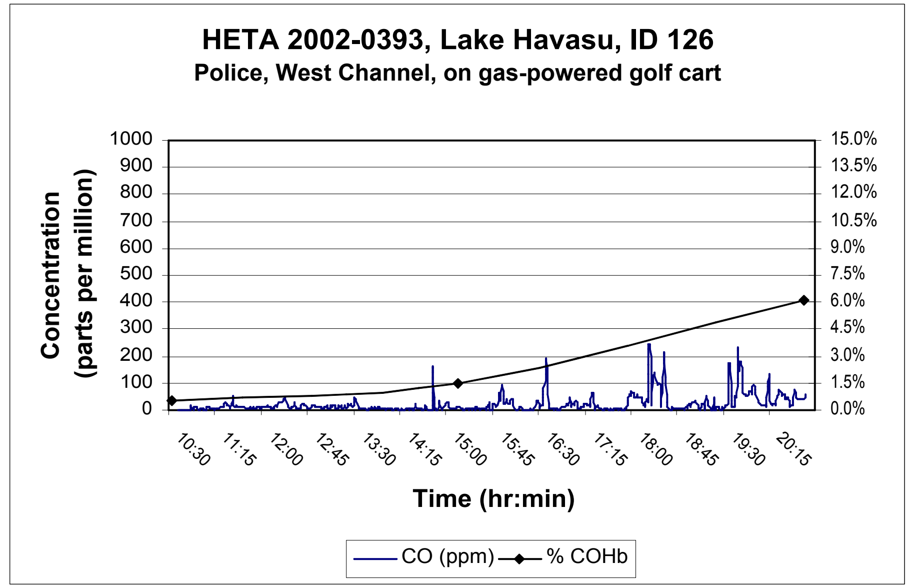


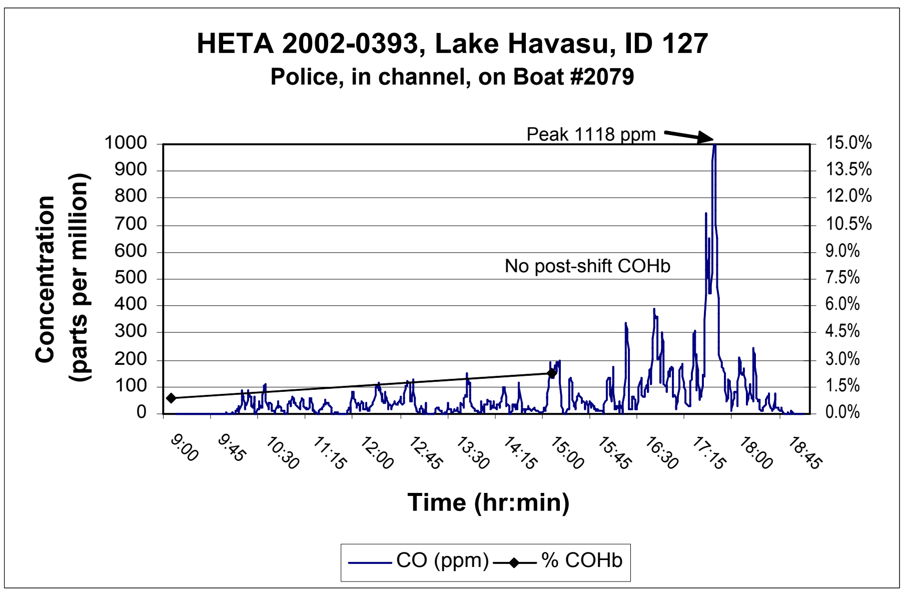


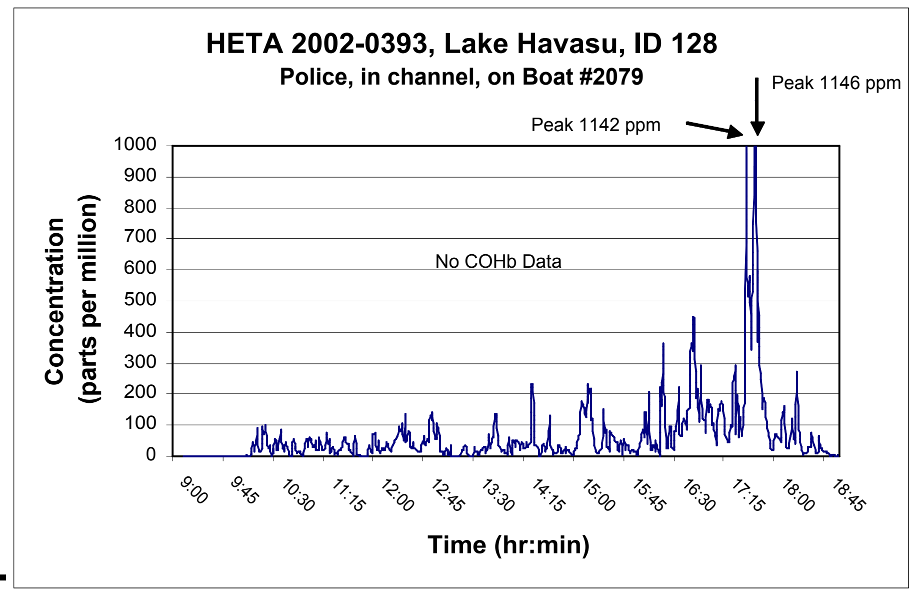


Figures 29-32 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

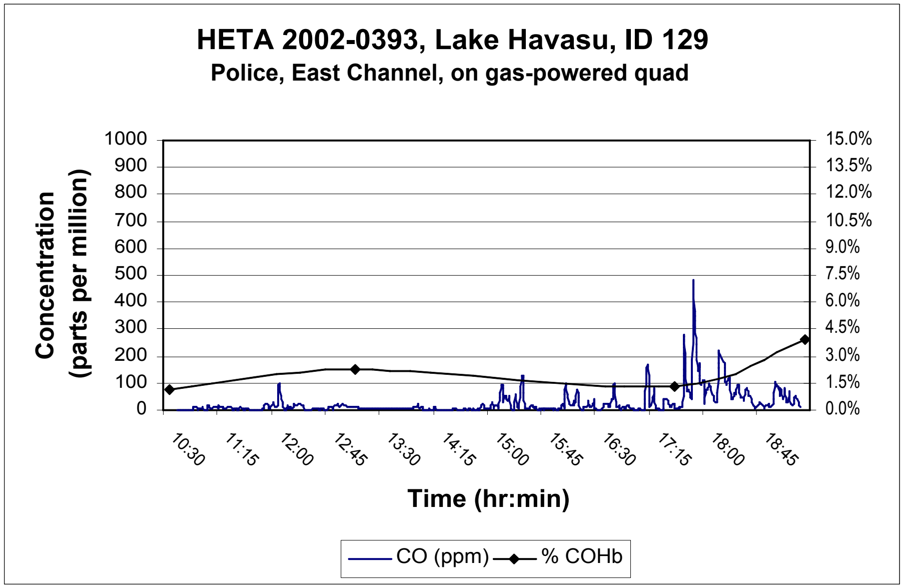


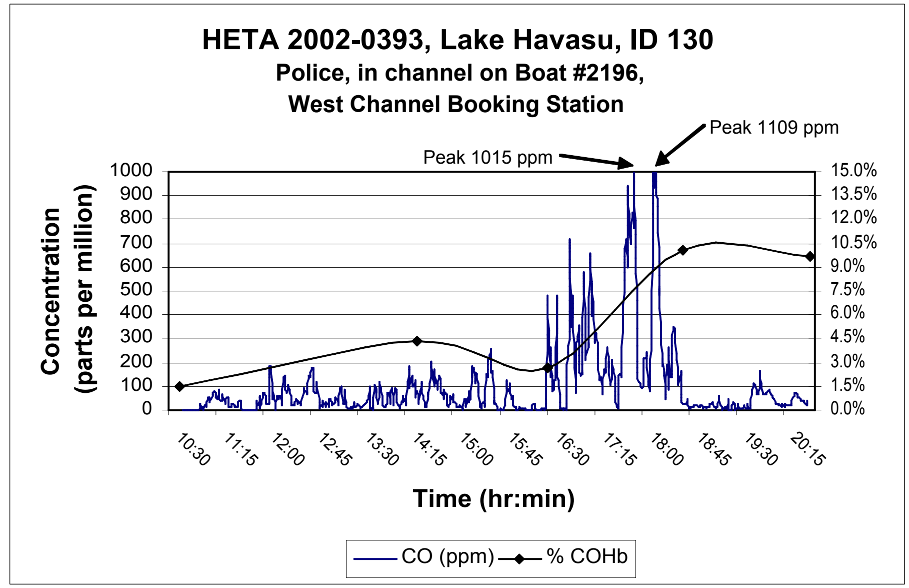


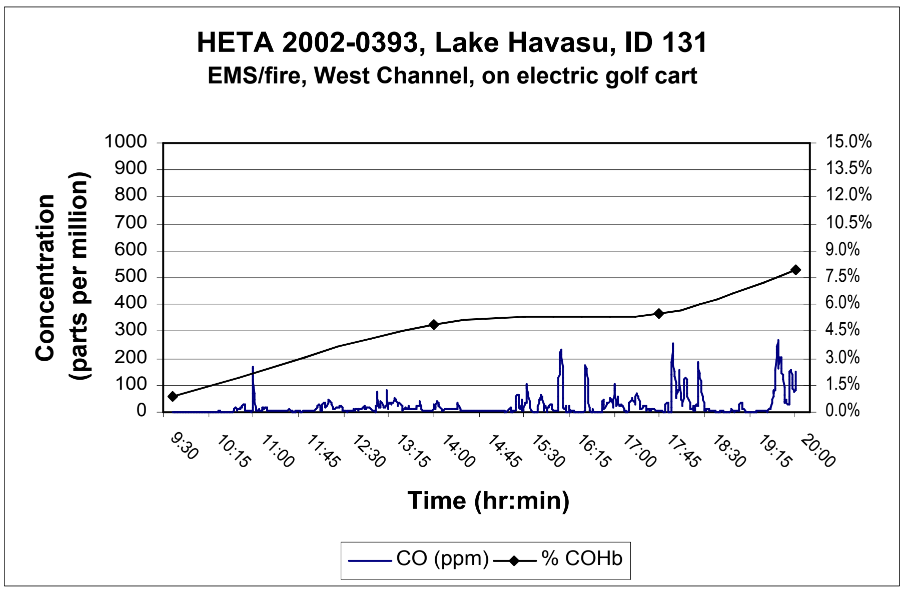


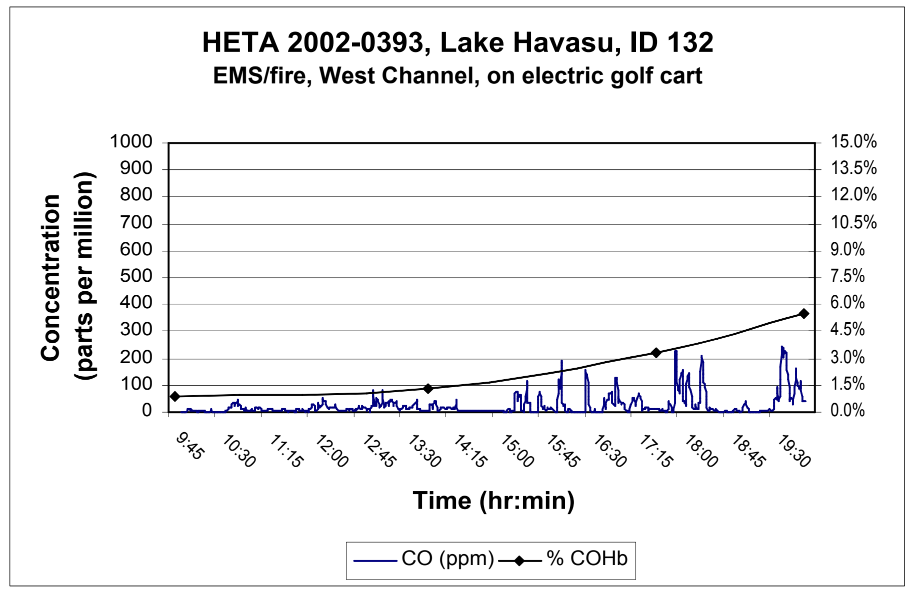


Figures 33-35 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

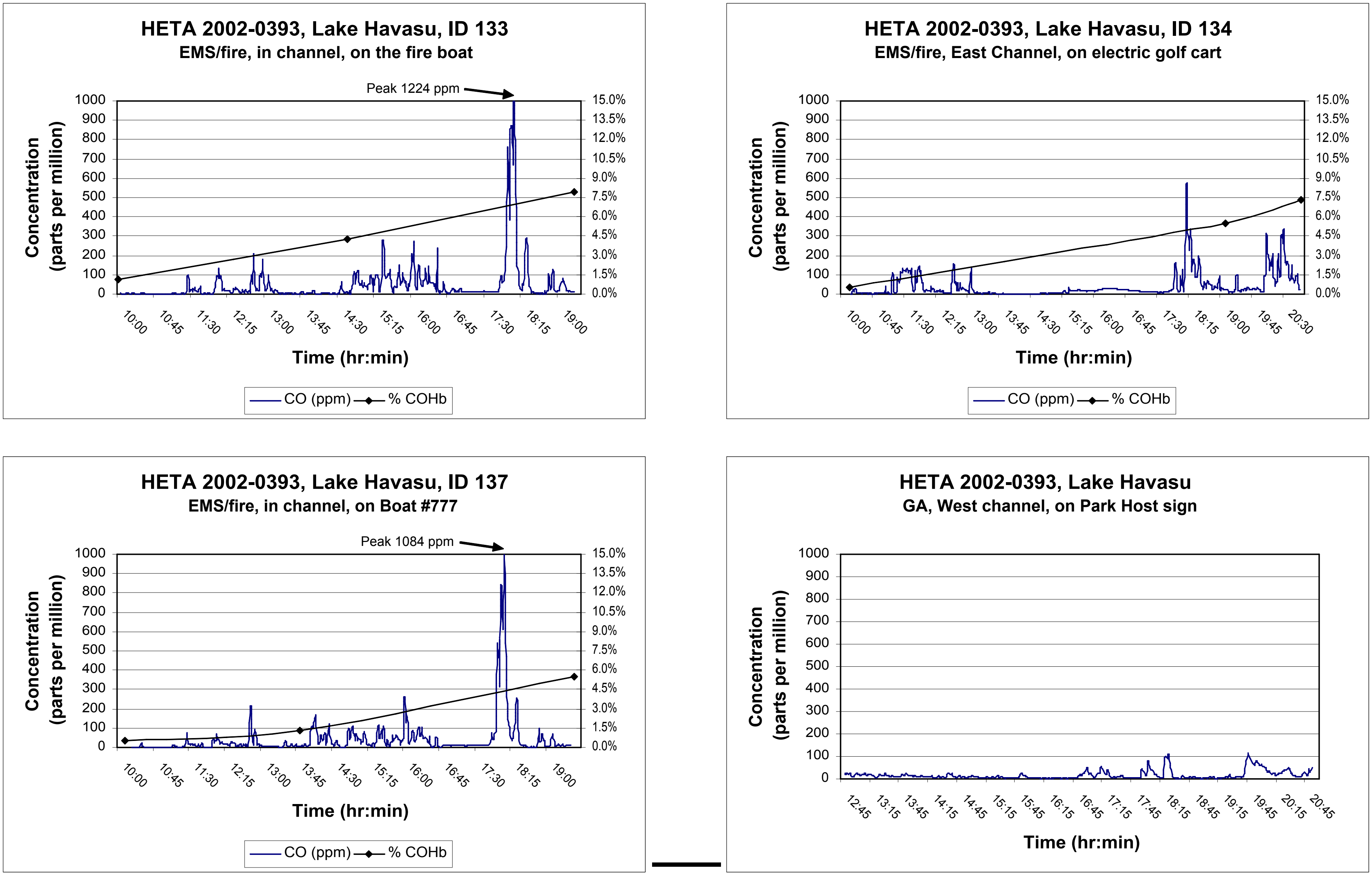




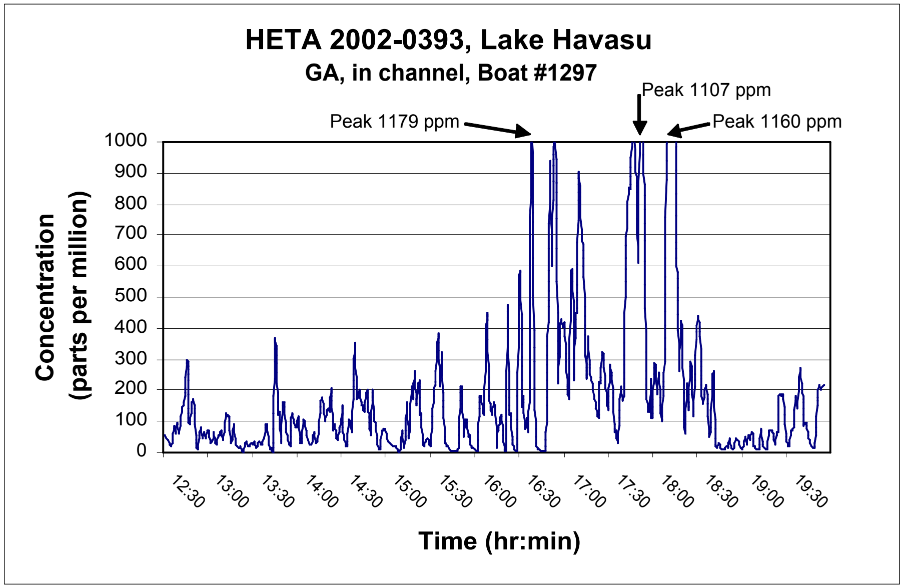


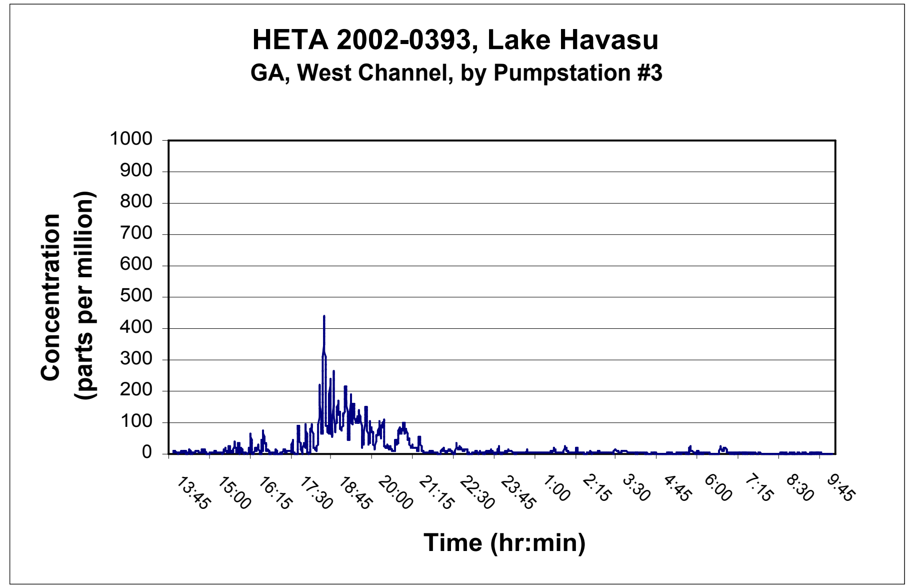


Figures 36-39 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona



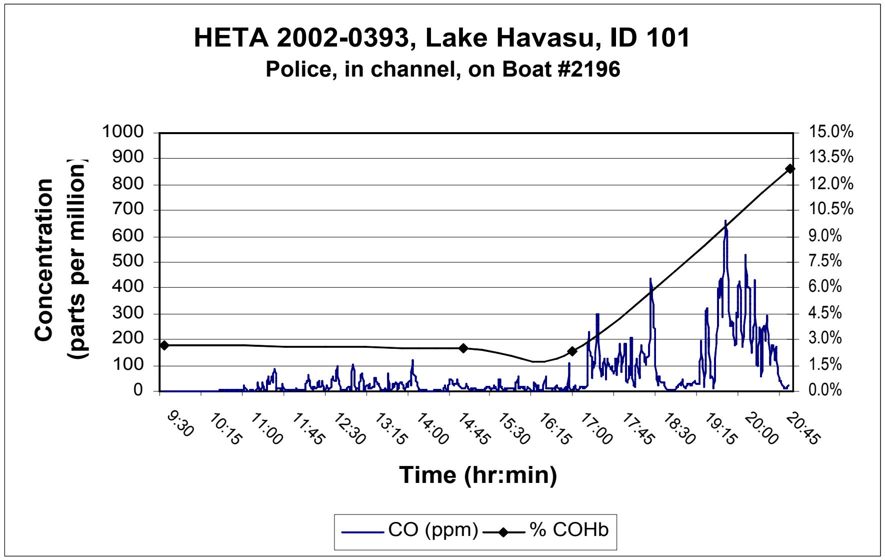
Figures 40-41 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 24, 2003 at Lake Havasu, Arizona

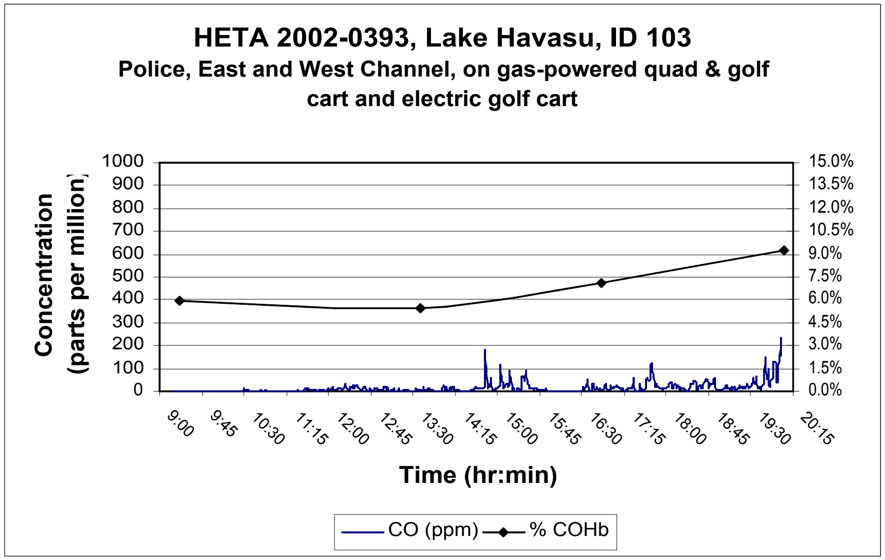


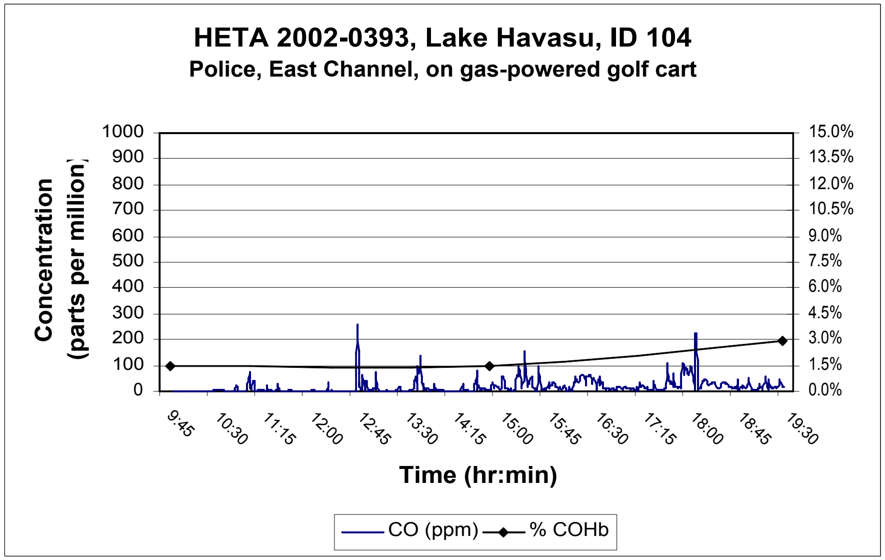


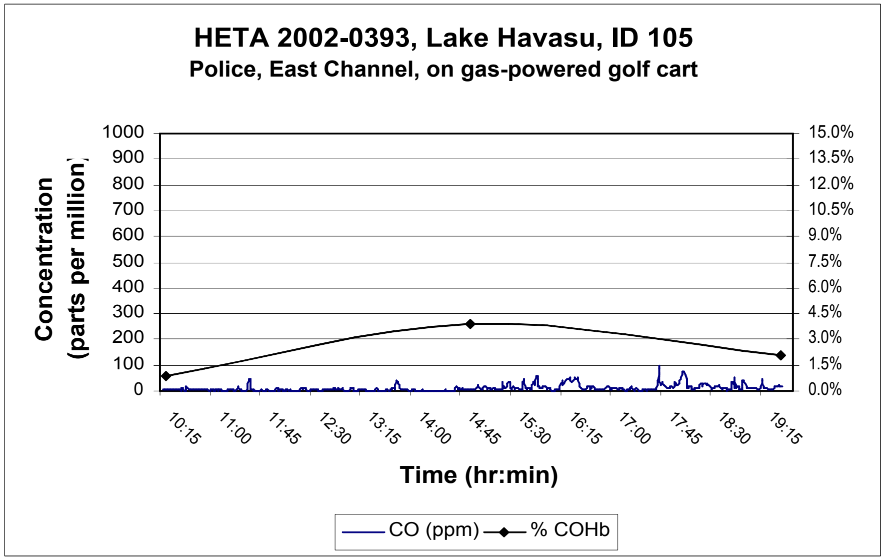
May 25, 2003

Figures 42-45 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

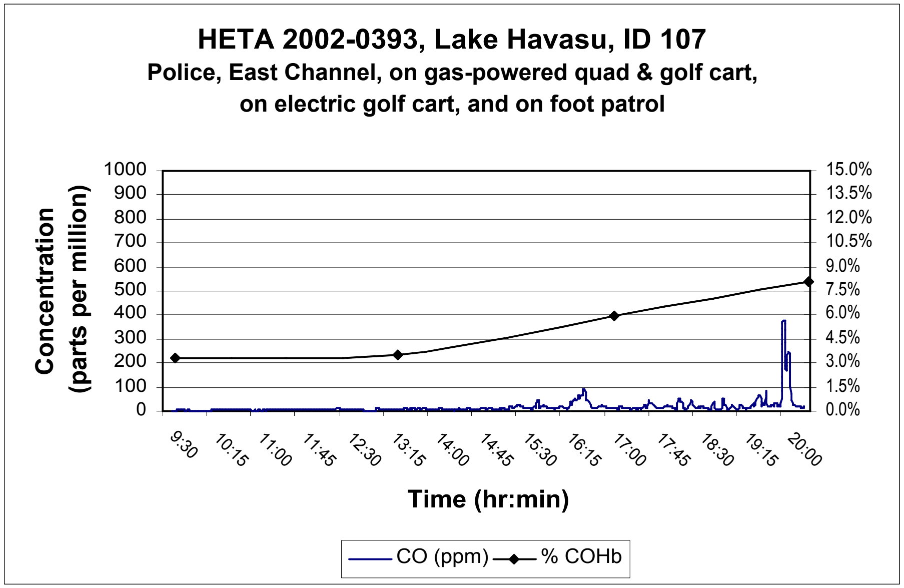


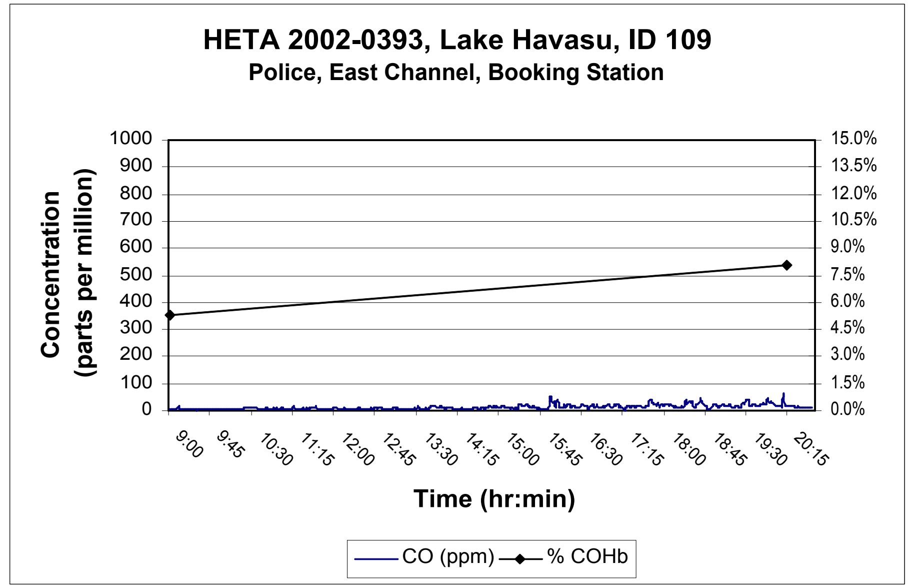


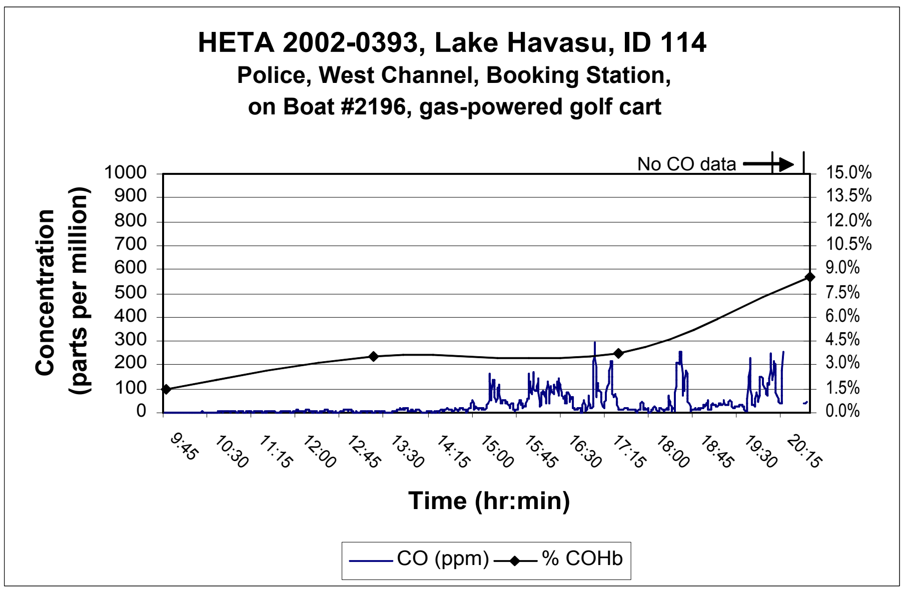


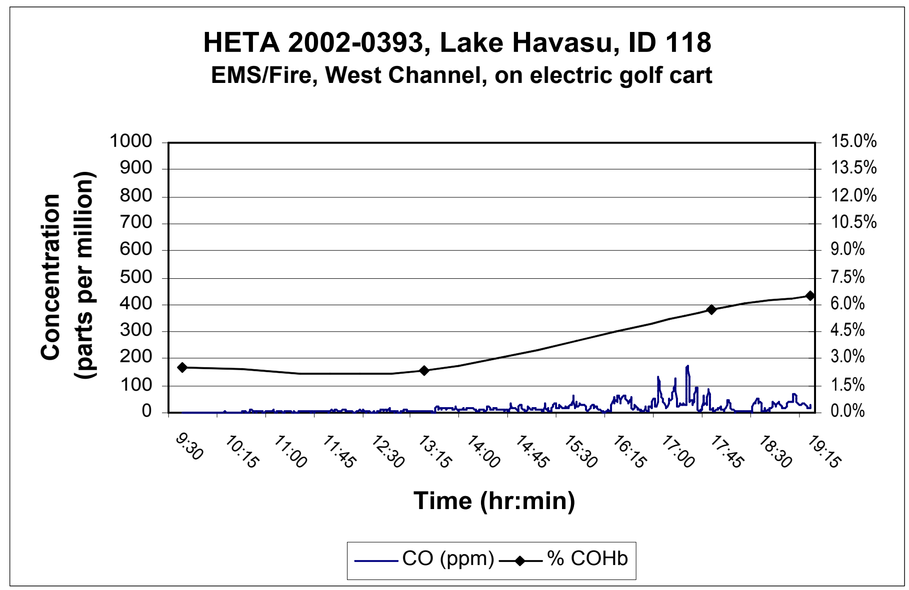


Figures 46-49 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

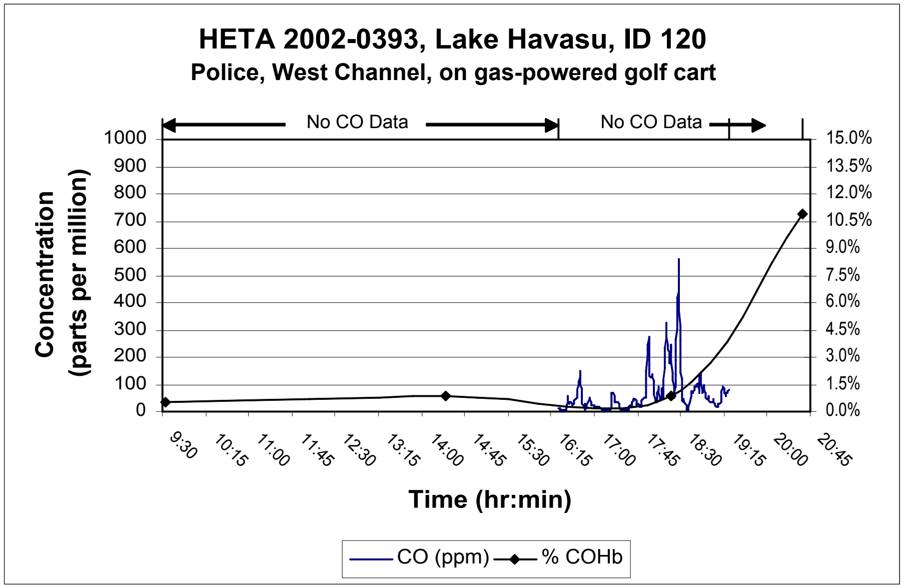


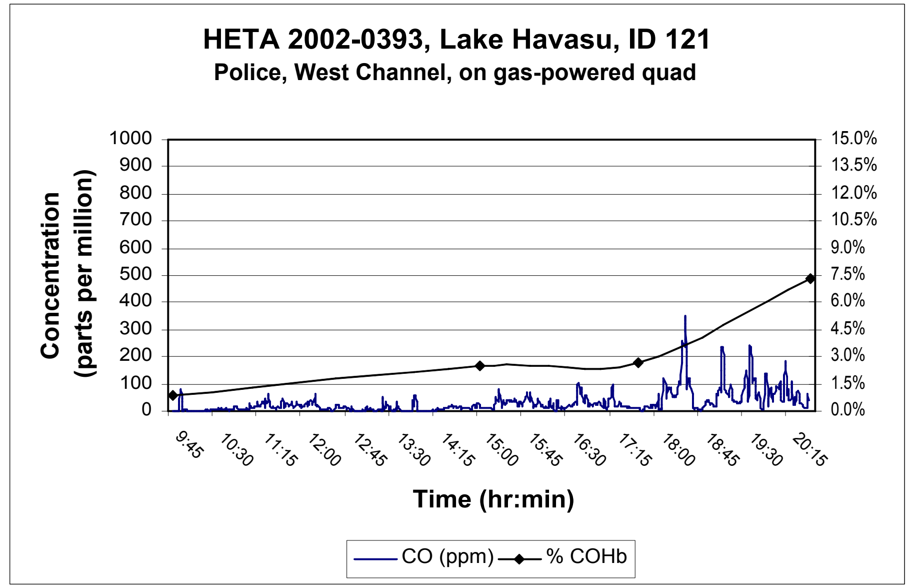


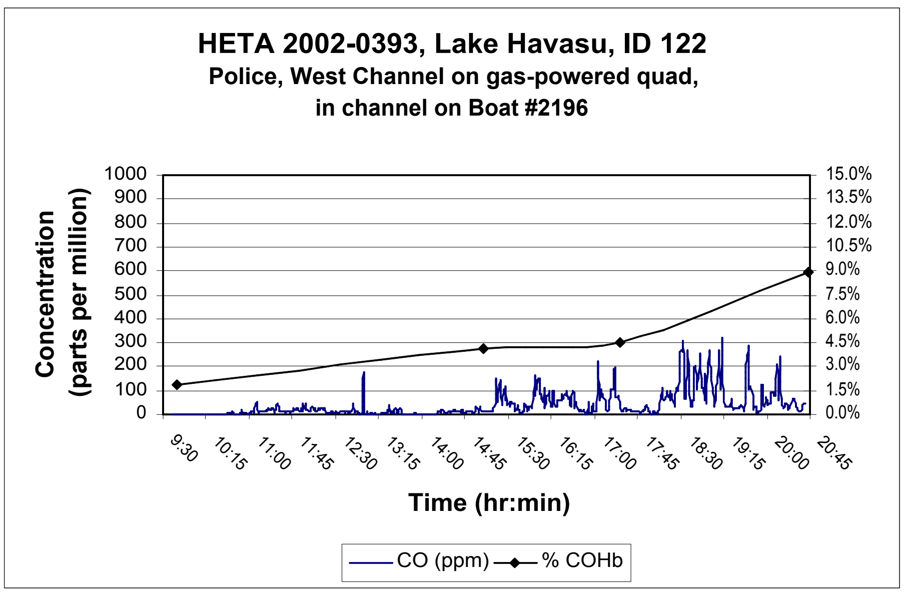


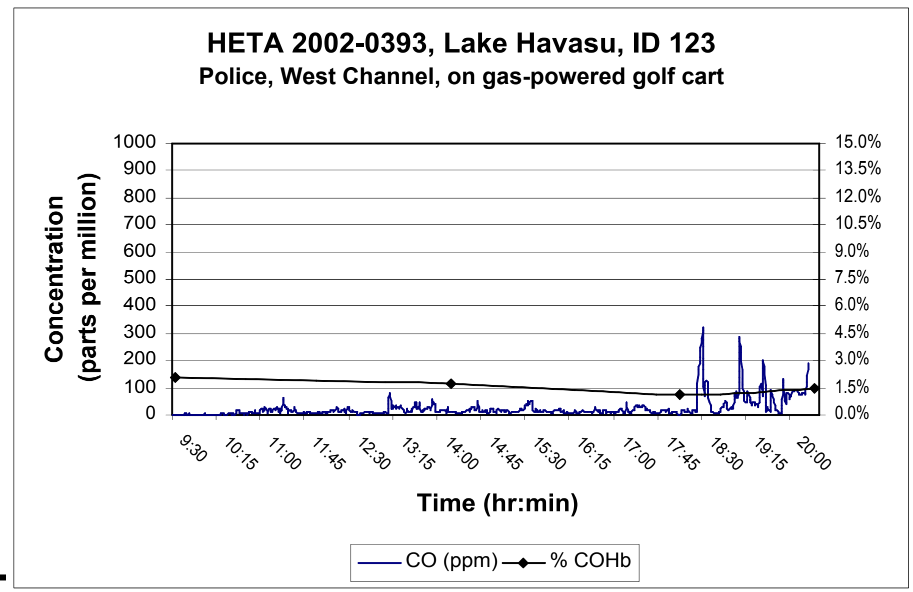


Figures 50-53 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

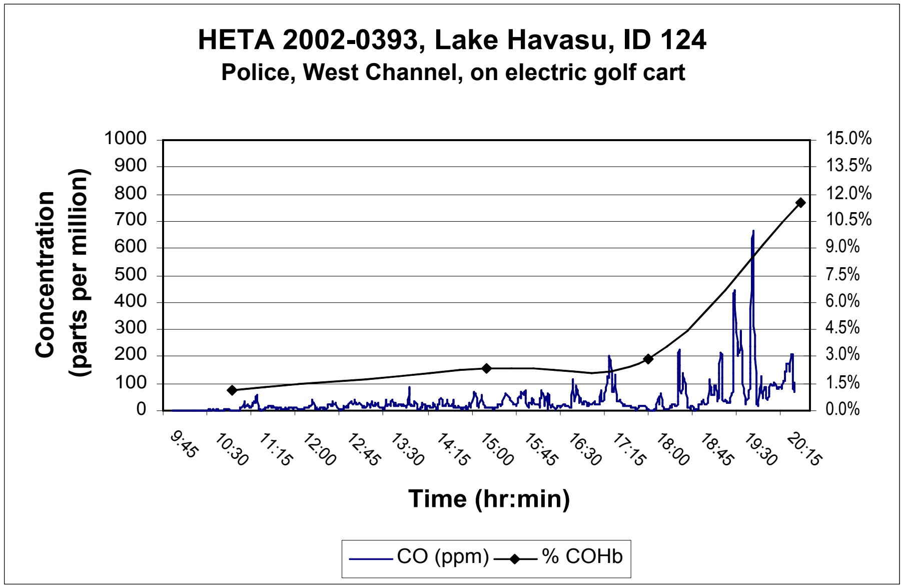


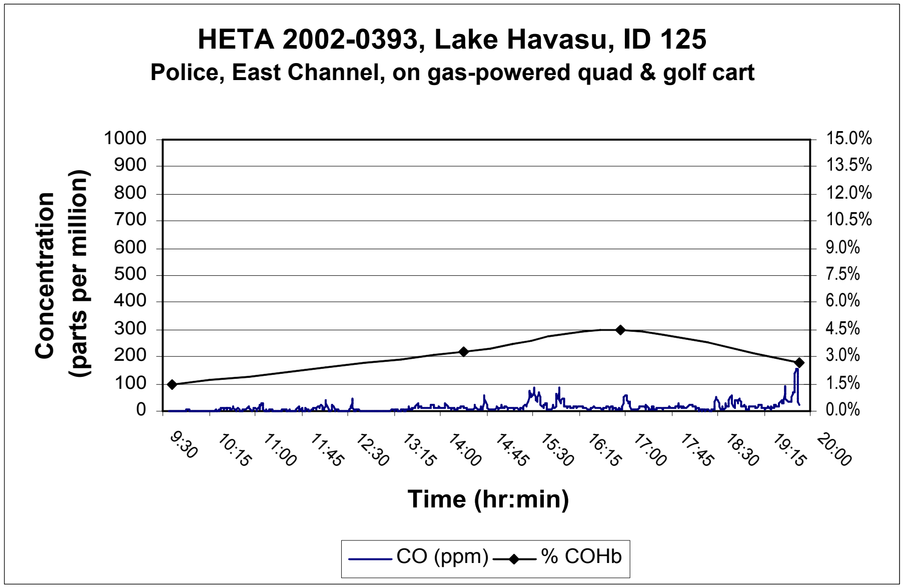


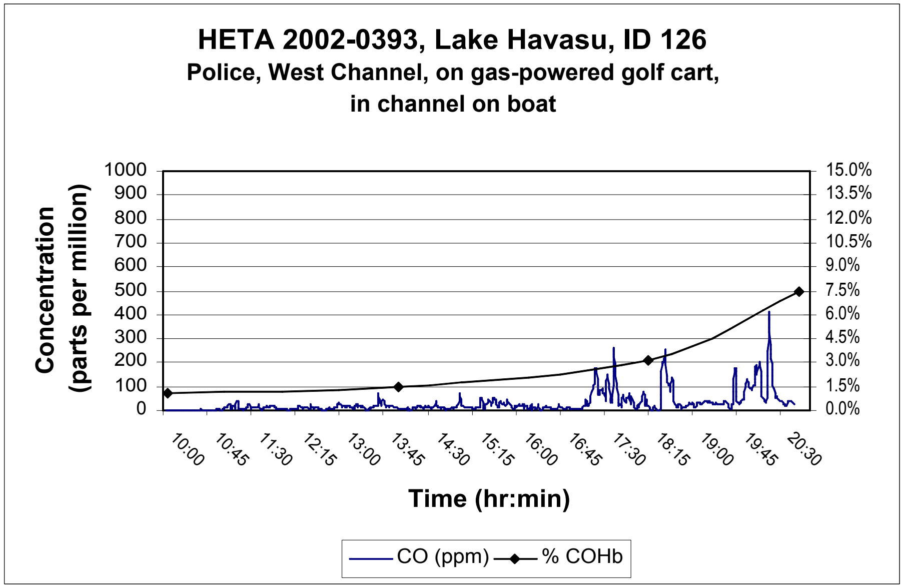


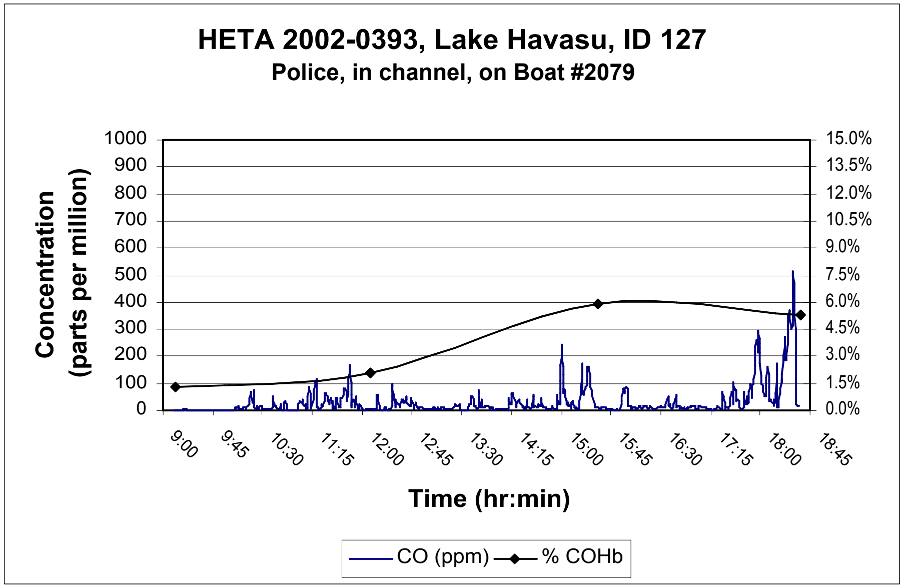


Figures 54-57 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

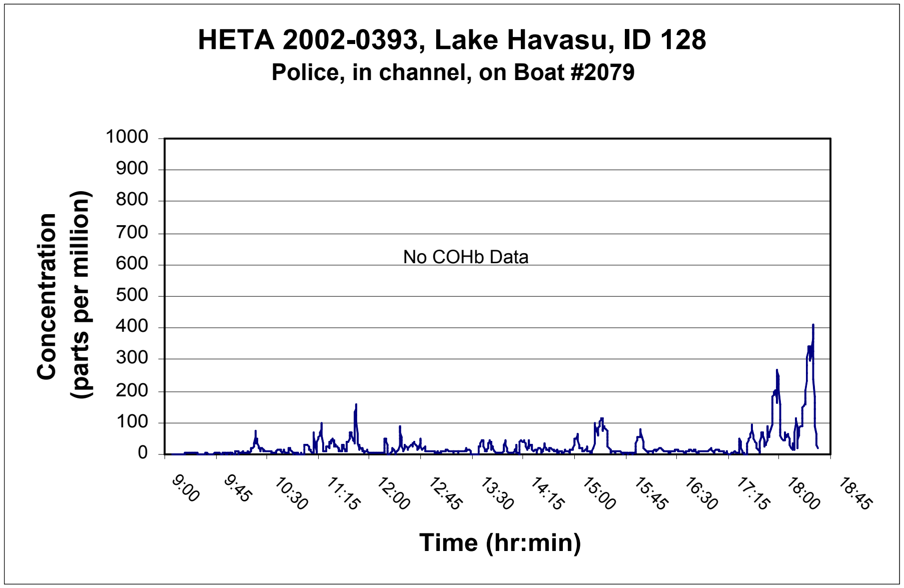


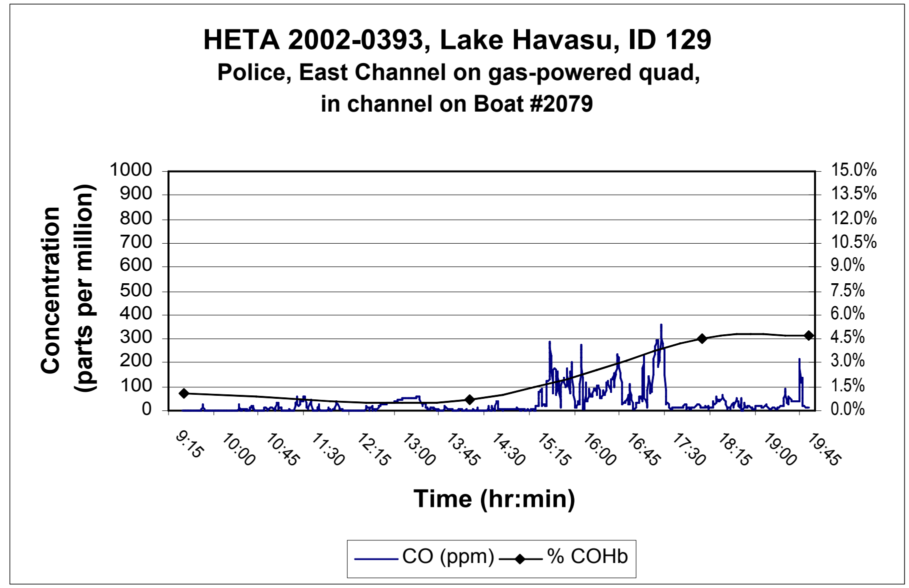


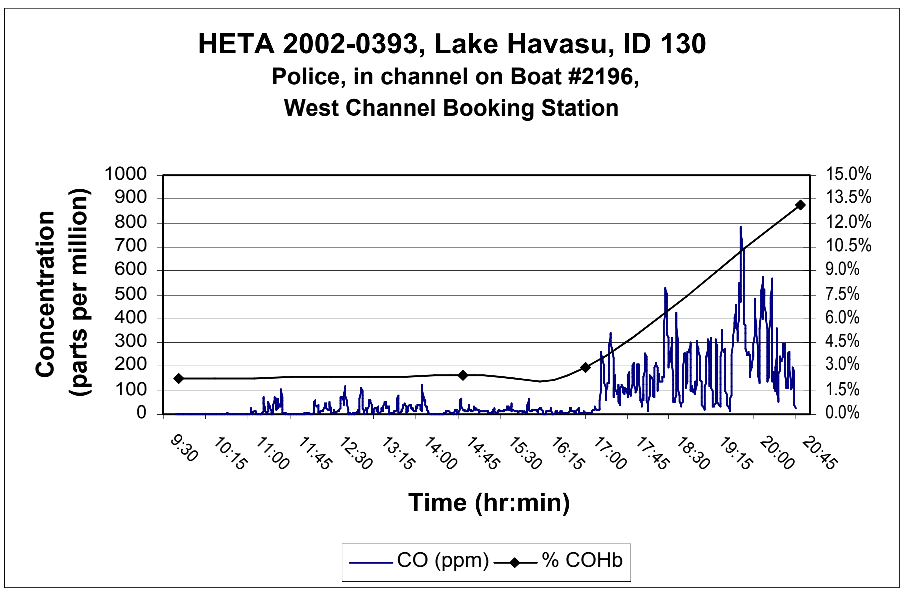


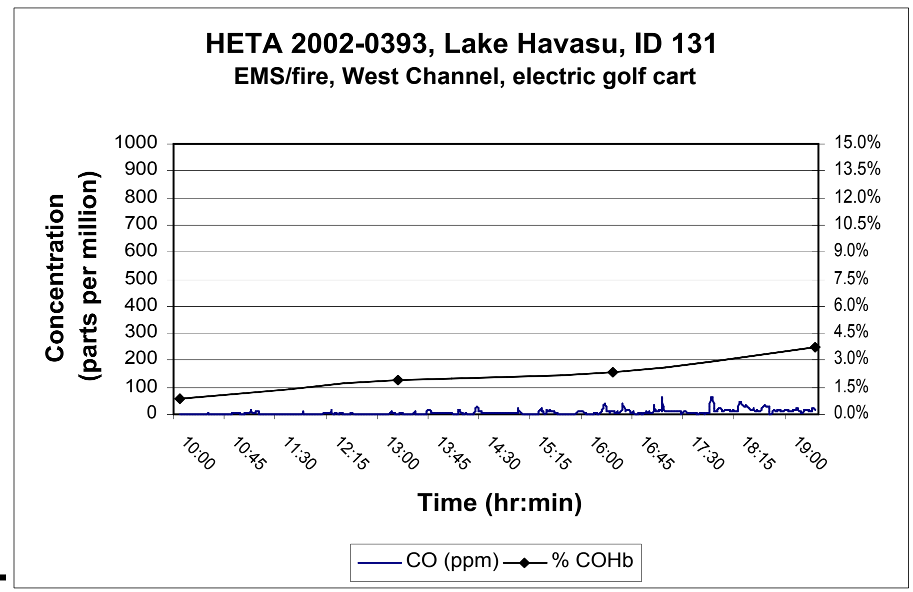


Figures 58-61 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

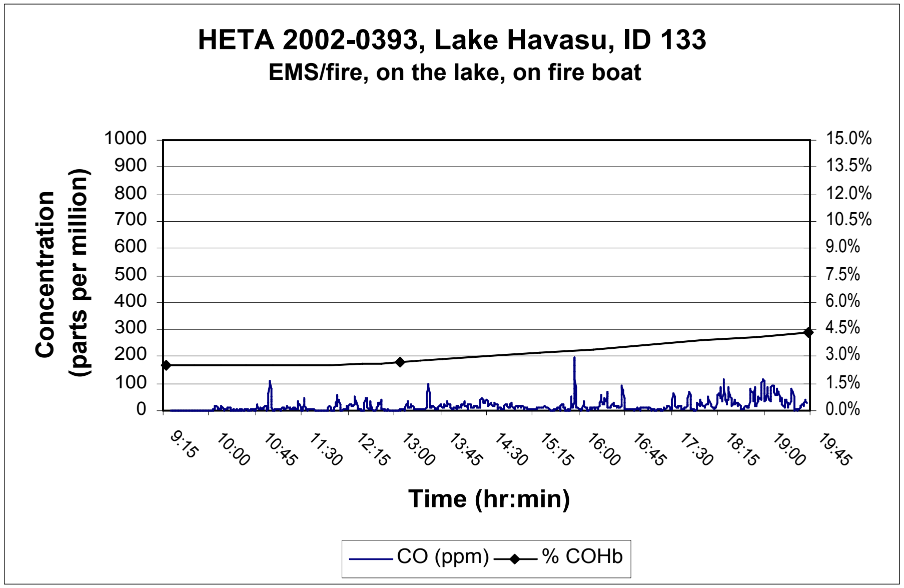


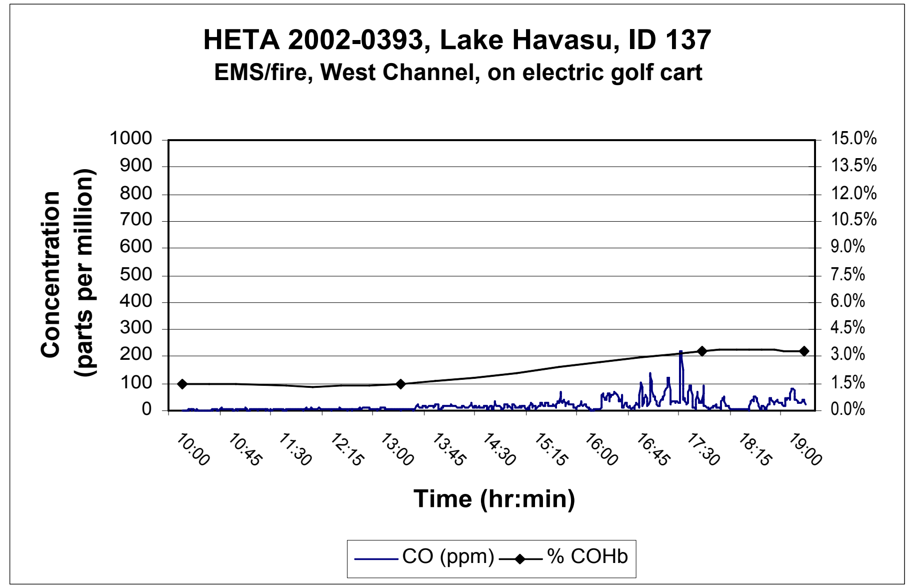


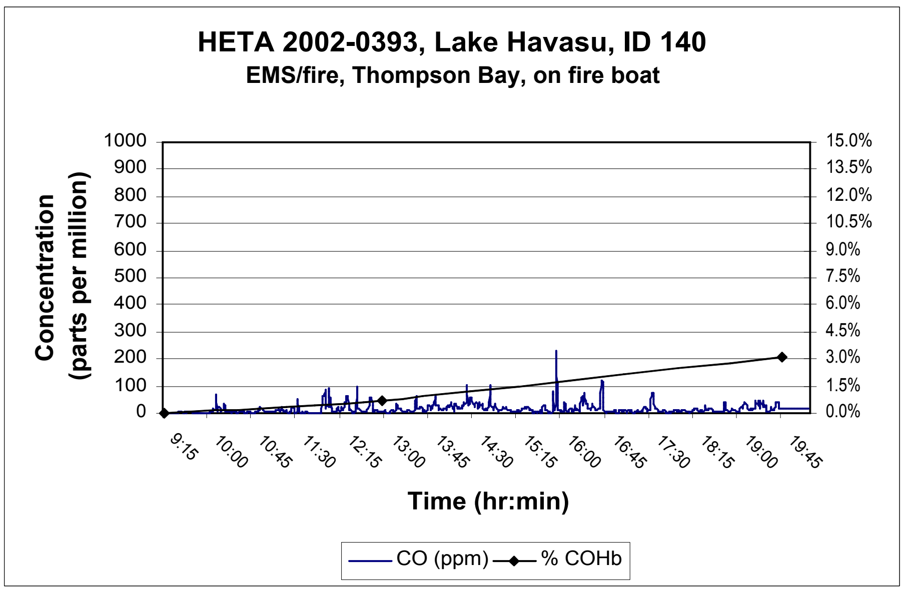


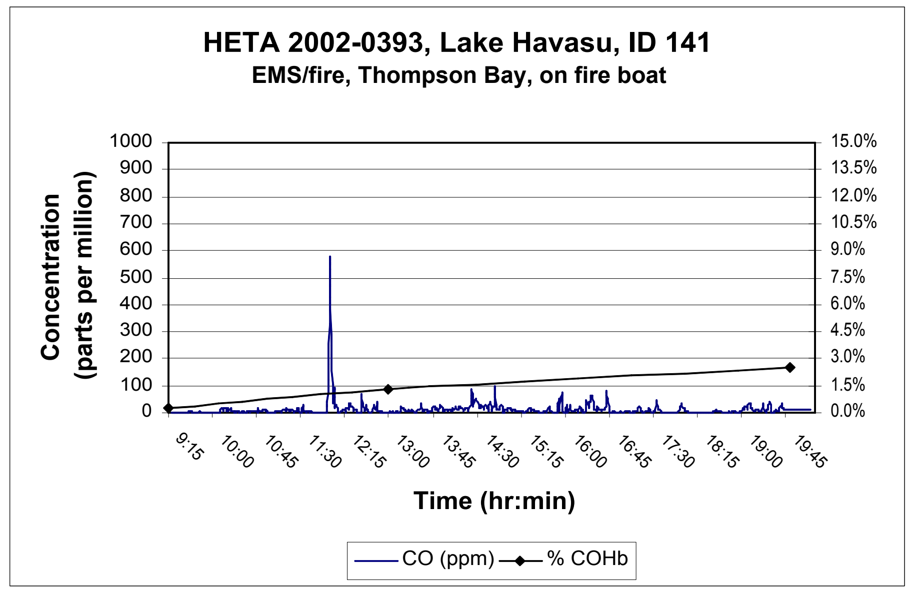


Figures 62-65 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

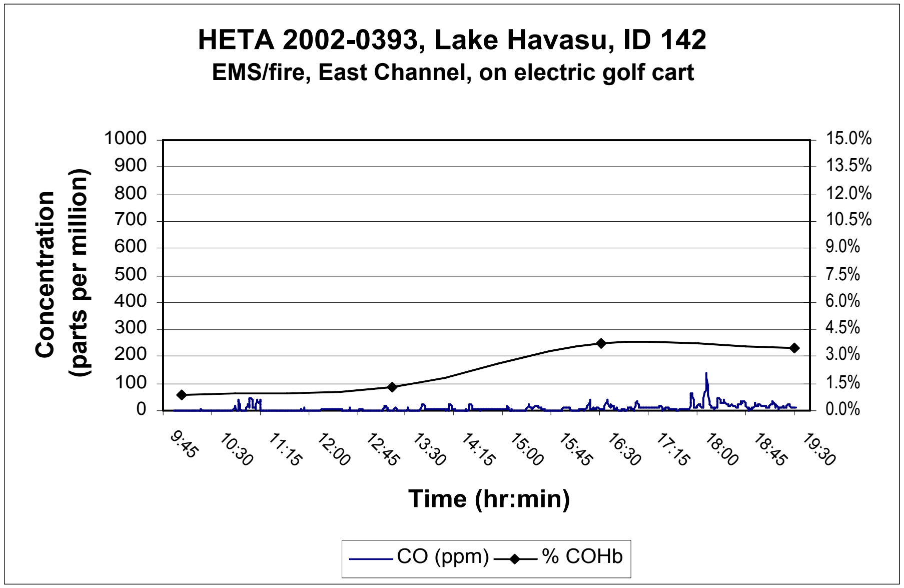


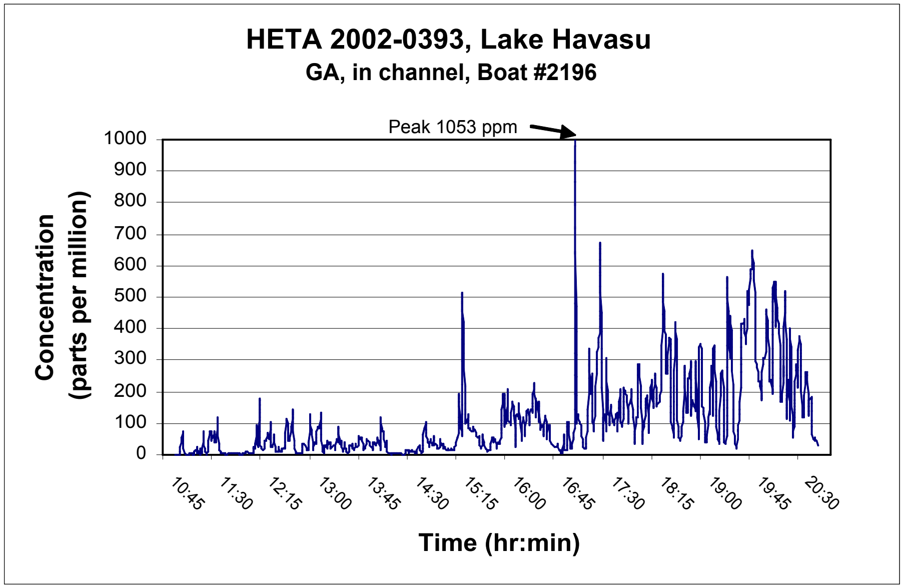






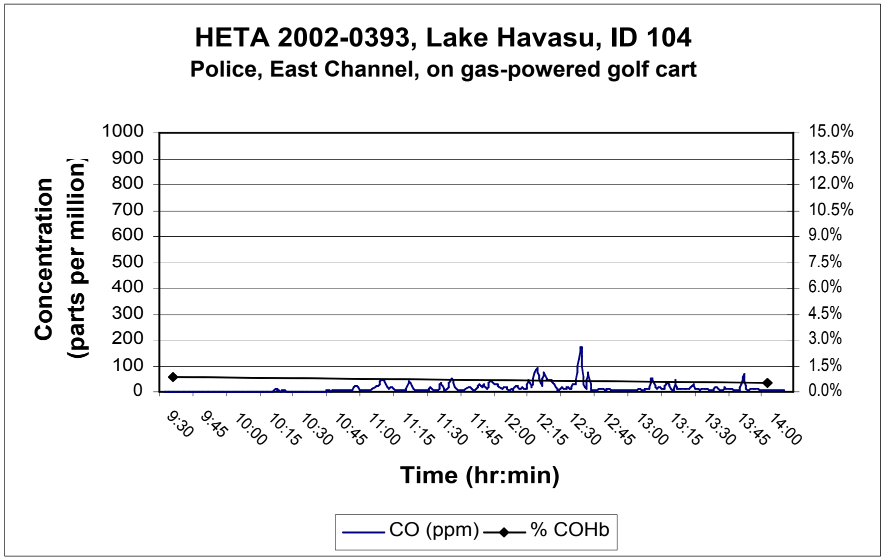
Figures 66-68 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 25, 2003 at Lake Havasu, Arizona

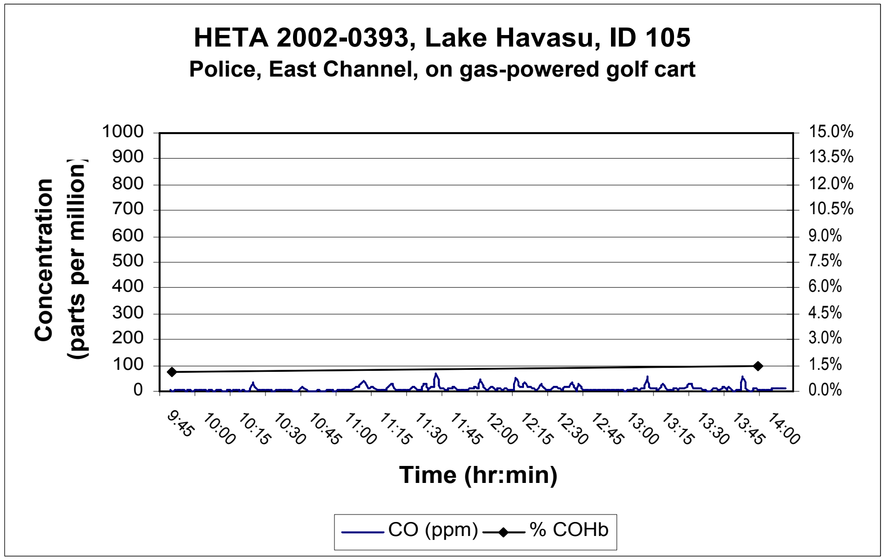


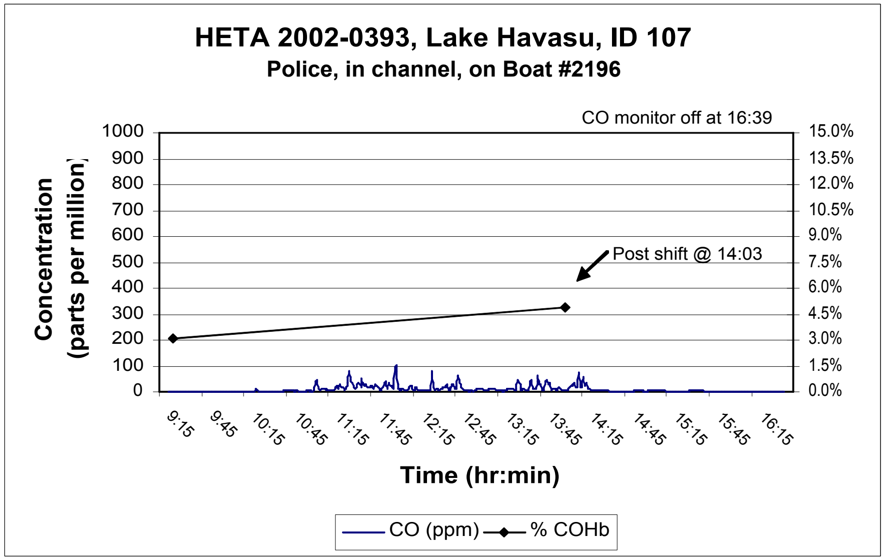


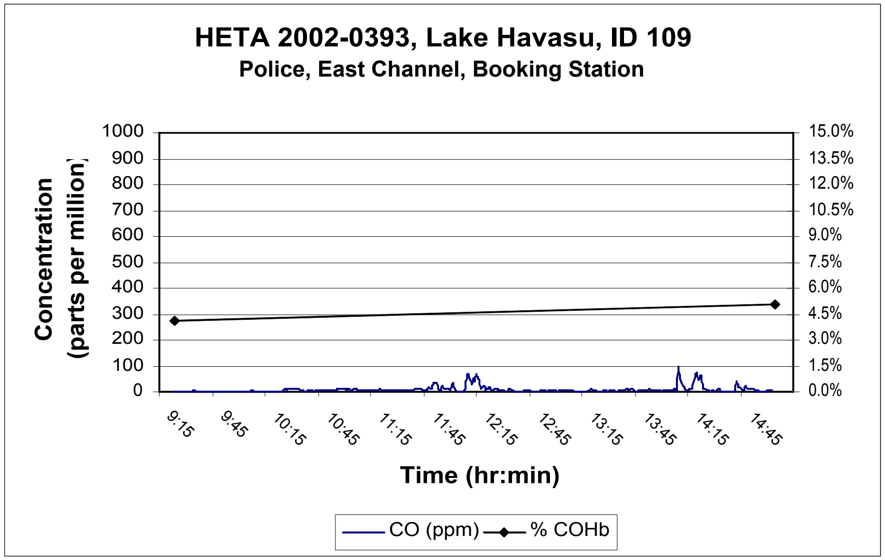
May 26, 2003

Figures 69-72 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 26, 2003 at Lake Havasu, Arizona

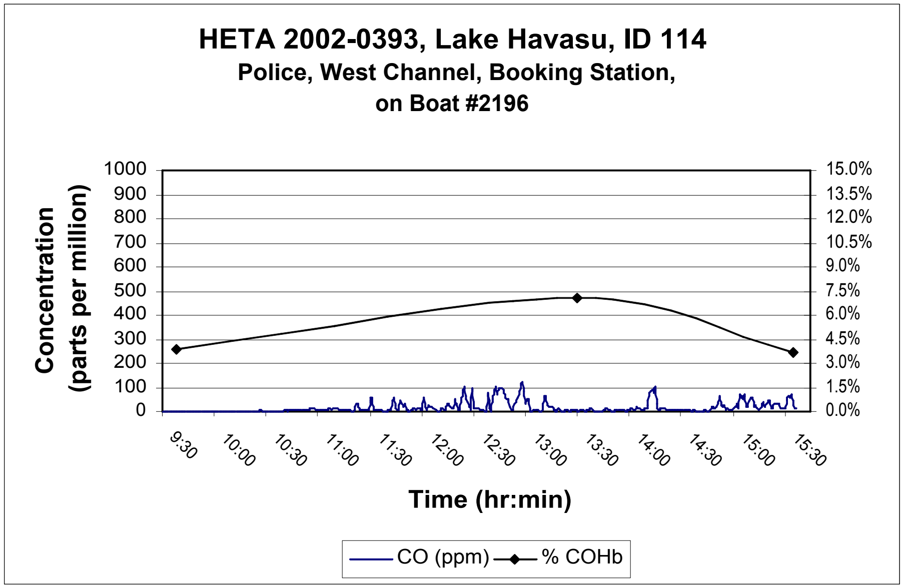


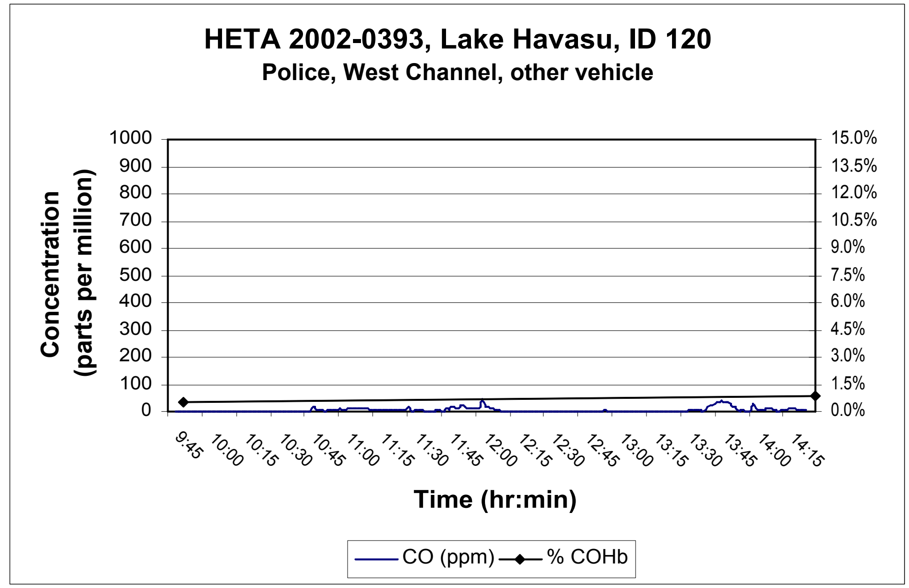


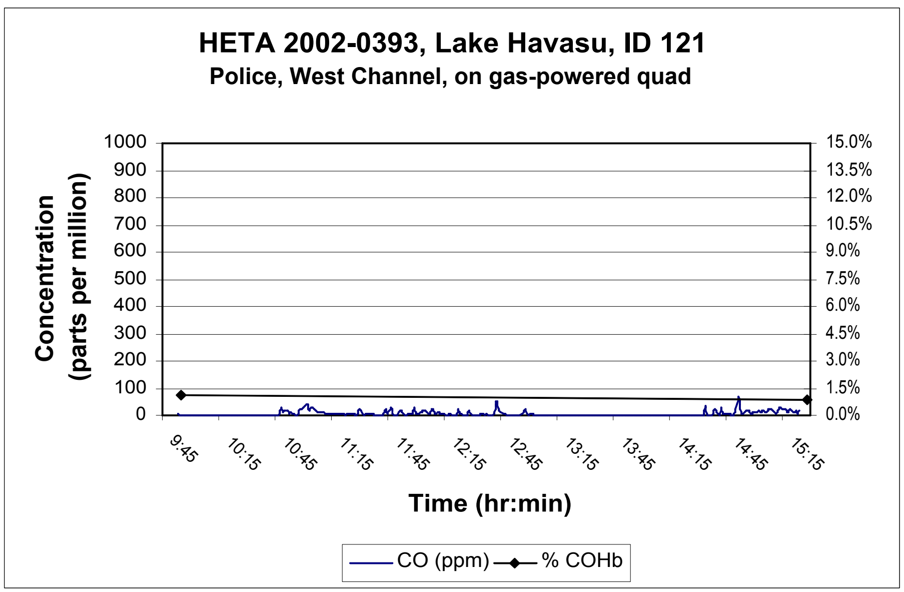


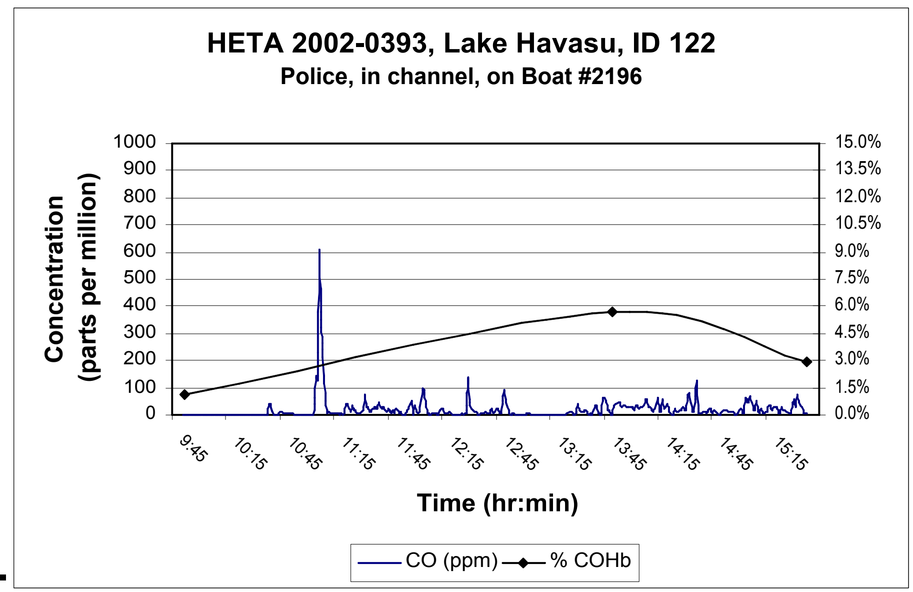


Figures 73-76 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 26, 2003 at Lake Havasu, Arizona

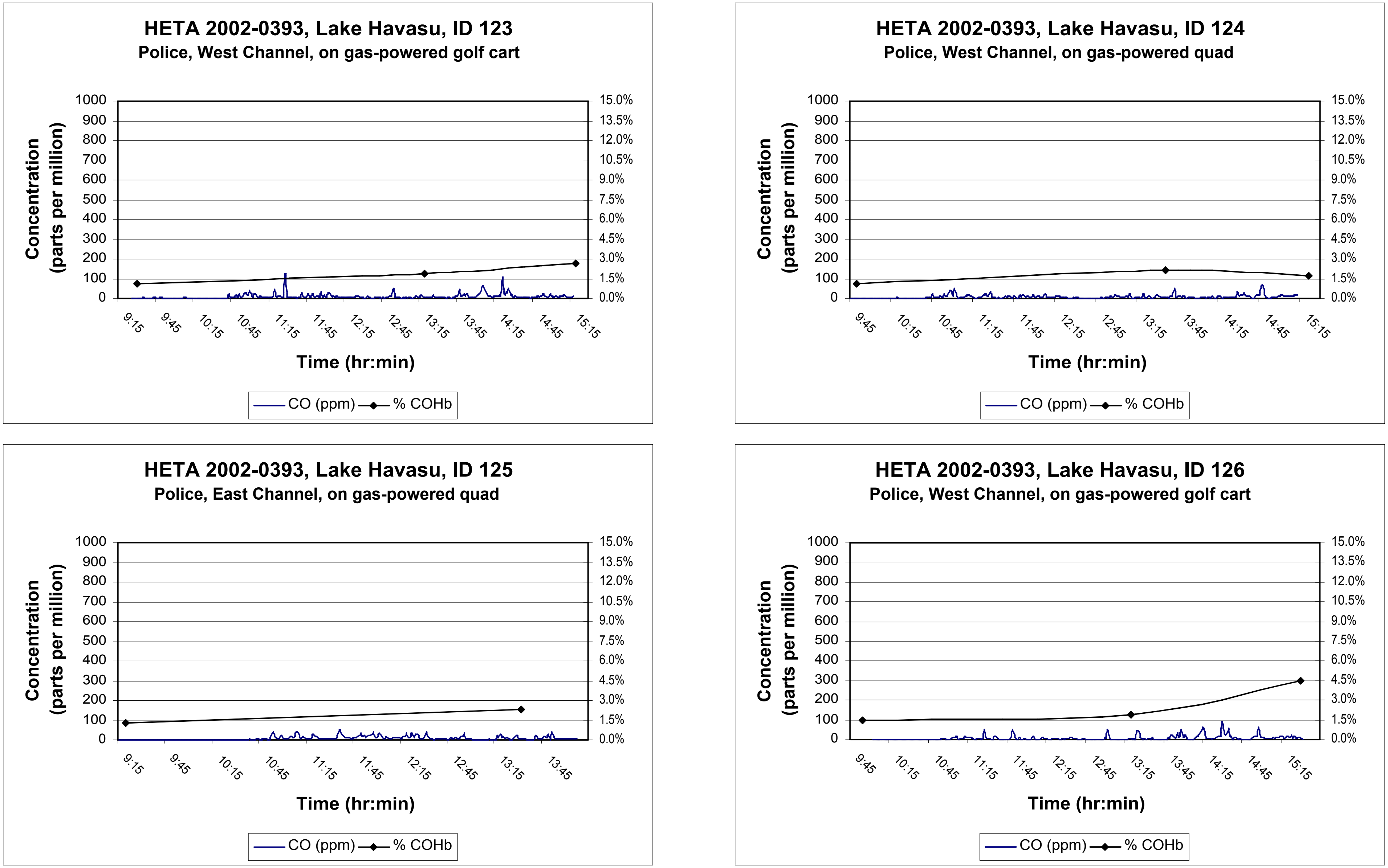




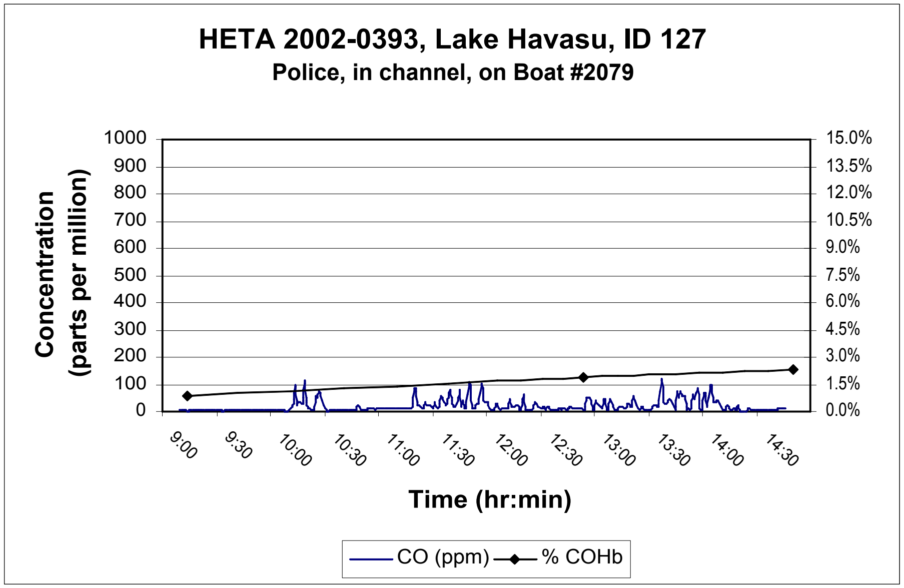


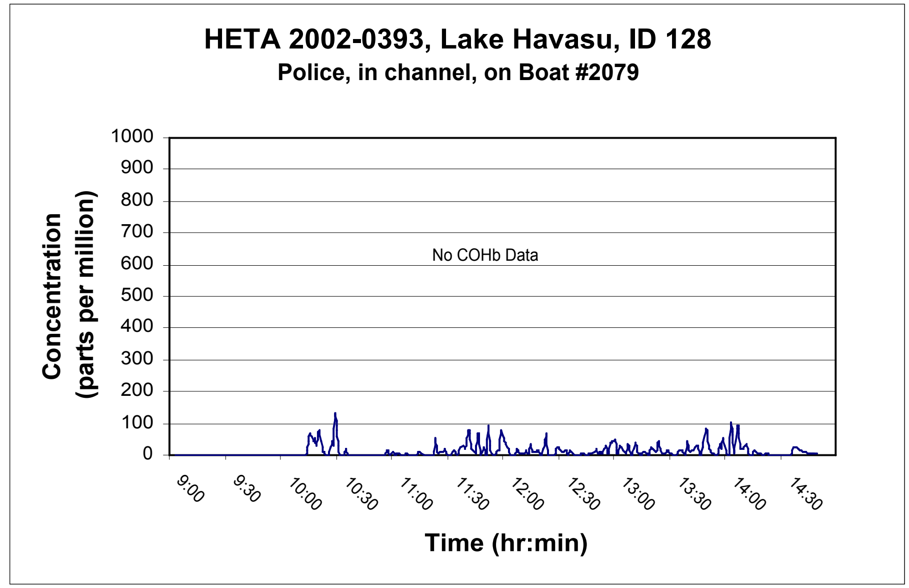


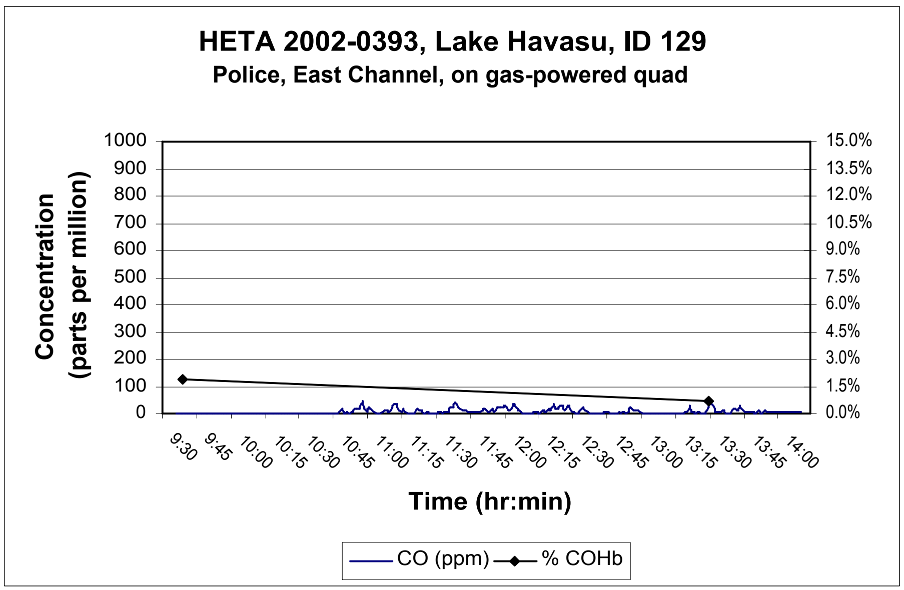
Figures 77-80 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 26, 2003 at Lake Havasu, Arizona



Figures 81-84 (L to R). Real-time CO Concentration Readings and Estimated %COHb Levels on May 26, 2003 at Lake Havasu, Arizona







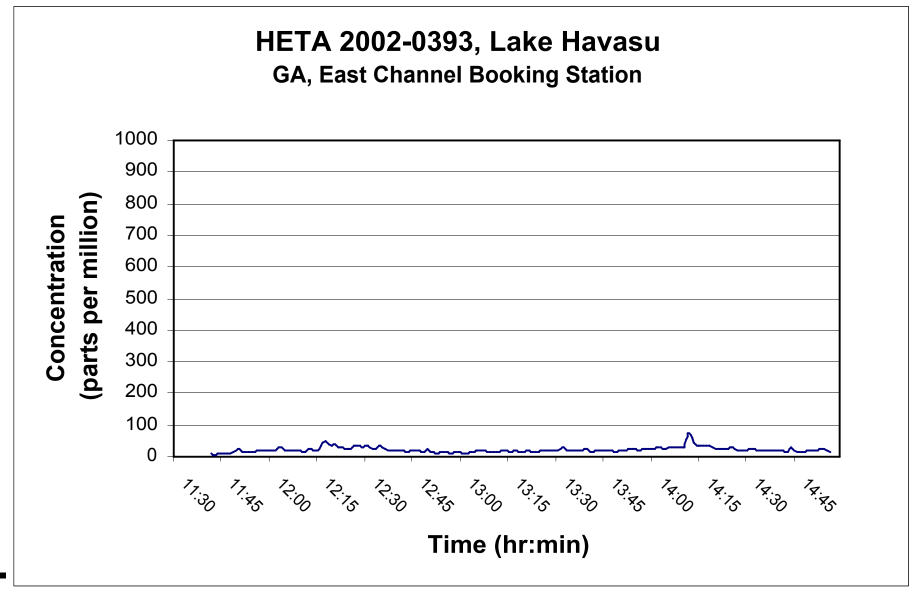
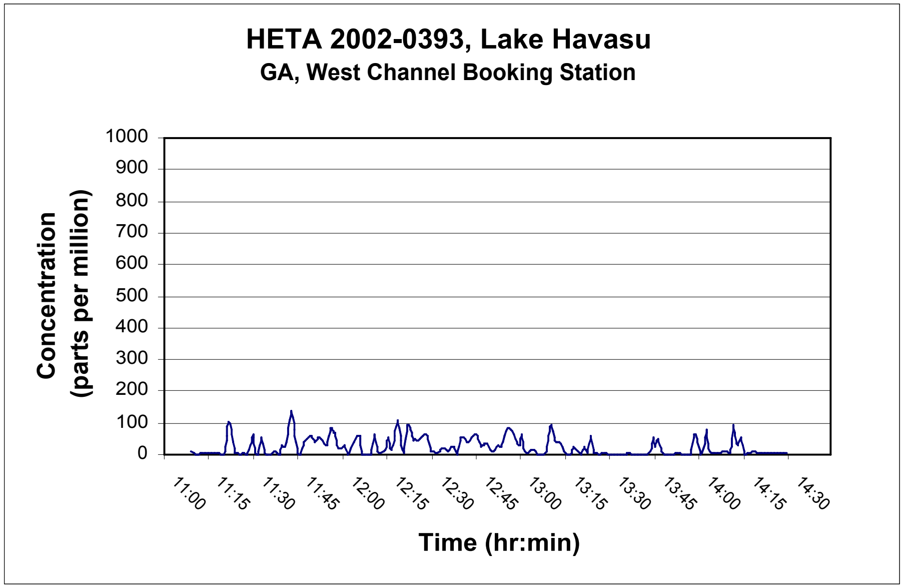


Figure 85. Real-time CO Concentration Readings and Estimated %COHb Levels on May 26, 2003 at Lake Havasu, Arizona



APPENDICES

Appendix A. 2002 Labor Day Weekend Interim Report

National Institute for Occupational Safety & Health

Denver Field Office

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

HETA 20020393
Interim Report

December 5, 2002

Michael Ward, D.O.
Medical Director, Emergency Medical Services
Havasu Regional Medical Center
101 Civic Center Lane
Havasu, Arizona 86403

Dear Dr. Ward:

Thank you for the opportunity to work collaboratively to evaluate boat-related carbon monoxide (CO) exposures at Lake Havasu, Arizona. The purpose of this letter is discuss the results of our preliminary collaborative work during the 2002 Labor Day holiday weekend. This letter summarizes our findings and conclusions. Detailed information about the health effects of exposure to CO and related evaluation criteria are included in Attachments 1 and 2.

General Background

On August 23, 2002, you requested assistance from the National Institute for Occupational Safety and Health (NIOSH) in performing field-testing for CO. Your concern stemmed from the fact that you and your partners had seen four to six patients in the Emergency Department (ED) over the past several years who had been poisoned by their exposure to CO while in the London Bridge channel at Lake Havasu. These patients had carboxyhemoglobin (COHb) concentrations greater than 30%, indicating severe poisoning. Your request delineated concern that Police and Fire Department personnel that patrol the waterway may be exposed to high levels of CO on holiday weekends when the boat traffic is excessive. You also pointed out that many people are unaware of the deadly potential of unrecognized CO poisoning, and that data were necessary to characterize any hazards that might exist. You asked for help in measuring airborne CO and expired (exhaled) CO levels in Fire and Police personnel as well as willing visitors in your waterways during the upcoming Labor Day holiday weekend.

Although we were unable to coordinate employee exposure monitoring upon such short notice, NIOSH was able to assist you in gathering other preliminary exposure assessment data. NIOSH provided Emergency Department staff with equipment to measure CO in exhaled breath of patients that had been boating prior to coming to the hospital for treatment. NIOSH also worked with hospital staff to concurrently measure airborne CO concentrations along the London Bridge channel. The purpose of this preliminary work was to determine if there was a need to collect more extensive data in a future research effort.

CO Air Sampling Methods and Results

CO concentrations in the channel were measured using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) equipped with CO sensors. These monitors are direct-reading instruments that record data that is then transferred to a computer through an optical interface. The monitors have an accurate detection range from 0 parts of CO per million parts of air (ppm) to 1000 ppm. The monitors were calibrated before and after each day's use according to the manufacturer's recommendations.

On August 31st, I walked along both sides of the London Bridge channel to measure CO concentrations along the walkway. I walked along the area of the channel most congested with operating and moored boats and people (South from the bridge to the open lake). The walkway is 100 feet or more from the center of the channel. Throughout the day, the channel was filled with vacationers on moored boats along the water's edge and vacationers immersed in the water near the exhaust of the numerous boats moving through the channel. Numerous law enforcement officers patrolled the shore line as well as the congested channel waterway. (See Figure 1.) I measured ambient CO concentrations as high as 177 ppm, which was higher than World Health Organization (WHO) recommended limits for short term exposures (Attachment 2).

Figure 1. Law enforcement officers in the London Bridge Channel, Lake Havasu AZ

On September 1st, data-recording CO monitors were placed at various locations on a platform boat to gather information about CO exposures that boat occupants such as law enforcement officers might experience while in the channel. One monitor was also suspended from the bow of the boat near vacationers in the water to determine the range of CO concentrations at these stationary locations along the channel. The boat was then moved through the entire length of the channel twice, returning to travel twice again through the most congested part of the channel.

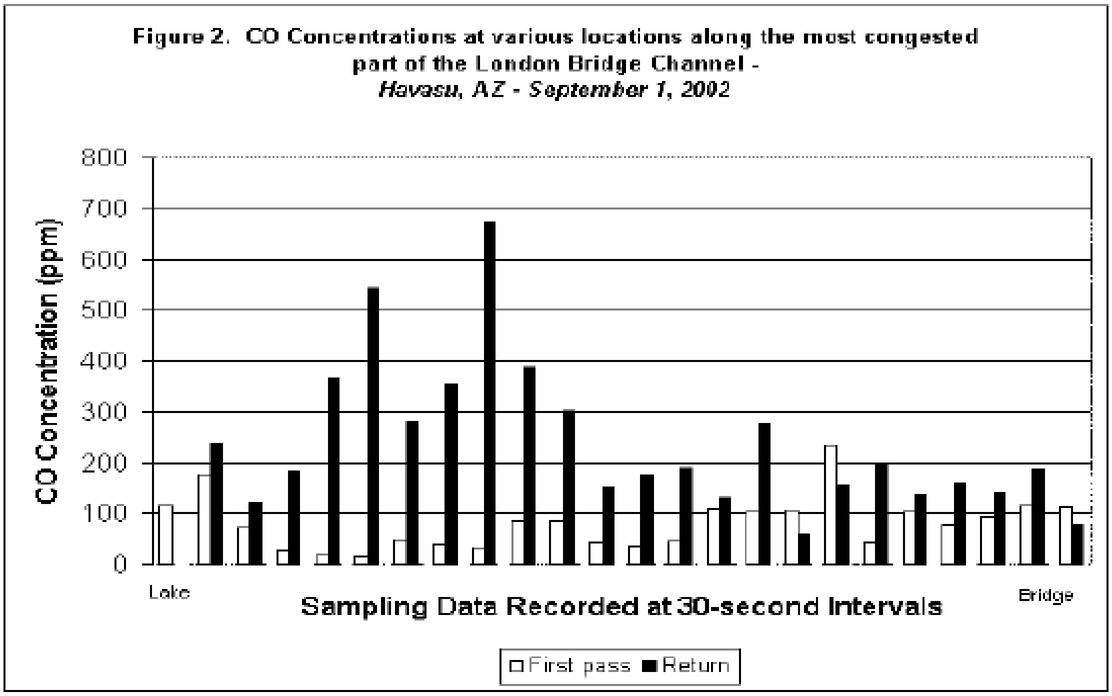
Table 1 shows the average and highest CO concentration measured from within the boat during the time we spent in the channel. The measured concentrations were averaged to estimate exposures of boat occupants (such as law enforcement officers) moving through the channel during high traffic periods.

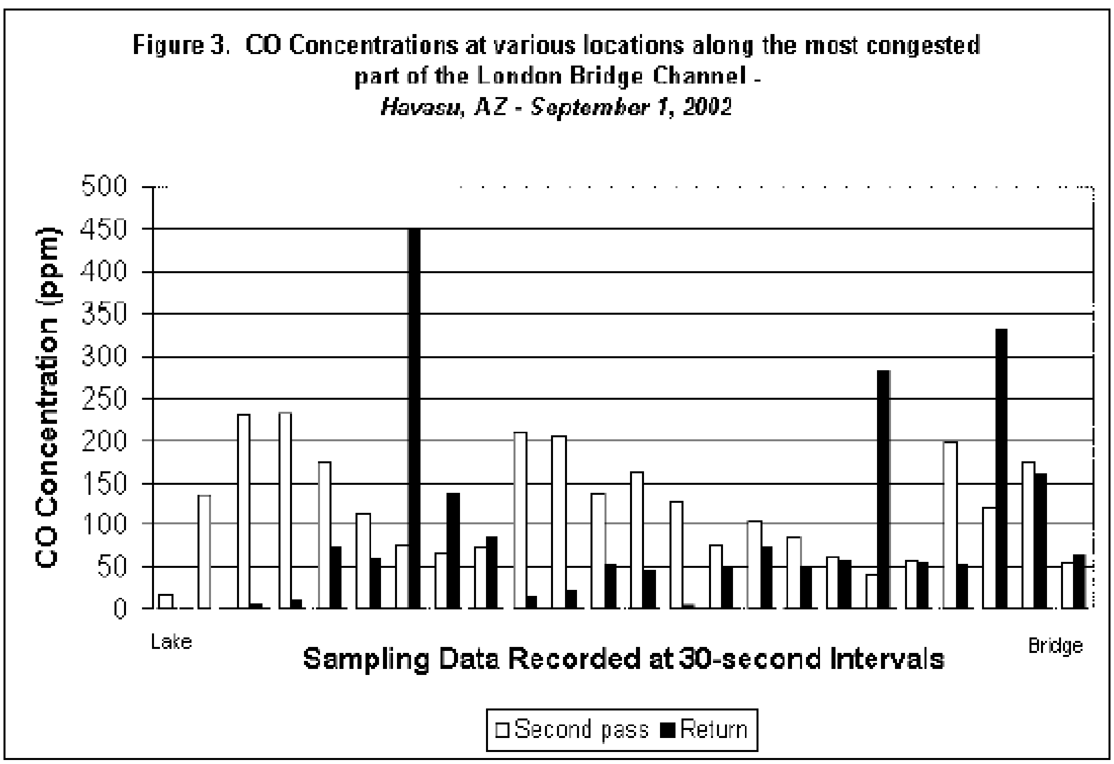
Table 1. CO concentrations measured on the moving boat, London Bridge Channel

Location of monitor	Duration of sampling (minutes)	Average CO Concentration (ppm)	Highest CO Concentration (ppm)
Rear seat of boat (opposite helm) during two passes through the most congested part of the channel only	21	131	439
Rear seat of boat (opposite helm) during two passes through the entire length of the channel	38	93	250
Personal sample (boat occupant moving around in the boat) during two passes through the entire length of the channel	39	77	277
Cup holder on the boat during two passes through the most congested part of the channel only	24	114	293
Personal sample (boat occupant seated at the bow of the boat) during two passes through the entire length of the channel	41	77	277
Personal sample (boat occupant seated at the bow of the boat) during two passes through the most congested part of the channel only	22	114	293

Figures 2 and 3 show the CO concentrations measured at water level from the bow of our boat as we moved through the most congested part of the channel (again, the portion of the channel South of the London Bridge). These CO concentrations are not averaged because they were intended to provide point measurements of CO exposure where vacationers were positioned either on moored boats or standing in the water along the channel. Because these vacationers were not moving, their average exposure concentration would be in the range of the concentration measured where they were positioned.

Appendix A. 2002 Labor Day Weekend Interim Report





Expired CO Measurement Methods and Results

The ED was provided with two monitors that measure CO in exhaled breath. These monitors allow estimation of carboxyhemoglobin (COHb) concentrations. ED staff were trained in the proper use of these monitors to evaluate COHb concentrations of patients who had been boating prior to reporting to the hospital for emergency care. The ED staff measured CO in exhaled breath for 13 patients on August 31st and September 1st. All of the patients were non-smokers, and had sought ED care for a variety of reasons. Four of these 13 patients had COHb concentrations greater than 9%.

The patient with the highest COHb concentration was an 18-year-old female that lost consciousness on September 1st, just after we completed air sampling for CO in the channel. She had been in the channel all day and was positioned at the back of a boat when her eyes rolled back and she began to convulse. A bystander caught her as she collapsed. It is not clear if she was on a boat that was moored or moving, and the precise source of her exposure (whether it was operating engines on the boat she occupied, or on boats moving by her) was not specified. Upon arrival at the ED, after 27 minutes of oxygen therapy, her COHb was 28.3%. A computer program is available that allows calculation of COHb concentration before it is reduced by oxygen therapy. Using this program, we calculated that her COHb would have been 40% when she lost consciousness, a concentration that is certainly sufficient to cause this symptom of severe poisoning. (See the discussion of CO poisoning symptoms and related COHb concentrations presented in Attachment 1.)

Discussion

Outdoor boat-related CO poisonings have been poorly defined and likely poorly detected in the past. Unfortunately, it is becoming apparent that acute, severe, and fatal poisonings outside of boats are not as rare as originally thought (see the listing of reported incidents and related information at internet website http://safetynet.smis.doi.gov/COhouseboats.htm).

The data collected during these two days at Lake Havasu indicate that employees and vacationers spending lengthy periods within the London Bridge Channel during days of high traffic may be experiencing CO poisoning more frequently than has previously been recognized. This statement is based upon the following:

- A severe poisoning occurred during the second day of sampling. If the hospital had not been conducting exhaled CO measurements as part of this research, this patient's loss of consciousness may well have been attributed to other factors, such as heat stress, dehydration, etc.

- Thirty one percent of patients reporting to the emergency department had COHb concentrations greater than 9%. Guidelines related to general population CO exposure recommend that COHb concentrations not exceed 2.5 % (WHO) or 2.1 % (EPA). As we discussed by telephone, it would useful to review the records of these patients to determine why they reported to the hospital.

- Spot checks of CO concentrations near vacationers on and near moored boats in the channel were well in excess of every short term exposure evaluation criteria listed in Attachment 2. The impact of exposure depends on a number of factors, including: the concentration of exposure; how physically active the person is while being exposed; and how long the person is exposed. For example, if a lightly active non-smoker was standing in one of the locations where we measured 100 ppm CO, it could take as long as 300 minutes for their COHb concentration to rise to 10%, a level at which you would expect symptoms of CO poisoning. At 300 ppm, it could take only about 60 minutes to reach the same COHb concentration (10%), and at 600 ppm, it could take about 30 minutes.

- The average CO concentrations measured over a short duration (20 to 40 minutes) on the moving boat indicate that employees who spend lengthy periods patrolling the channel or responding to incidents may be overexposed to CO. It must be remembered, however, that law enforcement officers would not be moving straight through the channel as we did. They would be more likely to stop within the channel near operating boats as they conduct their duties. As such, their actual exposures could be much higher than those measured here. Conversely, their average exposures could be lower overall depending on how much of their workshift is spent in the channel.

Recommendations

1. Full workshift CO exposures of law enforcement officers patrolling the channel and EMS staff who respond to medical events in the channel should be measured to determine if they are overexposed to CO during high traffic days. Pre- and post-shift exhaled CO should also be measured. Employees should also be interviewed to determine if they experience symptoms of CO overexposure during their duties within the channel.

2. The possibility of collecting further information about visitor CO exposures within the channel should be explored. Possible approaches would be to measure CO in exhaled breath of visitors, and/or to place stationary CO air sampling monitors at fixed locations among the moored boats where visitors linger during high traffic days.

3. The hospital should consider routinely measuring COHb on ED patients who have been boating in the channel during high traffic days. This recommendation is based on the likelihood of high CO exposures, the number of elevated COHb concentrations measured by the hospital during this two-day period, and the previously detected CO poisonings reported by the hospital.

4. The hospital should work with appropriate local public health officials to develop a more comprehensive research and intervention program related to the issue of boat-related CO exposures.

We were pleased to provide this assistance in addressing mutual concerns about employee health. If you have any questions about information contained in this report, or further collaborative evaluation, please don't hesitate to call me.

Sincerely,

Jane Brown McCammon, CIH
Director, NIOSH Denver Field Office

Enclosures

Attachment 1
Health Effects of Exposure to Carbon Monoxide

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

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

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

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

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

Altitude effects the toxicity of CO. With 50 ppm CO in the air, the COHb level in the blood is approximately 1% higher at an altitude of 4,000 feet than at sea level. This occurs because the partial pressure of oxygen (the gas pressure causing the oxygen to pass into the blood) at higher altitudes is less than the partial pressure of CO. Furthermore, the effects of CO poisoning at higher altitudes are more pronounced. For example, at an altitude of 14,000 feet, a 3% COHb level in the blood has the same effect as a 20% COHb at sea level.[8]

References

1. NIOSH [1972]. Criteria for a recommended standard: occupational exposure to carbon monoxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 73-11000.

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Attachment 2
Evaluation Criteria

Occupational criteria for CO exposure are applicable to employees who have been shown to be at risk of boat-related CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities) because occupational standards do not provide the same degree of protection they do for the healthy worker population. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin.[(1)] Standards relevant to the general population take these factors into consideration, and are listed following the occupational criteria.

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

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[(2)] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®), [(3)] and (3) the legal requirements of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs),[(4))] Employers are encouraged to follow the more protective criterion listed.

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

The NIOSH REL for CO is 35 ppm for full shift TWA exposure, with a ceiling limit of 200 ppm which should never be exceeded.[(5,6)] The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[1] NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm.[(7)] An IDLH value is defined as a concentration at which an immediate or delayed threat to life exists or that would interfere with an individual's ability to escape unaided from a space. The ACGIH recommends an eight-hour TWA TLV of 25 ppm based upon limiting shifts in COHb levels to less than 3.5%, thus minimizing adverse neurobehavioral changes such as headache, dizziness, etc, and to maintain cardiovascular exercise capacity.[(8)] ACGIH also recommends that exposures never exceed 5 times the TLV (thus, never to exceed 125 ppm).

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.[(9)]

Health Criteria Relevant to the General Public.
The US EPA has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a one-hour average.[(10)] The NAAQS for CO was established to protect "the most sensitive members of

the general population" by maintaining increases in carboxyhemoglobin to less than 2.1%.

The World Health Organization (WHO) had recommended guideline values and periods of time-weighted average exposures related to CO exposure in the general population.[11] WHO guidelines are intended to ensure that carboxyhemoglobin levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

100 mg/m^3 (87 ppm) for 15 minutes
60 mg/m^3 (52 ppm) for 30 minutes
30 mg/m^3 (26 ppm) for 1 hour
10 mg/m^3 (9 ppm) for 8 hours

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Appendix B. AZ Department of Health Services CO Study

Health Consultation

Investigation of Carbon Monoxide Exposure
in the London Bridge - Rotary Beach Area

May 25 – 26, 2003

Lake Havasu City, Arizona

June 18, 2003

Arizona Department of Health Services
Office of Environmental Health
Phoenix, Arizona

Introduction

Carbon monoxide is an odorless, colorless gas that results from incomplete combustion of carbon compounds. Until recently carbon monoxide poisonings were thought to occur in enclosed, poorly ventilated areas. However, open-air cases of poisoning have recently been reported including exposures from exhaust from various kinds of watercraft including houseboats, cabin cruisers and ski boats. Unlike automobiles, boat engines do not have mechanisms to reduce carbon monoxide emissions.

Large numbers of boaters use the channel of water beneath the London Bridge for recreation on weekends during the summer. There are hundreds of watercraft in the channel water at Rotary Beach on holiday weekends. The density of watercraft and the large numbers of people using the channel creates the opportunity for individuals to be exposed to excessive carbon monoxide emissions. Indeed, the Havasu Regional Medical Center Emergency Department has seen a number of patients in the last several years that have been diagnosed with carbon monoxide poisoning while recreating in or near the channel of water beneath the London Bridge in Lake Havasu City.

This exposure investigation examines the extent of carbon monoxide exposure in recreational boaters in the Rotary Beach area near the London Bridge in Lake Havasu City, Arizona during the Memorial Day Holiday in 2003 (5/24/03 – 5/25/03). The Rotary Beach area is a very popular location for recreation including boating, swimming, sunbathing, shopping and other activities.

The objective of the investigation is to determine whether a public health hazard from carbon monoxide exposure exists in an area heavily used by recreational boaters.

Methods

We examined the concentration of carbon monoxide in the exhaled air of participants recreating in the Rotary Beach area near the London Bridge in Lake Havasu City during the Memorial Day Holiday in 2003 (5/24/03 – 5/25/03). Exhaled carbon monoxide was used as a measure of the amount of carboxyhemoglobin (COHb) in the participant's blood.

Volunteers provided samples by blowing exhaled air into a single-use mouthpiece. Each mouthpiece was discarded after each individual use. A Scott/Bacharach Instrument Carbon monoxide Sniffer with a Breath Analysis Module was used to analyze the exhaled air samples. The module includes an internal mechanism to ensure that ethanol does not interfere with the analytical results.

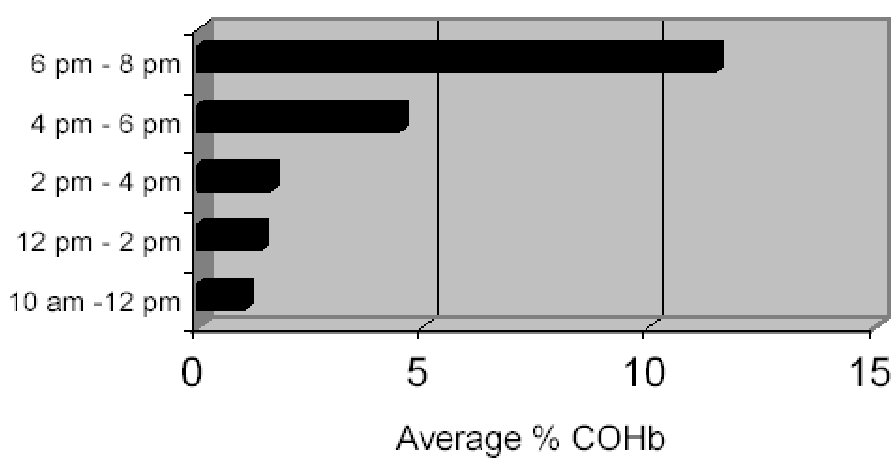
An Arizona Department of Health Services investigator administered a short questionnaire while the sample was being analyzed in the field. Participants were asked whether or not they are a smoker, what kinds of recreation activities they had been participating in, and how many hours they had been recreating in the area. The investigator did not collect personal identifiers. A total of 62 individuals participated in the study.

The investigator recorded the time of day, the general weather conditions, and the concentration of carbon monoxide in the exhaled air of the participant. Exhaled carbon monoxide levels were converted to % COHb using a standardized conversion chart. The results were input into Microsoft Access® for analysis.

Results

The results of the analysis suggest that significant carbon monoxide exposure occurred among participants during the investigation. The % COHb among non-smoking participants increased from an average of 1% between 10 am and 2 pm to 11% between 6 pm and 8 pm (Figure 1). Similarly, among smokers, the average % COHb increased from 3% between 12 pm and 2 pm to 13% between 6 pm and 8 pm (Figure 2).

Figure 1. Average % COHb in Nonsmokers by Time of Day - Rotary Beach
5/24/03 - 5/24/03 (n=46)



The average % COHb was greater in all participants that had been recreating outdoors in the areas for longer periods of time. The average %COHb among non-smoking participants ranged from 1.4 % for those recreating outdoors for 1 hour, to more than 5 % for those recreating outdoors for 5 hours or more (Figure 3).

2

Similarly, the average % COHb among smokers increased from 3% after 1 hour of recreation , to 7 % for those recreating outdoors for 5 hours or more (Figure 4).

Figure 2. Average % COHb in Smokers and Non Smokers by Time of Day 5/24/03 - 5/25/03 (n=62)

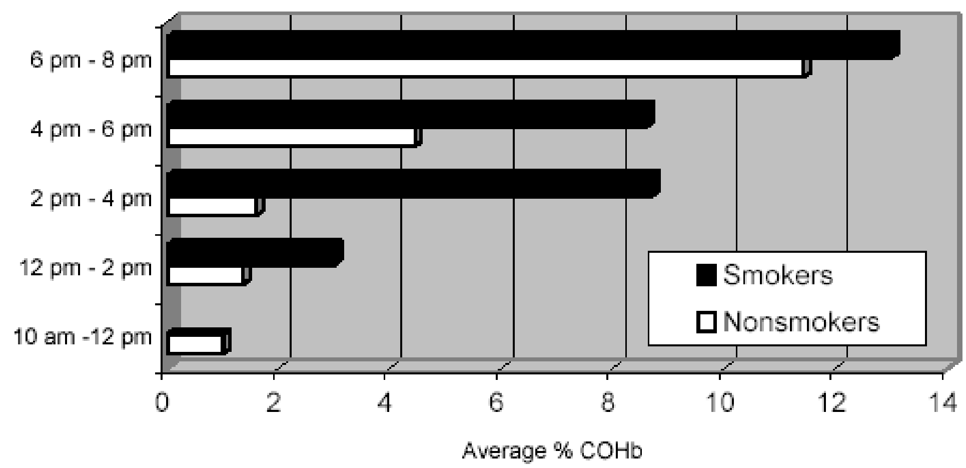
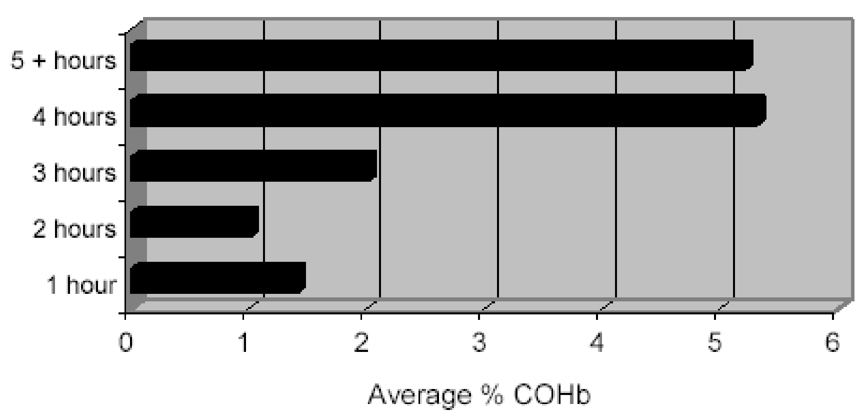


Figure 3. Average % COHb in Nonsmokers by Number of Hours at Rotary Beach 5/24/03 - 5/25/03 (n=46)



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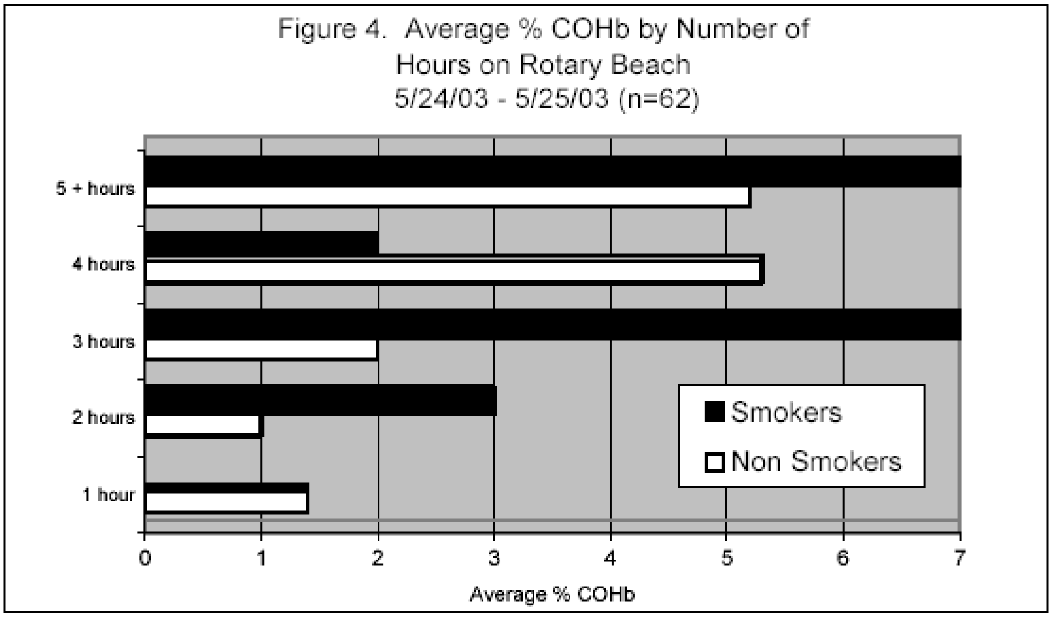

Discussion

Carbon monoxide is a colorless, odorless, tasteless gas produced by incomplete burning of gasoline. The initial symptoms of carbon monoxide poisoning may include headache, dizziness, drowsiness, or nausea. Symptoms may advance to vomiting, loss of consciousness, and collapse from prolonged or high exposure. Coma or death may occur if high exposures continue.[1-6] The symptoms vary widely from individual to individual, and may occur sooner in sensitive persons such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes. Table 1 displays the symptoms associated with exposure to carbon monoxide.

Table 1. Health Effects from Overexposure to Carbon Monoxide

% COHb	Symptom
< 5%	None
5-10%	Slight headache, decreased exercise tolerance
10-20%	Mild dyspnea on exertion, headache
20-30%	Throbbing headache, mild nausea, some impaired judgment
30-40%	Severe headache, nausea and vomiting, impaired judgment
40-50%	Confusion and syncope
50-60%	Syncope, coma, seizures
60-70%	Coma, seizures, cardiorespiratory depression, death
>70%	Failing hemodynamic status, death

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

Blood has an estimated 210-250 times greater affinity for carbon monoxide than oxygen. Carbon monoxide in the blood interferes with oxygen uptake and delivery to the body. Once absorbed into the bloodstream, the half-life ranges from 2 to 6.5 hours.[7] If oxygen is administered to the exposed person, as happens in emergency treatment, the half-life time is decreased again by as much as 75% (or to as low as approximately 40 minutes). Delivery of oxygen under pressure (hyperbaric treatment) reduces the half-life to approximately 20 minutes.

The average % COHb among non-smoking participants was low (1% COHb) between 10 am and 2 pm and among those non-smokers that had spend less than 2 hours recreating outdoors. These participants were below symptom thresholds. However, the average % COHb among non smoking participants increased to 11% between 6 pm and 8 pm, suggesting that these persons may have had a headache or decreased exercise tolerance as a result of their exposure to environmental carbon monoxide.

Smoking participants showed a similar increase in COHb over time. However, smoking cigarettes and other tobacco products increases COHb, and the increase in COHb levels in these participants is likely due to both environmental exposures and active smoking of tobacco products. These persons likely experience chronic mild symptoms of carbon monoxide exposure including headache or decreased exercise tolerance as a result of their active smoking.

The maximum COHb level observed for non-smokers was 23% COHb, and the maximum for smokers was 26%. These participants were likely experiencing more significant symptoms of carbon monoxide exposure including more severe headache, nausea, and impaired judgment. These data suggest that while the average COHb concentrations found were still in the mild carbon monoxide poisoning range, some individuals may have significantly more exposure, resulting in the potential for more serious consequences such as drowning. A 31-year-old drowning victim during the weekend of this investigation had a 47 % COHb concentration at the time of autopsy, suggesting that his death was at least partially due to carbon monoxide exposure.

Alcohol consumption was common among the participants. Alcohol consumption is well documented to cause similar symptoms as carbon monoxide including headache, impaired judgment, nausea and vomiting. The combination of alcohol consumption and carbon monoxide exposure likely creates a more significant health

hazard. In addition, the recreational activities conducted during the investigation were predominately in or near water, creating a drowning hazard for those with impaired judgment or more severe symptoms of carbon monoxide exposure or alcohol consumption. Additional hazards in the environment include those associated with moving propellers and other moving watercraft.

Conclusion

The results of the analysis suggest that significant carbon monoxide occurred among participants during the investigation. The cumulative carbon monoxide exposure increased as the day progressed. The COHb levels observed late in the day posed a public health hazard.

The combination of alcohol consumption and carbon monoxide exposure likely creates a more significant health hazard. In addition, the recreational activities conducted during the investigation were predominately in or near water, creating a drowning hazard for those with impaired judgment or more severe symptoms of carbon monoxide exposure and alcohol consumption.

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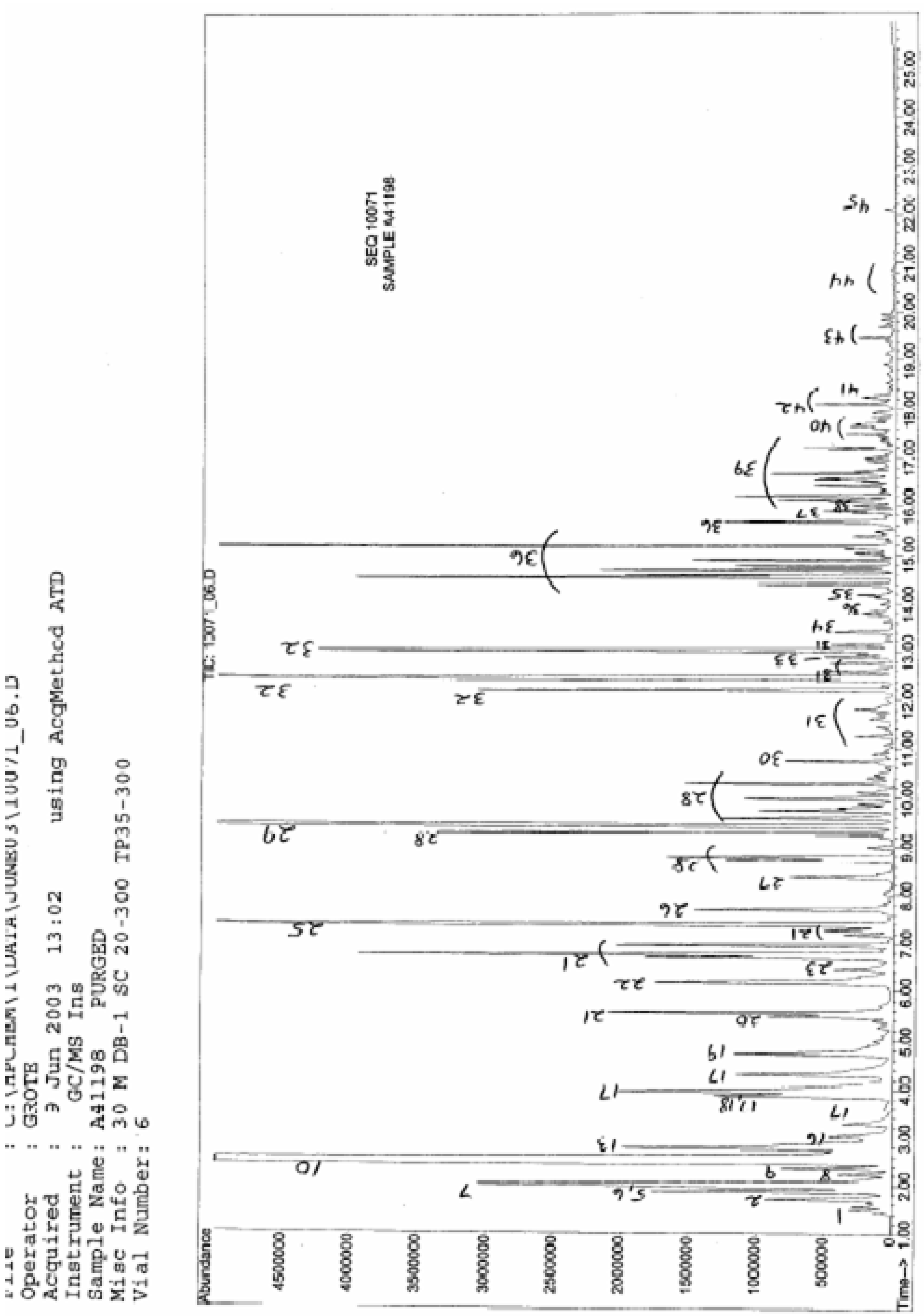
Appendix C. Volatile Organic Compounds

SEQ 10071-AA
THERMAL DESORPTION TUBES
PEAK IDENTIFICATION

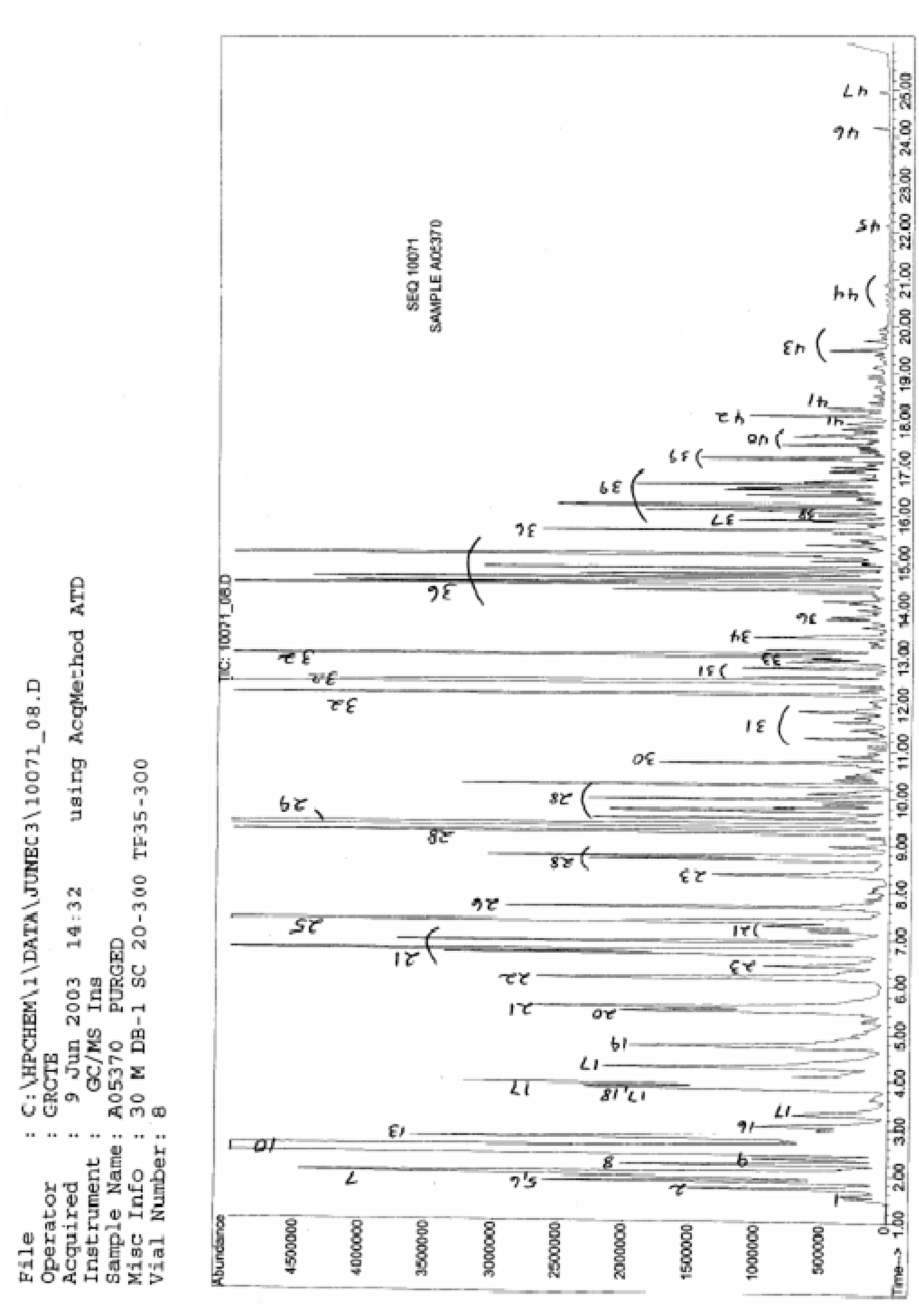
1) Air*/CO_2*
2) Cyclopropane/propene
3) 1-Chloro-1-fluoroethane
4) Sulfur dioxide
5) Methanol*
6) Isobutane
7) Butane/butene
8) Ethanol
9) Acetonitrile
10) Acetone*
11) Isopentane*
12) 1-Fluoro-1-chloroethane
13) Pentane*
14) Methyl acetate*
15) C_5H_8 isomer (isoprene)
16) C_5H_{10} isomers
17) C_6 aliphatics (methyl pentanes)
18) Methyl tert-butyl ether (MTBE)
19) Hexane
20) Methylcyclopentane
21) C_7 aliphatic hydrocarbons
22) Benzene*
23) Cyclohexane
24) 1-Methoxy-2-propanol*
25) Isooctane
26) Heptane
27) Methylcyclohexane
28) C_8 aliphatic hydrocarbons
29) Toluene
30) Octane
31) C_9 aliphatic hydrocarbons
32) Ethyl benzene/xylene isomers
33) Styrene
34) Nonane
35) Benzaldehyde
36) C_9H_{12} alkyl benzenes (trimethyl-propyl-, ethyl methyl benzenes)
37) Indan
38) Indene
39) $C_{10}H_{14}$ alkyl benzenes (ethyl dimethyl-, methyl propyl-, tetramethyl benzenes)
40) Methyl indans
41) $C_{11}H_{16}$ alkyl benzenes
42) Naphthalene
43) Methyl naphthalenes
44) Dimethyl naphthalenes
45) Diethyl phthalate*
46) Salicylic acid
47) Trimethylcyclohexyl salicylate

*Compounds also detected on some field blanks and/or system blanks.

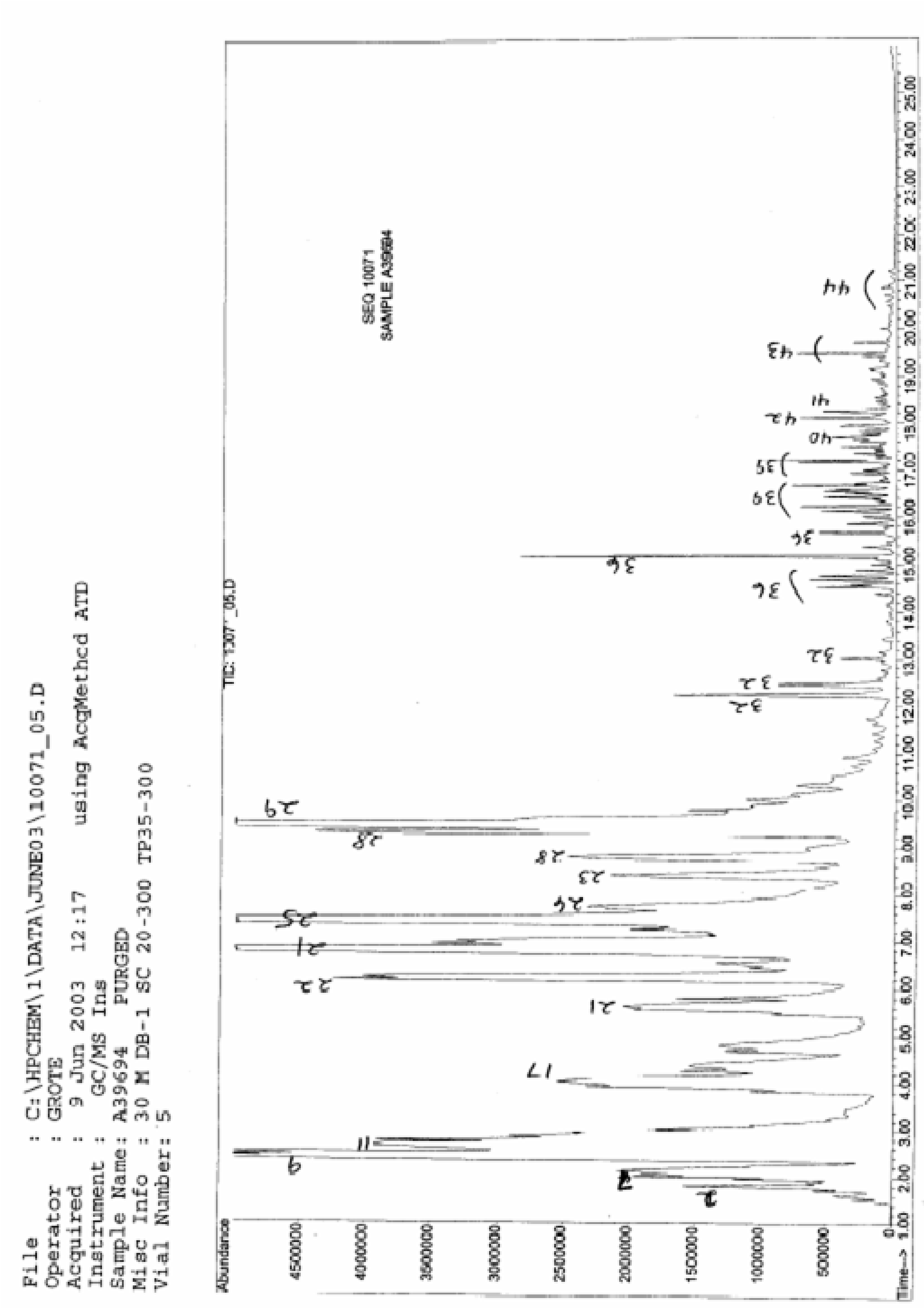
Appendix C. Volatile Organic Compounds



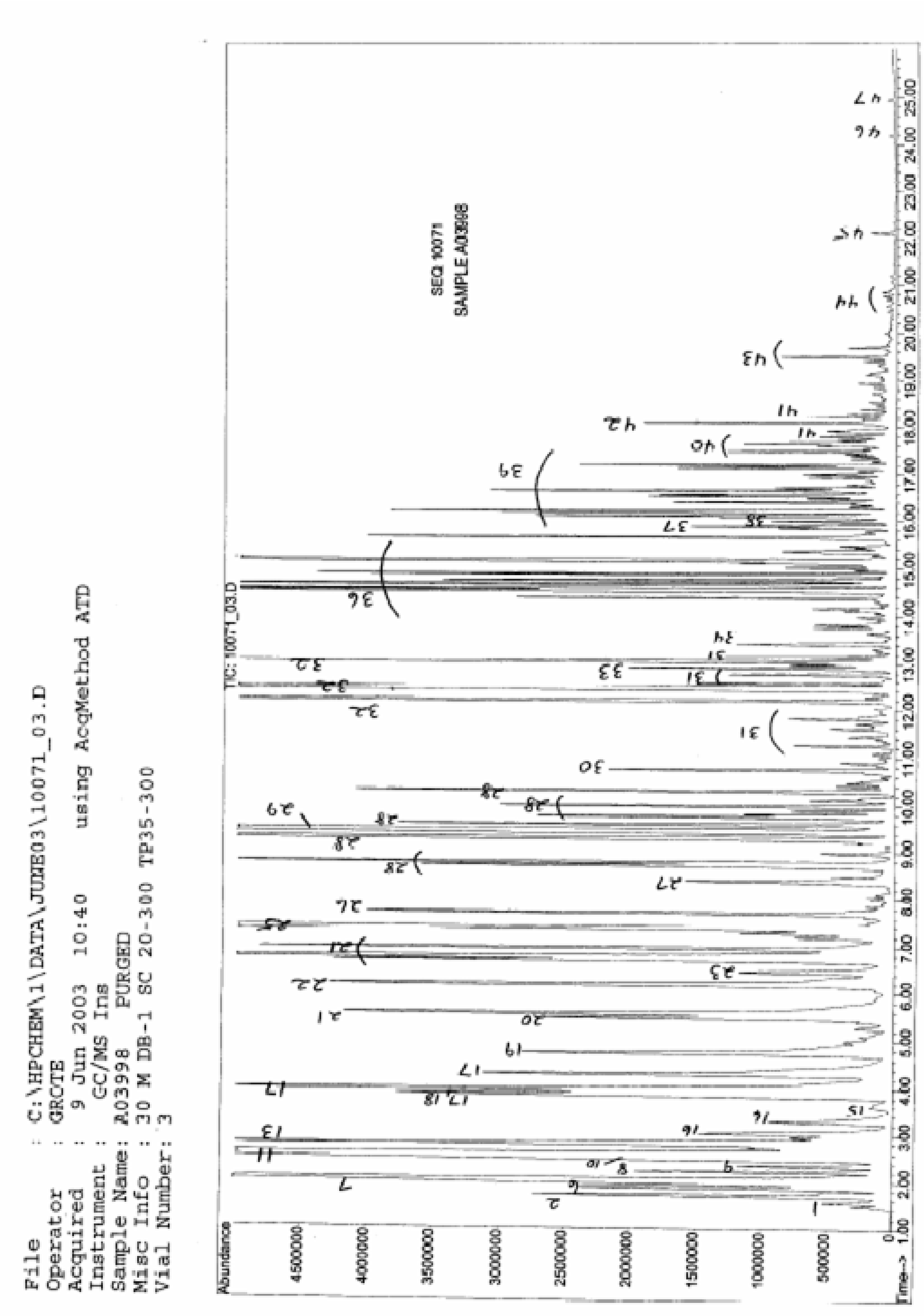
Appendix C. Volatile Organic Compounds



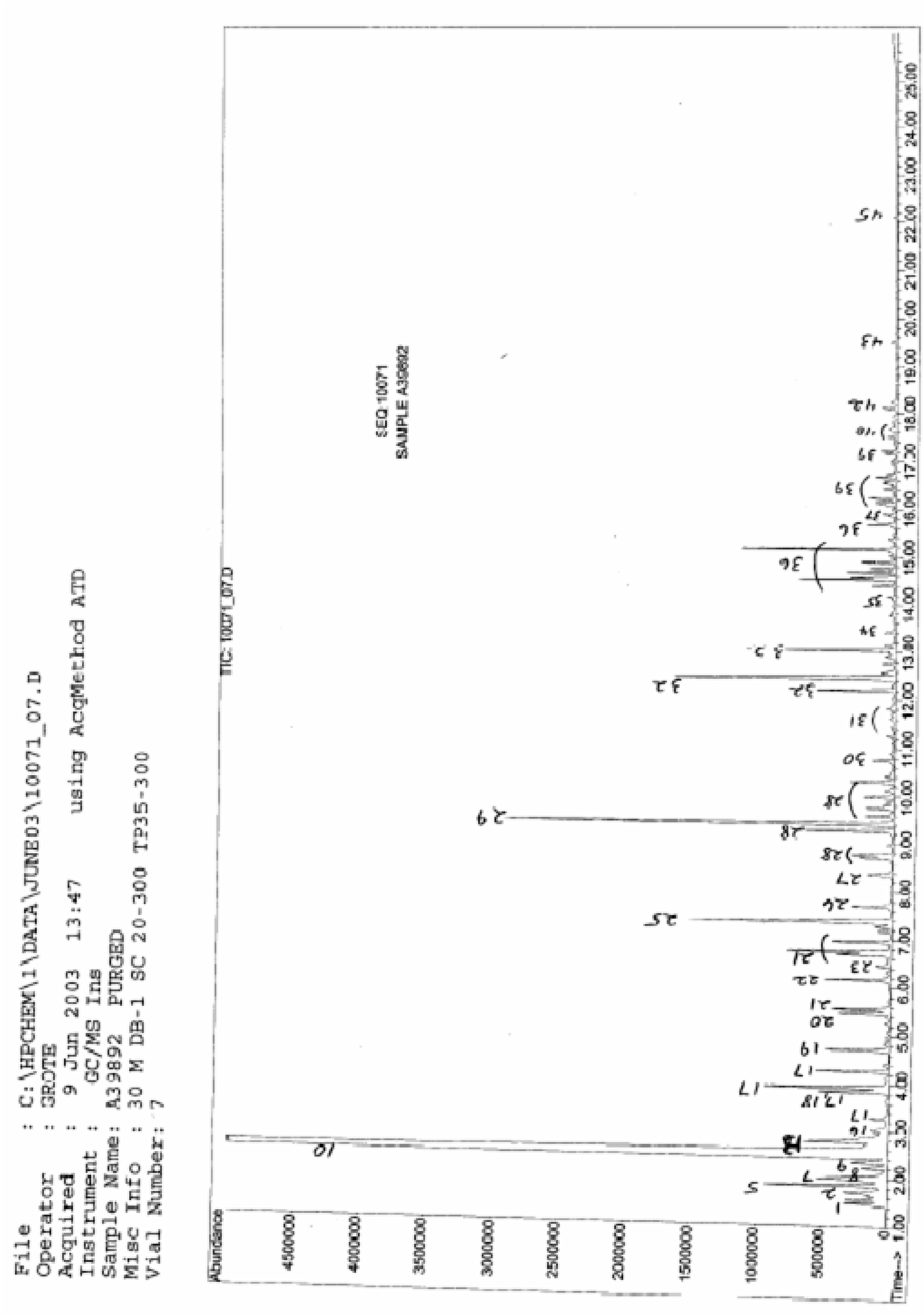
Appendix C. Volatile Organic Compounds



Appendix C. Volatile Organic Compounds



Appendix C. Volatile Organic Compounds



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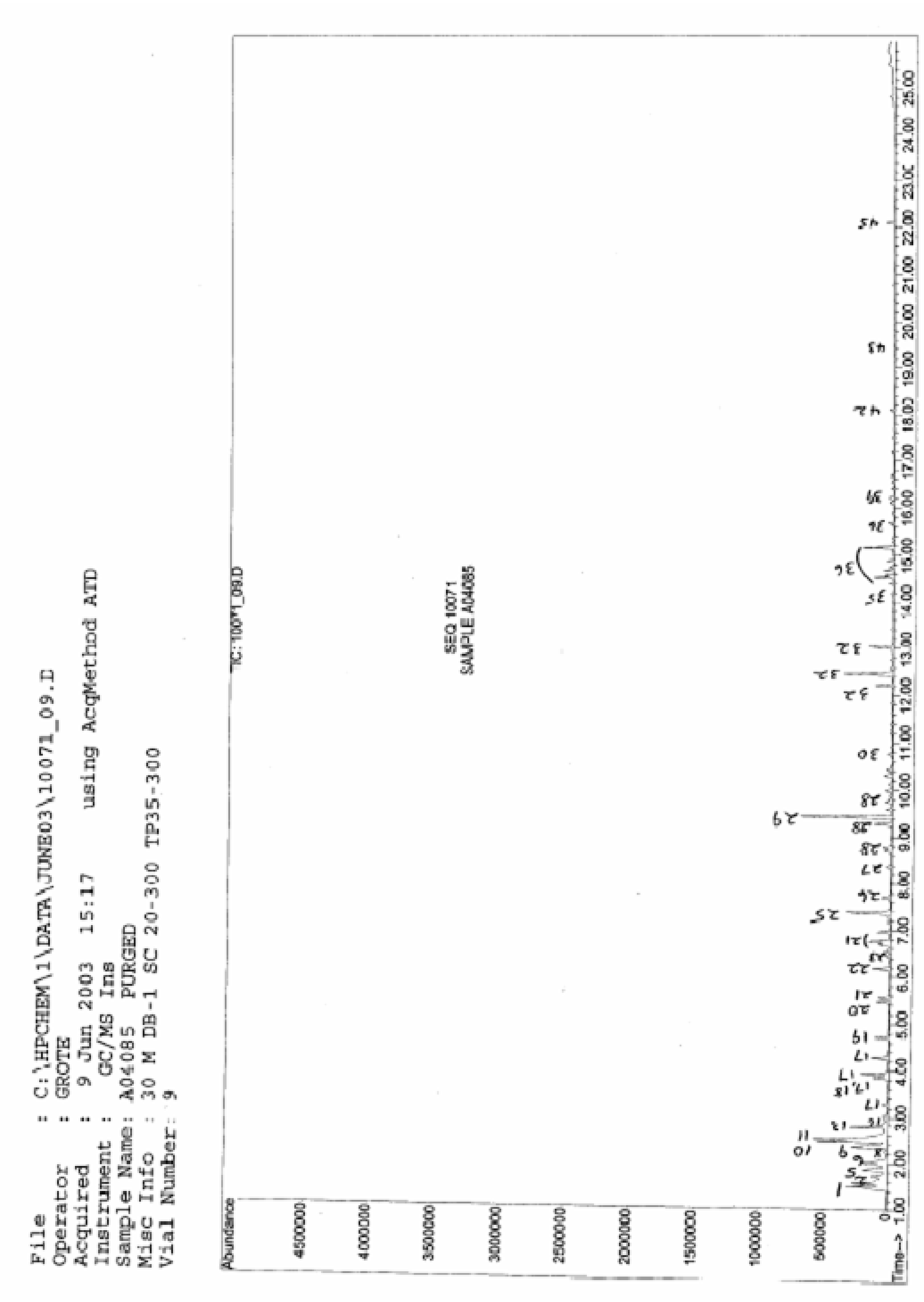
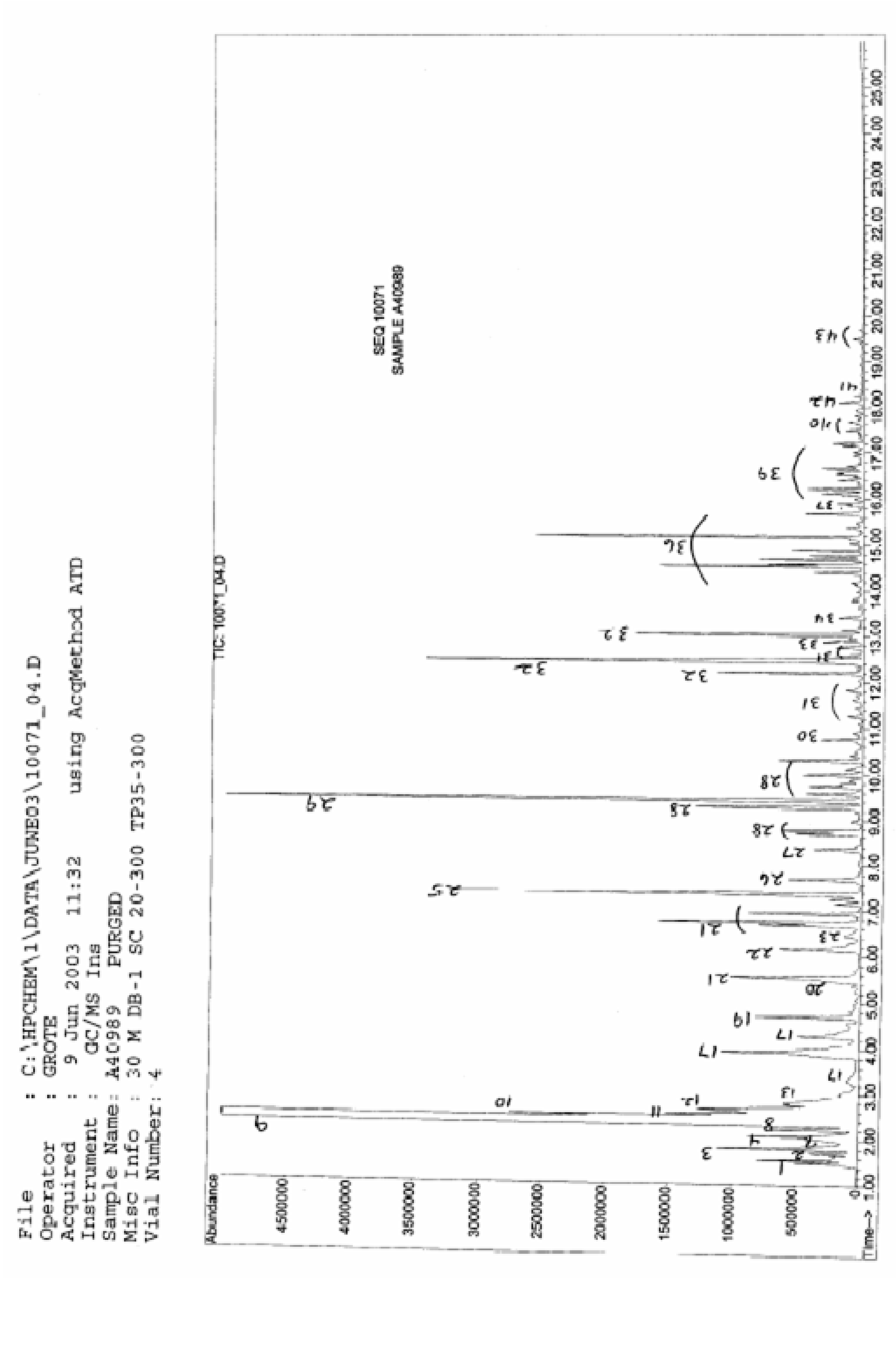


Appendix C. Volatile Organic Compounds



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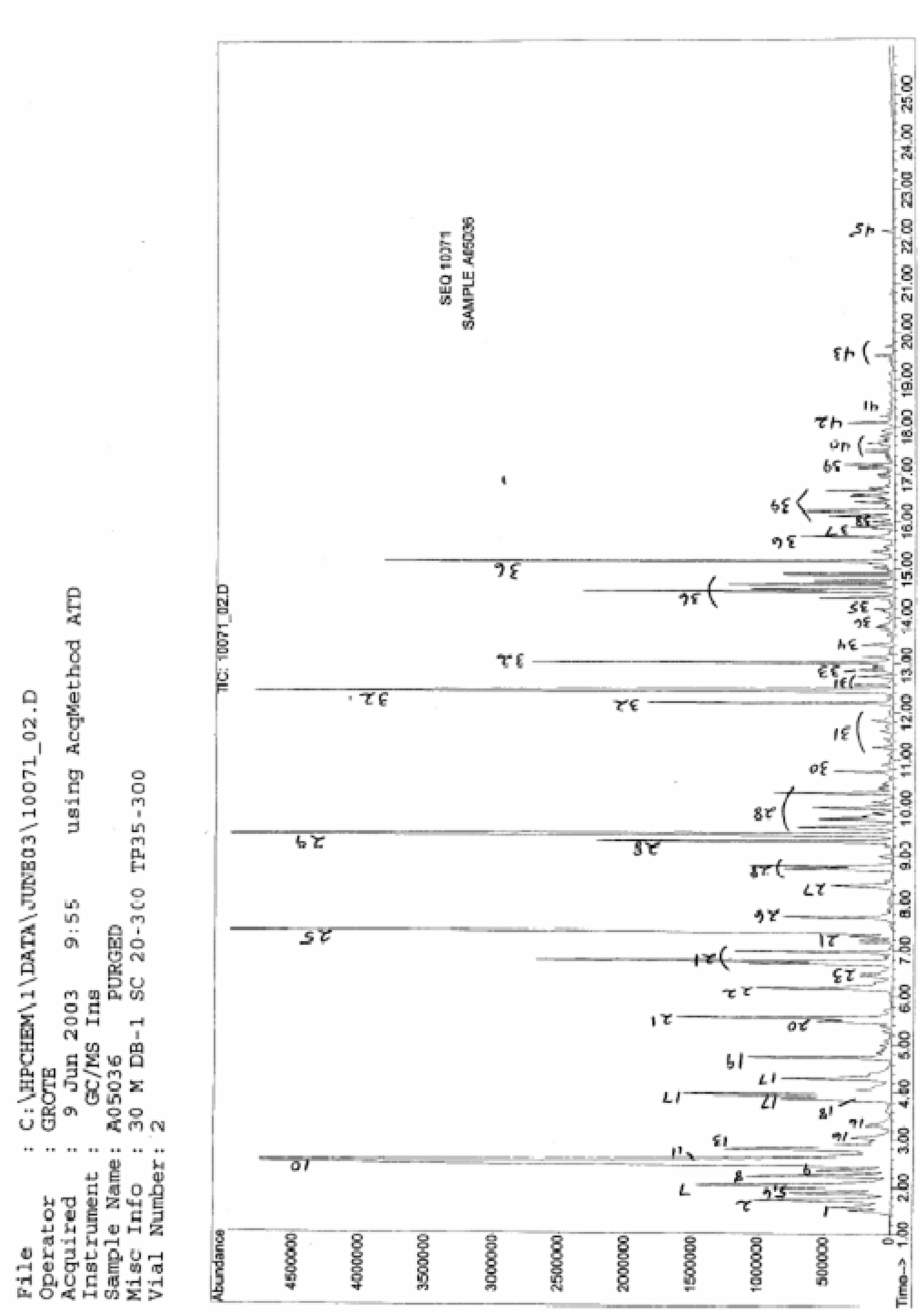

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