CDC
Workplace Safety and Health

Evaluation of Carbon Monoxide Exposures During Rescue Operations Using Personal Watercraft – Florida

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The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

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Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
BEI®	Biological exposure index
CFR	Code of Federal Regulations
CO	Carbon monoxide
COHb	Carboxyhemoglobin
EPA	Environmental Protection Agency
HHE	Health hazard evaluation
IDLH	Immediately dangerous to life and health
mph	Miles per hour
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppm	Parts per million
PWC	Personal watercraft
REL	Recommended exposure limit
STEL	Short-term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
WEEL™	Workplace environmental exposure level

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received an employer request for a health hazard evaluation at a county fire rescue department in Florida. The employer submitted the request because they were interested in evaluating carbon monoxide (CO) exposures during rescue operations that used personal watercraft (PWC).

What NIOSH Did

- We measured CO exposures in August 2009.
- We measured fire fighters' exposure to CO in the air.
- We measured CO concentrations during simulated surf rescues using two PWC.

What NIOSH Found

- PWC can create hazardous levels of CO. The highest levels were when the PWC was stationary or moving at slower speeds.
- Some fire fighters' CO exposures were above the peak occupational exposure limits.
- Higher PWC speeds reduced the amount of CO around the PWC.
- Using a rescue board helped direct exhaust away from the PWC.

What Managers Can Do

- Review the NIOSH Fire Fighter Fatality Investigation report F2006-14. The recommendations in this report may help prevent deaths related to PWC rescues.
- Require the use of a rescue board during responses and training. Response and training procedures should include this requirement.
- Develop a maintenance schedule for the PWC. This schedule should follow the manufacturer's recommendations.
- Consider replacing older PWC with newer models that have emission controls.

What Fire Fighters Can Do

- Use a rescue board during emergency responses and training.
- Minimize the amount of time that PWC idle or operate at slow speeds during emergency responses and training.
- Maintain PWC according to the manufacturer's recommendations.
- Review the NIOSH Fire Fighter Fatality Investigation report F2006-14. The recommendations in this report may help prevent deaths related to PWC rescues.

Summary

NIOSH evaluated CO exposures during simulated PWC rescue operations. CO concentrations exceeding 1,000 ppm were measured when PWC operated while remaining stationary, at slower speeds, and under an increased load. We recommend using rescue boards during PWC training and rescues, minimizing operating PWC at slow speeds, maintaining PWC according to the manufacturer's directions, and replacing older PWC with newer PWC that have emission controls.

NIOSH received an employer request for an HHE at a county fire rescue department in Florida. The employer submitted the request because of interest in evaluating CO exposures during rescue operations using PWC. This interest was generated by a NIOSH Fire Fighter Fatality Investigation and Prevention Program report published in December 2007 that described how CO poisoning may have contributed to the death of a fire fighter participating in a surf rescue training session. That report recommended that fire departments with PWC rescue units evaluate CO exposures during simulated PWC rescue operations. In response to this request, NIOSH investigators evaluated CO exposures in August 2009.

We measured real-time CO air concentrations using up to three different methods on an older unmaintained PWC and a new PWC. We evaluated eight different trials (out of the water, stationary in the water, no wake speed [2–3 mph], non-planing speed [10–15 mph], planing speed [≈ 40 mph], no wake speed while a fire fighter held on to a tow strap, and mock rescues in calm water and slightly choppy water). Different versions of some trials were conducted with a fire fighter on the PWC as a "rescuer" or on the rescue board as a "victim."

Our results show that PWC can create hazardous levels of CO, especially while remaining stationary, operating at slower speeds, and operating under an increased load (with a rescuer on the PWC and a victim on a rescue board). The highest CO concentrations measured during these trials (> 1,000 ppm) tended to be near the back of the PWC. Higher PWC speeds greatly reduce the amount of CO around the PWC. However, when the PWC slows down from higher speeds, the exhaust continues to move over the top of the PWC resulting in elevated CO concentrations at the back of the PWC. For both PWC tested, the use of a rescue board seemed to redirect the exhaust away from the back of PWC and the victim lying on the board. The new PWC produced lower CO concentrations than the older PWC. This is likely because of regular maintenance and stricter emission standards.

We recommend that fire departments and other agencies with surf rescue responsibilities review the NIOSH Fire Fighter Fatality Investigation report (F2006-14) for recommendations to prevent fatalities related to rescues using PWC. Recommendations relating to CO include using a rescue board during emergency responses and training, minimizing PWC idling or operating at slow speeds for extended periods, maintaining PWC according to the

manufacturer's directions, and replacing older PWC with newer PWC that have emission controls.

Keywords: NAICS 922160 (Fire Protection), fire, rescue, marine, personal watercraft, PWC, carbon monoxide, CO

Introduction

NIOSH received an employer request for an HHE at a county fire rescue department in Florida. The employer submitted the HHE request because of interest in evaluating CO exposures during rescue operations using PWC. This interest was generated by a NIOSH Fire Fighter Fatality Investigation and Prevention Program report (referred to as the NIOSH fatality report) published in December 2007 that described the events leading to the death of a fire fighter participating in a surf rescue training session [NIOSH 2007].

The NIOSH fatality report indicated that the victim, another student, and an instructor were participating in a 4-hour training session on ocean surf rescue operations. This session included 2 hours of PWC maneuverability drills (each student with his or her own PWC), a 30-minute rest period on the beach, and then 2 hours with each student operating a single PWC with the other student as a passenger. While participating as the passenger, the victim fell off and reboarded the PWC several times because of the rough surf. After a wave knocked both students from the PWC, the victim indicated that he was unable to reboard. The instructor attempted several times to tow the victim to shore using a tow strap attached to the back of the PWC (the rescue board was not attached). The PWC exhausted to the rear of the PWC near the breathing zone of the victim. At that point, the victim lost consciousness, and the instructor swam the victim to shallow water where a safety officer helped transport the victim to shore. While on shore, they called an ambulance and initiated cardiopulmonary resuscitation. The victim regained a heart rhythm in the ambulance, but never regained consciousness and died in the hospital a day later. The victim's carboxyhemoglobin level was calculated to be approximately 20%, indicating substantial CO exposure. The NIOSH investigation concluded that exhaustion, hypothermia, and exposure to CO all contributed to the victim's death. One recommendation from the NIOSH investigation was "...assess the significance of carbon monoxide exposures and carbon monoxide poisoning among operators of PWC during simulated rescue operations."

The county fire rescue department asked NIOSH investigators to evaluate the potential for CO exposure to personnel conducting water rescues with PWC. In response to this request, NIOSH investigators evaluated CO exposures in August 2009. This evaluation was intended solely to assess exposures when PWC were used for rescue operations.

Trial Description

We measured real-time CO air concentrations on two PWC operating in eight different trials (out of the water, stationary in the water, no wake speed [2–3 mph], non-planing speed [10–15 mph], planing speed [≈ 40 mph], no wake speed while a fire fighter held on to a tow strap, and mock rescues in calm water and slightly choppy water [up to 1-foot waves]). Planing is the point where the speed of the watercraft is enough to raise the hull out of the water. Different versions of some trials were conducted with a fire fighter on the PWC as a "rescuer" or on the rescue board as a "victim." For the rescue board trials, a clip at the rear of the PWC attached to the front of the rescue board. The clip kept the front of the rescue board on top of the rear floorboard and out of the water, while the remainder of the rescue board was in the water. Additional trials were conducted in which each PWC dragged a victim holding on to a 2–3-foot long tow strap attached to the back of the PWC, and with and without a rescuer onboard.

Mock rescues were performed in calm water and slightly choppy water. During mock rescues the operator drove up to the victim, and the rescuer entered the water, moved the victim onto the rescue board, and held the victim while the PWC resumed moving between non-planing and planing speeds. A number of these mock rescues were performed during a trial. The PWC engine was running during all but one of the mock rescue trials.

We conducted the trials using two PWC. One PWC was a 2002 Kawasaki Jet Ski® 1100 STX® DI (referred to in this report as the "old" PWC) that was decommissioned, unmaintained, and had approximately 10 hours run time in the last 6 months. The other PWC was a 2009 Kawasaki Jet Ski® STX®-15F (referred to in this report as the "new" PWC) that had been recently purchased. The PWC exhaust described in the NIOSH fatality report exited at the waterline near the jet of water leaving the back of the PWC. Both of the PWC we evaluated exhausted near the waterline, removed from the jet of water and at a downward angle.

<u>2002 Kawasaki Jet Ski® 1100 STX® DI</u>

- 1071 cubic centimeter, 2-stroke direct fuel injection, 3-cylinder, 130 horsepower
- 122.8 inch length by 46.5 inch width
- 692 pound weight
- 14.3 gallon fuel capacity
- Approximately 55 miles per hour top speed
- 1-star low emission rating

2009 Kawasaki Jet Ski® STX®-15F

- 1498 cubic centimeter, 4-stroke digital fuel injection, 4-cylinder, 160 horsepower
- 122.8 inch length by 46.5 inch width
- 844.5 pound weight
- 16.4 gallon fuel capacity
- Approximately 60 miles per hour top speed
- 3-star ultra low emission rating

Sampling Methodology

For all non-stationary trials, real-time CO monitors (BW Technologies GasAlert Extreme Monitors, BW Technologies, Ltd., Calgary, Alberta, Canada) were placed at the front and back of the PWC and on the operator and rescuer's personal flotation device. A fire fighter wore a helmet fitted with a CO monitor when playing the role of a victim lying on the rescue board or as the rescuer during mock rescues. During the stationary trials, a CO monitor was attached to the front of the operator's personal flotation device and to the front and back of the rescuer's personal flotation device. All participants wore a personal flotation device during these trials.

We used an emissions analyzer (Ferret Gaslink LT Five Gas Emissions Analyzer, GxT Inc., Cheboygan, Michigan) to provide a direct reading CO measurement in PWC exhaust during stationary trials in and out of the water. Additionally, we used detector tubes (Dräger AG, Lübeck, Germany) to measure CO concentrations. During the in-water stationary trial, the PWC operator moved the PWC approximately 10 feet from the dock and tried to keep the PWC as stationary as possible. The rescuer on the PWC faced the back of the PWC and held the emissions analyzer probe as close to the PWC exhaust as possible without saturating it with water. During the out-of-water stationary trial, each PWC was strapped to a trailer while water from a hose flushed through the PWC to clean the system of salt water. The emissions analyzer probe was placed directly into the PWC exhaust port.

Additional details about these sampling methods are available in Appendix A, and a discussion of occupational exposure limits and health effects is available in Appendix B.

Results

Detailed air sampling results are presented in Appendices C and D. Tables in Appendix C present CO data (emissions analyzer and detector tube data) collected from both PWC while stationary in the water and while on a trailer removed from the water. Appendix D presents the real-time CO concentration data in graph form for each individual trial over the course of the evaluation. Both days of the evaluation were sunny, with temperatures in the low 90s and an east-northeast wind at < 5 mph.

Stationary Trials

Table 1 below summarizes the CO concentrations measured with the emissions analyzer and CO detector tubes when operating both PWC while stationary in the water and on a trailer removed from the water. CO concentrations from both PWC operating while stationary in the water were consistent with each other (< 100–200 ppm). This set of measurements may underestimate the peak CO concentration as the probe was close to, but not directly in, the exhaust stream because we were concerned about saturating the probe with water. The CO concentrations for both PWC were higher when operating out of the water. Initial startup of both PWC showed varying CO results (< 100 ppm for the old PWC and 2,800 ppm for the new PWC), but both measured 1,300 ppm by the end of the trial. The initial 2,800 ppm reading from the new PWC could be the result of a cold start; higher concentrations were measured initially with a reduction over the first few minutes. Detector tubes showed slightly higher CO concentrations than the emissions analyzer during the trials.

Table 1. Summary of CO concentrations (in ppm) near the exhaust of two PWC while stationary in the water and on a trailer removed from the water

PWC	Stationary in the Water		On Trailer Removed from Water	
	CO Emissions Analyzer (range)	CO Detector Tube (ppm)	CO Emissions Analyzer (range)	CO Detector Tube (ppm)
Old 2-stroke	< 100–200	500	< 100–1,300*	1,500*
New 4-stroke	< 100–200	100	900–2,800†	Not taken

*PWC was operating on two cylinders instead of three.

†2,800 ppm reading during the first minute of startup, subsequent readings were ≈ 1,000 ppm.

Figures D1 (old PWC) and D2 (new PWC) present the CO monitor sampling data collected while the PWC was stationary in the water. The highest CO concentrations measured on both PWC were in front of the passenger (facing the exhaust holding the emissions analyzer). The passenger on the old PWC (> 900 ppm) had much higher CO peaks than on the new PWC (< 100 ppm). The operator of the old PWC had CO peaks approaching 100 ppm, while the new PWC operator showed < 30 ppm. There is no clear reason for the varying CO concentrations between the emissions analyzer and the CO monitors while the old PWC was in the water, except that wind may have shifted exhaust away from the probe during that time.

Idle, Non-planing, and Planing Speeds

Figures D3–D8 present results of the PWC trials conducted on both PWC with a driver and a passenger at no wake, non-planing, and planing speeds. As expected, the increase in PWC speed resulted in lower CO concentrations on all CO monitors on both PWC. At no wake and non-planing speeds on both PWC, the CO concentrations exceeded the NIOSH ceiling limit (200 ppm) at the back of the PWC and the passenger. The CO concentration at the back of the passenger of the old PWC during the no wake speed trial reached the CO monitor limit of 1,000 ppm. However, this high CO concentration occurred during the transition from the idle to non-planing speed trial and subsequently decreased to 50 ppm in less than 1 minute. The planing speed trial indicated CO peak concentrations over the NIOSH ceiling limit only after the PWC slowed to idle at the end of the trial, resulting in the exhaust moving from back to front. As Figure D7 indicates, the old PWC planing speed trial was stopped for roughly 2 minutes to remove and reset the CO monitor alarm.

Idle, Non-planing, and Planing Speeds with a Rescue Board "Victim"

Figures D9–D14 present the PWC trials conducted on both PWC with a driver and a victim on a rescue board at no wake, non-planing, and planing speeds. Except for the old PWC no wake trial, the CO concentrations were < 50 ppm during all trials. The helmet-mounted CO monitor during the new PWC no wake trial measured most of the concentrations close to 50 ppm; all other monitors measured CO at much lower concentrations. As occurred during the driver/passenger trials described above, the CO concentrations did rise because of the exhaust traveling over the PWC when it slowed down at the end of the test. The CO concentrations measured during most of the old PWC no wake trial were < 100 ppm, but some peak measurements at the back of the PWC and on the helmet-mounted CO monitor during the middle of the trial were over the NIOSH ceiling limit of 200 ppm.

PWC at Varying Speeds with a Rescuer and Rescue Board Victim

Figures D15–D16 present the PWC trials conducted at various speeds on both PWC with a driver, passenger, and victim on a rescue board. As Figure D15 shows, all CO monitors measured concentrations above the NIOSH ceiling limit of 200 ppm and some to the limit of the monitor (1,000 ppm) during the old PWC no wake trial. As the old PWC transitioned to the non-planing speed, the CO concentrations were drastically reduced to < 50 ppm until the PWC slowed at the end of the trial.

PWC at No Wake Speed with a Victim Holding a Tow Strap and with/without a Rescuer

Figures D17–D20 present the real-time CO sampling data collected while a victim held onto a tow strap. Because of the powerful propulsion force of the PWC, the victim could only hold onto the tow strap at no wake speeds. A rescuer was onboard a PWC in three of the four trials; these trials showed consistently high CO concentrations (peaks of > 1,000 ppm) at the back of both PWC, suggesting that an increased load could increase exhaust emissions. The helmet CO monitor on the victim showed overall lower CO concentrations from the new PWC with a peak of 85 ppm. The old PWC trial showed CO peak concentrations approaching the NIOSH ceiling limit of 200 ppm on the helmet-mounted CO monitor.

Results (continued)

Mock Rescue Trials

Figures D21–D25 present the mock rescue trials conducted in calm water and slightly choppy water. The mock rescues using the old PWC did show CO concentrations exceeding the NIOSH ceiling limit in calm and choppy waters. These exceedances and other CO peaks were measured at roughly the same time mock rescues (drop off and pickup) were conducted (Figures D21, D22, and D24). CO concentrations during mock rescues using the new PWC were generally less than 50 ppm (engine was off during the calm water trial, Figure D23) except for a peak above the NIOSH ceiling limit at the back of the PWC when the surf was slightly choppy. This peak did not coincide with a mock rescue.

Discussion

The CO concentrations measured during these trials indicate that PWC can create hazardous levels of CO, especially while remaining stationary or operating at slower speeds. The highest CO concentrations during these trials tended to be near the back of the PWC. Higher PWC speeds greatly reduce the amount of CO around the PWC. However, when the PWC slows down from higher speeds, the exhaust continues to move over the top of the PWC, resulting in brief periods of elevated CO concentrations at the back of the PWC. For both PWC tested, the use of a rescue board seemed to redirect the exhaust away from the back of PWC and the victim lying on the board. One exception occurred when the old PWC was underway at a no wake speed with a rescuer on the PWC and a victim lying on the rescue board. Although not directly comparable, the old PWC consistently produced more CO during these trials than the newer PWC. This is expected as the old PWC was not regularly used or maintained and was not manufactured under the same emission standards as the new PWC.

Trials showed that the operator is less likely to be exposed to hazardous CO concentrations than the rescuer or victim because of the increased distance from the exhaust. Although the CO monitor at the back of the rescuer measured high concentrations of CO during some trials, the CO monitor positioned in front of the rescuer rarely showed the same high concentrations. This suggests that the rescuer's body shields him/her from exposure to the exhaust emissions. In general, CO monitors closer to the exhaust measured higher CO concentrations.

PWC trial results while stationary and operating at slow speeds suggest that high concentrations of CO could have been present in the scenario described in the NIOSH fatality report. These trials more closely represent the operation and speed of the PWC as described in the NIOSH fatality report than the non-planing or planing trials. Additionally, the tow strap described and shown in the NIOSH fatality report would put the victim's breathing zone in the same general area where we measured hazardous CO concentrations.

CO concentrations measured during the mock rescue trials were lower overall than stationary or slow speed trials. This was especially true for the new PWC in these evaluations. The lower CO concentrations could be a result of the rescue board redirecting exhaust away, as was shown from data collected in other rescue board trials. Results from mock rescue trials under somewhat choppy water conditions did not differ from those conducted under calm water conditions. Further evaluation of PWC in conditions more consistent with those described in the NIOSH fatality report is needed.

This CO exposure assessment provides additional information on two recommendations contained within the NIOSH fatality report: (1) never boarding a PWC when the engine is running, and (2) using a rescue board. If the PWC is not operating, the potential for CO exposure is greatly reduced for the operator, rescuer, and victim during exercises or actual rescues. However, when the engine is shut off the operator loses the ability to steer the PWC. During training and emergency responses in strong surf, the inability to steer can be very dangerous for the operator and all passengers. This evaluation seems to show a reduction in the CO exposures at the back of the PWC by redirecting exhaust away from the victim when the PWC is moving slowly, but does not do this as well when the PWC is stationary.

This evaluation has some limitations. First, we only tested two PWC from one manufacturer during this evaluation. Second, the individual trial results and the PWC cannot be compared to each other because they were not operated at the same time or under the same environmental conditions. Third, the results from this evaluation cannot be directly compared to the scenario described in the NIOSH fatality report as trials were not conducted in the same conditions (surf, air and water temperature) or with the same equipment (PWC make/model). Finally, there were differences

Discussion (continued)

in CO concentrations between individual trials and methods. Variations in instrument readings could be the result of (1) wind direction, speed, and PWC position relative to wind direction; (2) instrument limitations; and (3) position of samplers during collection (the emissions analyzer could not be placed directly in the PWC exhaust during the stationary trials in the water, resulting in a concentration difference between stationary in water and stationary on the trailer).

Original EPA regulations for exhaust emissions were covered under 40 CFR 91 (published in 1996) and were intended to reduce hydrocarbon and nitrous oxide emissions, but did not include CO. Newer exhaust emission standards that apply to 2010 and later model PWC engines cover hydrocarbon, nitrous oxide, and CO emissions [EPA 2011; 40 CFR 1045].

Previous NIOSH boating investigations have collected limited CO data from PWC [NIOSH 2003a,b]. In these previous evaluations, detector tubes and evacuated cylinders measured CO during a cold start. Both detector tubes measured 500 ppm, while two evacuated cylinders measured 124 ppm and 2,600 ppm. These measurements are consistent with measurements collected using detector tubes and the emissions analyzer during this evaluation.

Conclusions

PWC can generate CO in concentrations exceeding the NIOSH ceiling limit when idling, moving slowly, and when operating under a load. When PWC are not maintained, the amount of CO generated can increase greatly. At faster speeds, CO concentrations are considerably reduced except when exhaust moves across the PWC during sudden slowing. Although the CO concentrations measured during these trials suggest a potential safety hazard to personnel participating in surf rescue training sessions or rescues, additional studies are needed to evaluate this hazard as this effort was limited by the number of machines and trials.

Recommendations

On the basis of our findings, we recommend the actions listed below to create a more healthful workplace. We encourage all fire departments and other agencies with surf rescue responsibilities to use a labor-management health and safety committee or working group to discuss the recommendations in this report and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at each fire department or agency. Our recommendations are based on the hierarchy of controls approach (refer to Appendix B: Occupational Exposure Limits and Health Effects). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and/or personal protective equipment may be needed.

Administrative Controls

Administrative controls are management-dictated work practices and policies to reduce or prevent exposures to workplace hazards. The effectiveness of administrative changes in work practices for controlling workplace hazards is dependent on management commitment and employee acceptance. Regular monitoring and reinforcement is necessary to ensure that control policies and procedures are not circumvented in the name of convenience or production.

1. Review the NIOSH Fire Fighter Fatality Investigation report available at http://www.cdc.gov/niosh/fire/pdfs/face200614.pdf for recommendations to prevent fatalities related to rescues using PWC.
2. Use a rescue board during emergency responses and training.
3. Minimize PWC idling or operating at slow speeds for extended periods.
4. Maintain PWC according to the manufacturer's recommendations.
5. Consider PWC with emission controls as opportunities arise to purchase new machines. Continually assess the cost benefit of maintaining older equipment versus purchasing equipment with more effective controls.

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Appendix A: Methods

A Ferret Instruments (GxT Inc., Cheboygan, Michigan) Gaslink LT Five Gas Emissions Analyzer characterized emissions from the PWC. The five-gas emissions analyzer measures CO, carbon dioxide, hydrocarbons, oxygen, and nitrogen oxides. The instrument expresses CO, carbon dioxide, and oxygen as percentages (1% is equivalent to 10,000 ppm) and hydrocarbons and nitrogen oxides in ppm. The CO measurement range for this instrument is 0%–15.00%. For this report, percentages have been converted to their equivalent ppm concentrations.

CO air concentrations were measured in the personal breathing zone of rescue personnel and at general area locations on the PWC using BW Technologies GasAlert Extreme Monitors (BW Technologies, Ltd., Calgary, Alberta, Canada) with CO sensors. All GasAlert Extreme 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 1-minute sampling interval. The instruments have a detection range from 0 to 1,000 ppm.

CO concentrations were measured in the area near the PWC exhaust using detector tubes (Dräger AG, Lübeck, Germany) with a CO range of 10 ppm to 3,000 ppm. A bellows-type pump draws air through the detector tube, and the resulting length of the stain in the tube (produced by a chemical reaction with the sorbent) is proportional to the concentration of the air contaminant.

Appendix B: Occupational Exposure Limits and Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a 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 employee to produce adverse health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where adverse health effects are caused by exposures over a short period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act of 1970. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2010]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the United States include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2011]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2011].

Outside the United States, OELs have been established by various agencies and organizations and include both legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA, Institute for Occupational Safety and Health of the German Social Accident

Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/en/gestis/limit_values/index.jsp, contains international limits for over 1,500 hazardous substances and is updated periodically.

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause 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, NIOSH investigators encourage employers to make use of other OELs when making risk assessments and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health that focuses resources on exposure controls by describing how a risk needs to be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement the OELs, when available.

Below we provide the OELs for the compounds we measured, as well as a discussion of the potential health effects from exposure to these compounds.

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 [NIOSH 1972, 1977, 1979, 2010; Hathaway and Proctor 2004; ACGIH 2007]. 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 pre-existing heart or lung diseases that inhibit increased cardiac output.

Blood has an estimated 210 to 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 "halflife") 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 halflife can be expected to range from 2 to 6.5 hours [WHO 1999]. 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 halflife 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 halflife to approximately 20 minutes.

COHb levels vary in persons without occupational exposure to CO. Nonsmokers range from less than 2% to 3%, tobacco smokers range from 5% to 20%, and commuters on urban highways can have levels of 5% or more [EPA 1991; ACGIH 2007].

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 pre-existing 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 [Kales 1993].

The NIOSH REL for CO is 35 ppm for full-shift TWA exposure, with a ceiling limit of 200 ppm that should never be exceeded [NIOSH 1992]. The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5% [NIOSH 1972]. NIOSH has established the IDLH value for CO as 1,200 ppm [NIOSH 2010]. 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 on the basis of limiting shifts in COHb levels to less than 3.5%, thus minimizing adverse neurobehavioral changes such as headache and dizziness and to maintain cardiovascular exercise capacity [ACGIH 2011]. ACGIH also recommends that exposures never exceed five times the TLV (thus, never to exceed 125 ppm) [ACGIH 2011]. ACGIH recommends a BEI for end of shift exhaled breath analysis in nonsmoking workers (exposed to CO) of 3.5% COHb (or 20 ppm) [ACGIH 2011]. 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 because smokers have been shown to have COHb levels between 4% and 10% [Tomaczewski 2002; ACGIH 2007] and can exceed 15% in heavy smokers [Lauwerys and Hoet 2001].

The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure [29 CFR 1910.1000].

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Table C1. CO concentrations from the 2-stroke old PWC exhaust while stationary in the water and while on a trailer removed from the water

Stationary in the Water			On Trailer Removed from Water†		
Time (military)	CO Emissions Analyzer (ppm)*	CO Detector Tube (ppm)	Time (military)	CO Emissions Analyzer (ppm)*	CO Detector Tube (ppm)
1522	< 100		1836	< 100	
1523	200		1837	600	
1524	< 100		1838	600	
1525	< 100		1839	600	1,500
1526	100		1840	1,300	
1527	< 100				
1528	< 100				
1529	< 100				
1530	100	500			

*Analyzer provides the CO concentration in % (two decimal places): 1.00% = 10,000 ppm.
†PWC was operating on two cylinders instead of three.

Table C2. CO concentrations from the 4-stroke new PWC exhaust while stationary in the water and while on a trailer removed from the water

Stationary in the water			On Trailer Removed from Water	
Time (military)	CO Emissions Analyzer (ppm)*	CO Detector Tube (ppm)	Time (military)	CO Emissions Analyzer (ppm)*
1554	200		1628	2,800
1555	< 100		1629	900
1556	< 100		1630	1,000
1557	< 100		1631	1,100
1558	100		1632	1,200
1559	100		1633	1,300
1560	100			
1561	< 100			
1562	100			
1563	< 100	100		
1564	< 100			

*Analyzer provides the CO concentration in % (two decimal places): 1.00% = 10,000 ppm.

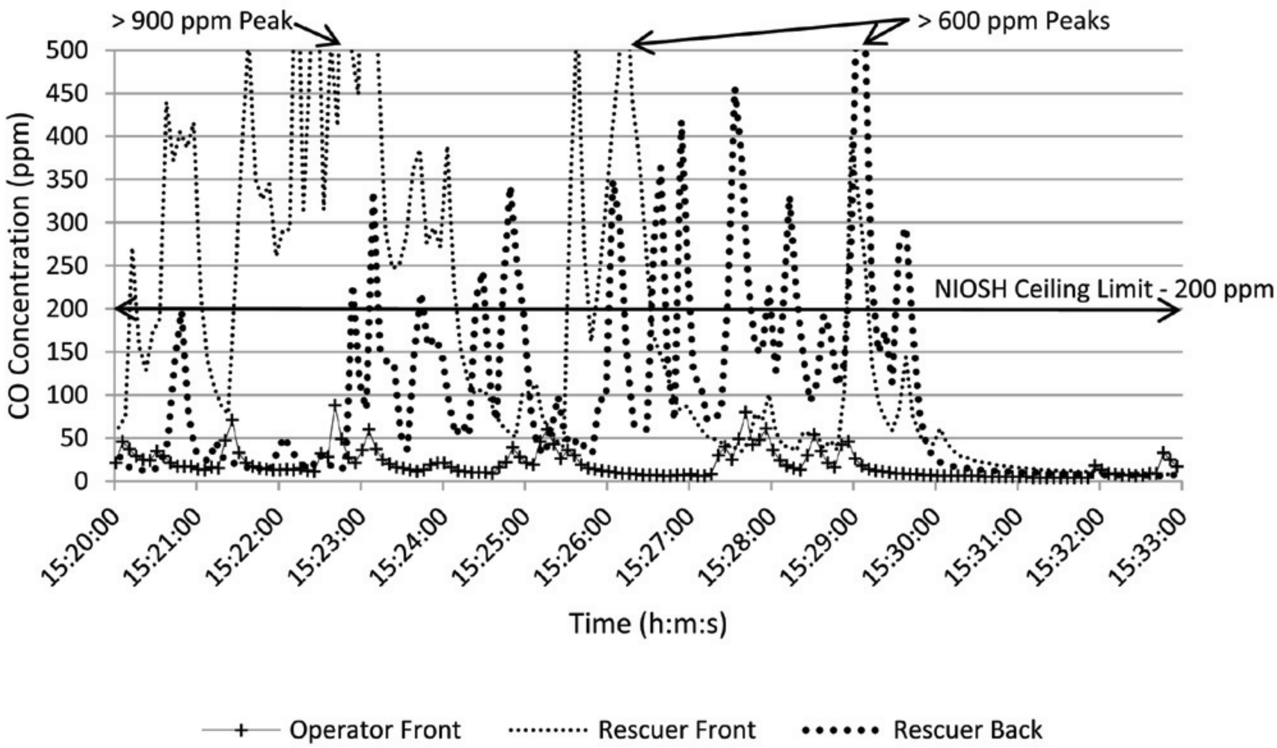

Figure D1. Old PWC real-time CO concentration data – stationary in the water at the dock.

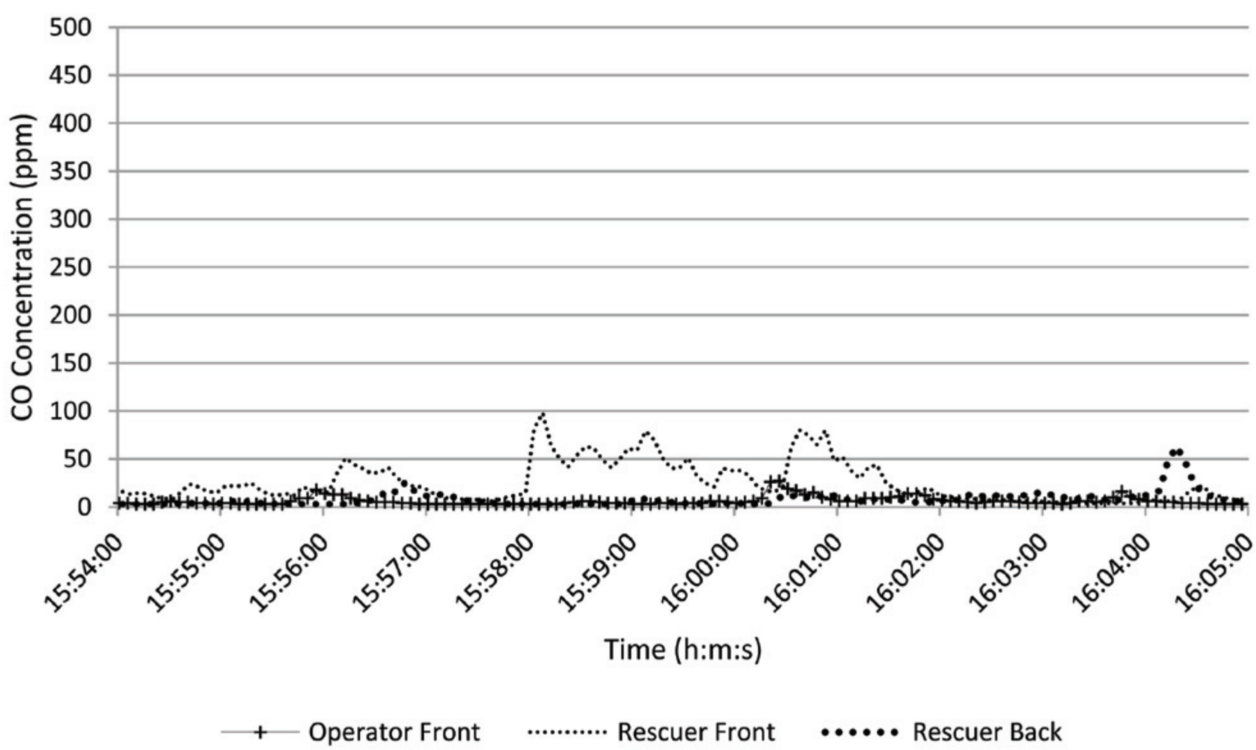

Figure D2. New PWC real-time CO concentration data – stationary in the water at the dock.

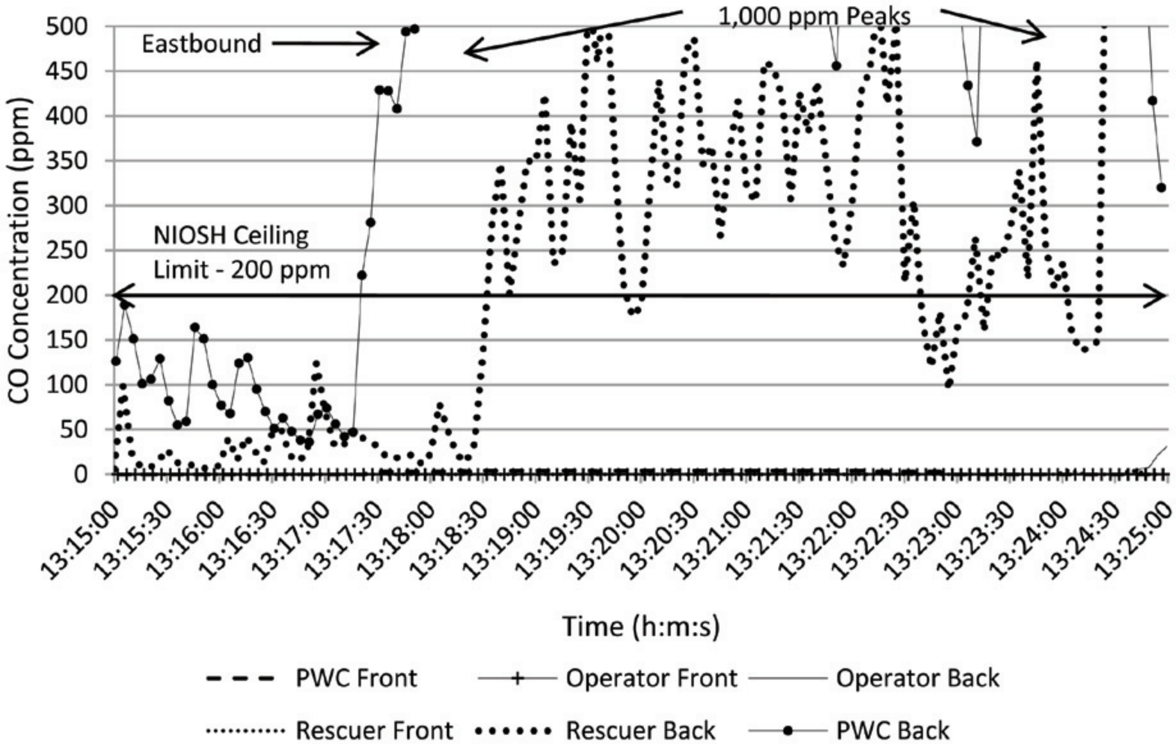

Figure D3. Old PWC real-time CO concentration data – no wake speed (< 5 mph).

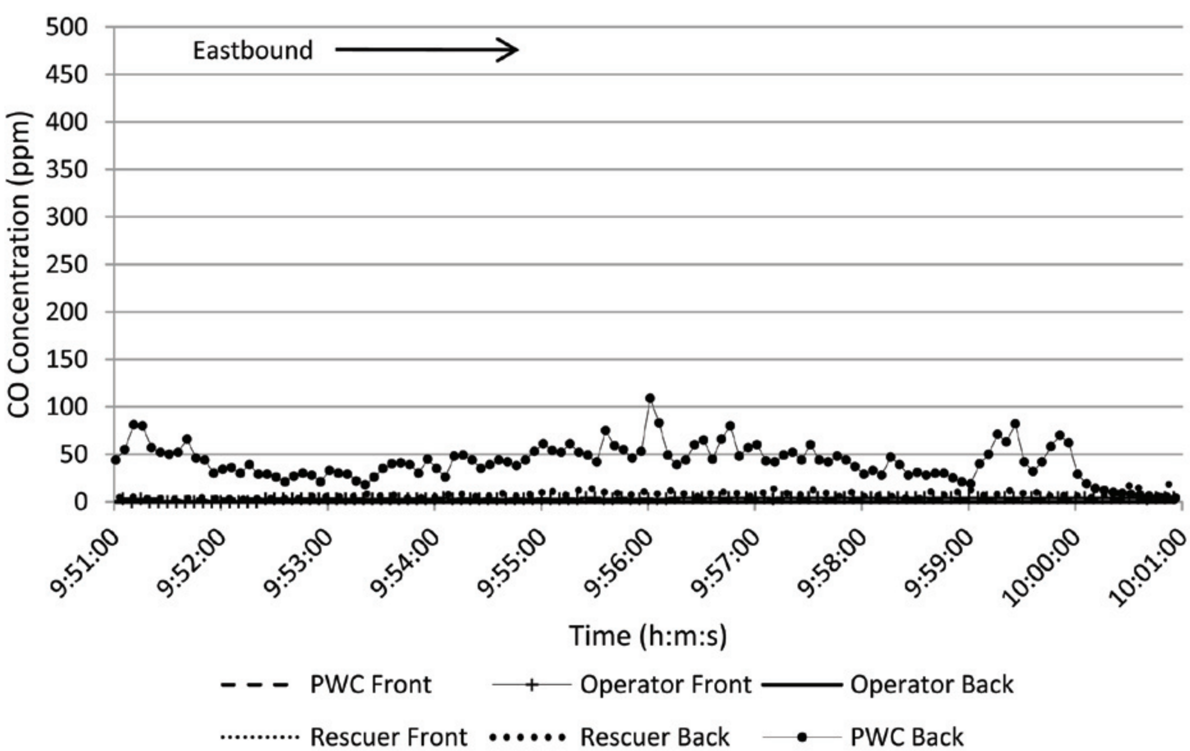

Figure D4. New PWC real-time CO concentration data – no wake speed (< 5 mph).

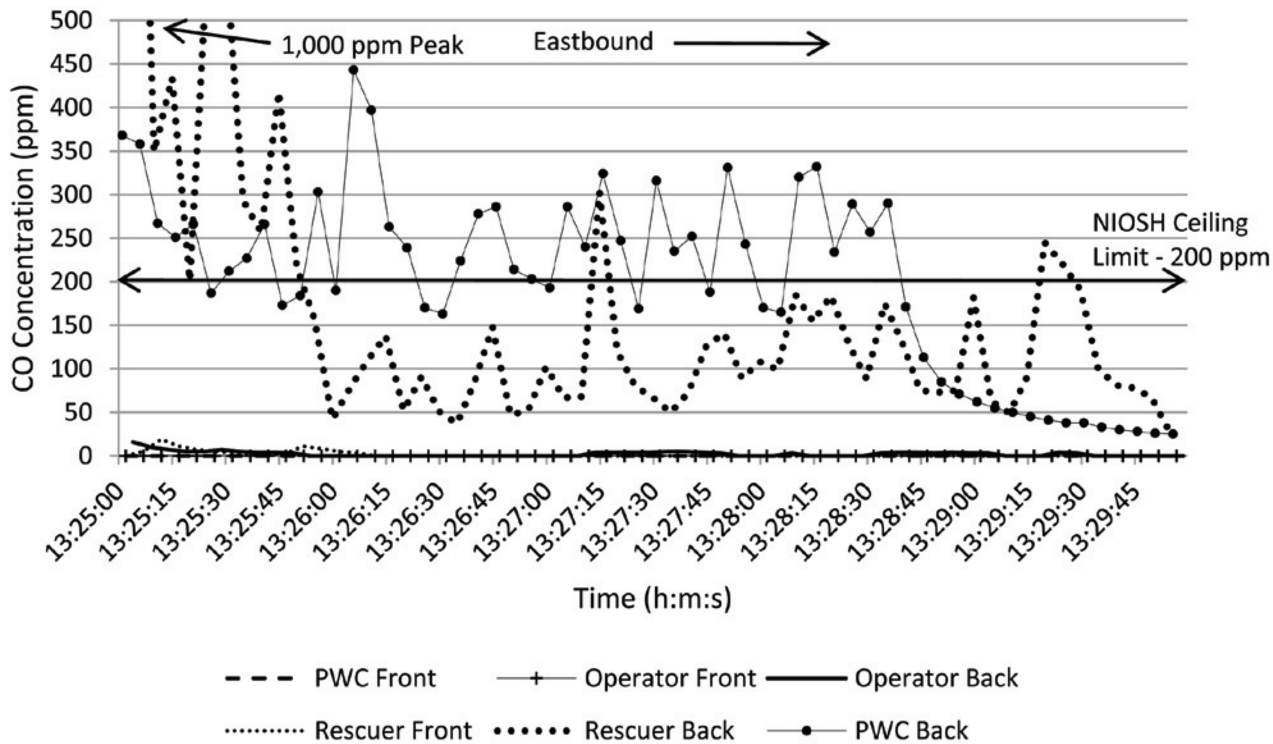

Figure D5. Old PWC real-time CO concentration data – non-planing speed (10–15 mph).

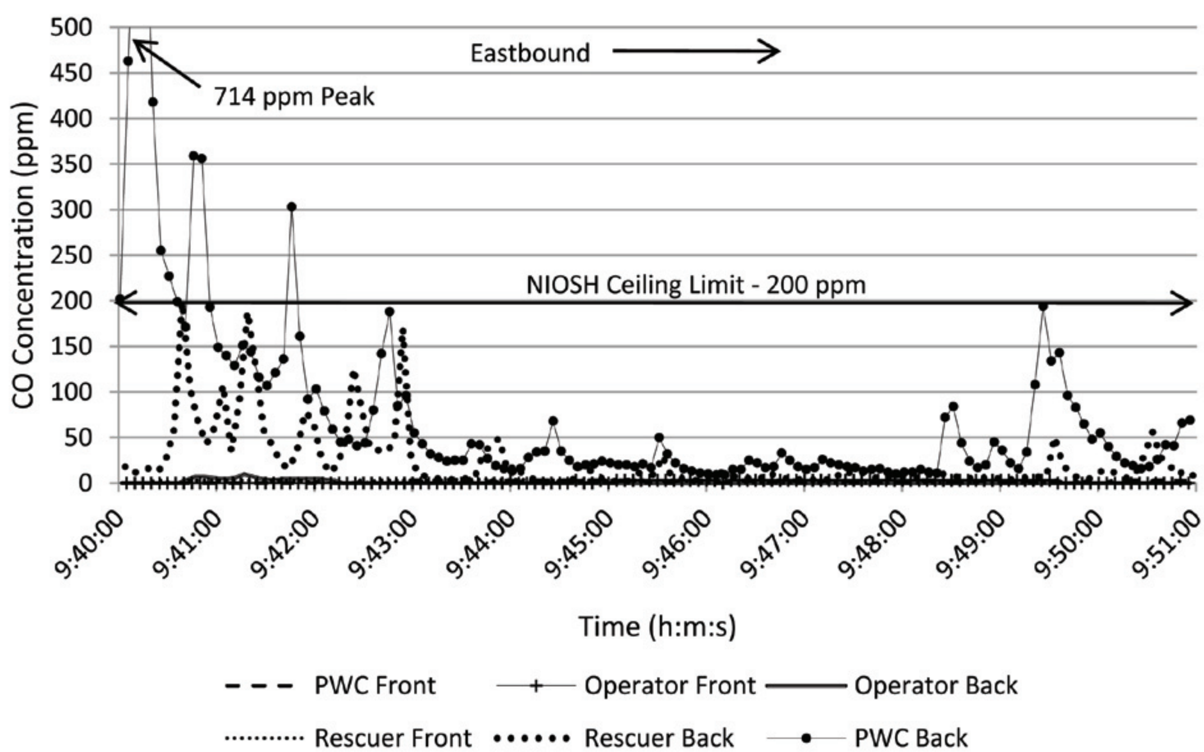

Figure D6. New PWC real-time CO concentration data – non-planing speed (10–15 mph).

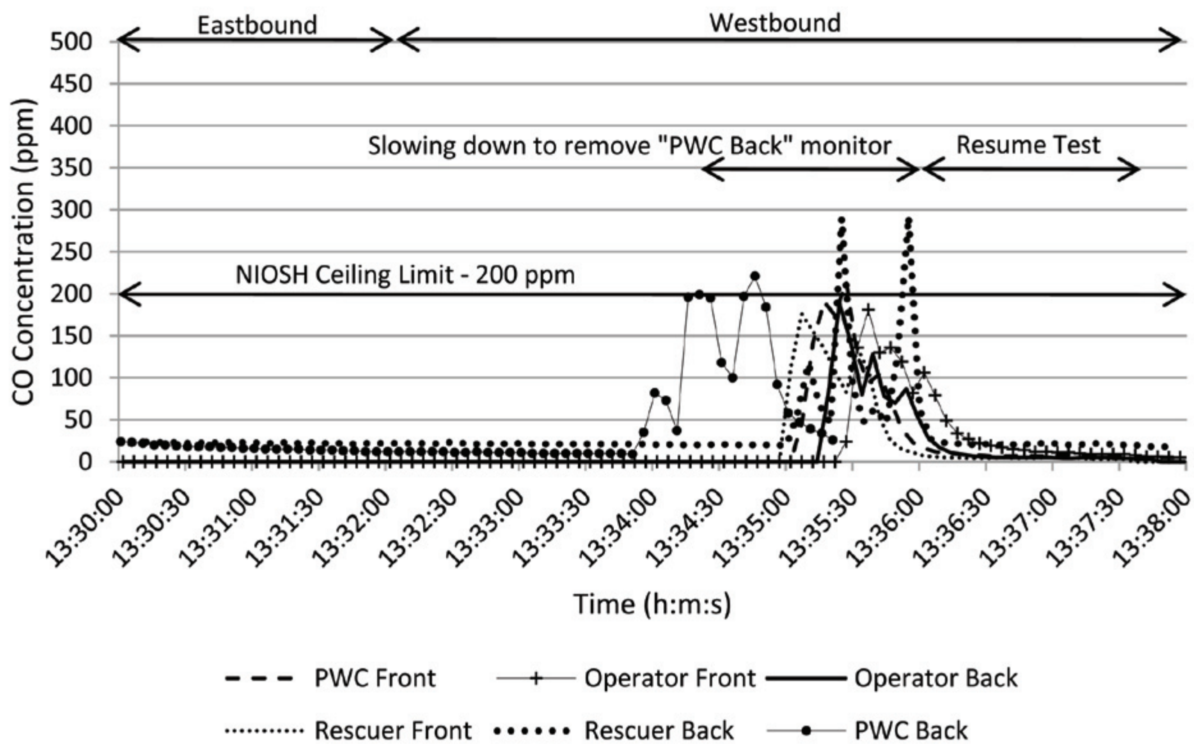

Figure D7. Old PWC real-time CO concentration data – planing speed (≈ 40 mph).

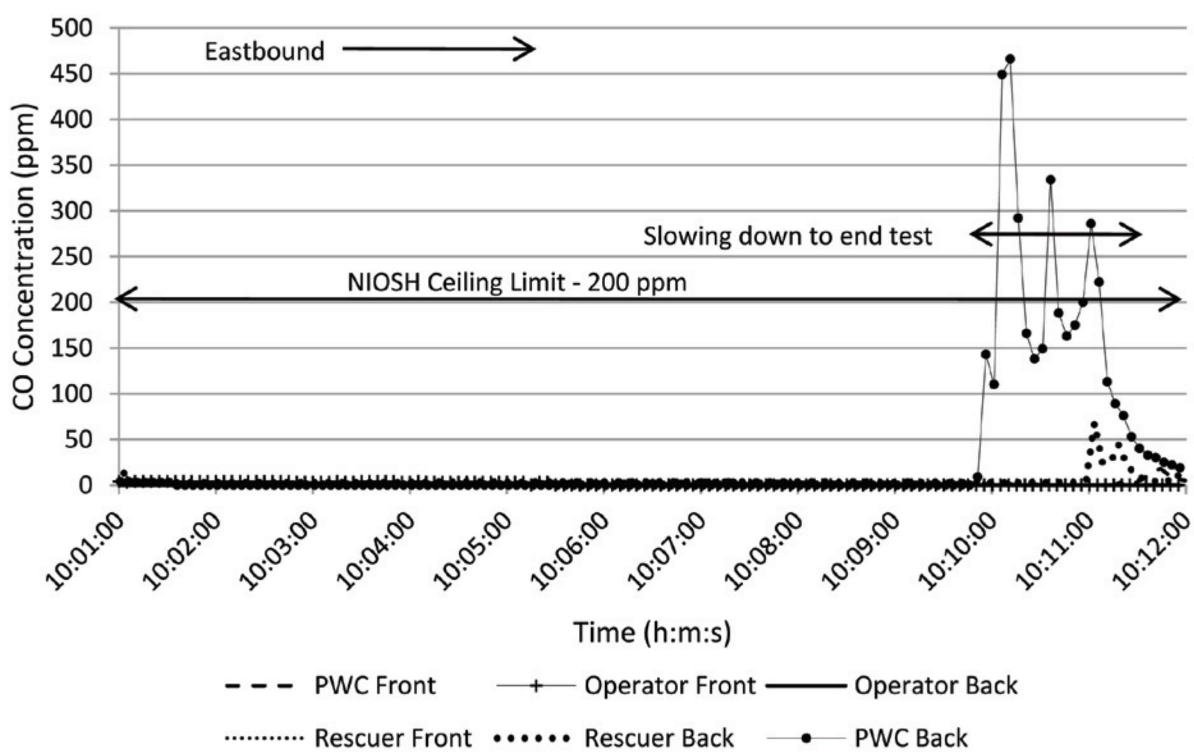

Figure D8. New PWC real-time CO concentration data – planing speed (≈ 40 mph).

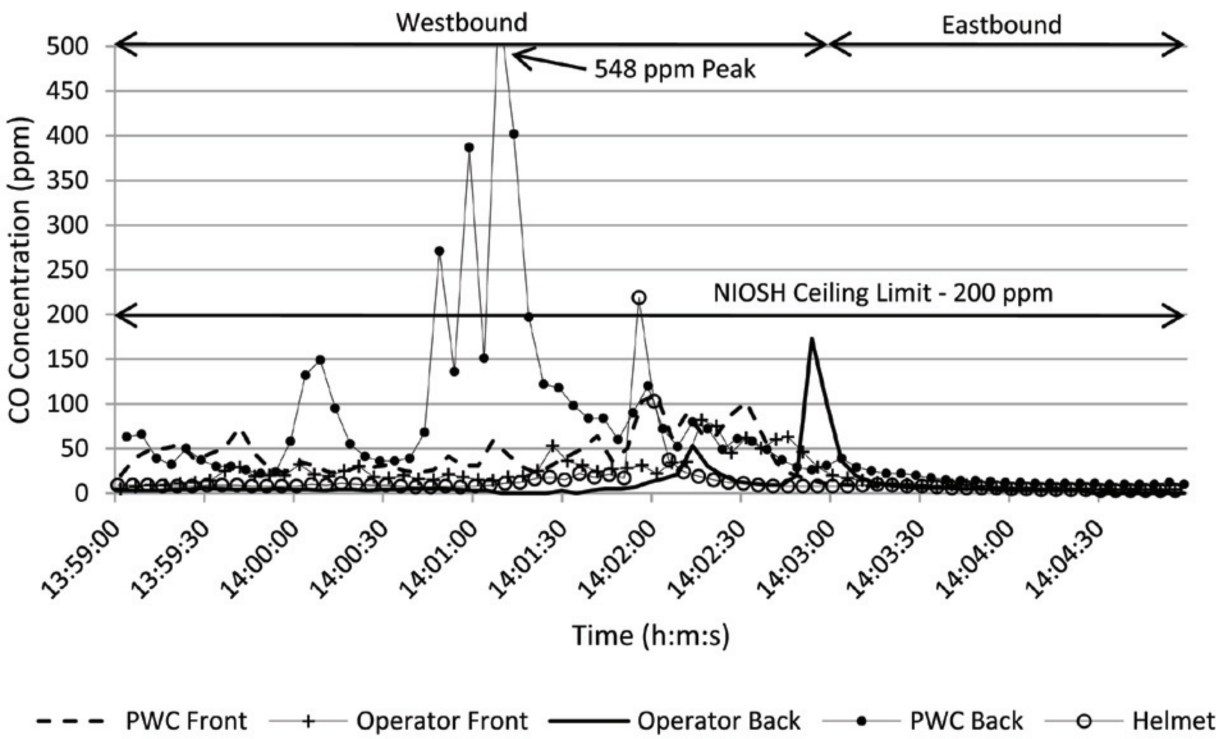

Figure D9. Old PWC real-time CO concentration data – no wake speed (< 5 mph), victim lying on rescue board. Note: no rescuer on the PWC.

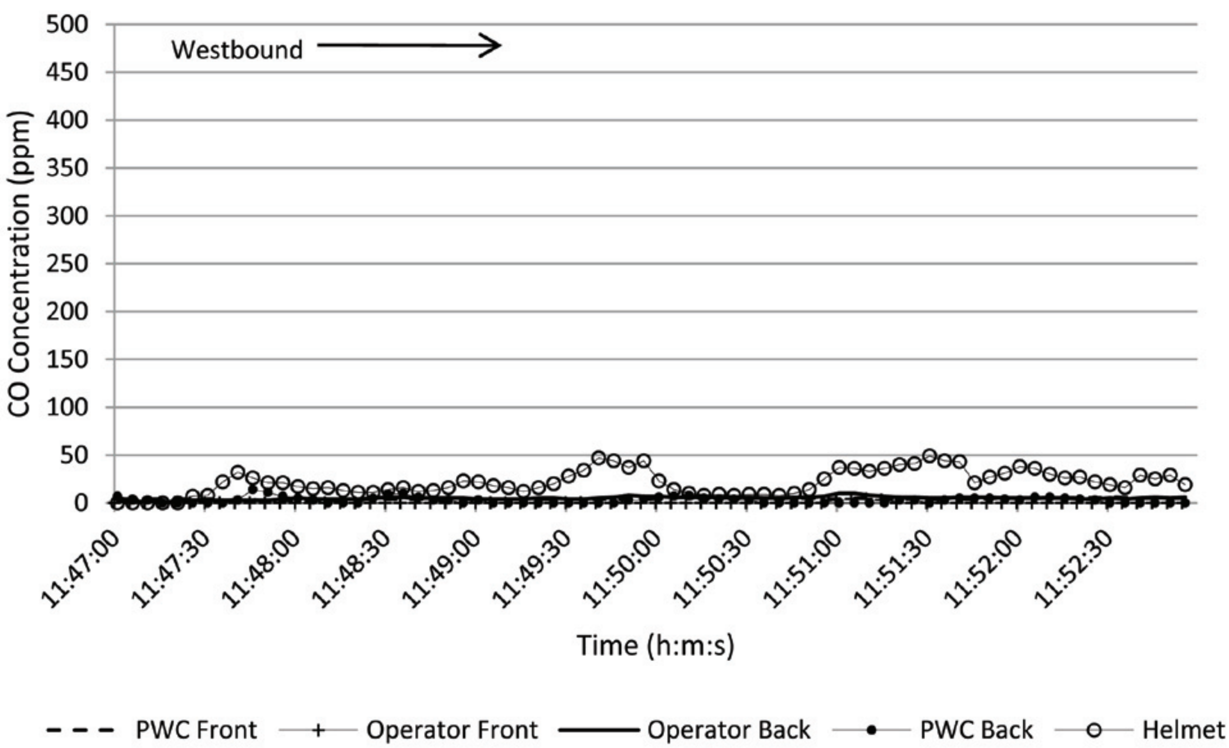

Figure D10. New PWC real-time CO concentration data – no wake speed (< 5 mph), victim lying on rescue board. Note: no rescuer on the PWC.

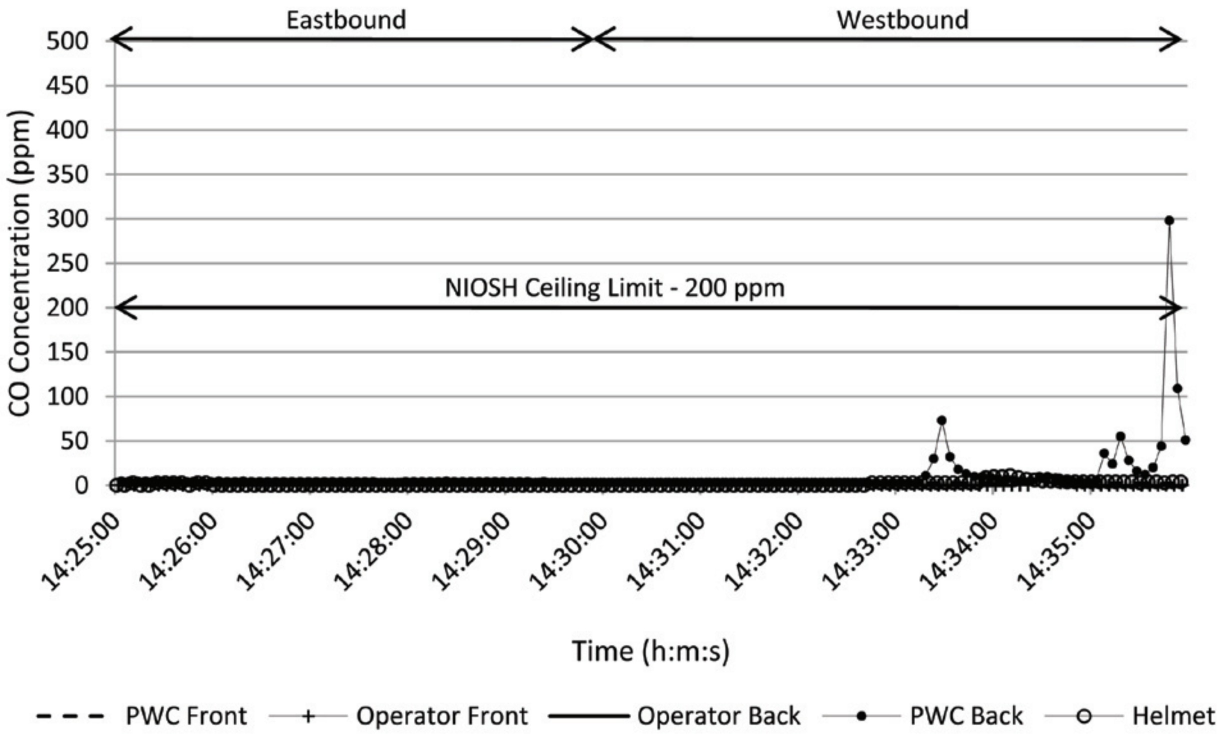

Figure D11. Old PWC real-time CO concentration data – non-planing speed (10–15 mph), victim lying on rescue board. Note: no rescuer on the PWC.

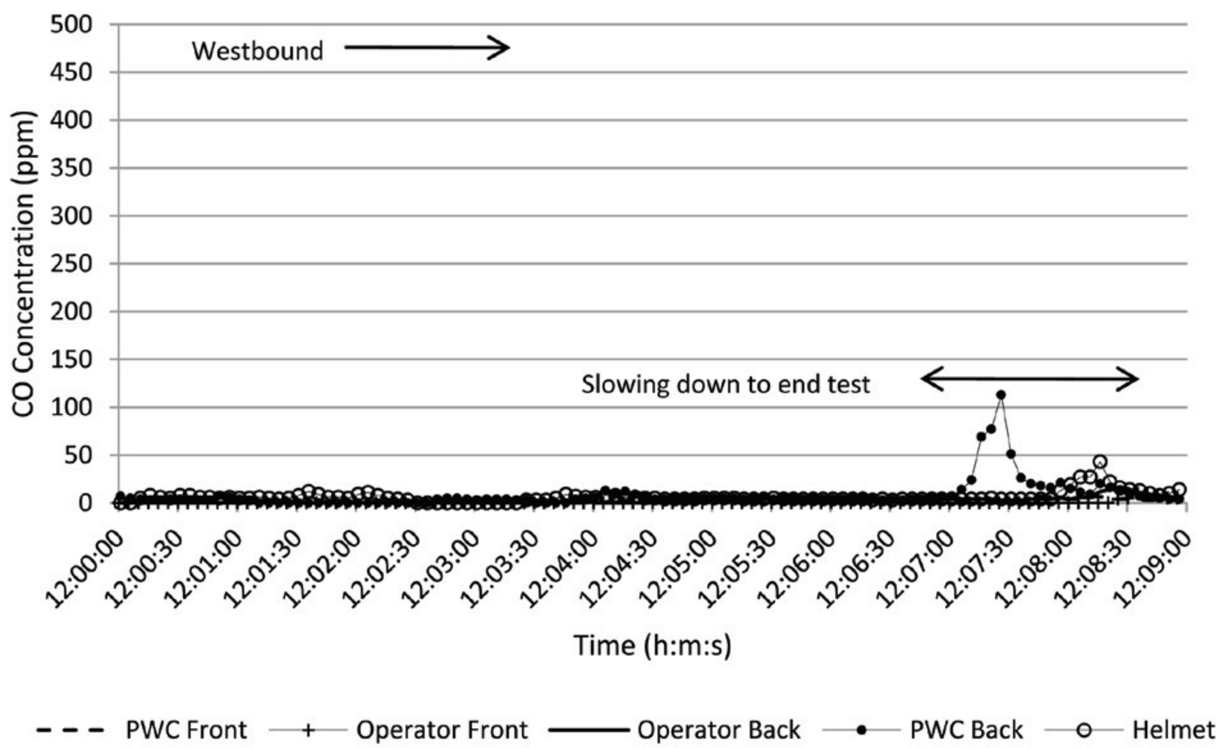

Figure D12. New PWC real-time CO concentration data – non-planing speed (10–15 mph), victim lying on rescue board. Note: no rescuer on the PWC.

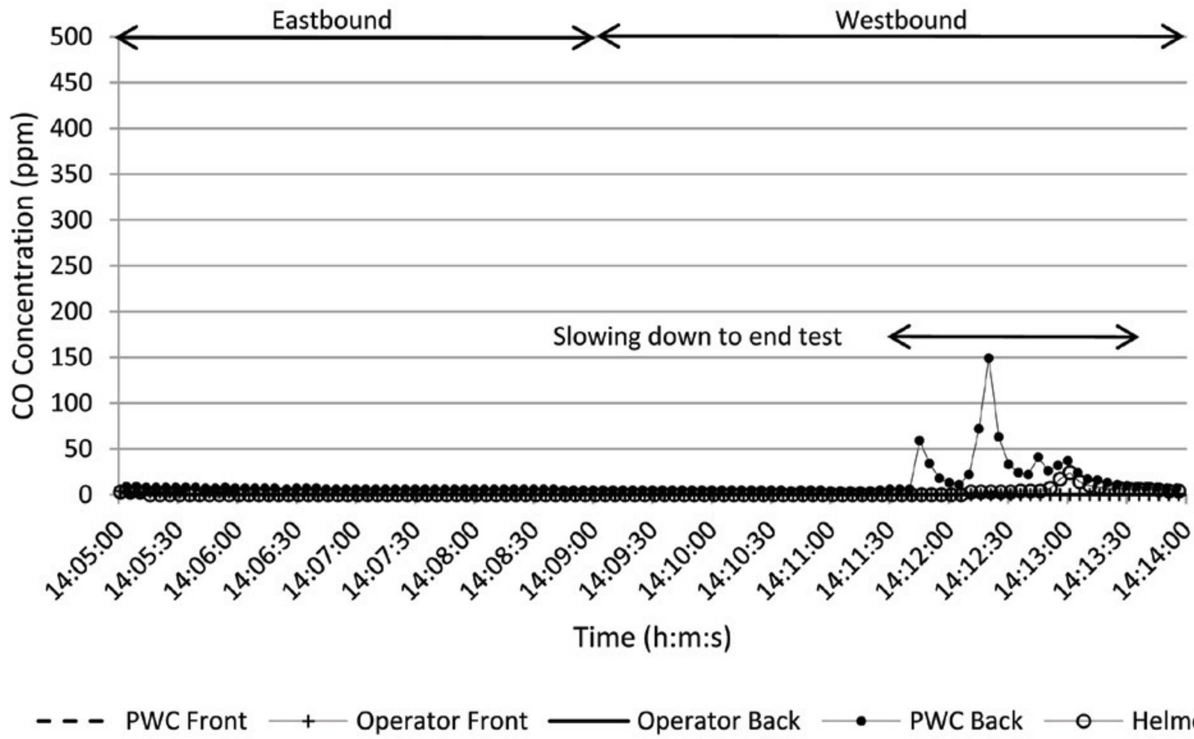

Figure D13. Old PWC real-time CO concentration data – planing speed (≈ 40 mph), victim lying on rescue board. Note: no rescuer on the PWC.

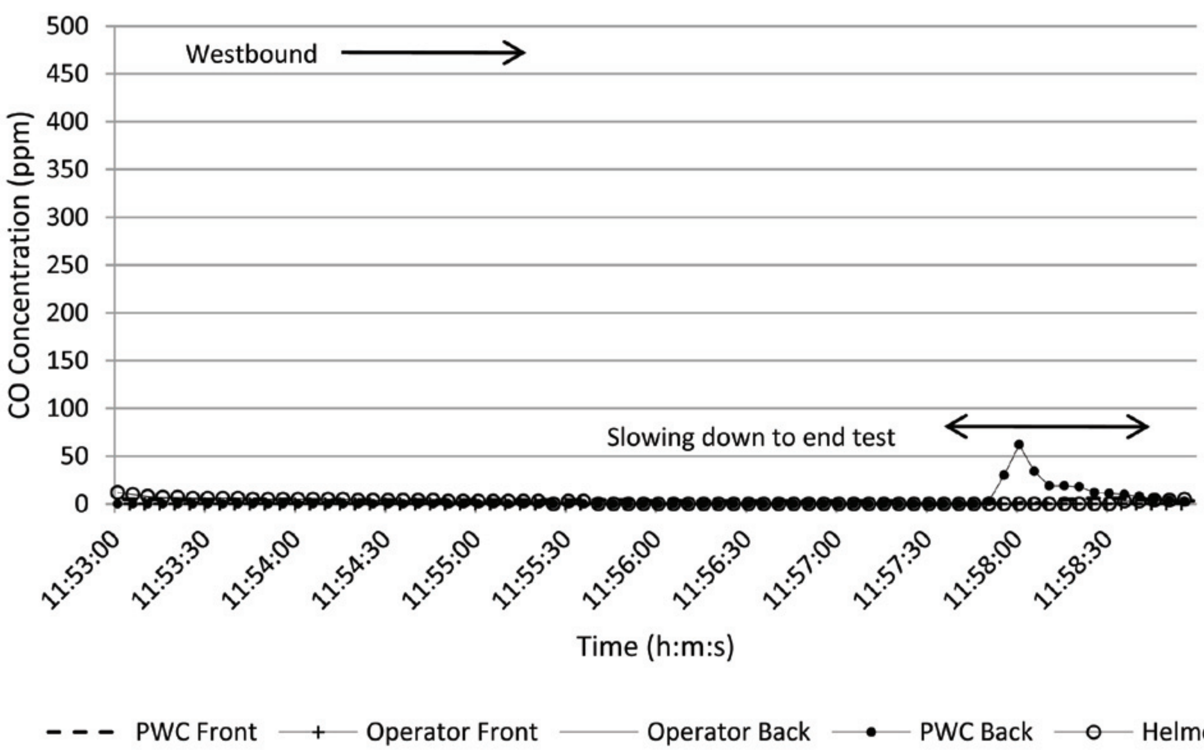

Figure D14. New PWC real-time CO concentration data – planing speed (≈ 40 mph), victim lying on rescue board. Note: no rescuer on the PWC.

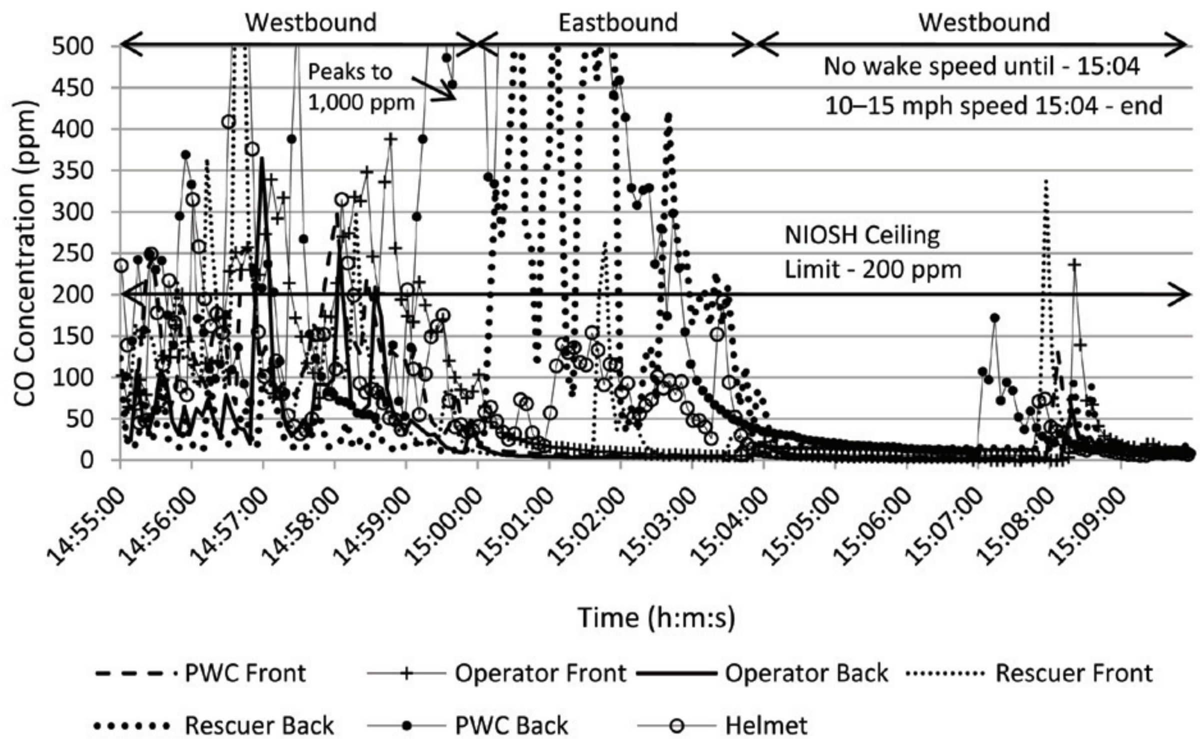

Figure D15. Old PWC real-time CO concentration data – no wake speed (< 5 mph) and non-planing speed (10–15 mph) with a rescuer on the PWC and a victim on the rescue board.

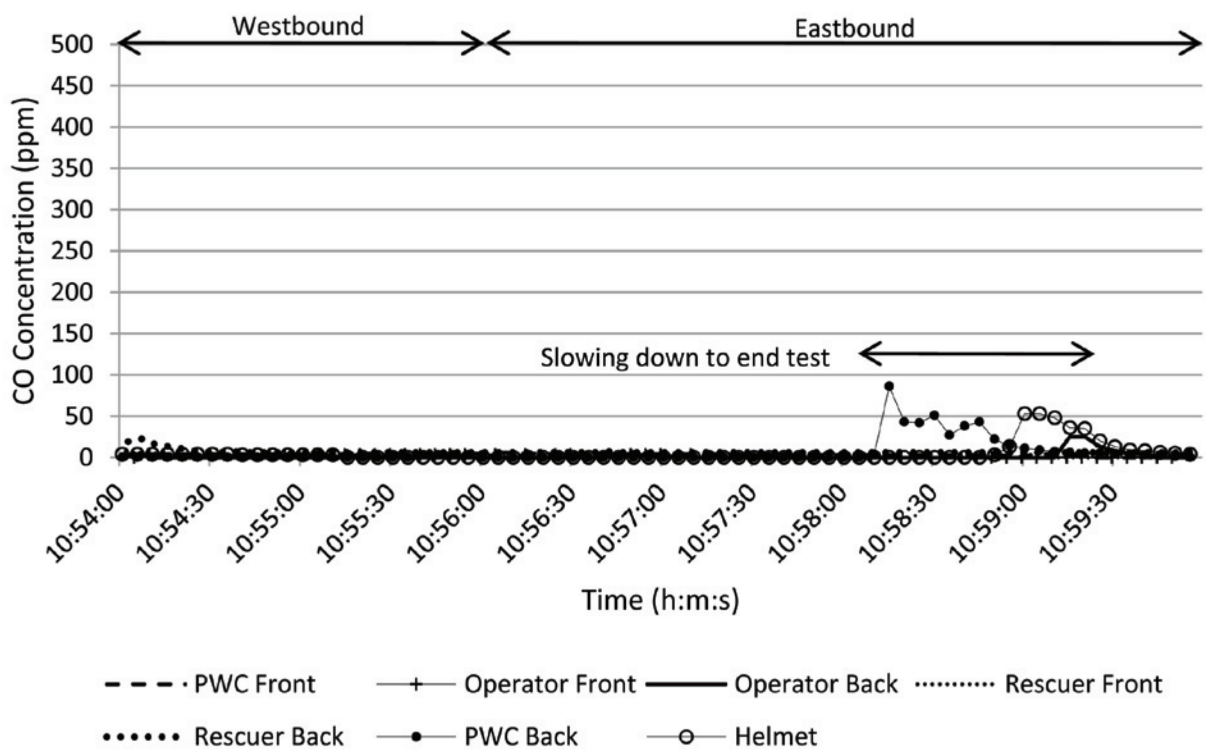

Figure D16. New PWC real-time CO concentration data – planing speed (≈ 40 mph) with a rescuer on the PWC and a victim on the rescue board.

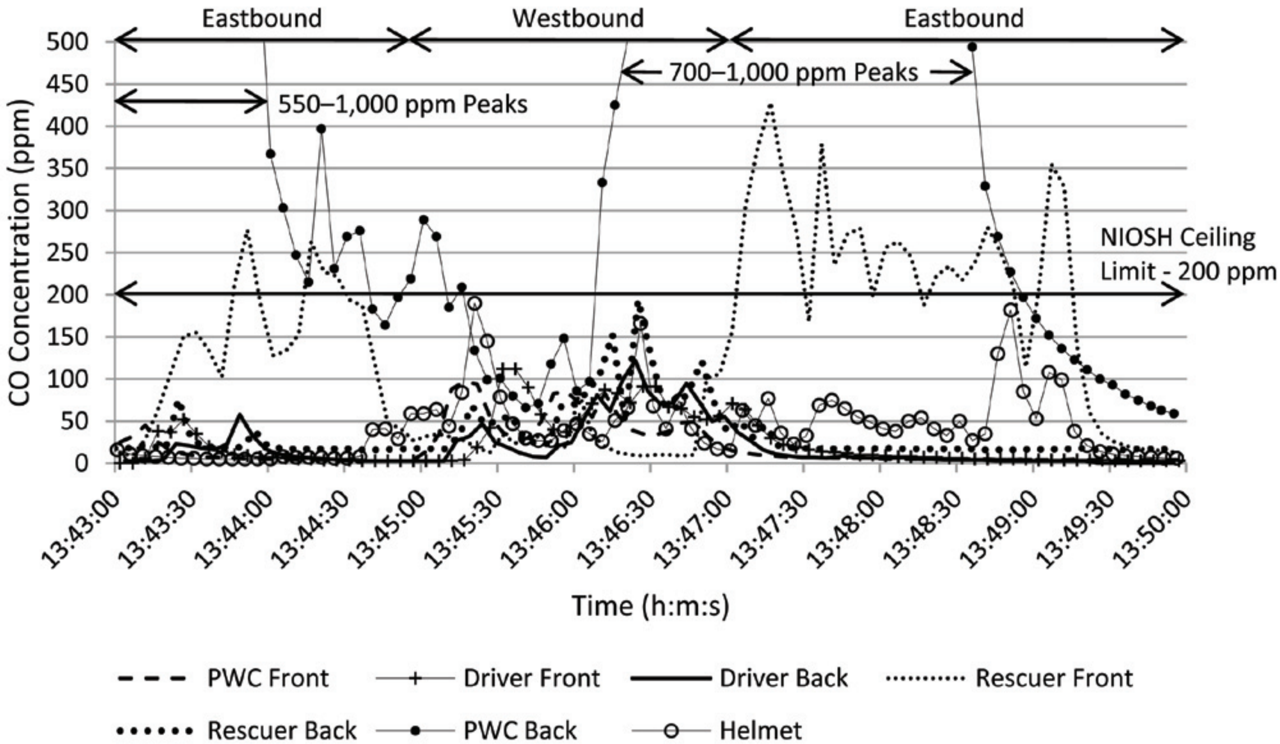

Figure D17. Old PWC real-time CO concentration data – no wake speed (< 5 mph), rescuer on the PWC flipped around to look at the victim holding on to tow strap.

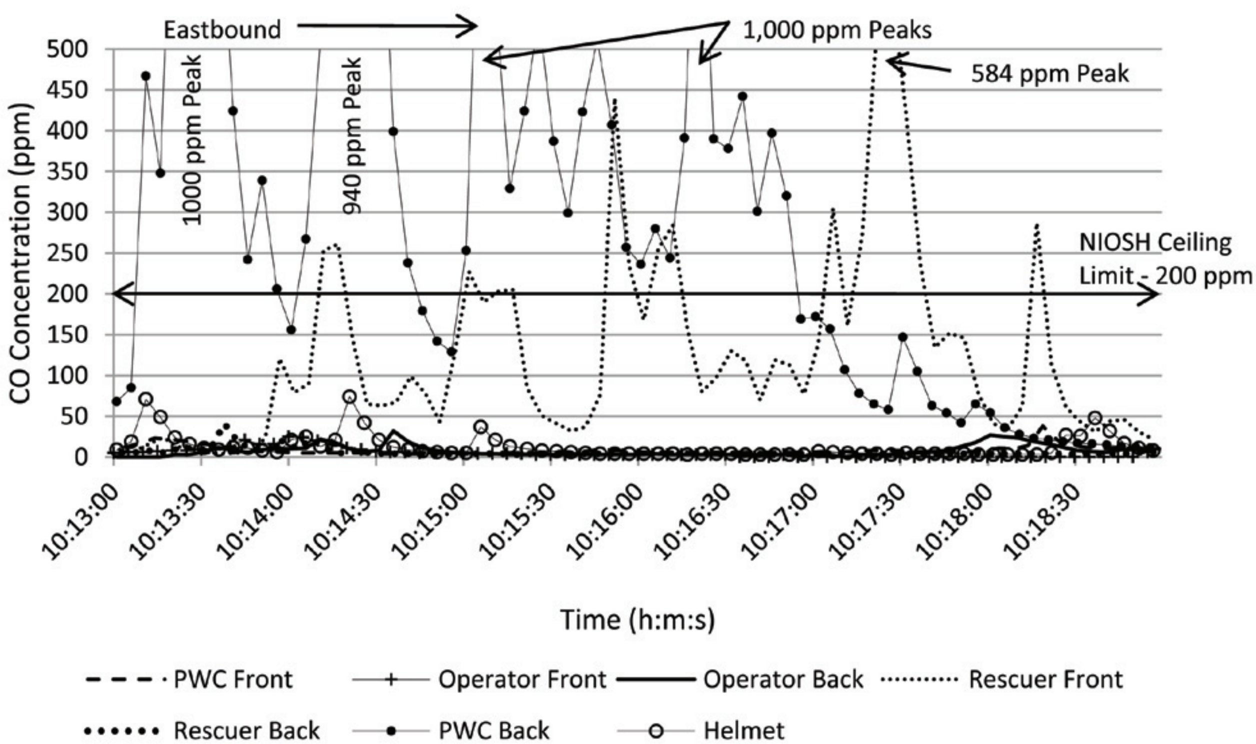

Figure D18. New PWC real-time CO concentration data – no wake speed (< 5 mph), rescuer on the PWC flipped around to look at the victim holding on to tow strap.

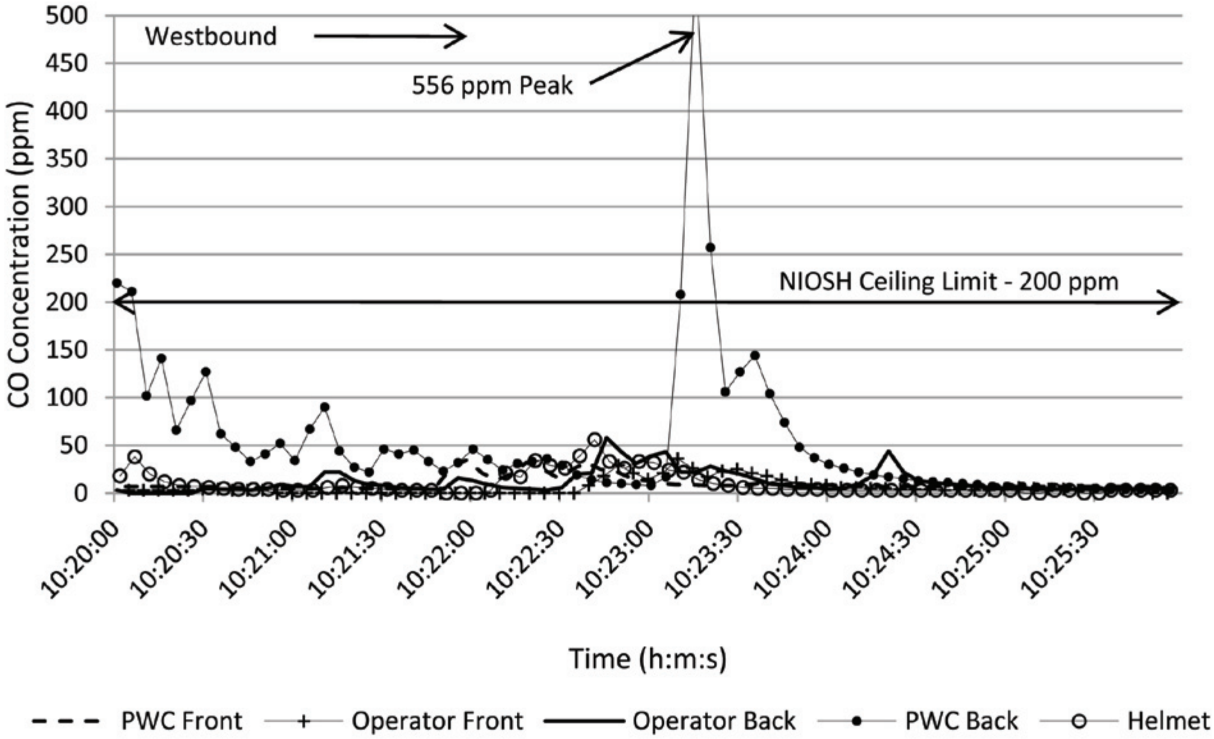

Figure D19. New PWC real-time CO concentration data – no wake speed (< 5 mph), victim holding on to tow strap. Note: no passenger on the PWC.

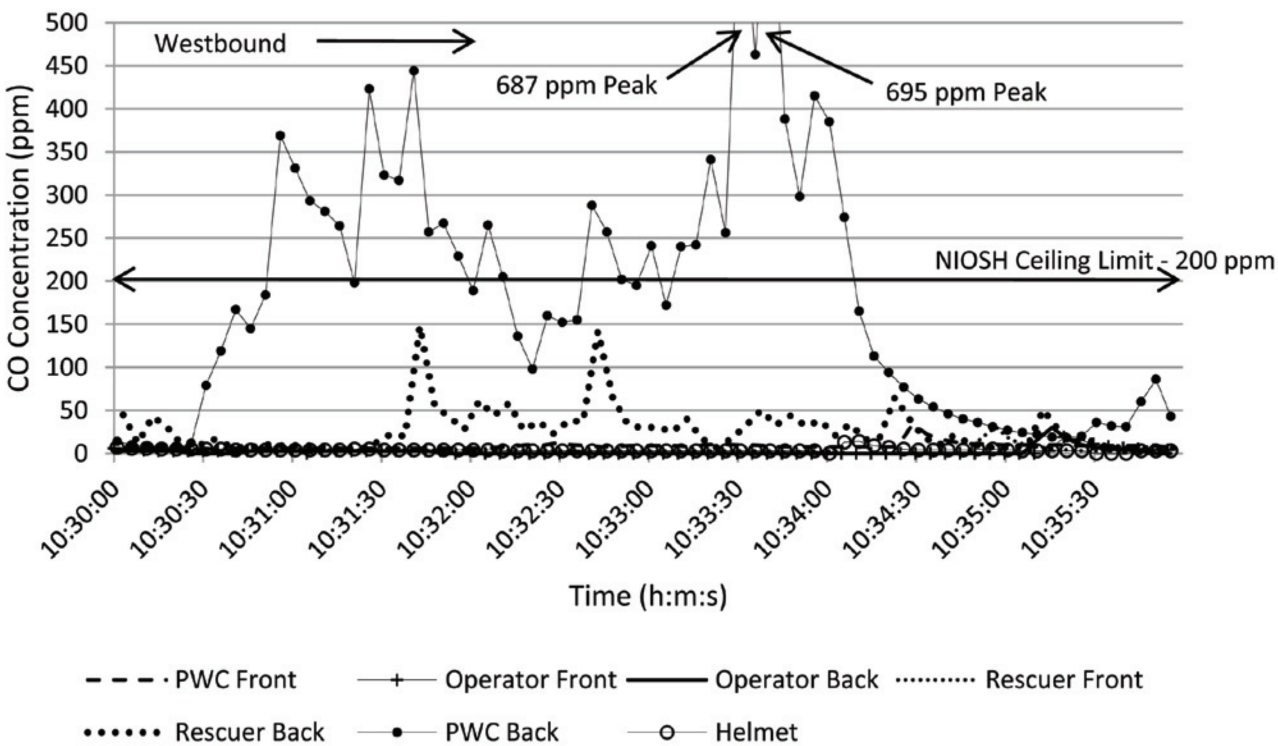

Figure D20. New PWC real-time CO concentration data – no wake speed (< 5 mph), rescuer on the PWC facing forward not looking at victim holding on to tow strap.

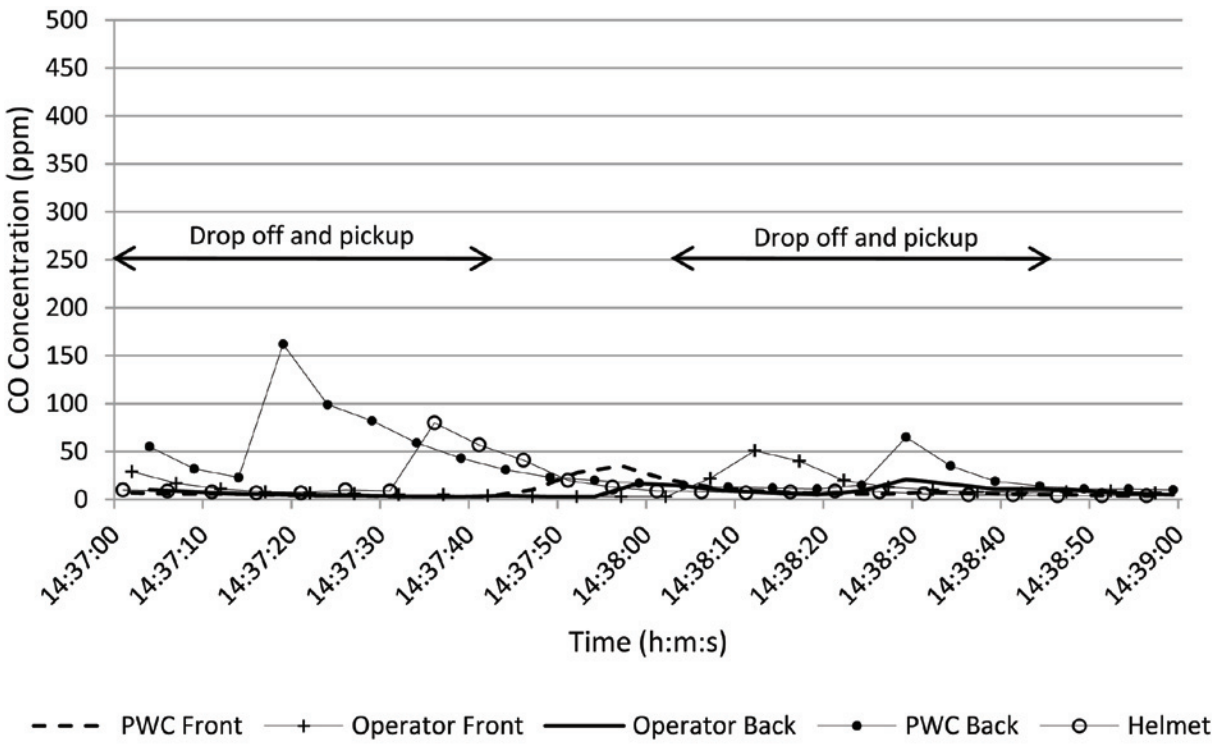

Figure D21. Old PWC real-time CO concentration data – mock rescue in calm water.

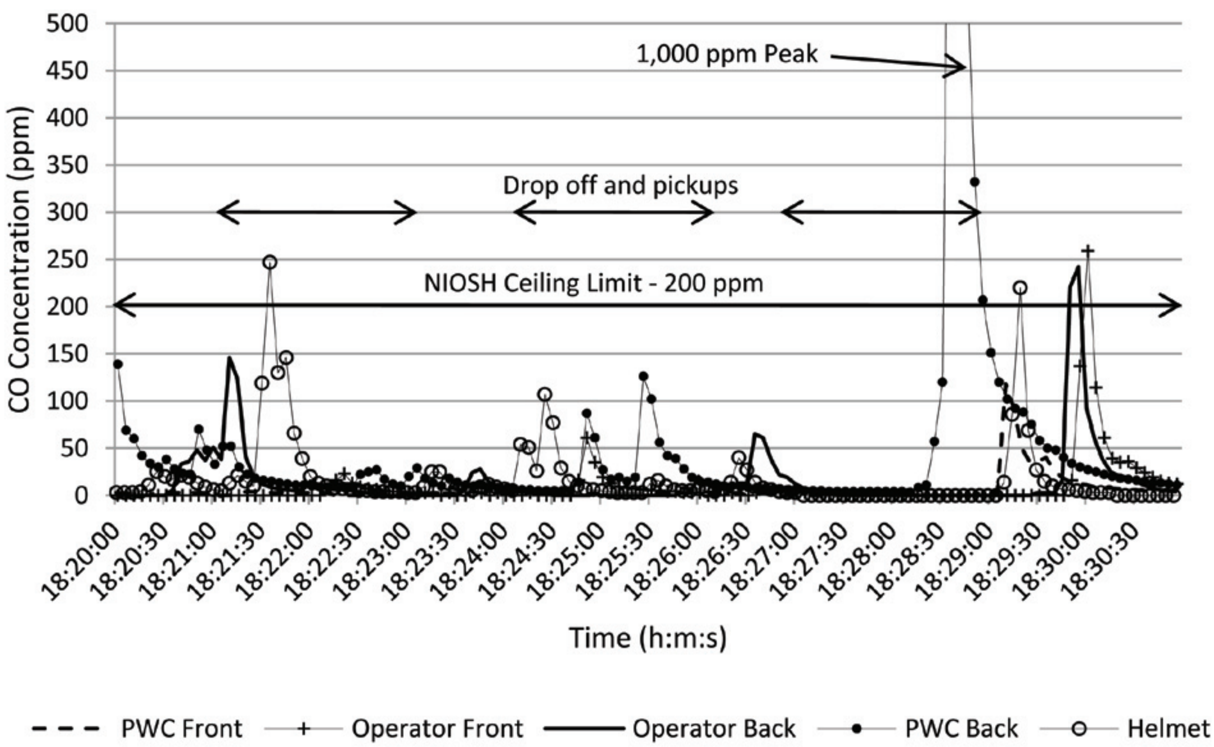

Figure D22. Old PWC real-time CO concentration data – mock rescue in calm water.

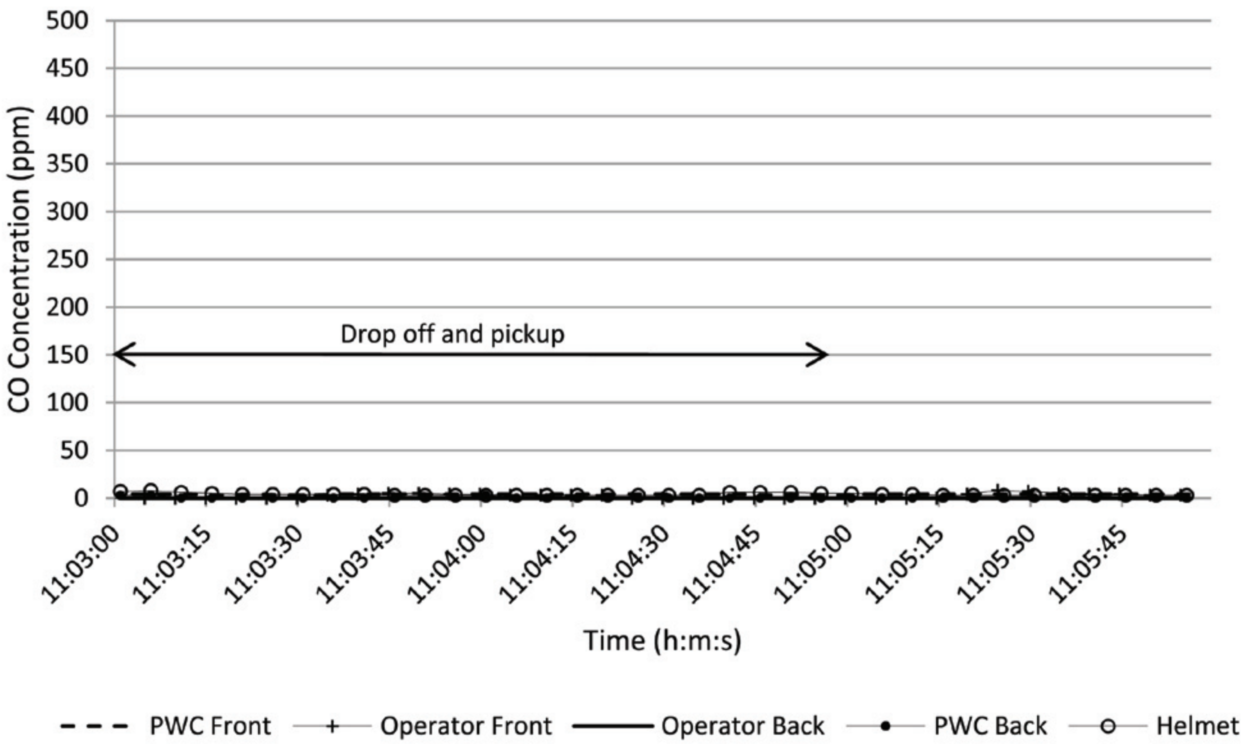

Figure D23. New PWC real-time CO concentration data – mock rescue in calm water, engine off.

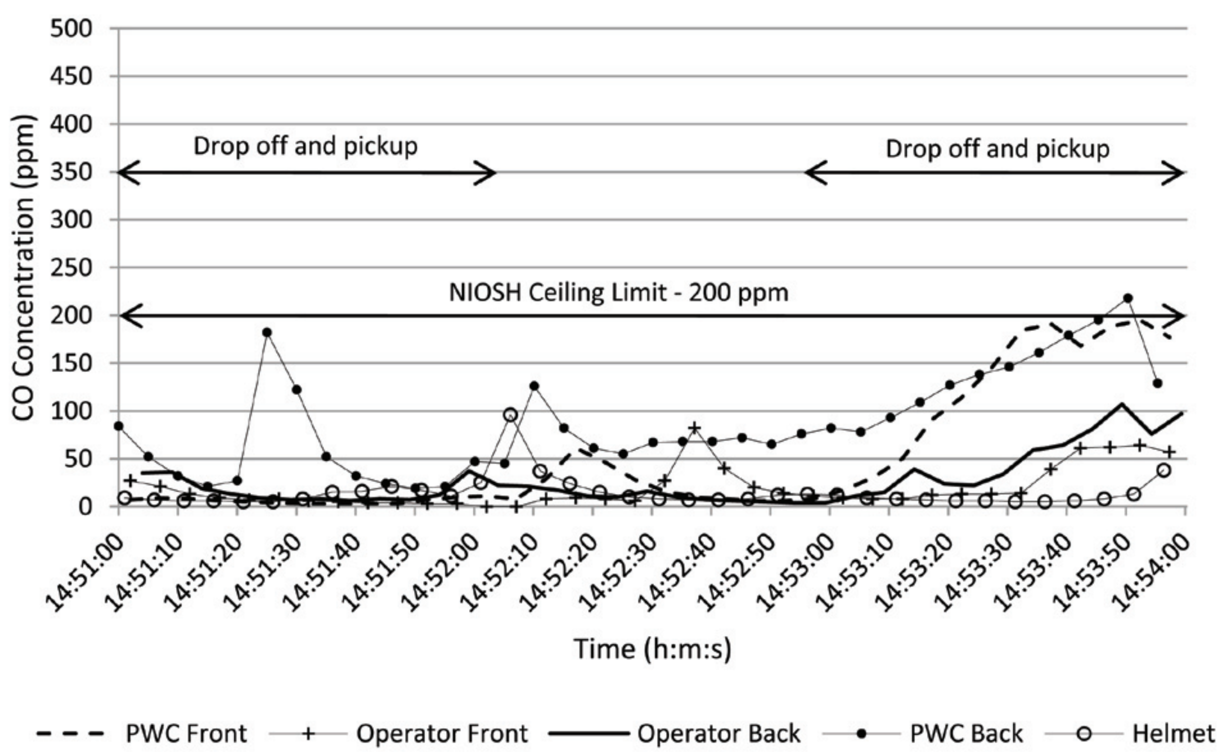

Figure D24. Old PWC real-time CO concentration data – mock rescue in choppy water.

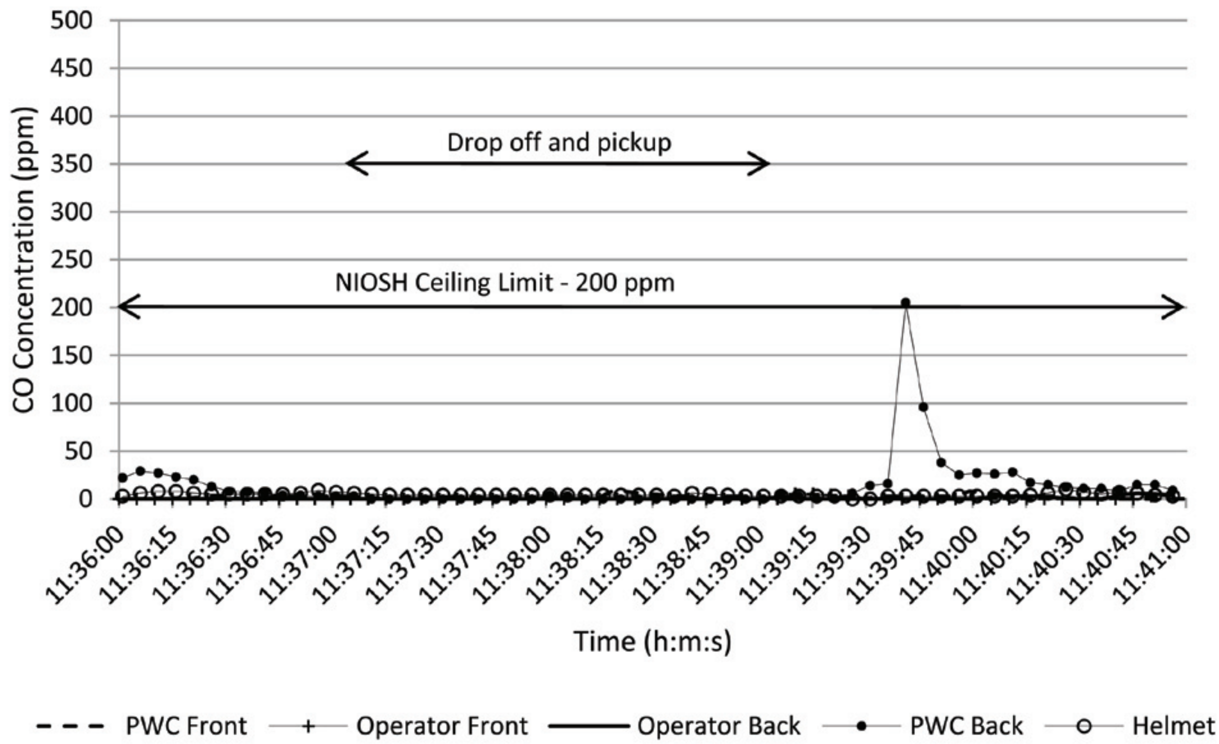

Figure D25. New PWC real-time CO concentration data – mock rescue in choppy water.

Acknowledgments and Availability of Report

The Hazard Evaluations 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 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 employer 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.

This report was prepared by Robert E. McCleery of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies and Alberto Garcia of the Engineering and Physical Hazards Branch of the Division of Applied Research and Technology. Industrial hygiene equipment and logistical support were provided by Donald Booher and Karl Feldmann. Health communication assistance was provided by Stefanie Evans. Editorial assistance was provided by Ellen Galloway. Desktop publishing was performed by Greg Hartle.

Copies of this report have been sent to employee and management representatives of the county fire rescue department, the state health department, and the Occupational Safety and Health Administration Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed at http://www.cdc.gov/niosh/hhe/. Copies may be purchased from the National Technical Information Service at 5825 Port Royal Road, Springfield, Virginia 22161.

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