United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General
Technical Report
PNW-GTR-448
March 1999

Guide to Monitoring Smoke Exposure of Wildland Firefighters

Tim E. Reinhardt, Roger D. Ottmar, and Michael J. Hallett

Authors

TIM E. REINHARDT is an industrial hygienist, Radian International LLC, 11711 S.E. Eighth Street, Suite 200, Bellevue, WA 98005; and ROGER D. OTTMAR is a research forester and MICHAEL J. HALLETT is a physical science technician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 4043 Roosevelt Way NE, Seattle WA 98105.

Abstract

Reinhardt, Tim E.; Ottmar, Roger D.; Hallett, Michael J. 1999. Guide to monitoring smoke exposure of wildland firefighters. Gen. Tech. Rep. PNW-GTR-448. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Fire managers and safety officers concerned with smoke exposure among fire crews can use electronic carbon monoxide (CO) monitors to track and prevent overexposure to smoke. Commonly referred to as dosimeters, these lightweight instruments measure the concentration of CO in the air the firefighter's breathe. This guide outlines the protocol developed for sampling smoke exposure among firefighters with CO dosimeters. It provides a basic template for managers and safety officers interested in establishing their own smoke-exposure monitoring program.

Keywords: Fire, smoke, human health, occupational exposure, safety, smoke exposure.

Contents

This page has been left blank intentionally.
Document continues on next page.

Introduction

Fire managers and safety officers concerned with smoke exposure among their fire crews can use electronic carbon monoxide (CO) monitors to track and prevent over exposure to smoke. Commonly referred to as dosimeters, these lightweight instruments measure the concentration of CO in the air that firefighters breathe. The electronic dosimeter continuously senses the amount of CO in the air it encounters, and when the dosimeter is near the firefighter's face, it measures the CO that the firefighter is exposed to during the workday. Unlike passive sorbent tube dosimeters that indicate CO exposure via a color change, the electronic dosimeter contains electronic circuitry to measure and automatically indicate unsafe levels of CO. Electronic CO dosimeters are versatile, economical tools that can give fire managers instant data about the safety of their crews' working conditions. Advanced models also can record and transfer the data to a computer for a permanent record.

For the past 5 years, the USDA Forest Service, Pacific Northwest Research Station (PNW) in Seattle, Washington, has conducted studies on smoke exposure among wildland firefighters (fig. 1). Through the course of this work, comparisons between CO dosimeter results and traditional CO-exposure sampling methods have proven dosimeters to be accurate and precise, giving minute-by-minute updates of current smoke conditions. Although there are several other hazardous substances in smoke that are difficult and costly to monitor, they are sufficiently correlated with CO to allow measurements of CO exposure to be used to estimate exposure to these additional hazards. This guide outlines the protocol developed at PNW for sampling smoke exposure among firefighters with CO dosimeters. It provides a basic template for managers and safety officers interested in establishing their own smoke-exposure monitoring programs.

Objective of Measuring Carbon Monoxide

Carbon monoxide is a toxic gas and is a common byproduct of incomplete combustion. Dense smoke produced from a wildfire has high concentrations of CO, similar to the exhaust from an automobile engine. The Occupational Safety and Health Administration (OSHA) regulates workplace CO exposure to prevent occupational illnesses. Because CO has no color, odor, or taste, it can be dangerous to firefighters at wildfires and prescribed burns. Although firefighters are usually exposed to less CO than city dwellers, occasionally they encounter higher concentrations on the fireline. Recent measurements of CO exposure among firefighters at both wildfires and prescribed burns have shown that exposure to CO can exceed recommended occupational exposure limits between 1 and 5 percent of the time (Reinhardt and others 1994b). When this occurs, firefighters may have the following symptoms:

- Reduced work capacity
- Loss of time awareness
- Decreased vigilance
- Difficulty with decisionmaking
- Difficulty performing complex tasks
- Headache
- Dizziness
- Nausea

Figure 1—Pike hotshot crew members being sampled for smoke exposure during the County Line Fire.

The consequences of these symptoms can be serious at a wildfire or prescribed burn, where the safety of many people may depend on the actions of someone affected by CO exposure. The symptoms disappear after a few hours in a CO-free environment, but if exposure to high CO levels is sustained, the effects can be more harmful. Firefighters with angina or cardiovascular disease, or those who are pregnant, have an increased risk of adverse health effects from CO exposure. Smokers also may be susceptible to adverse effects from occupational CO exposure because they are already exposed to CO from cigarettes.

There is no suitable respirator currently available to protect firefighters from CO exposure. Organizations that manage wildland fire must accomplish their primary mission; yet their concern about the health of their employees and their legal obligation to provide a safe work environment may conflict with effective fire management. Routine CO monitoring can help to achieve both these goals.

Electronic Dosimeter Capabilities

There are three basic types of electronic dosimeters. Fundamental differences in their capabilities make the selection of the appropriate dosimeter important. The three types are as follows:

- Monitors that simply measure ambient CO levels continuously and alarm when the CO level goes above a preset limit. The Mine Safety Appliance Corporation (MSA) Cricket™ and Industrial Scientific Corporation (ISC) GasBadge™ are two examples of these low-cost devices.[1]

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

- Dosimeters that (1) continuously measure the CO concentration, (2) have alarm capabilities, and (3) calculate an average work shift exposure for comparison with work shift exposure limits. The Draeger® Model 190 dosimeter, MSA MiniCo™, and ISC STX70 display version are examples of these useful dosimeters.

- Datalogging dosimeters (dataloggers) that not only measure and display the ambient and work shift average CO concentrations but also store the data for later analysis on a computer. The Draeger Model 190 datalogger, ISC STX70 datalogging monitor, and the MSA MicroMAC™ personal alarm are examples of dataloggers.

Dosimeters differ in cost and size—some are smaller than a pack of cigarettes. Display and nondisplay versions are available. All models are equipped with an alarm to alert the user when the CO concentration reaches a specific level. Ruggedness, water resistance, ambient temperature limits, and shielding from radio frequency interference are important features to consider when purchasing a dosimeter. (Three manufacturers are listed in the appendix.)

The inexpensive nondisplay dosimeter is useful because it instantly alerts the user when ambient CO concentrations reach the alarm level. No interpretation of numbers is necessary. Although effective at warning users during peak exposure situations exceeding a 200-parts-per-million (ppm) CO ceiling limit, the least sophisticated models are not as effective when CO levels are moderate but variable during the work shift.

As an example, firefighters often will encounter CO levels that rise and fall but usually remain below the ceiling limit. The time-weighted average (TWA) exposure is the important measurement for work shifts during which the ceiling limit is not exceeded. Think of this as an average exposure over the work shift—the “weighting” is a simple formula, important only when the average is based on two or more samples of unequal duration. Depending on the health and safety agency with jurisdiction over the organization (that is, OSHA or an equivalent state agency), the permissible exposure limit (PEL) or threshold limit value (TLV) are the criteria against which the TWA exposure is compared (we recommend a TLV of 25 ppm CO and a ceiling limit of 200 ppm CO).

The TWA is calculated and displayed by the latter two types of dosimeters. As long as the TWA exposure limit is not exceeded, firefighters may continue to work without concern, because periods when CO is above the limit are compensated for by periods when CO is below the limit. When the TWA exposure limit is exceeded, further CO exposure above the limit is unsafe for that work shift. For example, if a crew had accumulated a 25-ppm TWA exposure after the first 4 hours of their 8-hour work shift, the last 4 hours of their shift would have to average less than 25 ppm to keep the total work shift TWA exposure under 25 ppm. By using both the peak and TWA CO-exposure data from a dosimeter, a manager can make informed decisions in the field, thereby preventing hazardous smoke exposure, and yet accomplishing work objectives.

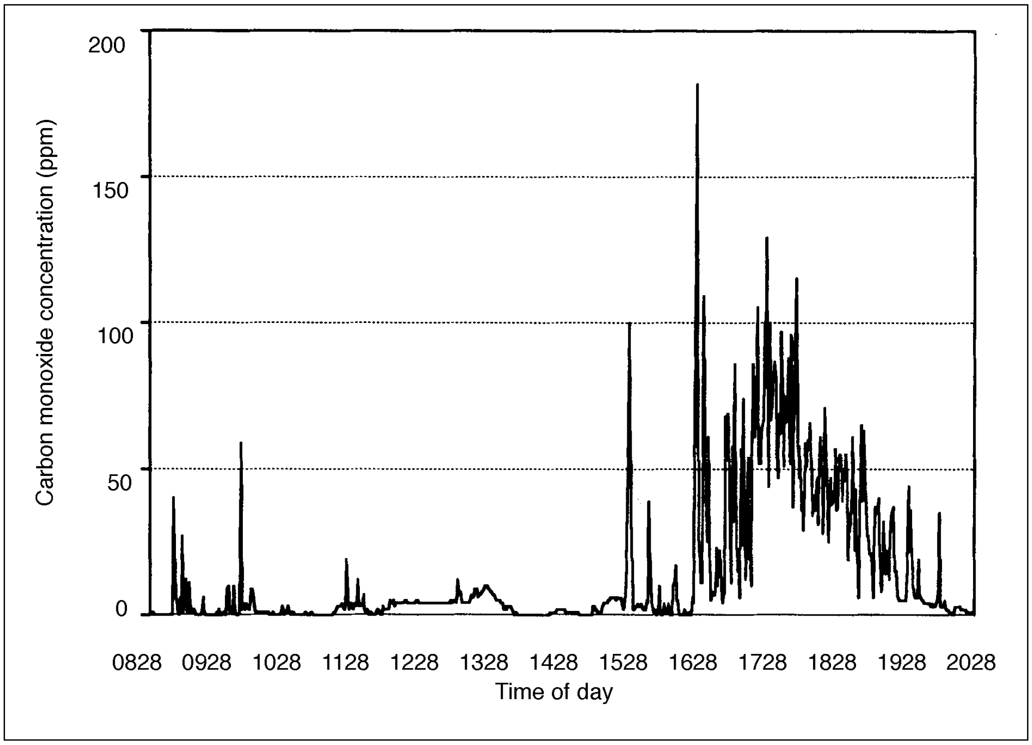

Figure 2—Carbon monoxide exposure at wildfire, August 1994. This record of exposure was taken from a firefighter holding fireline and mopping up during a burnout operation at the Libby Complex, Libby, Montana (Reinhardt and others 1994a).

The great advantage of the datalogging dosimeter is data storage. Data storage, transfer to a computer, and graphing of each CO-exposure "profile" allows the crew supervisor or safety officer to identify which work activities and fireline situations caused hazardous CO exposure during a work shift. Figure 2 shows a graph of CO exposure prepared from such data. This record of exposure was taken from a firefighter holding fireline and mopping up during a burnout operation in August 1994 at the Libby Complex, Libby, Montana (Reinhardt and others 1994a).

In this particular case, local winds increased during the afternoon firing operation, causing significant smoke exposure among personnel holding line. This can be seen by many vertical peaks in CO concentrations between 1630 and 1900 hours. These peaks correspond to periods of dense smoke from the fire. From such graphs, daily CO exposure can be reviewed by managers and safety officers, and crews can be trained to recognize unsafe conditions. In a comprehensive smoke-exposure management program, exposure data can be tracked over many years to evaluate whether smoke-exposure management strategies are effective. Each data file from the datalogger becomes a permanent record of the CO exposure, which is an important consideration when employer liability issues are of concern.

Basic Equipment

The following equipment is needed for calibration and sampling with one of the advanced datalogging electronic dosimeters:

- Electronic datalogging CO dosimeters.
- Replacement CO sensors, filters, and batteries.
- Leak-free tubing and a squeeze bottle of soapy water to check for leaks.
- Certified standard calibration gas mix of CO in air, the concentration of which should be roughly 50 percent of the highest expected exposure, or as specified by the manufacturer.
- Certified quality-control calibration check gas mix of CO in air, the concentration of which should be roughly 50 percent of the calibration gas.
- Grade 5 nitrogen or air for baseline zero check.
- High-pressure regulator for each gas and the necessary adapter fittings to deliver the gases to the dosimeters.
- Soap film flowmeter or calibrated rotameter for setting flow rates if using adjustable regulators (optional).

To be in compliance with OSHA regulations, an effective monitoring program must include adequate documentation of calibrations, sampling, and data analysis. Signed and dated records are best for all aspects of the program. A permanent record of calibration and maintenance data should be maintained in a notebook. Figure 3a shows the minimum calibration check data that should be recorded on each day of monitoring. Identify serial numbers of equipment and keep copies of certifications from gas manufacturers—attention to all details is necessary to prove the validity of the results.

Working with a straightforward data form helps ensure that all necessary information is obtained. Figure 3b shows an example of a data form. Forms should be simple and to the point, with prompts for basic daily information concerning the fire and the firefighter name and duties. Shift and datalogger start and stop times must be noted, and additional information about events such as smoke intensity during the work shift, cigarette breaks, and exposure to engine exhaust may prove useful for data interpretation.

Suggested Protocol

Many choices of equipment, strategy, and protocol may be made when planning a monitoring program. By adhering to a few basic steps, managers can easily obtain accurate and representative CO exposure data. On the other hand, shortcuts can lead to errors and useless data. A general calibration and monitoring protocol is outlined below to help ensure that results are dependable. Whether establishing a monitoring program for a prescribed burning program or a large wildfire, the calibration and equipment management for the monitoring program is best assigned to one or two individuals. The actual monitoring may be accomplished by any responsible field person after some introductory training. Details of the operation of a particular model of datalogger are described in the owners manuals and will not be repeated here.

A

Date	Fire name:									Location:
				Datalogger results (ppm CO)						
	Date	Time	Gas ID	A	B	C	D	E	F	
Pre Zero:										
Pre QCCK:										
Post Zero:										
Post QCCK:										
Calibration checked by:				Signature:						

B

Date:	Fire name:	Location:

Site data		
Windspeed:	Humidity	Fuel type/loading

Carbon Monoxide Exposure Monitoring Date					
Datalogger	Firefighter:		Datalogger	Firefighter:	
A	Time	Activities/smoke	B	Time	Activities/smoke
shift start:			shift start:		
log start:			log start:		
log stop:			log stop:		
shift stop:			shift stop:		
Notes:			Notes:		
Datalogger	Firefighter:		Datalogger	Firefighter:	
C	Time	Activities/smoke	D	Time	Activities/smoke
shift start:			shift start:		
log start:			log start:		
log stop:			log stop:		
shift stop:			shift stop:		
Notes:			Notes:		
Datalogger	Firefighter:		Datalogger	Firefighter:	
E	Time	Activities/smoke	F	Time	Activities/smoke
shift start:			shift start:		
log start:			log start:		
log stop:			log stop:		
shift stop:			shift stop:		
Notes:			Notes:		
Data recorder (signature):			Location/date:		

Figure 3—(A) data form for daily use in the field and (B) exposure monitoring data form.

Calibration

The objective of calibration is to first set the zero baseline of the datalogger in CO-free conditions, and then to set the upper end of the range to a known concentration of CO in air. After calibration, the datalogger should read accurately between these values. The accuracy of the calibration is confirmed each day by the quality-control check (QCCK) results described below. For many dataloggers, calibration is conducted monthly or when necessary as indicated by daily QCCK results.

Calibration can be accomplished in less than an hour by using both a cylinder of nitrogen (or pure air) and a certified (or primary standard) calibration mix containing CO in air. These items and the necessary adapters for the electronic dataloggers are available from the manufacturers as a standard kit. If ambient CO is less than 1 ppm, the nitrogen (or pure air) cylinder is unnecessary. There are many sizes and configurations of cylinders for gases. The best choice depends on the number of dataloggers or dosimeters that must be calibrated, the U.S. Department of Transportation (DOT) compliant transportation options available, and the gas regulators available. Some popular cylinder sizes that emphasize low cost and high transportability are listed in table 1.

Table 1—Typical calibration gas cylinder options

DOT cylinder designation	Capacity	Size	Weight	Approximate number of calibrations per cylinder
	Liters	*Inches*	*Pounds*	
39	17	3 x 11	1.1	25
39	105	3 x 14	2.3	200
3AL	1,019	7 x 16	15	1,700

The type 39 cylinders are nonrefillable but portable. The 3AL cylinders are still small and light but are better for larger monitoring programs where continuity of calibration gases is important because they contain more gas. Compressed gas cylinder transportation must be done according to DOT regulations. Many shippers (especially airlines) will not handle pressurized cylinders of gas, even though the CO-air mixtures and nitrogen are classified as relatively nonhazardous "Compressed Gas-NOS." Finally, be aware that the regulators for gas delivery have specific fittings for each type of gas, and these are not interchangeable among many styles of disposable cylinders. Before working with compressed gases, make sure that personnel know how to handle them safely and that the work space is properly ventilated.

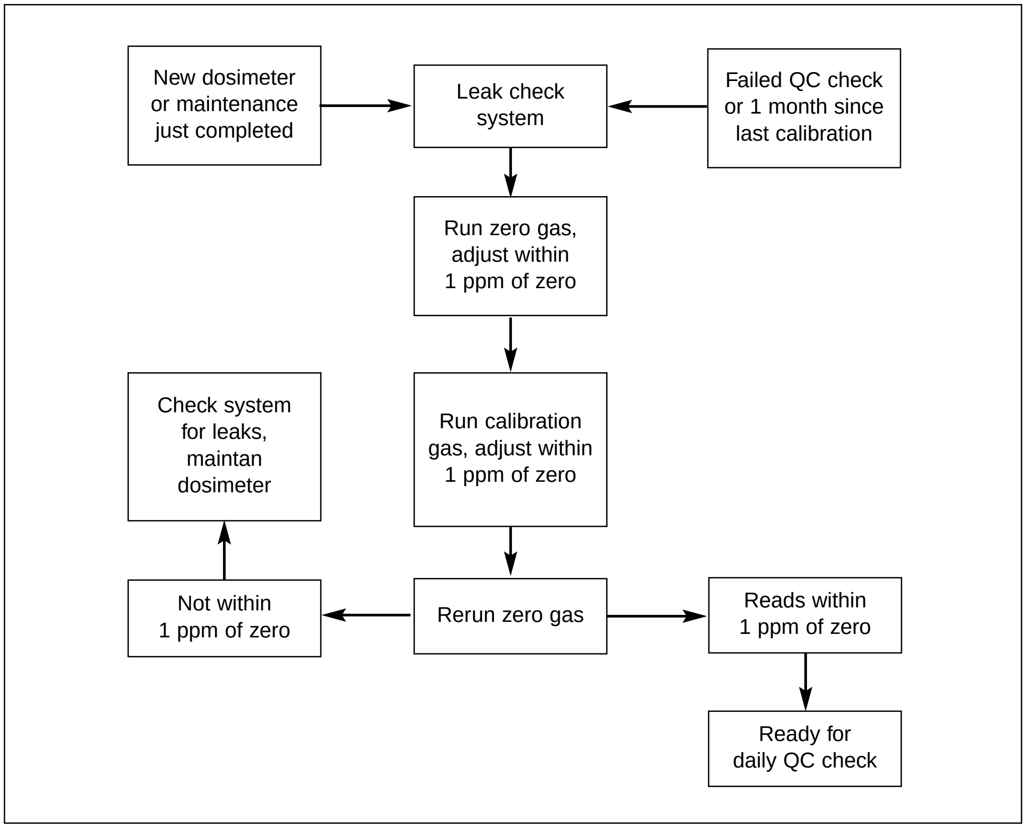

Figure 4—Calibration procedure.

At the PNW lab in Seattle, the calibration gas concentration is 125 ppm, about 50 percent of the highest CO concentration expected. By using the appropriate regulator for each cylinder, a calibration adapter connected to the regulator by tubing delivers the gas supply to the datalogger. The adapter must fit snugly over the sensor, surrounding it with only the selected gas. If an adjustable regulator is used, the gas flow should be set to a constant rate recommended by the manufacturer--use an inline rotameter to ensure that gas is flowing to the sensor during the entire calibration. All connections must be leak free, so each connection is checked for leaks before calibrating. (Apply soapy water to the connections, then pressurize with gas and look for bubbles.) The datalogger is consecutively exposed to the nitrogen (or clean air) and the calibration gas (fig. 4). After equilibrating for a short period, the displayed CO values should be within 1 ppm of the expected value. If not, adjust the calibration reading according to the manufacturer's recommendation. After reexposing the datalogger to nitrogen and ensuring that a zero ppm reading is attained, the instrument is calibrated. If the values displayed by the datalogger are inaccurate or variable during the calibration process, the setup should be doublechecked for leaks and proper gas flow, and maintenance performed on the instrument if necessary.

Alarm Adjustment

Dosimeters are equipped with an audible alarm activated when CO levels reach a specified concentration. On many models, the alarm can be adjusted to serve as an early warning device to alert firefighters before the CO exposure becomes hazardous.

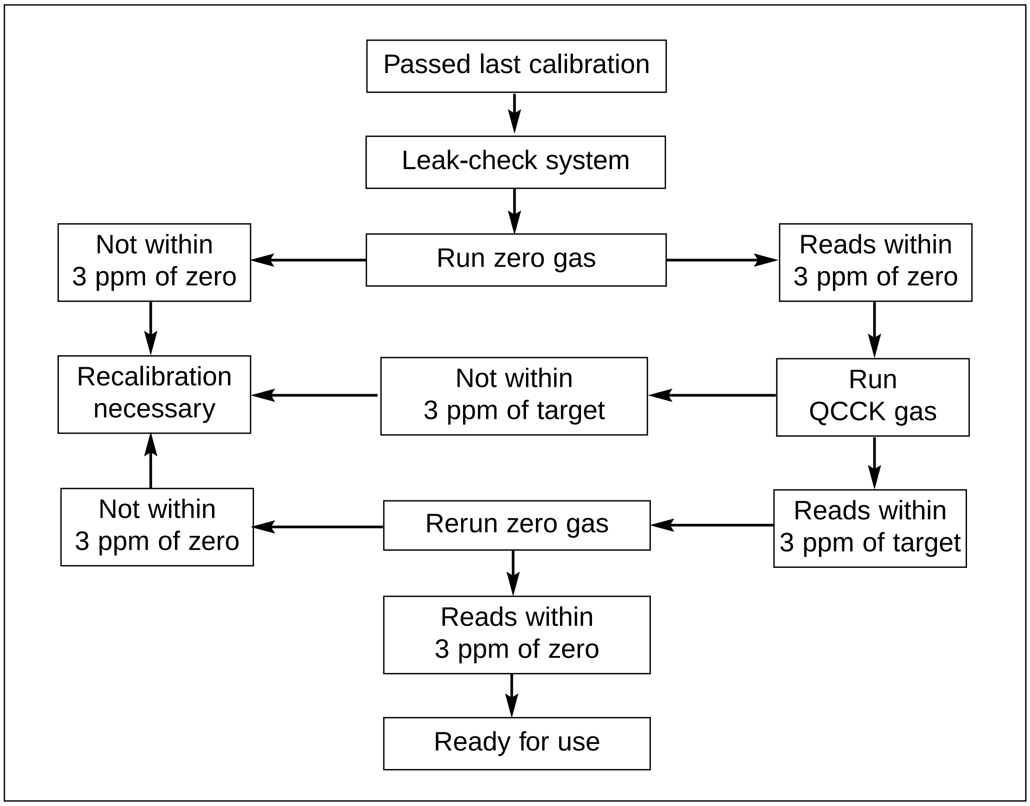

Figure 5—Daily quality-control check.

Setting the alarm level to a CO concentration that is too low could cause workers to develop a habit of ignoring the alarm or removing the dosimeter; the alarm level should be selected with care. The alarm is set to the desired ppm value by a simple adjustment.

Quality-Control Check

At the beginning of each work shift or sample period, the datalogger is run through a brief QCCK evaluation. This assesses the performance of the instrument for the day, ensures that the instrument is correctly calibrated, and gives an indication of the stability and remaining life of the sensor. All pertinent data should be recorded on the zero and QCCK data form (fig. 3a). Ideally, the datalogger calibration is tested before and after each work shift to ensure that the instrument was functioning properly during the monitoring period. Like the calibration, the QCCK process uses the same tubing and adapters but should require less time per datalogger. Skipping the QCCK process leaves an important gap if the goals of the CO monitoring program include obtaining data that can stand up to critical scrutiny.

The QCCK is a two-step process (fig. 5). First, the zero reading of the datalogger is recorded in clean ambient air to ensure that the instrument will not give false high results. If the ambient air is not free of CO, as during atmospheric inversions or near engine exhaust, purified air or nitrogen is used. Unlike calibration, it is important to leave the zero levels unadjusted. After recording the zero reading, the response of the instrument is tested against the independently prepared QCCK gas. Like the calibration gas, this QCCK gas should be a mix of CO in air, but in a range more representative of average exposure levels. At the PNW lab, this gas is procured at roughly 50 ppm.

The independently prepared QCCK gas identifies whether leaks or recording errors have occurred during calibration and verifies the accuracy of the response of the instrument in a range more consistent with actual exposure of firefighters. The QCCK gas also checks on the linearity of the response of the datalogger between zero and the upper calibration point. Datalogger responses that deviate more than a few ppm from either the zero or QCCK value should be considered failure of the QCCK process. In that case, the datalogger may need to be recalibrated or repaired before being used.

Monitoring

The process of selecting firefighters for monitoring has an effect on the data collected, and can cause overestimation or underestimation of exposure if not done in accordance with the objectives of the monitoring program. Random selection is the best approach when objectives of monitoring include tracking the long-term effectiveness of smoke-exposure management efforts. Random selection of a representative firefighter from among the entire crew (or group of drivers, pilots, or fire-camp personnel) is used to help assure that the results are statistically representative of all crew members. Choosing from volunteers does not guarantee representative results. For example, a particular volunteer may avoid smoke because they are concerned about their health; their CO exposure would underestimate the exposure of those who do not avoid smoke. Include all workers in the selection pool to avoid unrepresentative results.
An alternative strategy is to select a likely most-exposed individual. Although this can overestimate the crews' exposure to smoke, it also provides for a margin of safety in hazardous situations. This is a good strategy when the objective is to prevent any CO overexposure, but sometimes selecting the most-exposed individual in advance is impractical.

Once the firefighter is chosen, the datalogger is switched into the logging mode and the start time recorded (fig. 3b). The datalogger is attached to the firefighter's clothing with the sensor in an unobstructed position in the breathing zone, within about 18 inches of the subject's face, and CO-exposure monitoring begins (fig. 6).

Actual CO exposure is continuously recorded by the datalogger. The display for some models will cycle through a readout of current CO concentration, shift TWA, and peak exposure. If the CO alarm sounds during the shift, the crew supervisor can use this information to decide whether to move the crew to safety. We recommend that the TWA exposure to CO should be maintained below 25 ppm, with no peak exposure over 200 ppm. Using the field data form (fig. 3b), record firefighter activity, apparent smoke concentration, and the time of day when conditions change to help interpret the data. During use, avoid exposing the datalogger sensor to cigarette smoke or engine exhaust if these are not representative of crew exposures. An exception may be made for sawyers and swampers, who may endure more CO exposure than others because of chainsaw operation. Crew managers can measure this exposure by using the datalogger and take action if CO exposure during these tasks exceeds recommended limits. Nothing else needs to be done with the datalogger until the end of the shift.

Figure 6—Datalogger in the breathing zone.

At the end of the shift, the instrument is removed and the time is recorded (fig. 3b). After this, the zero and QCCKs are repeated to ensure that the datalogger gave valid results during the entire shift (fig. 4). All data are recorded on the appropriate forms (fig. 3a). Then the stored datalogger results can be downloaded to a personal computer through an adapter to an RS-232 port. If the user is working in the field away from power, a portable computer and a small battery for the RS-232 adapter can be used to transfer the data.

To comply with OSHA and state regulations, notify workers of all monitoring results within 30 days, maintain adequate records, and train workers about the health hazards associated with their work. To ensure the adequacy of the records, the calibration gases should be certified standards, and detailed, signed records of calibrations, QCCKs, and all monitoring results should be kept on file. For assistance with technical questions, planning the program, or interpreting results, consult an industrial hygienist.

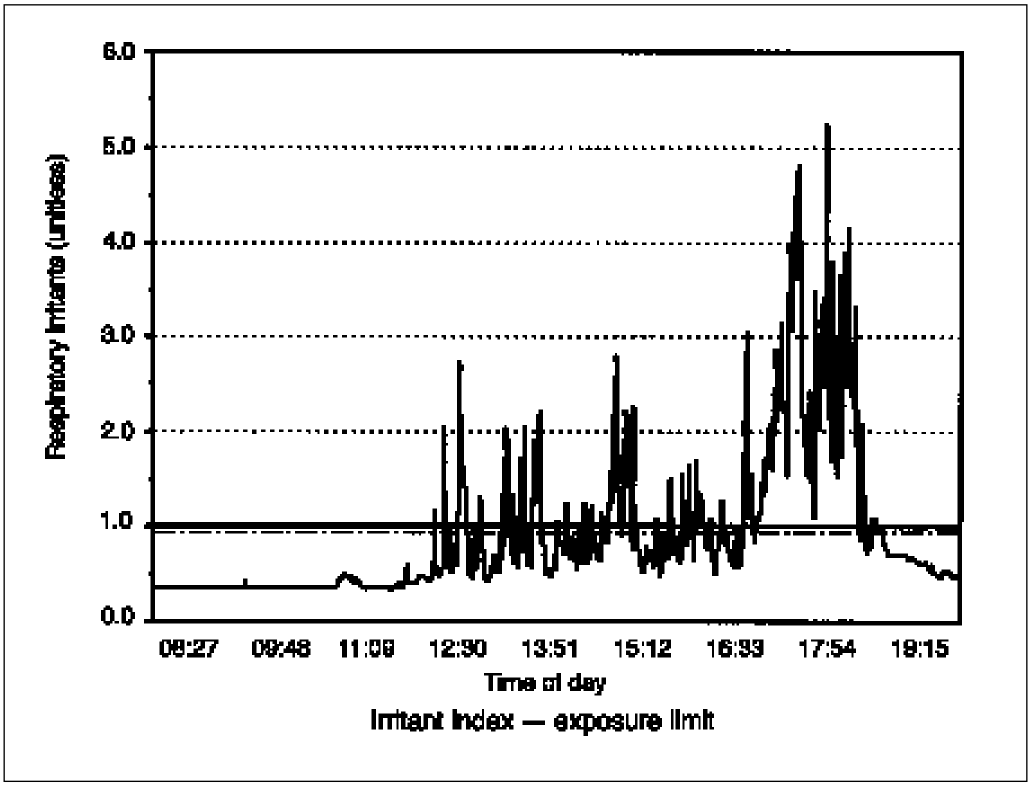

Figure 7—Irritant exposure calculated from a firefighter on the 1994 Libby Complex wildfire, Libby, Montana.

Carbon Monoxide and Other Smoke Hazards

Carbon monoxide-exposure data can be used to estimate exposure to other components of smoke, including benzene and respiratory irritants such as acrolein, formaldehyde, and respirable particulate matter. As in the case of CO, each of these pollutants has its own occupational exposure limit. When assessing exposure to multiple irritants in smoke, their combined impacts should be considered because they all affect the respiratory system (benzene is excluded because it is not a respiratory irritant). One way to do this is with a combined exposure index (fig. 7).

By using CO as a surrogate measurement, exposure estimates are first obtained for the respiratory irritants. Table 2 contains several equations relating pollutant exposure to CO in smoke. These equations were developed at PNW from data obtained at wildfires in the Western United States and may not work for other regions.[2] The benzene equation does not apply if sources of gasoline vapor or engine exhaust affect the worker, because the equation was developed only for wood smoke, not the additional benzene from those sources. Exposure to each irritant in smoke is estimated by applying the appropriate regression equation for each irritant. Next, the combined exposure is calculated by summing each irritant exposure divided by its exposure limit, to calculate a unitless index of exposure, E_m. This index must be maintained below 1.0 to ensure a hazard-free workplace, as it was in figure 7.

[2] Reinhardt, T.E.; Ottmar, R.D. [In prep.]. Smoke exposure at western wildfires.

Table 2—Equations to correlate respiratory irritants to CO in smoke

Pollutant	Units	Regression equation for analyte	r^2 value
Formaldehyde	ppm	[HCHO] = 0.0034x[CO]+0.003	.77
Respirable Particulate	mg/m^3	[PMc.5] = 0.049x[CO]=.88	.74
Acrolein	ppm	[ACRO]=0.0004x[CO]=0.004	.57
Benzene	ppm	[BENZ]=0.0011x[CO]+0.003	.95

For example, assume that the TWA CO exposure of a firefighter is 23 ppm. By using the four regression equations, the following tabulation shows the corresponding pollutant exposures:

Pollutant	**TWA exposure regression result**	**Recommended TWA exposure limit**
Formaldehyde (HCHO)	0.08 ppm	0.3 ppm
Respirable particulate	2.15 mg/m^3	3 mg/m^3
(PM3.5)		
Acrolein (ACRO)	.01 ppm	.1 ppm
Benzene (BENZ)	.03 ppm	.3 ppm

The combined irritant exposure is calculated as shown in the following equation:

$$E_M = \frac{[HCHO]}{0.3} + \frac{[PM3.5]}{3} + \frac{[ACRO]}{0.1}$$

$$E_M = \frac{[0.08]}{0.3} + \frac{[2.15]}{3} + \frac{[0.01]}{0.1} = 1.08 \; .$$

Because the irritant exposure exceeds 1.0, it must be reduced to achieve compliance with recommended irritant exposure limits. Although the firefighter was not overexposed to CO, the exposure to respiratory irritants should be reduced. With proper advance training in respirator use, a lightweight half-mask respirator for fine particles could achieve this irritant control, but CO exposure must continue to be monitored closely in similar situations. This is especially important when using a respirator, because although it affords relief from respiratory tract irritation, it does nothing to reduce CO exposure.

These straightforward calculations provide much more information from the datalogger—not only the CO data, but also a good indication of what the exposure is to respiratory irritants and benzene. Using this approach alleviates the need to monitor each pollutant separately. The correlations give a more complete picture of smoke exposure, providing managers with the information necessary to judge whether respiratory protection is needed to control irritant exposure, or whether the CO hazard still is high enough to warrant moving the crew into clean air.

Conclusion

Smoke-monitoring programs can be easy to implement when using CO dataloggers. Data collection can be done at both prescribed burns and wildfires with a minimal investment of time. For that investment, managers can gain valuable information to help recognize and control unhealthy smoke-exposure situations. The simplest dosimeter can alert firefighters to high levels of CO and other smoke-related hazards. Objective smoke-exposure information removes the guesswork when making decisions about firefighting strategy and crew safety, and provides detailed data when reviewing events for planning, training, and management purposes. By using this guide to start a comprehensive smoke-exposure monitoring program, you can be assured that the right steps will be taken to collect useful information. Once the data collection becomes routine, managers can evaluate the results and determine whether smoke-exposure management strategies are working. When managers can reduce the health stress that smoke exposure causes, fire crews will have more work capacity and less illness and lost work days, thereby resulting in a more productive workforce.

Literature Cited

Reinhardt, T.E.; Black, J.; Ottmar, R.D. 1994a. Smoke exposure at Pacific Northwest wildfires. [Place of publication unknown]: [Publisher unknown]; final report; Radian Corporation contract 53-05m6-2-0032. 129 p. Available from: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 4043 Roosevelt Way NE, Seattle, WA.

Reinhardt, T.E.; Hanneman, A.H.; Ottmar, R.D. 1994b. Smoke exposure at prescribed burns: health hazards of smoke. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center: 2-3.

Appendix

Manufacturers for purchasing CO dataloggers

Industrial Scientific Corporation
1001 Oakdale Road
Oakdale, PA 15071-1500
(412) 788-4353
(800) DETECTS

Mine Safety Appliances
P.O. Box 426
Pittsburgh, PA 15230
(800) MSA-2222

National Draeger, Incorporated
101 Technology Drive
Pittsburgh, PA 15275
(412) 787-8383
(800) 922-5518

This page has been left blank intentionally.
Document continues on next page.

This page has been left blank intentionally.
Document continues on next page.

This page has been left blank intentionally.
Document continues on next page.

Reinhardt, Tim E.; Ottmar, Roger D.; Hallett, Michael J. 1999. Guide to monitoring smoke exposure of wildland firefighters. Gen. Tech. Rep. PNW-GTR-448 . Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Fire managers and safety officers concerned with smoke exposure among fire crews can use electronic carbon monoxide (CO) monitors to track and prevent overexposure to smoke. Commonly referred to as dosimeters, these lightweight instruments measure the concentration of CO in the air the firefighter's breathe. This guide outlines the protocol developed for sampling smoke exposure among firefighters with CO dosimeters. It provides a basic template for managers and safety officers interested in establishing their own smoke-exposure monitoring program.

Keywords: Fire, smoke, human health, occupational exposure, safety, smoke exposure.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208