USDA
United States Department of Agriculture

Wildland Firefighter Smoke Exposure

Forest Service
National Technology & Development Program
1351 1803
5100—Fire Management
October 2013

Wildland Firefighter Smoke Exposure

By

George Broyles
Fire Project Leader

EXECUTIVE SUMMARY

- Exposure to carbon monoxide (CO), respirable dust (PM4) and crystalline silica (SiO2) was measured on wildland firefighters and incident camp personnel.
- Firefighters exceeded the Occupational Safety and Health Administration (OSHA) 8-hour exposure level 3.5 percent of the time at prescribed fires and 5.6 percent of the time at project fires. See table 3.
- Exposure to wildland smoke, even at low-to-moderate levels, presents a safety and health hazard to wildland fire personnel.
- Training on the safety and health hazards of smoke is critical in order to assure the safety of all personnel.
- Training needs to be directed at all levels of the agency including firefighters, fire management personnel, and line officers.
- Mitigation measures to reduce exposure must be accepted and enforced.

INTRODUCTION

At the request of the National Wildfire Coordinating Group (NWCG) Equipment and Technology Committee, the Technology and Development Center of the Forest Service, an agency of the U.S. Department of Agriculture, undertook a project to determine the exposure levels of wildland smoke to firefighters. In 2010, at the request of the NWCG Risk Management Committee, the study was expanded to include all personnel assigned to wildland fires, specifically those in support positions (NWCG Tasking Memo TM-2008-04). This report discusses the preliminary findings from a 4-year assessment of exposure to smoke and respirable dust from wildland and prescribed fires and includes a discussion of the health and safety concerns associated with smoke inhalation.

Wildland firefighters work in a dynamic environment and often are faced with a variety of hazards from fire to fire and from shift to shift. One common, but often overlooked hazard is exposure to potentially harmful levels of contaminants in wildland smoke. This also may be one of the least understood risks of wildland firefighting (Reisen et al. 2009).

Wildland firefighters are subject to exposure from a variety of inhalation irritants ranging from carbon monoxide, aldehydes, particulate matter, crystalline silica, and polycyclic aromatic hydrocarbons. Some of the compounds in wildland fire smoke are confirmed carcinogens (benzene, formaldehyde, and certain polynuclear aromatic hydrocarbons (PAH)) or suspected carcinogens. Health effects may include short-term conditions, such as headaches, fatigue, nausea, and respiratory distress while long-term health effects may include an increased risk of cardiovascular disease. In order to assess the risks associated with wildland firefighting, a comprehensive study of exposure was necessary. By identifying the conditions and activities that lead to high exposure, firefighters and fire managers can be better prepared to reduce exposures that exceed the levels identified as safe.

Particulate exposure during inversion, Roosevelt IHC, Tumblebug Fire, 092609

Vegetative Smoke Concerns

Vegetative smoke contains numerous inhalation irritants with the potential to cause short- and long-term health hazards to wildland firefighters in the normal course of their duties (Reinhardt 1991; Reinhardt and Ottmar 1997, 2004).

Previous NWCG-sponsored smoke exposure studies indicate that employees were overexposed to CO approximately 5 percent of the time at wildfires and 10 percent of the time at prescribed fires (Reinhardt et al. 2000). The National Institute for Occupational Safety and Health (NIOSH) has done several studies that indicate a concern for both wildland firefighters and support personnel working at incident command posts (ICPs) and other fire camps. However, there has not been a study that encompasses the wide geographic area where wildland firefighters work, nor has a study covered sufficient numbers of firefighters that would allow the Forest Service to accurately determine exposures for the various duties, environments, and other variables associated with wildland firefighting.

Regulatory Organizations

Federal agencies establish safety and health laws and recommendations. This includes Federal laws established by the Occupational Safety and Health Administration (OSHA) and NIOSH recommendations, which are called recommended exposure levels (RELs). Nongovernmental organizations, such as the American Conference of Governmental Industrial Hygienists (ACGIH) also publish threshold limit values (TLVs®). Together these are called occupational exposure levels (OELs) designed to protect the health and safety of workers.

Occupational Safety and Health Administration

Wildland firefighters are covered by the regulations set forth by OSHA as are all workers, regardless of who they work for, where they work, or the type of work performed. There are no exemptions from these regulations because they are Federal employees or work in emergency situations.

All employers are legally required by the Occupational Safety and Health Act to meet the levels specified by an OSHA standard. Federal employees are covered by OSHA standards under Executive Order 12196 (Feb. 26, 1980, 45 Federal Register 12769, 3 Code of Federal Regulations, 1980), Occupational Safety and Health Programs for Federal Employees of 1980. According to Executive Order 12196 , the head of each agency shall: “Furnish to employees places and conditions of employment that are free from recognized hazards that are causing or are likely to cause death or serious physical harm.” OSHA sets permissible exposure limits (PELs) for all Federal employees and private employees not covered by a State agency. These PELs are legally binding and enforced by the Federal government.

The original PELs established by OSHA in 1970 were adopted from the ACGIH TLVs® from 1968 and the standards of the American National Standards Institute.

National Institute for Occupational Safety and Health

NIOSH provides guidance to OSHA on health hazards and establishes recommended exposure limits (RELs). NIOSH recommended standards are based on concerns relating to the prevention of occupational disease. Although NIOSH standards are often based on more recent scientific research than OSHA PELs, they have no legal authority. NIOSH often follows the guidance set by ACGIH.

American Conference of Governmental Industrial Hygienists

The ACGIH standards also are recommended standards and have no legal authority. ACGIH publishes revised TLVs® yearly; consequently, these are the most current OELs available and are based on the latest scientific research. In most cases, the TLVs® are more restrictive than OSHA PELs.

Environmental Protection Agency

The Environmental Protection Agency (EPA) also establishes exposure limits called the National Ambient Air Quality Standards (NAAQS). The NAAQS are established under Title 40 U.S Code of Federal Regulations Part 50 and cover a limited number of pollutants called “criteria” pollutants. These standards are designed to protect the health of all citizens including those at higher risk or sensitivity, such as children, asthmatics, and the elderly. Consequently, the EPA guidelines typically are much more restrictive than those established for the workplace. The exception to this is for carcinogens, which do not have toxicity thresholds because they pose a potential risk regardless of the exposure level. Exposure to carcinogens is evaluated by assessing the level of cancer risk posed by the exposure and compared to “acceptable risks,” which are established by the EPA or other agencies, such as OSHA.

Occupational Exposure Limits

OSHA, NIOSH, ACGIH, and some States set exposure limits for airborne irritants for various time frames (see table 1). OELs are based on an exposure level (dose) and time. Dose is the amount of irritant going to a target organ and is dependent on the level and duration of exposure as well as the rates of uptake and elimination by the body. The time is an average time for the exposure and can be set at any amount, but it is dependent on the toxicity of the specific irritant.

Time weighted average (TWA) is commonly set for a “normal” 8- to 10-hour workday and a 40-hour workweek. It is an average concentration across the daily and weekly work shift that should not be exceeded and will provide a safe work environment for a career-length exposure.

Short-term exposure limit (STEL) is a 15-minute TWA exposure that should not be exceeded at any time during the workday. These typically are set for quick-acting toxins. These are established by ACGIH and some States.

Ceiling (C) limits, established by NIOSH, are exposures that should never be exceeded, even instantaneously. Ceiling limits are appropriate for very fast-acting agents, particularly if there could be irreversible health effects.

Immediately Dangerous to Life and Health (IDLH) limits, established by NIOSH, originally were developed to ensure that a worker could escape without injury or irreversible health effects from the exposure. Although the IDLH was based on a 30-minute exposure, they are not intended to imply workers should stay in that environment for 30 minutes but should in fact leave immediately. This is used for fast-acting toxins.

Special Considerations for OELs in the Wildland Fire Environment

OELs are established for traditional work schedules and environments, and therefore may not provide the expected level of safety for workers in nontraditional jobs, such as wildland firefighting. They are based on an 8-hour workday/40-hour workweek, and sedentary work. In addition, these OELs do not account for exposure to multiple toxins simultaneously. The exposure duration and irritant uptake assumptions used to develop OEL criteria may not be appropriate for wildland firefighters. Therefore, in order to accurately assess wildland firefighter exposure, these differences must be accounted for. Adjustments must be made to the occupational exposure criteria to account for work schedules, exertion, and concurrent exposures that create a synergistic or additive health risk. These adjustments are required to maintain the peak dose below the level that workers would experience in a “standard” workplace.

NIOSH set the CO REL based on an 8-hour workshift, sedentary work activity, dry barometric pressure in the lungs, and the partial pressure of oxygen in the capillaries. The last two variables are affected by altitude, and NIOSH used sea level for their standard of 35 parts per million (ppm). Although several of the variables in the equation used to calculate the REL are constants due to physiological processes, some of them can be changed to better describe the work environment for wildland firefighters. These are length of shift, level of work activity, and altitude. When exposure occurs at elevations above 5,000 feet, NIOSH recommends lowering the CO REL to compensate for the loss in the oxygen-carrying capacity of the blood. Two other variables also are used to compensate for different work conditions: the CO diffusion rate through the lungs (DL) and the ventilation rate (VA).

Both DL and VA have values for sedentary, light, and heavy work activity levels. When calculating a safe REL for wildland firefighters, NIOSH recommends using the heavy work level for DL and VA to ensure an exposure level that would result in a carboxyhemoglobin (COHb) level of 5 percent. COHb levels of 5 percent or less pose no significant harmful effects. By adjusting for the appropriate DL and VA, a lower 8-hour REL can be calculated to provide a safe exposure level for CO.

WILDLAND FIRE SMOKE

Components of Wildland Fire Smoke

It is common knowledge that fires produce smoke—although the components within smoke are complex and often misunderstood. Smoke is the most obvious product of wildland fires and results from the incomplete combustion of forest fuels, which are carbon-based compounds, both organic and inorganic. As the smoke interacts with the atmosphere, intermediate chemicals also are formed (U.S. Department of Agriculture, Forest Service 1989).

As a wildland fire progresses through its burning phases, different compounds/chemicals are released (Reisen and Brown 2009). In the initial stage, as the fuel heats up, liquid in the vegetation volatilizes and several volatile organic compounds (VOCs) are released. As decomposition of the fuel occurs, volatile gases are released including carbon monoxide (CO), carbon dioxide (CO_2), and oxygenated-VOCs (OVOCs). OVOCs include methanol, acetic acid, acetone, and furan. The flaming phase releases gas-phase emissions, primarily oxidized compounds such as CO_2, nitrous oxides (NO_x), sulfur dioxide (SO_2), hydrogen chloride (HCl), and aerosols. Burling et al. (2010) identified the following compounds associated with flaming combustion: CO_2, NO, NO_2, HCl, SO_2, and HONO (nitrous acid). The fire then reverts to the smoldering phase/glowing combustion phase, which releases CO, methane (CH_4), ammonia (NH_3), and SO_2. As a wildland fire moves across the landscape, all these phases may occur simultaneously. However some fuels, such as grasses and other fine fuels, will be dominated by the flaming phase (Barboni et al. 2010; Burling et al. 2010; Bytnerowicz et al. 2009). Barboni et al. (2010) identified 79 compounds in smoke produced from prescribed fires on the island of Corsica (France). These fires were in typical Mediterranean vegetation, which is similar to that found in many areas of southern California.

There are several irritants in wildland smoke that are of particular concern to wildland firefighters due to their potential health consequences. Polynuclear aromatic hydrocarbons (PAH) are contained within the fine particulate matter and are a byproduct of the combustion of organic matter such as wood (U.S. Department of the Interior 1992). Aldehydes, most notably formaldehyde, also are produced from the incomplete combustion of burning biomass (Ward 1998). Reinhardt and Ottmar (2004) also identified several compounds of particular concern in wildland fire smoke including CO, benzene, acrolein, formaldehyde and, of course, particulate matter.

The visible portion of smoke is composed of particulate matter (PM). There are two primary classes of particulates: fine particles with a mean aerodynamic diameter of less than 2.5 micrometers (µm) and coarse particulates which have a mean aerodynamic diameter less than 10 micrometers (PM_{10}). Exposure criteria for PM 2.5 and PM 10 apply to the general population. Respirable dust is commonly used for occupational exposure.

As products of combustion react in the atmosphere, intermediate chemicals are formed. The majority of these intermediate chemicals are free radicals (U.S. Department of Agriculture, Forest Service 1989). Nitrous oxide gas (HONO), also present in the smoke, becomes a source of hydroxyl (OH) radicals (Burling et al. 2010). Although many of the free radicals may dissipate quickly after leaving the flaming zone, some may persist for up to 20 minutes.

Not all phases of combustion are equal in their production of chemical compounds. Smoldering combustion can produce several times more mass of pollutants compared to a fire in which the majority of the fuel is consumed in the flaming phase (Bytnerowicz et al. 2009).

Fuel types can influence the primary type of combustion. For example, peat, rotten logs, and deep duff will tend to smolder whereas dry, light fuels will tend to be consumed in the flaming stage; and therefore, less particulates and CO will be released.

Although not a result of the burning of biomass, crystalline silica (SiO_2) poses a health concern to wildland firefighters. SiO_2 is a basic component of soil, and quartz is the most common form (Occupational Safety and Health Administration 2002b). Exposure to SiO_2 occurs when it is present in the soil and firefighter activity makes it airborne, for example when traveling on dusty roads, hiking on trails or through burned areas, and especially during mopup.

Particulate exposure during hike, Wolf Creek IHC, Rooster Rock Fire, 080710.

Vegetative Smoke Concerns

Carbon Monoxide

As CO is inhaled it displaces O_2 as it attaches to red blood cells and forms COHb. COHb reduces the ability of the blood to carry oxygen and causes hypoxia (a condition in which the body does not receive sufficient oxygen). In an effort to compensate for this deficiency, the body increases the heart rate and blood flow to certain areas of the body, especially the heart and brain.

Due to their strenuous work, wildland firefighters often have increased respiratory rates, which will increase the amount of CO being inhaled when smoke is present. COHb has a half-life (the time it takes half of the COHb to dissipate from the body) of about 5 hours, and the CO will leave the body through exhalation when the person is breathing clean air (Occupational Safety and Health Administration 2002a).

Symptoms of CO exposure include headaches, dizziness, nausea, loss of mental acuity, and fatigue. Prolonged, high exposure can cause confusion and loss of consciousness. These symptoms can be more acute for people with heart or lung disease, smokers, and at high altitude. Coma and/or death may occur if high exposure continues (Occupational Safety and Health Administration 2002a).

Sulfur Dioxide

Sulfur dioxide (SO_2) exposure causes severe irritation of the eyes, skin, upper respiratory tract, and mucous membranes, and also can cause bronchoconstriction. SO_2 forms sulfuric acid in the presence of water vapor. SO_2 has been shown to damage the airways of humans, and long-term exposure reduces lung volume and its ability for gaseous diffusion (Bytnerowicz 2009).

Particulate Matter

Particulate matter is described by its mean aerodynamic diameter because the size of the particle determines how far it will travel through the human respiratory system. The smaller the size, the deeper it will penetrate the respiratory tract. Gases and liquids present in the smoke adhere to the particles and thus can enter the airway, lungs, and bloodstream. Respirable particulates are a major concern as they can be inhaled into the deeper recesses of the lungs, the alveolar region. These particles carry absorbed and condensed toxicants into the lungs (U.S. Department of Agriculture 1989; Bytnerowicz 2009).

Respirable particulate matter (RPM) inhalation can cause inflammation of the lungs, and short-term effects include cough, shortness of breath, and chest pain.

Aldehydes (VOCs)

Aldehyde compounds can cause immediate irritation of the eyes, nose, and throat, and inhalation can cause inflammation of the lungs. Short-term effects include cough, shortness of breath, and chest pain (Reinhardt 1991; U.S. Department of Agriculture 1989). Some aldehydes are carcinogens. The most abundant aldehyde in smoke is formaldehyde. When formaldehyde enters the body, it is converted to formic acid, which also is toxic.

Acrolein

Another aldehyde present in smoke is acrolein, which may increase the possibility of respiratory infections (Reinhardt 1991; U.S. Department of Agriculture 1989). Acrolein exposure can cause irritation of the nose, throat, and lungs. Long-term effects can include chronic respiratory irritation and permanent loss of lung function if exposure occurs over many years (U.S. Department of Agriculture 1989).

Benzene

Benzene, when inhaled, can cause headaches, dizziness, nausea, confusion, and respiratory tract irritation. Although the human body can often recover and repair damage caused by irritants, prolonged exposure from extended work shifts and poorly ventilated fire camps can overwhelm the ability to repair damage to genes and deoxyribonucleic acid (DNA) (U.S. Department of Agriculture 1989).

Crystalline Silica

Prolonged and excessive exposure to crystalline silica in mining dust can cause silicosis, a noncancerous lung disease that affects lung function. Crystalline silica is the second most common element in the earth's crust and is found throughout many areas of the world. Crystalline silica is classified as a human carcinogen (Occupational Safety and Health Administration 2002b).

Intermediate Chemicals

As smoke interacts with the atmosphere, intermediate chemicals are formed, the majority of which are usually in the form of carbon, hydrogen, and oxygen free radicals (Leonard et al. 2000; Leonard et al. 2007). These free radicals have been shown to cause a variety of health problems including bronchopulmonary carcinogenesis, fibrogenesis, pulmonary injury, respiratory distress, chronic obstructive pulmonary disease (COPD), and inflammation (Leonard et al. 2007).

As can be seen from the summary of these irritants several components in wildland smoke cause similar symptoms as they affect the same organs. This is particularly important as exposure to low or moderate levels of wildland smoke may cause immediate safety and health concerns due to the additive effect these irritants have on wildland firefighters.

Wildland Firefighter Studies

There have been numerous studies done to assess wildland firefighter exposure over the past 25 years. NIOSH began its' research in 1988 on the Yellowstone fires and many others have followed since. This research has helped identify health concerns with exposure to wildland fire smoke and many researchers have made recommendations for further research and have put forth recommendations to reduce exposure.

Most researchers agreed that more definitive exposure measurements were needed to more accurately identify areas of concern, and future research must account for the full range of exposures across the full range of geographic areas where wildland fires occur. A common thread throughout many of the studies discussed made it clear that a larger more comprehensive exposure assessment was required to address wildland firefighter exposure. For example, Reh and Deitchman (1992) echo many researchers when they state their small sample size made it impossible to make broad-based generalizations about firefighter exposure.

Lighter on prescribed fire, Payson IHC, 110410.

This Wildland Firefighter Smoke Exposure project was designed to address many of the recommendations made by previous researchers in an attempt to provide a better understanding of exposure to wildland firefighters. To that end, this project achieved several significant goals.

- Data was collected;
  - In 11 of the National Fire Danger Rating System (NFDRS) fuel models.
  - In 17 States.
  - On initial attack, prescribed, and large project fires.
  - On over 30 different job tasks.
  - During high exposure events.
  - In Incident Command Posts (ICPs) and spike camps.
  - During crystalline silica exposure.

Throughout the course of this project CO was measured with electronic datalogging dosimeters according to OSHA Method ID-209, using Mine Safety Appliances Altair Pro Fire single gas CO dosimeters. Dosimeters were placed in the breathing zone of the firefighter and directly recorded 1-minute peak and average CO levels throughout the work shift.

CO dosimeter and cyclone for PM4 measurement, Baker River IHC, Oak Flat Fire, 082010.

There are several reasons to measure CO exposure on wildland firefighters. Most importantly, CO can be used as a surrogate for the primary irritants of concern in wildland smoke near the combustion source. Reinhardt and Ottmar (2004) found a strong relationship between the level of CO in wildland smoke and several of these irritants including formaldehyde and respirable particulate matter. With the advances in exposure monitoring equipment accurate CO measurements can now be done on wildland firefighters. The Risk Management Committee's Smoke Exposure Task Group also requested that PM4 be measured with CO to validate the CO/PM relationship on a larger sample across different geographic areas of the United States.

Measuring respirable dust and SiO_2 requires the use of personal industrial hygiene sampling equipment. These measurements were made with Airchex XR 5000 industrial hygiene personal sampling pumps attached to a BGI Triplex Cyclone designed to have a 50 percent aerodynamic cutoff point of 4.0 µm. Respirable dust was measured in this project because it is more applicable to occupational exposures.

Work Activity. In order to determine if different activities are related to exposure, everything the firefighters did was directly observed and recorded. Job activities recorded during the data collection included fireline construction, hiking, mopup, holding, and briefing. Minute-by-minute observations were recorded for later analysis and comparisons of CO exposure versus activity. By remaining with the crew throughout the entire shift, accuracy of the data and accounting for any factors that may influence smoke exposure levels was ensured.

Environmental Conditions

Weather readings were taken hourly in order to assess the effect of wind, relative humidity, and temperature on exposure. Barometric pressure, fire behavior, and other environmental values also were recorded on an hourly basis.

COHb and oxygen saturation (SpO_2) readings were taken preshift, midshift, and postshift to evaluate the relationship between exposure and blood-oxygen levels.

Field replicates were done by placing two pumps and filter assemblies on the same firefighter and/or dozer and comparing analysis of the two filters. This procedure provides the relative percent difference to test the precision of field measurements and also was used to identify any potential equipment or field data collection problems.

Incident Command Posts and Spike Camps. Industrial hygiene personal sampling pumps and dosimeters also were set up in each ICP or spike camp the crews were working from. This equipment recorded exposure levels for 24 hours and provided exposure measurements for the incident camp personnel. Incident personnel also can be exposed to human-caused CO and respirable particulates in ICPs, which may present a health hazard. This equipment also measured CO from generators and vehicles and respirable dust from vehicle traffic.

Because CO data were collected on a minute-by-minute basis during operational shifts, it is possible to calculate several different occupational exposure metrics: 24 hour, shift, fireline, maximum 8 hour, maximum 5 minute, and maximum 1 minute.

Quality Assurance/Quality Control. The highest levels of quality assurance measures were taken and industrial hygiene standards were strictly followed. Adherence to these standards was assured by adhering to the following:

- Written study plan to guide data collection, data management, and analysis.
- Dedicated and trained data collectors.
- Daily review of data.
- Independent review of data by a certified industrial hygienist.
- NIOSH approved and industry standards for equipment calibration and function tests were followed.

Data Collection Summary

Handcrews, engine crews, dozer operators, and overhead personnel exposures were measured.

During the 4-year study, 7,517 hours of CO measurements on firefighters and 1,554 hours of CO measurements at ICPs and spike camps were taken. There were a total of 179 PM4 and SiO2 firefighter samples and 78 samples at ICPs and/or spike camps.

Data Analysis

The analysis presented here has been done by Tim Reinhardt (certified industrial hygienist) based on standard industrial hygiene methods. Industrial-hygiene specific statistics were done in R, using the package SAND (Frome et al. 2011). This analysis includes data from 2009 through 2011.

Data Analysis Assumptions

- Exposures were calculated by fire type: wildland, initial attack, prescribed, and prescribed natural fire
  - to determine the exposure characteristics associated with each fire management regime.
  - to account for differences in shift averages impacted by the amount of time firefighters were actually engaged in fire suppression.
- Shift TWAs included all the time firefighters were in paid status.
- One-minute average CO concentration was used for analysis.
- OSHA PEL formula (29 CFR 1910.1000 table Z-3) was used to calculate total particulate exposure.

The statistics presented here are the point estimate and boundaries for the 95th percentile, and indicate the percentage of firefighters who exceed various OELs. All calculations are done with 95 percent confidence. Although each statistic can be calculated for each fire type, the value of each type of statistic is dependent on the specific set of data being analyzed.

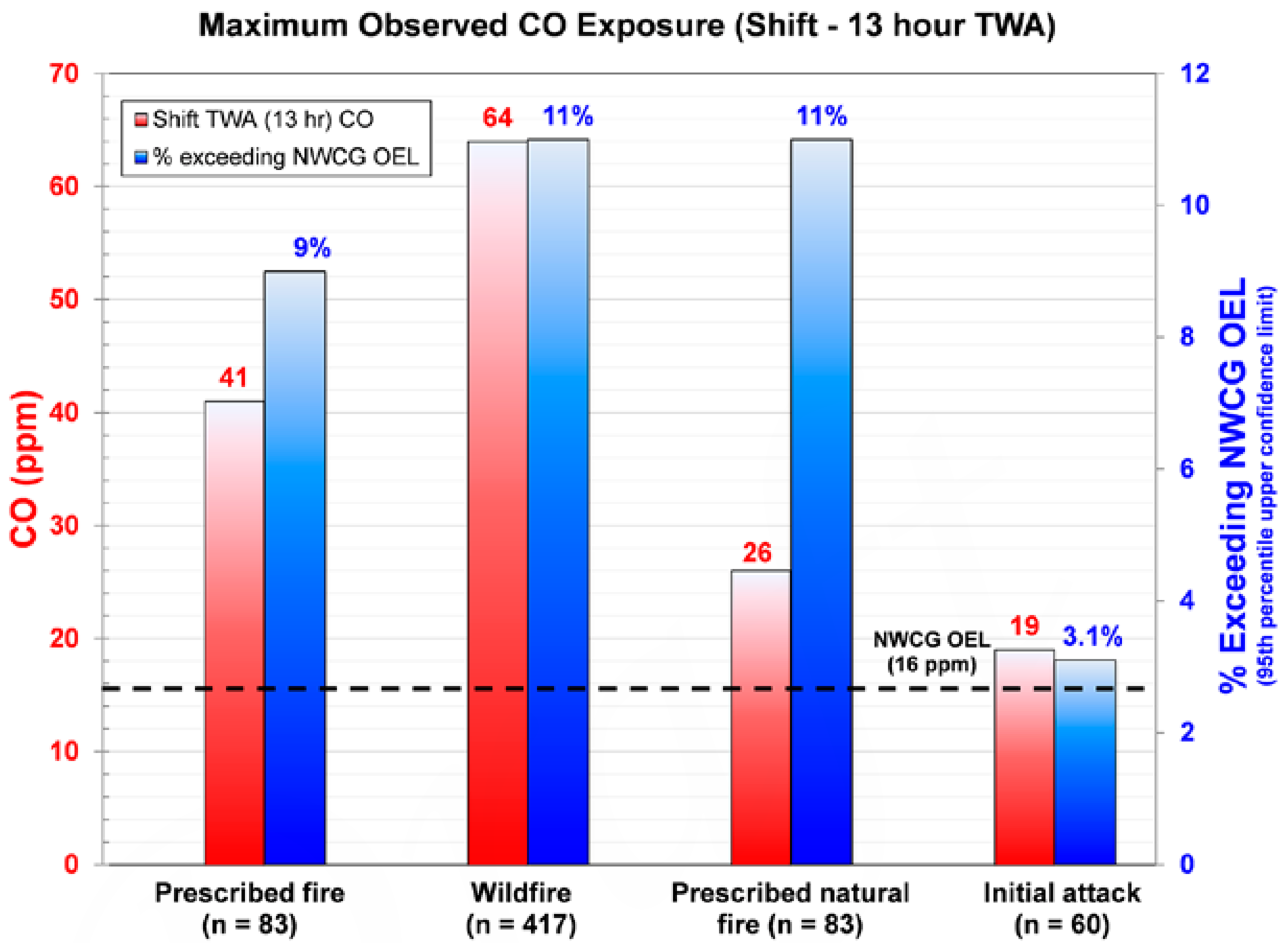
For each fire type analysis, the following assumptions are constant.

The statistically-estimated exposures are estimates based on the number of samples and the variability in the actual data. As with all industrial hygiene statistics, the key variables of interest are the upper confidence limits as these estimates provide the highest level of safety to employees.

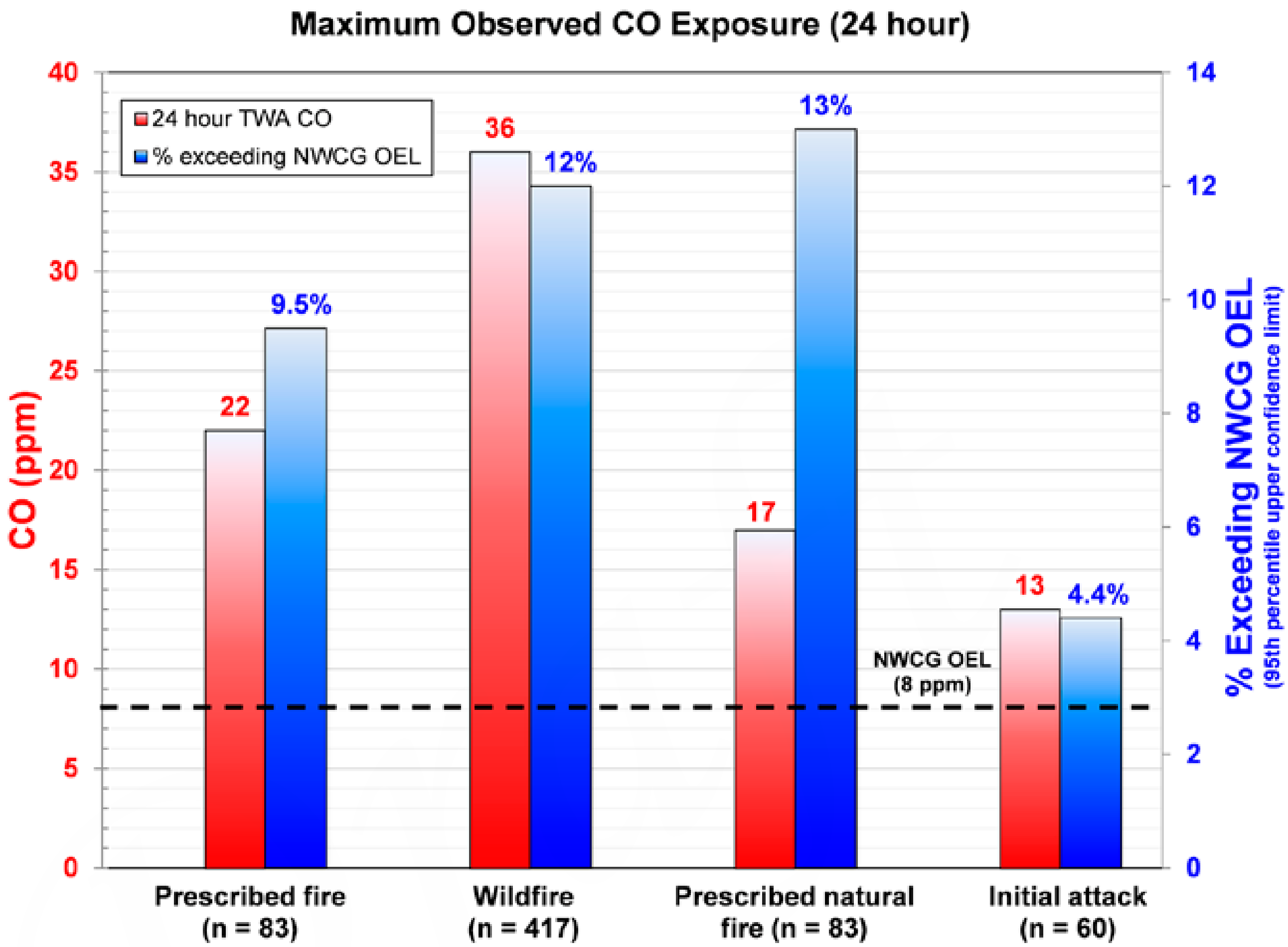
Occupational Exposure Limits. In order to determine whether wildland firefighters may be exposed to harmful levels of CO, exposures are compared to existing OELs and the recommended NWCG 2012 Guidelines (Smoke Exposure Task Group [SETG] interim OELs) for wildland firefighters. Table 1 contains the relevant OELs used for this analysis.

The NWCG Risk Management Committee created a SETG to assist in addressing exposure concerns. The SETG developed recommended interim OELs for wildland firefighters. The recommendations were based on the preliminary analysis from this project and other research and were developed to reduce exposures and provide guidance for additional actions by NWCG member agencies. These recommendations were distributed through the NWCG Memorandum NWCG #006-2012, "Monitoring and Mitigating Exposure to Carbon Monoxide and Particulates at Incident Base Camps." These OELs are especially important to consider because they acknowledge that wildland smoke contains numerous human irritants, several of which target the same organs. Therefore, in order to provide for the safety of wildland firefighters, the shift and 24-hour CO exposures must be maintained at safe levels. Based on the exposure data, wildland firefighters occasionally are exceeding the recommended NWCG recommended shift and 24-hour interim OELs (graphs 1 and 2) at each fire type. Exceeding these levels could put wildland firefighters at increased risk for both short-term and long-term health and safety consequences.

Graph 1—Shift exposure

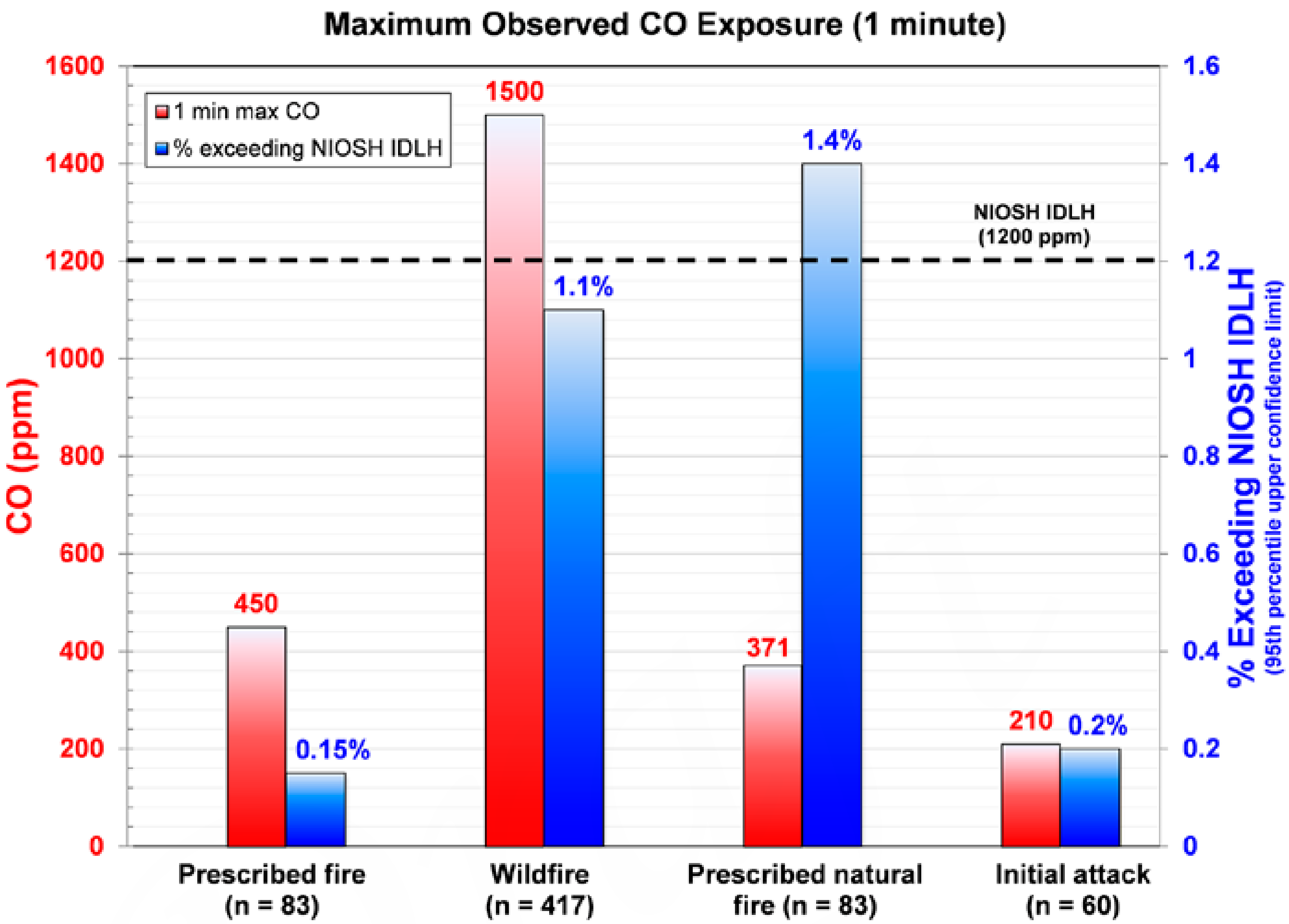


Graph 2—24-hour exposure



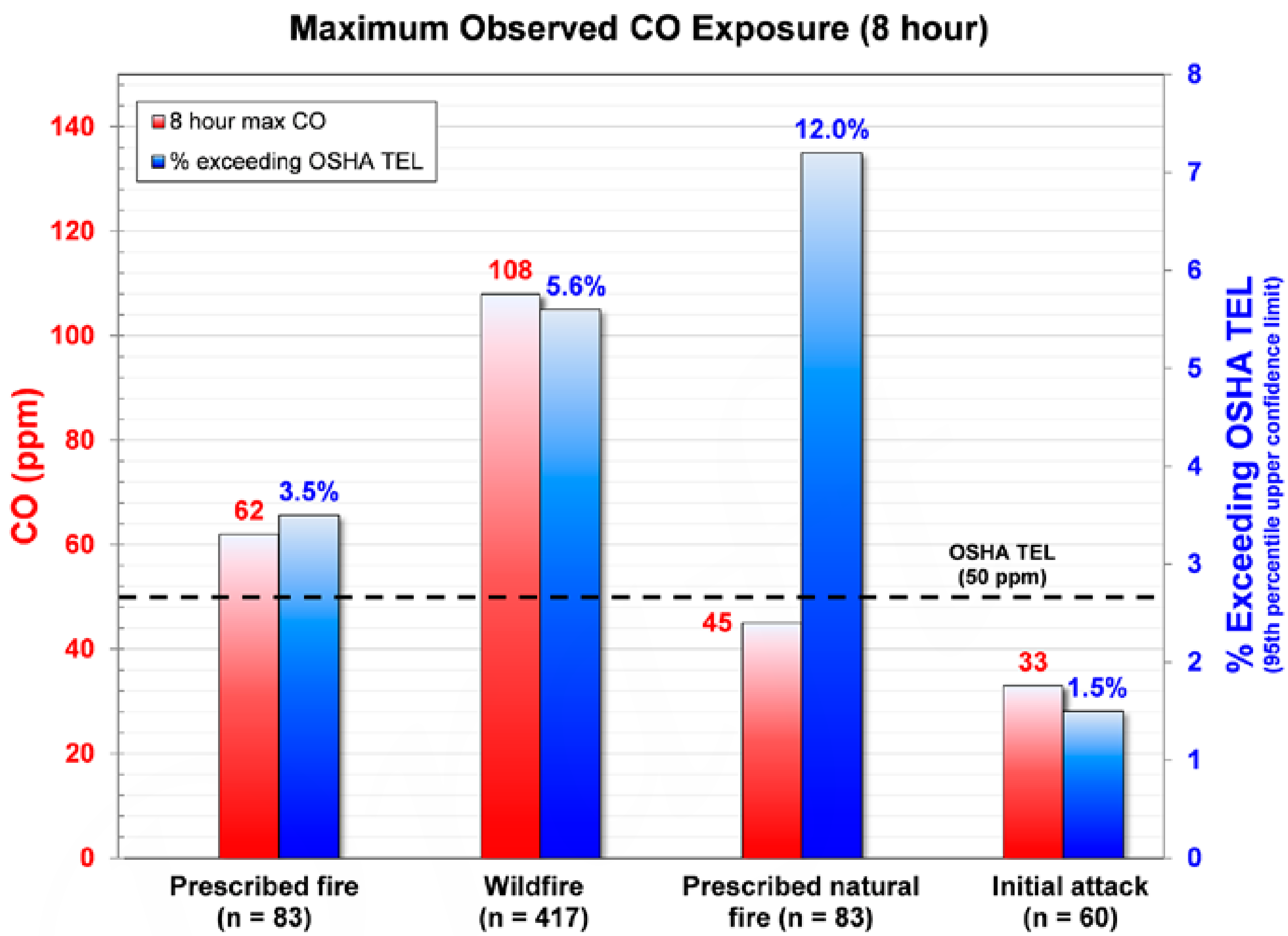
The highest 1-minute exposure value provides the peak exposure level for each firefighter on every shift. This is a good value to compare against the IDLH (graph 3).

Graph 3—1-minute exposures



A rolling 8-hour exposure was calculated and can be compared to 8-hour duration OELs. In cases where the firefighter was on the line for more than 8 hours, the highest continuous 8-hour exposure is used in the analysis. When the firefighter was on the line for less than 8 hours, the 8-hour exposure is calculated by adding the appropriate amount of time at zero exposure to the time of the measured fireline exposure, so the calculation can be made on an 8-hour exposure. This is an example of a time-weighted average (TWA) (graphs 4 and 5).

Graph 4—8-hour exposure, OSHA



The 8-hour exposure was compared to OSHA PEL, NIOSH REL, and ACGIH TLV. Both the 8-hour and 24-hour exposures can be used to determine both short-term and long-term health risks from smoke exposure. The 24-hour exposures are based on the NWCG 2012 guideline (SETG interim) OEL.

Shift exposures also were determined for each firefighter by using the total exposure during fireline operations and adding the total shift time to the calculations. The shift exposure is a TWA that includes exposure (or zero exposure) off the fireline. If the firefighters were in an inversion and were exposed—even though they were not on the fireline—this would be included in the shift average.

Graph 5—8-hour exposure, NIOSH

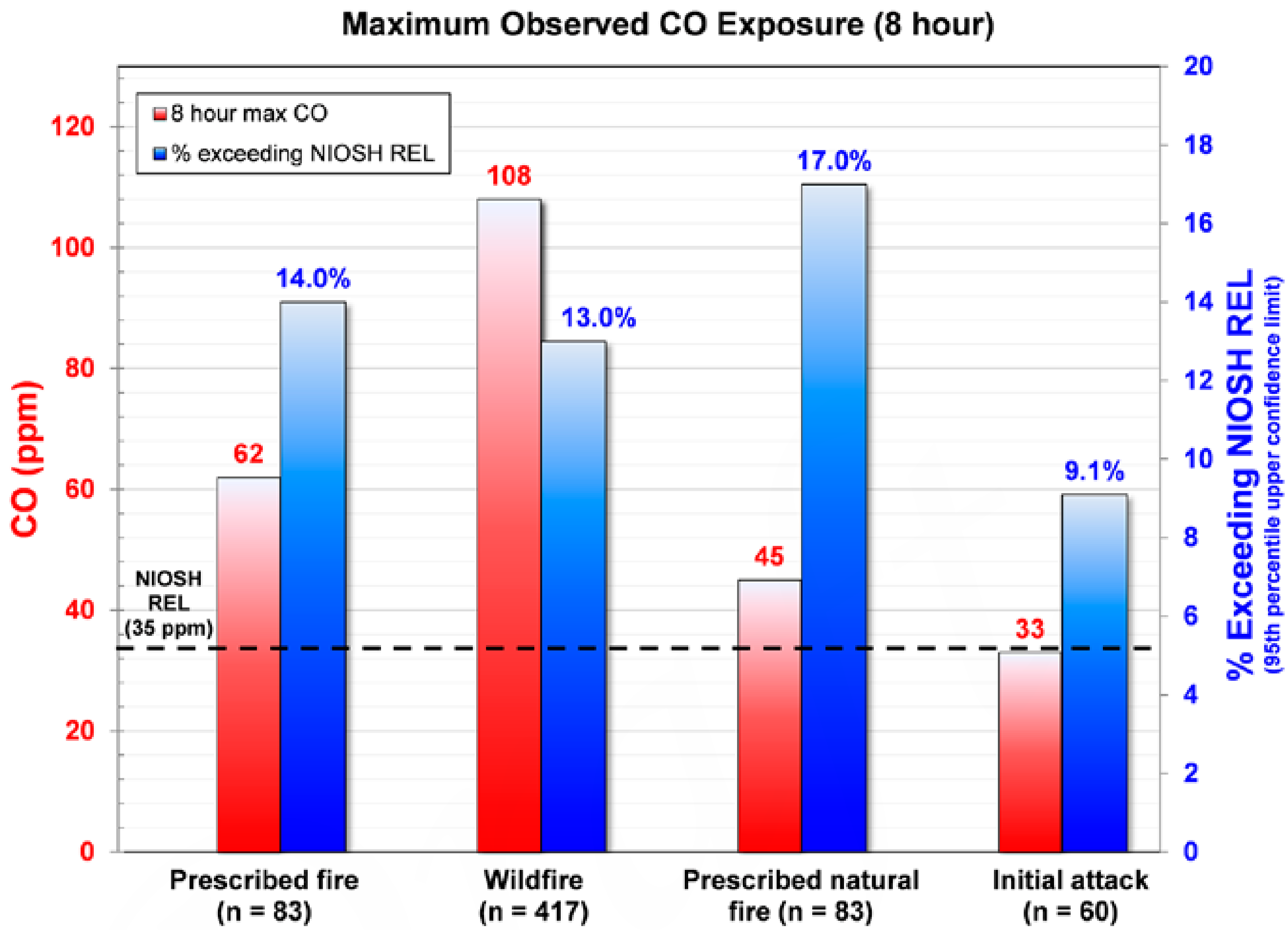


Table 1—Occupational exposure limits used for analysis

Exposure Duration	Occupational Exposure Limit	Source
1-minute maximum	1,200 parts per million (ppm) CO	NIOSH IDLH[1]
15-minute maximum	200 ppm CO	NIOSH ceiling, state STEL[2]
8-hour (hr) maximum	50, 35, or 25 ppm CO	OSHA PEL[3], State PEL, or ACGIH TLV[4]
Fireline TWA (10 hr)	35 ppm or 25 ppm CO	NIOSH REL, ACGIH TLV
Shift TWA (13 hr)	16 ppm CO	Interim NWCG 2012 OEL
24-hr TWA	8 ppm CO	Interim NWCG 2012 OEL
Fireline TWA (10 hr)	1.0 milligrams per cubic meter (mg/m^3) PM4	Interim OEL[5]
Shift TWA (14 hr)	0.7 mg/m^3 PM4	Interim OEL
Fireline TWA (10 hr)	0.1 mg/m^3 PM4	Interim OEL
Shift TWA (14 hr)	0.07 mg/m^3 PM4	Interim OEL

1. National Institute for Occupational Safety and Health (NIOSH) 1-minute average level immediately dangerous to life and health (IDLH).
2. Washington State 5-minute average short-term exposure limit (STEL).
3. U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) 8-hour average permissible exposure limit (PEL).
4. American Conference of Governmental Industrial Hygienists (ACGIH) 8-hour average Threshold Limit Value® (TLV®).
5. Smoke Exposure Task Group recommended interim OELs for wildland firefighters.

Table 2—Sample size, shift duration and fireline duration (2009–2011)

Sample size, shift duration and fireline duration					
		Prescribed Fire	Wildfire	Prescribed Natural Fire	Initial Attack
		n=83	n=417	n=83	n=60
Average shift duration	(hh:mm)	10:27	13:38	13:33	12:24
Maximum shift duration	(hh:mm)	17:00	17:00	16:30	16:30
Minimum shift duration	(hh:mm)	4:08	7:30	6:24	3:30
Average fireline duration	(hh:mm)	6:03	9:57	10:14	4:13
Maximum fireline duration	(hh:mm)	12:00	16:00	14:00	10:18
Minimum fireline duration	(hh:mm)	1:25	1:10	4:00	0:51

Table 3—Data analysis summary (2009–2011)

Analysis Summary						
		Prescribed Fire	**Wildfire**	**Prescribed Natural Fire**	**Initial Attack**	**OEL**
Highest 1-minute observed	CO PPM	450	1500	371	210	NIOSH IDLH 1200
Percent above IDLH*		0.15	1.1	1.4	0.2	
Highest 5-minute observed	CO PPM	271	933	166	129	Ceiling State STEL 200
Percent above STEL*		6.7	8.9	9.2	4.1	
Highest 8-hour observed	CO PPM	62	108	45	33	OSHA PEL 50
Percent above PEL*		3.5	5.6	7.2	1.5	
Highest shift observed	CO PPM	41	64	26	19	NWCG Shift 16
Percent above NWCG Interim		9	11	11	3.1	
Highest 24-hour observed	CO PPM	22	36	17	13	NWCG 8
Percent above NWCG Interim		9.5	12	13	4.4	
Respirable particulate (PM4)						SETG 0.7 mg/m^3
Average highest	mg/m^3	0.84	0.64	0.3	0.9	
Percent above SETG interim*		20	17	6.3	33	
Crystalline Silica (fireline)						OSHA PEL 0.1 mg/m^3
Percent above PEL*		6.7	8.9	0	43	

* 95% UCL estimate of the percent of firefighters that exceed the OEL at each fire type.
Observed = highest recorded exposure
SETG = NWCG Risk Management Committee's Smoke Exposure Task Group

Fire summary data

OSHA PELs are developed to protect workers from unsafe exposures. These PELs are based on an 8 to 10 hour workday and assume that a worker is exposed to only one irritant. When there are multiple irritants in the atmosphere, particularly irritants that affect the same organs, these PELs will not adequately protect worker health. Therefore, it is necessary to develop interim exposure criteria that will account for the additional hazard presented by multiple irritants.

RECOMMENDATIONS

For the past 25 years many researchers have made recommendations to wildland fire management agencies to minimize exposure. Many of these recommendations are consistent across all studies.

- Minimize mopup.
- Develop a medical surveillance program.
- Develop wildland fire-specific OELs.
- Train firefighters on smoke hazards.
- Reduce exposure by limiting shift length, and rotate crews out of heavy smoke areas.

Based on the findings from this project there has been no appreciable reduction in firefighter exposure and in some instances unsafe exposures are more severe than observed by previous research. Exposure to wildland smoke has direct consequences on the ability of firefighters to remain safe by compromising their ability to think clearly and function at their highest mental and physical level. Exposure to the harmful constituents in wildland smoke underlies virtually every aspect of risk management and must be addressed effectively in order to assure other risk management decisions are sound. Therefore, it is essential that sound smoke exposure mitigation strategies be developed, implemented, and enforced.

Task Group

Convene a task group of industrial hygiene experts, interagency incident management team members, firefighters, risk management, and safety representatives to develop a smoke mitigation implementation plan.

Training

Smoke exposure and the associated hazards are not required components in any of the basic and intermediate levels of required wildland firefighting training (Hyde et al. 2011). Every wildland firefighter must understand the risk associated with smoke exposure and learn how to reduce exposure. Training also must be given to agency administrators and incident management team members who make decisions that affect the exposure to firefighters. Suppression response and mopup guidelines need to be made that are consistent with operational needs and firefighter safety. Otherwise, risk is being transferred to firefighters rather than being shared with all including the incident commander, agency administrators, and the public.

Mopup

Mopup is a statistically significant cause of exposure during fire operations. Reducing the amount of time firefighters perform mopup operations will be crucial to reducing their exposure to CO, respirable particulate matter, and SiO2. Crew leaders, division supervisors, and other overhead personnel must understand that excessive mopup places firefighters at increased risk of exposure. Mopup guidelines should be guided by the principal of the right tool, at the right time, at the right place, for the right duration and the right reason.

Smoke and particulate exposure during mopup. Winema IHC, Rooster Rock Fire, 090710.

Holding

Holding on prescribed fires and project fires also is a statistically significant cause of exposure. Rotate crews out of heavy smoke when conducting holding operations. This will allow firefighters to recover from CO exposure.

Dozers

Dozer operators running open-cab equipment may be exposed to high levels of smoke and dust. Equip dozers with air-filtration systems. Open-cab dozers do not provide appropriate protection from smoke and dust on wildland fires.

Particulate exposure during dozer operations. Texas Forest Service initial attack, 082111.

Instituting Interim OELs

In order to provide the highest level of safety and protect the long-term health of wildland firefighters, adopt and enforce the NWCG recommended OELs.

FUTURE EFFORTS

The “Wildland Firefighter Smoke Exposure” project data can provide significantly more information on wildland firefighter exposures. Additional data analysis remains to be done in order to fully assess exposures and variables of interest.

Future data analysis will:

- Identify similar exposure groups.
- Determine the CO/PM correlation in various fuel models and geographic regions.
- Identify significant variables associated with wildland firefighter exposure.
- Develop exposure profiles for overhead personnel (2012 data).
- Assist in the reassessment of the SETG interim OELs.
- Identify needs for future exposure monitoring.
- Be used in the development of a long-term surveillance plan.
- Provide information for determining long-term health concerns.
- Understand the relationship between CO exposure and COHb/SpO2 values

Reviewed by:

Joe Domitrovich PhD., Ralph Gonzales, Dave Haston, and Trevor Maynard Forest Service National Technology and Development Center
Larry Sutton, USDA Forest Service, Risk Management
Corey Butler, MS - NIOSH

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