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Working in Smoke: Wildfire Impacts on the Health of Firefighters and Outdoor Workers and Mitigation Strategies

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Keywords

Wildfire; smoke; firefighters; outdoor workers; particulate matter

Introduction

During the peak of the 2018 wildfire season, approximately 30,000 personnel including wildland firefighters were mobilized across the United States to suppress wildland fires. [1] Wildland firefighters suppressing wildland fires or conducting prescribed burns work under arduous conditions often for work long hours (commonly shifts are 16 hours) and can be exposed to smoke. Wildfire smoke can contain carbon monoxide, benzene, formaldehyde, particulate matter (PM), acrolein, and polycyclic aromatic hydrocarbons (PAHs).[2] Unlike structural firefighters, wildland firefighters do not wear any respiratory protection, as there is no respirator currently available that meets specifications recommended by the National Fire Protection Association. [2] In addition to air contaminants in smoke, wildland firefighters may also be exposed to crystalline silica from soil and ash. [3] As the total number of burned acres has increased, so has the number of lost homes and structures due to the expansion of the wildland urban interface (WUI), where wildland vegetation and urban areas meet. [4,5] For wildland firefighters working in the WUI, not only are they exposed to wildfire smoke but they may also experience smoke exposure from urban fire sources without the personal protective equipment or decontamination procedures used by structural firefighters.

Wildland firefighters complete a variety of job tasks to suppress fires including operating a fire engine, constructing fireline, holding, mop-up, and firing operations. Figure 1 includes photos of some of these job tasks. Engine operators work as a part of an engine crew (3-7 firefighters) and operate the diesel pumps on an engine that provides water to crews working near the fire. Fireline construction involves clearing vegetation (first with chainsaws) and digging or scraping down to mineral soil with hand tools to create a break in burnable vegetation to stop the spread of a fire. Firefighters engaged in holding ensure that the active fire has not crossed the fireline or fuel break. After the fire has been controlled, crews will mop-up the area by extinguishing any burning or smoldering material by digging out the burning material or applying water to stop anything that may re-ignite a fire. Firing

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operations involve setting an intentional fire, typically with torches filled with a 3:2 diesel/unleaded gasoline mixture, to reduce the available flammable material for the wildfire to consume. Firing, holding and mop-up are common tasks that are performed on prescribed fires as well. Additionally, when working on a large wildland fire, firefighters will sleep and eat at a base camp (incident command post) that can be close to the fire and experience exposure to smoke, emissions from vehicles and generators (diesel exhaust) and road dust.

Exposures faced by wildland firefighters

Measuring exposure to toxic compounds in smoke for wildland firefighters is difficult due to the extreme work conditions, remote locations, and the high variability of smoke conditions in the fire environment. Past assessments of wildland firefighter exposures to smoke have commonly measured and reported concentrations of CO and fine particulate matter with an aerodynamic diameter of ≤ 2.5 μm ($PM_{2.5}$) and respirable particulate matter with an aerodynamic diameter of ≤ 4 μm (PM_4) (Figure 2).[6] The permissible exposure limits set by the Occupational Health and Safety Administration (OSHA) for an 8-hour work day is 35 ppm for CO and 5 mg/m^3 for respirable fraction for particles not otherwise regulated ("inert" dust that can include some PM_4 as well as larger particles).[7] However, wildland firefighters do not often work only an 8-hour work and particulate matter from wildfire smoke is more comparable to diesel particulate matter than it is to the inert dust on which the OSHA regulation is based. [6] For these reasons, more conservative occupational exposure limits (OEL) of 16 ppm and 25 ppm for CO at wildfires and prescribed fires, respectively, and 0.7 mg/m^3 for PM_4 have been recommended by Domitrovich and colleagues and the National Wildfire Coordinating Group.[2,3] Although field studies report different size fractions of PM ($PM_{2.5}$ or PM_4), it is likely that the particle size of combustion-generated particles is comparable across these wildfire smoke studies. [8]

Mean CO and PM concentrations measured across most prescribed fires and wildfires over the last 10 years did not exceed the OELs for CO or PM_4 (Figure 2). Mean CO and PM concentrations measured at prescribed fires were consistently higher than those measured at wildfires. Mean PM_4 and CO concentrations were highest for wildland firefighters performing mop-up (0.51 mg m^{-3}) and fireline construction (1.93 ppm). The highest mean concentration of $PM_{2.5}$ (1.2 mg m^{-3}) was reported by Neitzel and colleagues for firefighters conducting a prescribed burn in the southeast United States. [9] This mean concentration is above the OEL set for wildland firefighters. Reinhardt and Broyles collected smoke field data across many prescribed fires and wildfires in the continental U.S. and reported the highest mean concentration for CO (4.4 ppm) at prescribed burns. [3] Reisen and colleagues reported the highest maximum concentrations for PM2.5 (16 mg m^{-3}) and CO (120 ppm) during prescribed fires in Australia. [10] On wildfires, the highest maximum concentration for PM was 2.2 mg m^{-3} and CO was 19.8 ppm reported by Miranda and colleagues. [11] Wildland firefighters constructing fireline had higher maximum concentrations of PM4 (2.18 mg m^{-3}) compared to firefighters performing mop-up (0.68 mg m^{-3}). [12]

In addition, Reinhardt and Broyles examined factors in the wildfire environment that may predict PM_4 exposures for wildland firefighters and reported that work task, time spent performing the work task, wind position, and type of wildfire crew were important factors

predicting exposure at wildfires.[3] Using the same data for CO, Henn and colleagues also reported that fuel model, relative humidity, type of suppression strategy, and wind speed were significantly associated with elevated levels of CO exposure. [13] Furthermore, Reinhardt and Broyles reported that 22 and 20 percent of the measured PM_4 exceed OELs (derived specifically for wildland firefighters) at wildland fires and prescribed fires, respectively. [3]

Health Risks for Wildland Firefighters

Previous health assessments for wildland firefighters generally measured acute health effects across work shifts or a whole fire season. Lung function has often been used to examine acute health effects from smoke exposure. Across one fire season, Liu and colleagues found significant declines in lung function (FVC, FEV_1, and FEF_{25-75}) and an increase in airway responsiveness as measured by methacholine dose-response slopes for over 60 wildland firefighters in California. [14] For one Interagency Hotshot Crew in Colorado, Gaughan and colleagues measured a significant decline in lung function associated with high exposure to levoglucosan (a marker for wood smoke) across work shifts.[12]

In addition, biomarkers of exposure and effects have been measured in wildland firefighters to understand exposures from smoke as well as systemic inflammatory and oxidative stress responses [15-17]. After conducting a prescribed burn, nine hydroxylated metabolites of PAHs were reported to be elevated in the urine of 14 wildland firefighters. [18] Adetona and colleagues demonstrated that firefighters engaged in lighting operations during a prescribed burn had elevated measurements for serum amyloid, interleukin (IL)-8, and C-reactive protein, compared to firefighters involved in holding activities. [19] In addition, cross-work shift changes in creatinine-adjusted urinary mutagenicity, a urinary polycyclic aromatic hydrocarbon metabolite, malondialdehyde (marker of oxidative stress), and light absorbing carbon were measured in the same group of wildland firefighters conducting prescribed burns. [20] Most recently, Main and colleagues reported a significant increase after a 12-hour work shift for IL-6 and IL-8 among wildland firefighters working in Australia a week after a wildfire outbreak. [21]

Long-term health risks for wildland firefighters have not been as well studied as acute health effects. Semmens and colleagues surveyed wildland firefighters and found significant associations between the number of years worked as a wildland firefighter and history of ever being diagnosed with 2 cardiovascular health outcomes: hypertension and arrhythmias.[22] To examine lung cancer and cardiovascular disease (CVD) risk for wildland firefighters, Navarro and colleagues conducted a risk assessment to estimate mortality risk due to exposure to PM from smoke at wildfires. This study estimated that wildland firefighters were at an increased risk of lung cancer mortality (8% to 43%) and CVD (16% to 30%) across different exposure scenarios and career durations. [8]

To examine health impacts across multiple seasons, the National Institute for Occupational Safety and Health (NIOSH) is partnering with the U.S. Forest Service and National Park Service to measure exposure to smoke on fire lines and acute, sub-chronic and chronic health outcomes for six wildland fire crews across 3 fire seasons. This study will measure biomarkers of renal, cardiovascular and respiratory function, in the blood and conduct tests of cardiovascular and lung function. In addition, exposure to smoke will be measured

through air sampling and biomarkers of exposure, and audiometric tests will be performed to examine hearing loss. [23] More information can be found on the NIOSH study topic page (https://www.cdc.gov/niosh/topics/firefighting/wffhealthstudy.html) and in this video - https://www.youtube.com/watch?v=Ikb9LFvr-dY

Potential Solutions for reducing smoke exposure for Wildland Firefighters

For wildland firefighters, there is no easy way to reduce exposure to smoke; it is part of the wildland fire environment. Future research should examine how administrative controls on the fireline could reduce exposure to smoke. Fire managers and firefighters should take every precaution possible to reduce exposure to smoke. Small reductions in levels of smoke or the duration of exposure over a career may reduce health impacts.[8] Below are tasks that have been shown to be associated with higher exposures to particulate matter and other chemicals in smoke.[3,9,12,23] Included are possible administrative controls that may be considered to limit exposure to particulate matter and other chemicals in smoke.

- **Mop-up:** Exposure to PM_4 can be significantly higher for firefighters completing mop-up compared to non-arduous ancillary tasks such as operational breaks or waiting for assignments.[3] Firefighters may reduce exposure to ash and smoldering material by limiting the amount of time spent the in the burned area to reduce exposure to smoke. They should consider mopping-up to secure the line, and not go further into the burned area (the black) than needed to extinguish the fire and secure the fire perimeter.
- **Holding:** Reinhardt and Broyles specifically identified holding, as one where firefighters could reduce cumulative exposure to PM_4.[3] Firefighters performing holding can be instructed to stand along a fireline and watch for the fire escaping control lines which can involve being in areas of high smoke and low visibility. Firefighters may use personnel as patrols, periodically walking a fireline and checking for spots, rather than standing directly in the smoke for long periods of time.
- **Fire line construction:** When construction and digging fireline, firefighters may be close to the active fire's edge to stop forward progression of the fire. Firefighters are likely to be exposed to smoke when working close to this active fire edge. Gaughan and colleagues reported that wildland firefighters constructing fireline had higher PM exposures compared to those performing mop-up.[12] Using roads or natural features (rock bands or creeks) as an indirect fireline may reduce time near an active fireline and smoke.
- **Firing:** Adetona and colleagues report that wildland firefighters who performed firing using torches filled with diesel and gasoline had elevated inflammatory markers compared to firefighters tasked with holding.[23] The authors hypothesized that the additional exposure to combustion of diesel and gasoline could have led to this increase inflammatory markers. To reduce the concentration of smoke during firing operations, firefighters may consider starting firing operations when winds are favorable and will not send smoke towards the firefighters who are lighting the burn. How the burn is ignited

(through firing patterns) may produce more heat and result in more complete combustion and reduce the amount of PM in the smoke.

Fire managers and firefighters should continue to discuss strategies to reduce exposure at all levels of the fire organization. In addition, researchers assessing exposure to smoke should also evaluate how mitigations may reduce exposure to smoke. The Interagency Standards for Fire and Fire Aviation Operations states that any respiratory protection used must be certified by NIOSH, however respirators that are marketed to wildland firefighters but are not NIOSH-approved. [24] Negative pressure half face air purifying respirators with organic vapor and formaldehyde filters were evaluated previously for wildland firefighters in Australia. This study found that the respirators were effective in reducing exposures and provided protection for firefighter's airway. However, these firefighters only wore respiratory protection for 2 hours, not representative of a full shift (over 24 hours), did not perform any firefighting tasks, and were not protected against carbon monoxide exposure. [25] No respirator can currently provide protection to gases and particles for wildland firefighters working in extreme environments performing physically demanding work.

Outdoor Workers—In addition to wildland firefighters, workers in other outdoor occupations, such as agriculture, construction, landscape, utility and facility maintenance workers, can be exposed to wildfire smoke. Depending on how much time these workers spend outdoors on days when wildfire smoke concentrations are high and how much exertion their jobs require, the effective smoke exposures can be substantially greater than for the general public. Unfortunately, little direct evidence of health impacts of these exposures is available. That said, based on the $PM_{2.5}$ health effects exposure-response literature, estimated health risks can be generated. [27,28] In general, outdoor workers with pre-existing respiratory and cardiovascular diseases could experience increased risk of exacerbations of these diseases when air quality is poor due to wildfire smoke.

Current policy efforts to reduce exposures for outdoor workers

Recently, California adopted an emergency regulation, regulation 5141.1, *Protection from Wildfire Smoke under the California Code of Regulations*, Title 8, Division 1, Chapter 4, of the General Industry Safety Orders, to protect outdoor workers (excluding wildland firefighters) from wildfire smoke using PM2.5 as an indicator for exposure to smoke. [29] The regulation requires employers to determine the Air Quality Index (AQI) for $PM_{2.5}$ throughout a work shift, communicate and train employees about the hazards of smoke, and reduce exposures that are above an AQI of 151 for $PM_{2.5}$ (0.055 mg m^{-3}). To reduce exposures to under an AQI of 151, employers can implement engineering or administrative controls such as providing enclosed spaces with filtered air or changing work schedules, reducing work intensity, or providing more rest breaks. At an AQI of 151 but below 500, the regulation requires NIOSH-approved respirators be provided to employees for voluntary use, which does not require fit testing or medical evaluations. If the AQI is above 500, employers are required to provide respirators, and follow requirements under the respiratory protection regulation, that will reduce a worker's exposure to $PM_{2.5}$ to less than 0.055 mg m^{-3}.

Conclusion

Whether on a prescribed fire or wildfire, occupational exposure of wildland firefighters to smoke can have both short and long-term negative health effects. Decreases in lung function, increases in systematic inflammation, and an estimated higher risk for lung cancer and cardiovascular disease mortality have been reported in wildland firefighter research studies.[8,12,20,21] For outdoor workers exposed to smoke, there is little research measuring smoke exposure and possible associated adverse health effects. Increased residential development in the wildland-urban interface has correspondingly increased the risk of catastrophic fires spreading into urban neighborhoods where buildings and motor vehicles burn, which likely only increases the risk of adverse health impacts for the public and firefighters as there is more than just vegetation burning. For wildland firefighters, there is no easy way to reduce exposure to smoke, it is part of the wildfire environment. It is important for all fire personnel to understand the hazards of smoke and develop ways to mitigate exposure.

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Box 1 -

Federal Interagency Wildland Firefighter Medical Standards Arduous Duty Wildland Firefighter

Minimum medical fitness for arduous duty wildland firefighters are established by the Federal Interagency Wildland Firefighter Medical Standards based on ***5 CFR Part 339 Medical Qualifications Determinations***. [26] According to the standard, medical examinations are required for arduous duty wildland firefighters to determine an individual's ability to meet the medical standard by a designated physician. Standards included in the chest and respiratory system ensures that firefighters have a health respiratory system and can perform arduous exertion, carry heavy loads, and perform extensive movement across difficult terrain. Although not mandatory, a pulmonary function test should show a forced vital capacity (FVC) of at least 70% of the predicted value; a forced expiratory volume at 1 second (FEV1) of at least 70% of the predicted value; the ratio FEV1/FVC of at least 70%; and no evidence by physical examination and medical history of respiratory conditions likely to present a safety risk or to worsen as a result of carrying out the essential functions of the job. These standards are intended as a screen for further evaluation. Firefighters may be disqualified if they are diagnosed with an active pulmonary tuberculosis, history of bronchitis associated with decreased pulmonary function, lung access, spontaneous pneumothorax, emphysema, sarcoidosis, pulmonary embolism, pulmonary infraction, or pneumonectomy. Asthma is considered on a case-by-case basis and the use of an inhaler requires agency review. Any condition that may impair a firefighter's ability to perform their job tasks efficiently or safely should be evaluated on a case-by-case basis.

Key Points

- Wildland firefighters do not wear respiratory protection while working long hours and can be exposed to elevated concentrations of smoke.
- There is very limited research on long term health of wildland firefighters from smoke exposure across an entire career.
- New emergency regulations have been enacted in California to protect outdoor workers from wildfire smoke.

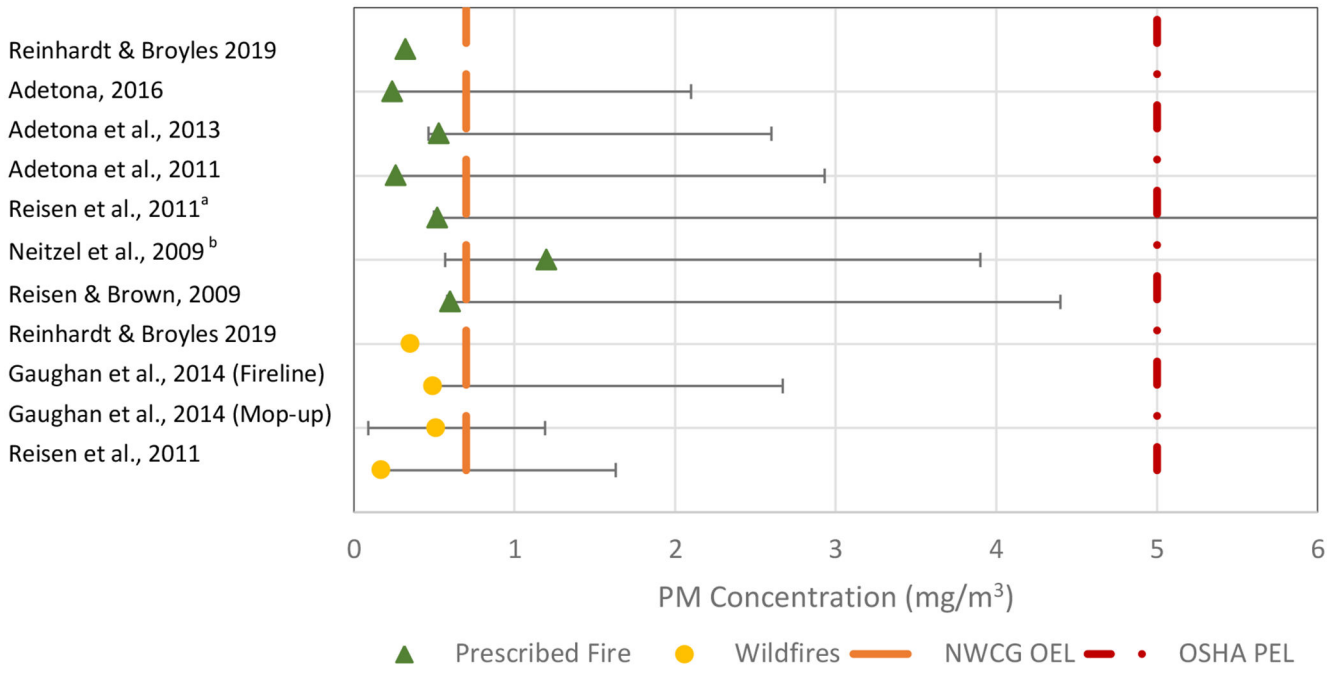
Synopsis:

Wildland firefighters work on wildland fires all over the United States and perform arduous work under extreme work conditions, including exposure to smoke. Wildland fire smoke is a mixture of hazardous air pollutants. For assessing wildland firefighter exposure to smoke, most studies measured CO and PM and report changes in lung health by measured lung function, airway responsiveness, and respiratory symptoms across individual work shifts and single fire seasons. All fire personnel should understand the hazards of smoke and develop ways to mitigate exposure to smoke.

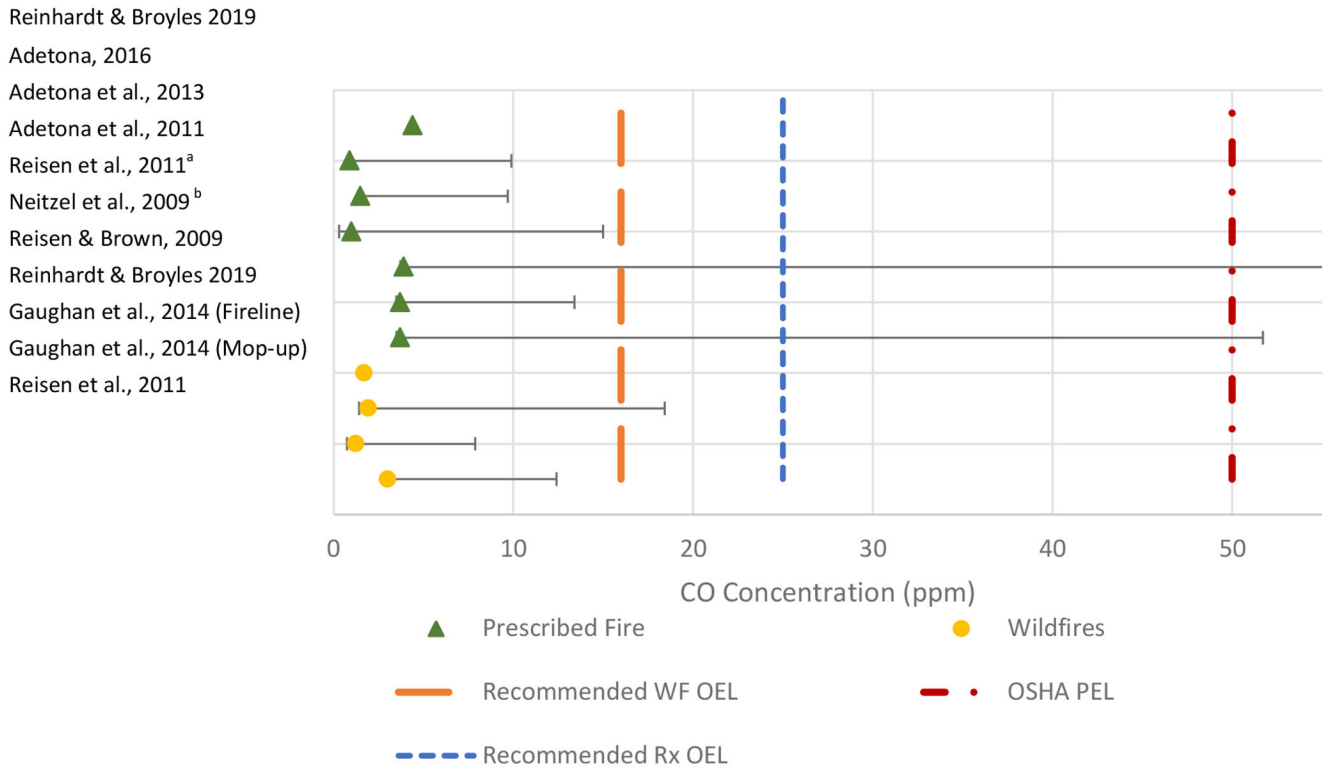
Clinics Care Points

- Clinicians should recommend regular health screenings including lung function testing for workers regularly exposed to wildfire smoke.
- Healthcare providers should consider advising patients working in the wildland fire environment on how to minimize exposure to high levels of air pollution

Figure 1:
Photos depicting mop-up and firing operations



a. Maximum ranged reported was 16 mg/m3
b. All studies, except Neitzel et al. 2009 reported geometric mean



a. Maximum ranged reported was 120 ppm
b. All studies, except Neitzel et al. 2009 reported geometric mean
c. WF – wildfire; Rx – Prescribed Fire

Figure 2: Summary of Particulate Matter and Carbon Monoxide Concentrations Measured on Wildland Firefighters in the last 10 years

A. Particulate Matter [3,9-15]

B. Carbon Monoxide[3,9-15]