

Wildland Fire Personnel Smoke Exposure Guidebook



Produced by the National Wildfire Coordinating Group Smoke Committee's
Training Subcommittee and the University of Idaho
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University of Idaho
College of Natural Resources



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Introduction

Working on a wildland fire incident, you are responsible for the safety of yourself and those around you. At high exposure levels, smoke inhalation can jeopardize this safety by impairing your decision-making abilities. If your health is impaired your judgment and decision making skills may also be impaired. This condition can put those around you at risk.

This guidebook addresses wildland fire personnel smoke exposure in three sections:

- **Smoke Constituents & Symptoms** - What is in wildland fire smoke
- **Personnel Risk** - What positions are frequently at risk from wildland fire smoke exposure
- **Mitigating Exposure** - How to reduce or eliminate smoke exposure

This guide covers situations in both wild and prescribed fires and is a more detailed supporting document for the National Wildland Fire Coordinating Group's module '[Smoke: Know the Risks](#)'. Please note that this guidebook is a draft document and a work in progress. The authors feel the guidance information within will be useful to wildland fire personnel, however in the future content may be added or edited, and page numbers may change.

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Part I. Smoke Constituents - What is in wildland fire smoke

Work on a wildland fire incident does not always occur in smoke, and in many cases the work may take place in clean air. However, when the air is smoky, the risks described herein are present. In this section we will describe constituents of smoke from the perspective of safety risks, performance impairment, and health risks. Short term and long term concerns are also addressed. The gases and particulates in smoke enter the airways and lungs causing irritation and inflammation. These toxic gases pass through the lungs to the bloodstream. Two aspects of greatest health concern in wildland fire smoke are respirable particulate matter and carbon monoxide gas. Other constituents of concern are aldehydes, nitrogen dioxide, and ozone. Additional substances not present in smoke, such as respirable crystalline silica dust, can also pose health risks on the fireline. Each of these is described below.

Carbon Monoxide (CO)

Carbon Monoxide (CO) is a natural byproduct of burning biomass, and many other fuels such as gasoline. Carbon monoxide gas is most highly concentrated close to the combustion source, or downwind from smoke sources. Base camps and spike camps are susceptible to downwind exposure, especially if they are located in close proximity to the fire front, or if prolonged atmospheric inversion has prevented the smoke from dispersing. The further away from the combustion source, the less concentrated this gas becomes.

As CO is inhaled it attaches to hemoglobin (red blood cells) thereby reducing the oxygen carrying capacity of the blood. The CO laden blood cells, referred to as carboxyhemoglobin (COHb), transfer CO throughout the body in place of oxygen (Figure 1). This COHb is an indicator of the CO inhaled over time and resulting percentage of CO in the bloodstream. The COHb blood levels are a rough guide to an individual's physiological response to CO. Increasing levels and duration of CO exposure result in increasing COHb concentrations and increasingly severe consequences as displayed in Table 1 (Raub *et al.* 2000, Struttman *et al.* 1998, Limmer and O'Keefe 2007).

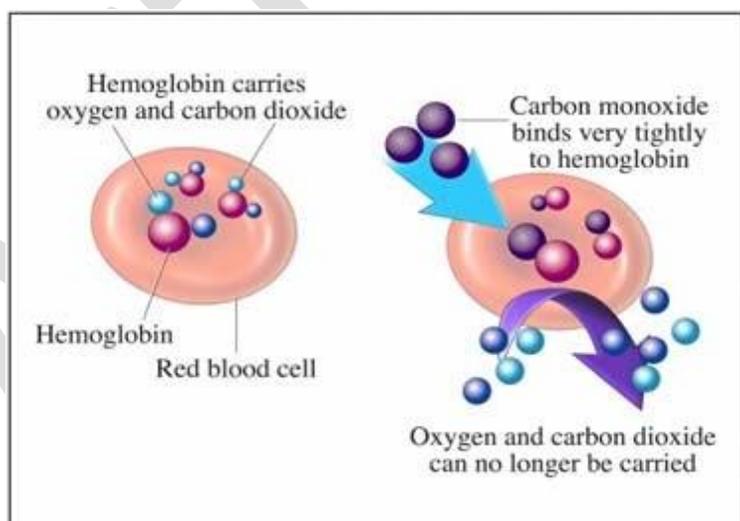


Figure 1. Binding sites on the red blood cells that would normally be occupied by oxygen are occupied by carbon monoxide.

Table 1. Levels of CO, COHb, and signs and symptoms of CO poisoning. Note: This table does not account for time exposed.

CO in atmosphere (ppm)	COHb in blood (%)	Signs and Symptoms
10	2	Without symptoms for healthy individuals
70	10	No appreciable effect for healthy individuals, except shortness of breath on vigorous exertion; possible tightness across the forehead
120	20	Shortness of breath on moderate exertion among healthy individuals; occasional headache with throbbing in temples
220	30	Headache; irritable; easily fatigued; judgment disturbed; possible dizziness; dimness of vision.
350-520	40-50	Headache, confusion; collapse; fainting on exertion
800-1220	60-70	Unconsciousness; intermittent convulsion; respiratory failure, death if exposure is long continued
1950	80	Rapidly fatal



Generally COHb levels can be halved with 4 hours of recovery time in clean air



Those with ischemia, advanced coronary artery disease, or heart arrhythmias may have more serious consequences at lower levels of exposure relative to healthy personnel.

Short term exposure to CO and other irritants in wildfire smoke result in consequences that all firefighters are familiar with: eye irritation, upper respiratory irritation, headaches, nausea and fatigue. As less oxygen becomes available the heart works harder to compensate. **This oxygen depletion leads to fatigue, headaches and potential loss of clarity in thinking. Long duration CO exposures at high levels, or relatively short exposures at very high levels, can result in loss of consciousness and ultimately death.** Some of the other gases in wildland smoke affect the same organs and produce similar responses in the body. This causes an additive and possibly synergistic effect so that low levels of exposure to multiple irritants may be similar to a higher exposure to CO alone.



As high levels of CO are inhaled, clouded thinking and impaired judgment occur. You become less capable of carrying out the 10 standard fire orders. This jeopardizes your safety and the safety of

your crew and those around you. Under these conditions it will be more difficult to:

- “Be alert and keep calm”
- “Think clearly”
- “Act decisively”
- “Give clear instructions and be sure they are understood”
- “Fight fire aggressively, having provided for safety first.”

Your potential for an accident, driving or on the fire line, will increase with your exposure.

Aldehydes - Formaldehyde and Acrolein

Aldehydes are chemical compounds containing some combination of carbon, hydrogen, and oxygen. Wildland fire smoke contains many aldehydes (Reinhardt and Ottmar 2000), of which formaldehyde and acrolein are among the most potent and create adverse health impacts. Short term effects include eye, nose and throat irritation, depression of breathing rates, and temporary paralysis of cilia (microscopic hairs lining the respiratory tract which help to remove dust and bacteria). The eyes and mucous membranes are especially sensitive to, and irritated by, acrolein (Kane and Alarie, 1977). Chronic exposure to formaldehyde is associated with nasal cancer (U.S. Department of Labor, Occupational Safety and Health Administration 1987).

Nitrogen Oxides (NO_x)

Nitrogen dioxide (NO₂) is one of the pollutants regulated by the Environmental Protection Agency (EPA) for human health impacts. Nitrogen oxides, including NO₂, are emitted as biomass burns. NO_x can irritate the airways when it is inhaled and it is also a key component of ozone formation.

Note: NO_x versus NO₂ NO_x refers to nitrogen oxides. NO₂, nitrogen dioxide, is a specific form of NO_x often discussed in association with wildland fire.

Ozone (O₃)

Ozone is another pollutant regulated by EPA and associated with human health effects including inflammation of the airways, shortness of breath, and reduced lung function. The formation of ozone occurs when nitrogen oxides and volatile organic compounds (VOCs) react in the presence of sunlight

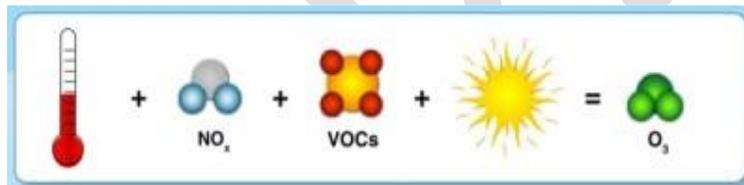


Figure 2. The formation of ozone occurs when nitrogen oxides and volatile organic compounds (VOCs) react in the presence of sunlight

(Figure 2). This reaction generally occurs away from the fireline, potentially causing impacts downwind including fire camps. Ozone can be present regardless of fire emissions and is commonly an issue in summer, downwind of urban areas, and can be especially problematic for asthma sufferers (EPA 2015a, 2015b).

Particulate Matter

Numerous studies have demonstrated that particulate matter (PM) can negatively impact human health both in the short and long term. The potential of particles to cause harm depends on their chemical composition and their size. Particulate matter can range in size from 100 microns in diameter to nearly the size of a few atoms (Figure 3).

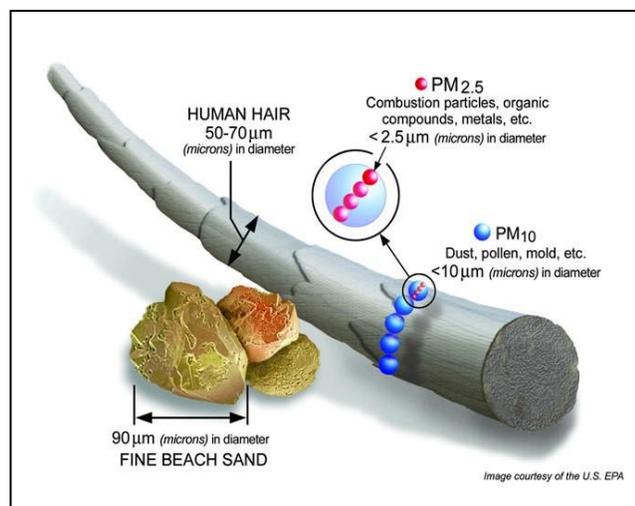


Figure 3. Particulate matter sizes compared with that of a human hair.

Fine particulates pose the greatest health risk as they can be inhaled [deep into the lungs](#) and are more difficult for the lungs to expel (Figure 4). Particulate matter levels for public health are regulated by the EPA via the [National Ambient Air Quality Standards](#), while levels for the workforce are regulated by the [Occupational Safety and Health Administration \(OSHA\)](#).

Fine particles cause upper and lower airway distress. This irritation results in coughing, sore throat, and diminished breathing, and can be especially hazardous to asthma sufferers (Allen *et al.* 2008). Prolonged exposure to particulate matter can also reduce a firefighter's work capacity. Irritation of the lungs and respiratory system and shortness of breath may make it increasingly difficult for individuals to sustain their

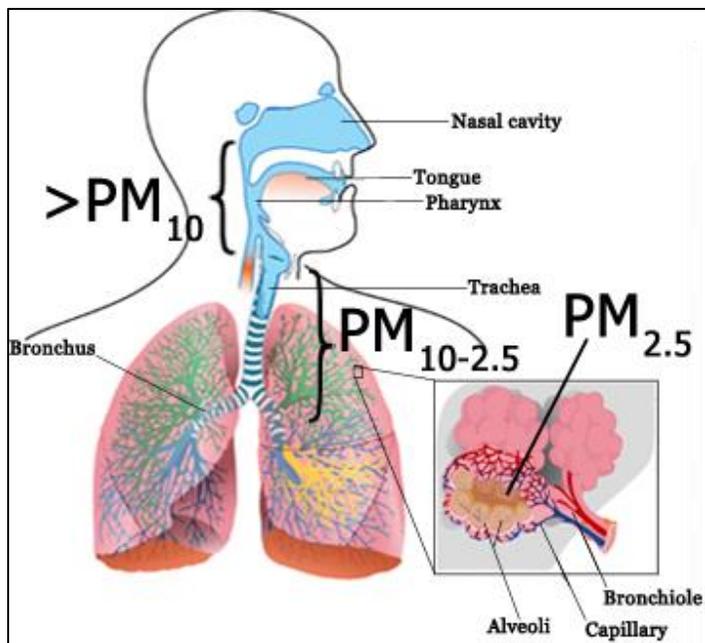


Figure 4. Larger particles are 'filtered; out by the respiratory system early on, while small particles can be inhaled deep into the lungs.

smoke. While many particles may be cleared from the body relatively shortly, some can take weeks or months to fully expel (Stuart 1984, Lippmann *et al.* 1980). Air pollution and public health research has confirmed an inflammatory effect in the lungs and bloodstream from small particles in the $PM_{2.5}$ range. Intermittent exposure to smoke may not pose a hazard to healthy individuals, but there is evidence that chronic exposure can increase the risk of hardening of the arteries (Naeher *et al.* 2007), and even an acute exposure may increase the risk of cardiac events among those with preexisting cardiovascular disease (Diaz 2012).

Note Air quality standards for the general public are measured in $PM_{2.5}$ (2.5 μm) However, occupation health standards consider a wider range of particle sizes, up to 4 μm (PM_4), all of which can be drawn deep into the lungs. Smoke concentrations measured with a $PM_{2.5}$ sampler will be slightly lower than those measured with the PM_4 sampler, but the concentrations would be very similar as the majority of fire smoke particulates are less than 0.6 μm in diameter (Reinhardt and Ottmar, *in draft*)

optimum performance. Wildland firefighters typically maintain high physical standards so the consequences may not be severe, however exposure to particulate matter may eventually compromise their ability to maintain these standards.

Given recovery time in clear air, your body will expel particulate matter. Smaller particles are also removed from the body via the immune system (Lippmann *et al.* 1980); **this process is impeded if you are constantly in smoky conditions where there is less clean air to allow your body to recover.**

Health effects from PM may be short term, experienced over a few days or throughout an incident, **reducing the body's capability to ward off infection and other pathogens and leading to increased susceptibility to 'camp crud' and other ailments.** Firefighters can inhale large amounts of particulates from

Contributing factors

- **Heat stress** from vigorous work in high temperatures may compound smoke effects.
- **Harder work and higher altitude** are conditions which facilitate more rapid formation of COHb
- **Higher breathing rates** during strenuous activity increases the volume of air, and smoke, that passes through the lungs in a given period of time.
- **Exposure to multiple pollutants** is worse than just one. Most studies focus on a single pollutant impacting the body, but in the case of wildland fire smoke, personnel are exposed to several pollutants concurrently which may compound and accelerate effects.
- **Physical condition** becomes a factor, especially considering smoke puts additional strain on the cardiovascular system. Personnel in arduous positions may be in better physical condition and at less risk for these issues, while non-arduous personnel may be less physically fit. Those with poor baseline cardiovascular or respiratory health issues may be at substantial risk of having their conditions worsened by smoke.
- **Pre-existing high levels of pollution**, such as in areas with urban and industrial activities, compound pollution from wildland fire to create even greater concentrations of pollutants to which people can be exposed.
- **Nitrogen Oxides** can be elevated in these smoky conditions and combined with other pollutants have been found to increase the likelihood of ischemic stroke (Wellenius *et al.* 2012).

Other exposure hazards

Aside from PM and CO, there are less common exposure hazards depending on your location and the incident. These hazards include crystalline silica, asbestos, oil and gas field emissions, and working around mine tailings.

Respirable Crystalline Silica (SiO₂): Silica is a common component of soils, and, and granite. Quartz, cristobalite, and tridymite are crystalline forms of silica that can occur as small jagged particles. High exposure to respirable crystalline silica causes silicosis, an irreversible respiratory disease that most often develops after years of exposure to such respirable dusts. Respirable silica dust has no unusual warning properties. It can be inhaled when the soil which has high levels of quartz is disturbed, such as during mop up activities, traversing dry trails and dirt roads, or through bare blackened areas. A job hazard analysis should be created in these areas if one does not already exist.

Asbestos: Asbestos exposure lays the groundwork for the human body to develop mesothelioma cancer years after the exposure. A large number of homes and commercial buildings constructed prior to the 1980s were built with asbestos materials. Those products are considered safe as long as they are contained or undisturbed. But once ripped, broken, burned, blown or washed away, the products become a possible health hazard. Materials of particular concern related to asbestos are insulation, roof materials, drywall, ceiling tiles, flooring and asphalt. Wildland fire personnel may encounter naturally occurring asbestos dust in areas where ultramafic rocks (volcanically-derived rocks containing small quantities of silica and large quantities of magnesium and iron) occur naturally and where the material was once mined or transported. A job hazard analysis should be created in these areas if one does not already exist.

Part II. Personnel Risk - Positions and Tasks frequently at risk from wildland fire smoke exposure

Safety risks are not only posed to those directly fighting the fire. Overhead, support staff, and base camp personnel are also affected by smoke. In addition, health screening standards are less stringent for support staff than for firefighters, resulting in situations where personnel may have a wide range of health and fitness levels, susceptibility to smoke, and physiological responses to exposure.

Research on wildland fire personnel exposure to pollutants is ongoing. In 2012 the National Wildfire Coordinating Group (NWCG) set interim exposure limits for wildland fire personnel. This was based on findings that 16 parts per million (ppm) or less of CO provided a safe exposure level for the combined effect of other pollutants of concern in wildland smoke (NWCG 2012). Research was requested to further evaluate the exposure to smoke of various personnel positions for a typical wildland fire shift (13 hours)(Broyles 2013). Here are some of the results reported:

- The occupational exposure limit of 16 ppm recommended by NWCG was exceeded¹ by 11% by wildfire personnel, 9% by prescribed fire personnel, and 3% for initial attack personnel during their shifts measured from 2009-2011 (Broyles 2013).
- Wildfire personnel experienced the highest five minute average CO levels (933 ppm), followed by prescribed fire personnel (271 ppm) (Broyles 2013).
- Location in relation to the fire is important. Exposure to smoky conditions tended to occur during direct attack when digging fireline adjacent to active fires, mopping up, and on mobile attack such as manning a fire hose from a slowly advancing vehicle (Reinhardt and Ottmar 2004)

Other observations from the field

During intense burning the smoke may be lofted up, while a reduction in heated air during less active periods may leave smoke closer to the ground. When a smoke plume falls to ground-level, or is not transported away by wind, it can remain in a given area where it can be of higher concentration, impacting personnel and increasing the risk of exposure.

Discussion Question: What positions have you been assigned in which smoke exposure was high? Was there an opportunity to mitigate for this circumstance?

¹ Based on 95% upper confidence limit estimate of the percent of firefighters that exceed the occupational exposure levels at each fire type from data in Broyles 2013.

Part III. Mitigating Exposure – How to reduce or eliminate smoke exposure

It is important to note that smoke is just one of the potential risks faced by wildland firefighters. When instituting these recommendations it is important to evaluate and balance all the risks associated with the operational objective. Use a risk analysis process when considering smoke impacts. The Incident Action Plan Safety Analysis ICS-215A is a good framework for this (FEMA 2013). Identifying risk posed by smoke is a critical step that can influence the strategy and tactics used on a fire. The risk is not just to line personnel, where the analysis is appropriate for direct line exposure to smoke, but also to impacts on transportation routes where smoke may affect visibility, or impacts to personnel in a base or spike camp. There are several actions that can be taken to minimize smoke exposure, thereby minimizing these health impacts, especially among mop up and holding positions, which data indicate can receive the highest exposure levels. Those using or working closely to equipment which generates exhaust, such as sawyers and pump operators, also experience increased exposure to CO due to their machinery.

Regardless of your duties on a fire, whether on the line or in a camp, you can take appropriate action to reduce exposure. It is your responsibility to be aware and proactive in reducing exposure to all hazards. Inform your supervisor if you are at risk from smoke exposure due to any pre-existing condition such as asthma or heart disease. If you are feeling the effects from smoke there are actions you can take to protect yourself and others. The response can be as simple as getting supplemental oxygen or a rest period in clean air.

The National Institute for Occupational Safety and Health (NIOSH) and OSHA provide general guidance on the most effective measures for reducing exposure to occupational hazards. This is called the Hierarchy of Controls (Figure 5). This hierarchy shows that the most effective method available is to eliminate the hazard and the least effective is personal protective equipment (PPE). Although smoke cannot be eliminated, you can distance yourself from the smoke to achieve the same result. The most effective means of protecting yourself from exposure is awareness and responsiveness to minimize the exposure at every opportunity.

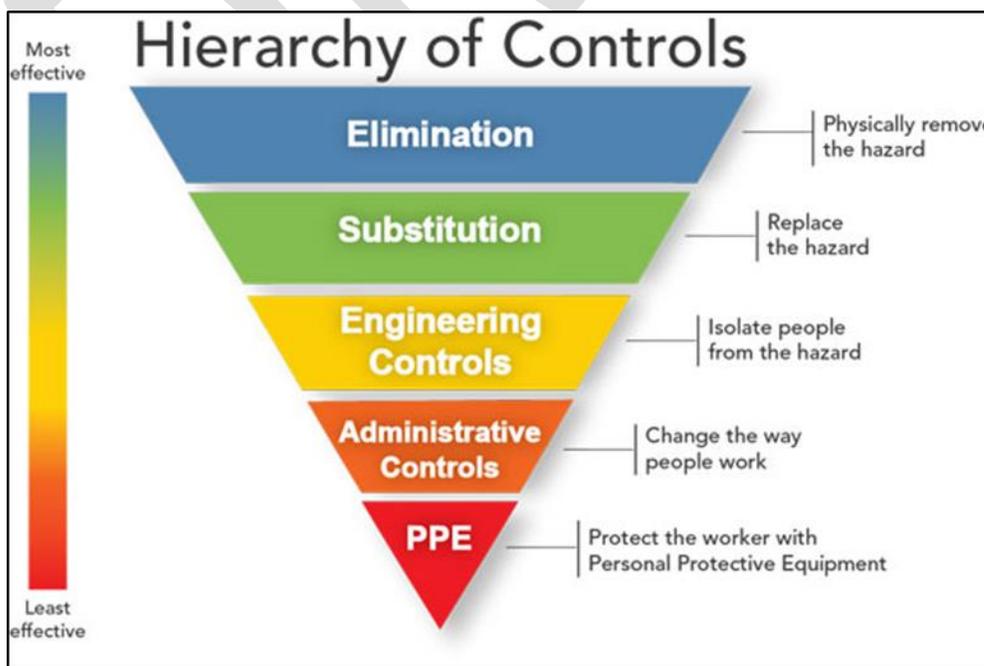


Figure 5. NIOSH Hierarchy of controls (NIOSH 2015).

Based on the Hierarchy of Controls, approaches to reduce your exposure include:

- **Elimination & Substitution** – Although smoke cannot be eliminated or substituted, you may have opportunities to move away from the smoke. This can include moving upwind of smoke when possible, and camping (spiking out) away from smoky areas. Rotating crews out of smoky conditions is another way to avoid smoke, and can also be considered an Administrative Control (see below).
- **Engineering Control / Physical Controls** - These are designed to remove the hazard at the source. In the fire environment this can include providing access to a clean air tent/sleeping trailers, or locating base operations to facilities with air handling capabilities. Medical unit leaders may consider implementing COHb monitoring to track exposure levels. Preemptively consider your location, and its probability of being impacted by smoke. Put measures in place ahead of time so engineering and physical controls are readily available when a smoke impact occurs.
- **Administrative Controls** –These include decisions such as minimizing mop up operations wherever appropriate, rotating crews to minimize smoke exposure, or making the decision to not utilize a spike camp that is continually inundated with smoke. **Smoke should also be addressed in safety briefings, and personnel should be made aware of smoke hazards.**
- **PPE** – currently there is no approved PPE for respiratory protection for wildland or prescribed firefighters.

Options to mitigate smoke exposure may vary depending upon specific positions. Below are specific mitigation measures for operations, arduous, mop-up, and base camp positions:

Mitigating Smoke Exposure for Wildland Fire Operations

- Rotate crews/individuals out of the smoke and into clear air
- Rotate lighters and holders
- When possible adjust tactics, such as using effective burnouts, to assure smoke moves into the fire rather than across the fireline.
- Do not stand any closer to the fire than necessary

Mitigating Smoke Exposure for Arduous Positions

Exposure to smoke can be mitigated by action to avoid exposure, limit exposure, recognize impairment, monitor exposure, and facilitate recovery.

Avoid Exposure

- Use time and patience to put the fire out (i.e. allow secured areas to burn out, rely on burn up instead of mop up, and use dozers or other mechanical equipment to spread out burn piles).
- In heavy smoke conditions consider establishing control lines where conditions allow for less smoke exposure to firefighters, even if more acreage is burned.
- Use equipment instead of people when possible in holding areas (sprinklers, retardant, foam, etc.).

Limit Exposure

- Minimize mop up when possible, use alternative means with less exposure.
- Establish mop up standards that meet containment objectives while minimizing exposing firefighters to smoke and respirable dust hazards.
- Adjust operation periods on mop up to avoid inversion periods.
- When possible, select strategy and tactics that minimize exposure (indirect attack).
- Provide more spacing between firefighters and vehicles when traveling in dusty conditions.

Recognize Risks & Impairment

- Expect higher CO concentrations in the following:
 - Near an active flame front and during smoldering phase of combustion.
 - Working around gasoline driven equipment, especially in ground support.
 - Prolonged exposure to low to moderate smoke level with no clean-air rest periods.
 - Topographic features and inversions that concentrate smoke (head of canyon, ravines, saddles or passes, depressions or basins).
 - Working smoldering fires where deep duff, organic soils are present have been documented for high release of CO, PM_{2.5} and other pollutants.
 - When working in areas of known high CO concentrations or PM_{2.5}.
- Set up monitoring protocols under the auspices of the Safety Officer, Medical Unit and / or Air Resource Advisor.
- Restrict workers from operating a vehicle if they display the symptoms or behavior associated with carbon monoxide exposure.
- Personnel who display the symptoms of abnormal behavior should be evaluated and determined fit for duty before their next work assignment.

Monitoring Exposure - Personal monitoring

It is recommended that firefighters monitor their health and their coworkers. Be watchful for the symptoms of exposure and respond appropriately. The best option is to move to clean air and reassess your situation.

- The most widely available method to “monitor” smoke exposure is to use your body. In the same way firefighters use their senses to evaluate their environment and adjust tactics to remain safe, smoke exposure should be monitored as well. When firefighters hear snags fall or rocks begin to roll downhill they reevaluate their safety. When storm cells move into the area they adjust their tactics to protect themselves. The same risk management approach is recommended for high smoke exposure situations. If it seems very smoky or dusty, you can be sure a potential health hazard is developing.
- When smoke is present firefighters and fireline leaders (Division Supervisors, Safety Officers, and overhead) all need to be attentive to the signs and symptoms of smoke exposure. Headaches, scratchy throats, tearing eyes may all be an indicator that the exposure is high and needs to be mitigated. Your body is telling you to reevaluate the situation and respond accordingly.

- There are many electronic monitors available to measure CO and other gases in wildland fire smoke, but many are unsuitable for the harsh wildland fire environment. Monitors to protect firefighters need to provide accurate information and meet specific criteria. They must be able to perform under severe environmental conditions, have radio frequency interference protection and not be compromised by other gases and particulates in smoke. These monitors are life-safety devices and require regular calibration, function tests and maintenance to assure they are working properly. Infrastructure, training and guidance on their use must be in place prior to operational use.
- Technology is available to non-invasively measure COHB levels. If high CO exposure symptoms are present or suspected, these devices may be useful to medical personnel; however, no established protocol has been developed for wildland fire. Current research by the Forest Service National Technology and Development Program has not found a good relationship over a shift between ambient carbon monoxide and these measurements of carbon monoxide in the blood. Research investigating this relationship between atmospheric CO and COHb in wildland fire personnel is currently ongoing.

Facilitate Recovery

- Rotate personnel (fireline and base or spike camp) out of heavy smoke areas
- Transfer workers to 'CO-free areas' when performance and safety are compromised by CO exposure symptoms or behavior
- Instruct personnel to take breaks in smoke-free or low-smoke areas, when possible.
- Encourage cigarette smokers to terminate or reduce smoking during fire assignment. Smoking significantly increases blood CO levels.



Figure 6. Rotating crews to areas with clean air is an effective means to avoid exposure and facilitate recovery time. Due to prevailing winds, crews on the eastern flank of the Grouse Fire in Yosemite National Park worked in clean air (right) while crews on the western flank (left) were continually working in smoky conditions. Photos courtesy of George Broyles, USFS.

Mitigating Smoke Exposure for Mop up

Evaluate mop up standards. Are we doing them because “that is what we have always done?” Minimize mop up when possible. Understand the leader’s intent and control objectives stated for the operational period. Typically the goal of mop up is to assure the fire will not escape the established firelines. However in some cases, especially when dealing with prescribed fire, more extensive mop up maybe necessary to avoid visibility problems on local roadways, airports, or smoke sensitive areas. This can become a major concern if fog potential is forecast.

For Planners

- Adherence to the mop up standards should always be designed to minimize exposure.
- Over-extending mop up increases exposure to inhalation risks as well as other risks inherent in mop up such as falling snags, but often does not increase the security of the fireline.

For Crew Personnel

- Use water for mopping up when available; and avoid making fine particulates and crystalline silica airborne. Wet water (in a 1/1000 or 0.01% solution) increases the effectiveness of the water, which can shorten the time spent in mop-up.
- Allow areas to burn out without mopping up when safe to do so.

Mitigating Smoke Exposure for Base Camps

Locate incident base and spike camp(s) in areas free of smoke and air pollution to maximize recovery from CO and other pollutant exposure. Such a location will help meet OSHA standards for fireline personnel. Topographic features that concentrate smoke (canyon heads, ravines, saddles or passes, depressions or basins) should be avoided if possible. If local knowledge indicates historic prevailing winds from the fire tend to move towards a proposed base camp, then alternatives should be considered.

Depending on the proximity and cause of the smoky conditions in a base or spike camp, CO may still be a concern if the camp is near the fire or prolonged inversions prevent air from mixing and clearing for long periods.

Planning and Monitoring

- Include smoke and respirable dust hazards on the Incident Action Plan Safety Analysis, ICS-215A worksheet, at planning and briefing sessions, and adjust operations accordingly.
- Address smoke and respirable dust impacts in job hazard analysis/risk assessments.

If a base camp either becomes smoky or avoiding smoke is not possible for safe operations, then further mitigation and monitoring should be considered (below). The National Institute of Occupational Health and Safety considers elimination, or avoidance, of hazard to be the most effective strategy for maintaining personnel health; personnel protective equipment is considered to be relatively less effective (NIOSH 2015). Some have considered the use of masks, including N-95 masks, in smoky conditions, however there are several caveats to using masks (Lipsett *et al.* 2013) and the use of masks may create more problems than they solve. If you are considering the use of masks, you should be considering all of the bulleted items below.

For Potentially Smoke Impacted Base & Spike Camps

- IF you know you have a medical condition that will be aggravated by smoke, tell your Team leader. Self-monitoring for adverse effects is important and avoidance is the best prevention.
- Utilize spike camps as alternatives to impacted camps or periodically rotate crews to clean air areas.
- High levels of smoke during rest periods can affect the adequacy of recovery and lead to greater fatigue. Consider rotations to clean air locations where quality rest is possible.
- Utilize facilities with filtered air systems such as hotels or other public facilities, etc.
- Order clean air tents or trailers with HEPA filtration (priority of use based on exposure of fire fighters, those exposed to high smoke levels and at-risk support personnel).
- Particulate matter PM_{2.5} smoke monitoring kits for base camps and other locations are available in the national cache system, and may be available using NFES 5840 or through your resource ordering system. These systems come with easy to follow directions and a video is available.
- If the base or spike camp is likely to be smoky for an extended period consider using health and fitness screened personnel (people not at greater risk from particles, NO₂, ozone, or CO) as support personnel.
- Reduce vigorous activity levels in base camp when smoky.
- Exposure can also be the result of equipment such as vehicles (exhaust & respirable dust) and combustion style space heaters and generators. Design camp layouts to provide adequate distance between these sources and sleeping and work areas.
- Address trends of respiratory illness rapidly and consider resting and rotating high exposure firefighters if they show symptoms of high smoke exposure (see symptoms listed above).
- Increase personal hygiene awareness to prevent spreading of viral disease.
- If monitoring is conducted, post corresponding Air Quality Index values at the ICP/Base Camp. Consider posting CO threshold values and symptoms (Table 1) at the ICP/Base Camp and consider discussion in briefings.

Discussion Question: What are some effective routes of communication to communicate this information to operations overhead and crew-members in your unit?

Closing Thoughts

It is important to consider all available options when mitigating the impacts of smoke. Using the 215A risk assessment process is a valuable tool when smoke exposure issues are present and allows a robust discussion of risk and mitigation response. Remaining open minded to a mix of mitigation strategies and the understanding that fire is dynamic and strategies may need to be modified is key to successful smoke exposure mitigation. Creative solutions for crew rotations, provisions for clean air facilities, vigilant tracking of symptoms from smoke exposure and even monitoring with pre-planned trigger points are among a suite of options available. Many of these mitigation measures can be planned in advance of fire season including addressing known areas or camp locations where smoke has been an issue previously. Incident close-out discussions frequently identify known smoke impact areas so identifying alternate or new Incident Command Post (ICP) and spike camp locations with emphasis on limiting smoke exposure is possible prior to the wildfire season. Agency administrators can play a significant role in insuring smoke exposure issues are addressed proactively. Clearly addressing smoke exposure in the Line Officers Delegation of Authority to Incident Management teams is also an important step which can then allow the team to design solutions including rotating resources and providing sleep trailers with filtration systems before smoke exposure and adverse symptoms occur.

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Terms to Know

Aldehydes: Chemical compounds containing a carbonyl group (carbon and oxygen) bonded to a hydrogen atom. The most potent aldehydes in wildland fire smoke include acrolein and formaldehyde.

Arrhythmia: A condition in which the heart-beat is irregular.

Carboxyhemoglobin: Blood cells which are laden with carbon monoxide (CO). As CO is inhaled it attaches to hemoglobin (red blood cells) thereby reducing the oxygen carrying capacity of the blood. Carboxyhemoglobin levels can be tested to determine the amount of CO in the bloodstream.

Cilia: Fine hair-like projections from certain cells. In the respiratory tract they move in unison and help to remove particles and fluids.

COHb: Abbreviation for carboxyhemoglobin.

CO: Carbon monoxide (CO), composed of one carbon atom and one oxygen atom, is a natural byproduct of burning biomass. When inhaled, it binds to red blood cells, thereby preventing the cells from carrying oxygen throughout the body.

Coronary artery disease: A disease in which a waxy substance (plaque) builds up inside the coronary arteries which supply oxygen-rich blood to the heart. The resulting restricted blood flow can cause complications including heart attack.

Crystalline Silica (SiO₂): Silica is a common component of soil, sand, and granite. Quartz, cristobalite, and tridymite are crystalline forms of silica that can occur as small, jagged particles. High exposure to crystalline silica causes silicosis, a respiratory disease that most often develops after years of exposure to such dusts.

Ischemia: The restriction of blood supply to tissues.

Nitrogen Oxides (NO_x): Nitrogen oxides are composed of oxygen and nitrogen molecules. NO_x includes nitrogen dioxide, which is emitted as biomass burns. NO_x can irritate the airways when it is inhaled and it is also a key component of ozone formation.

Ozone (O₃): Ozone is a combination of three oxygen molecules. It is formed when nitrogen oxides and volatile organic compounds (VOCs), such as those from smoke, react in the presence of sunlight. Ozone is associated with human health effects including inflammation of the airways, shortness of breath, and reduced lung function.

Phagocytic cells: Phagocyte cells are those that protect the body by ingesting (phagocytosing) potentially harmful foreign particles.

Particulate matter: Particulate matter in the context of wildland fire encompasses coarse particulates, or PM₁₀, which refer to particles with a diameter of 10 microns or less, and fine particulates, or PM_{2.5}, which refers to particles with a diameter of 2.5 microns or less. PM_{2.5} is often the particulate matter focused upon when discussing health impacts, because these small particles can be inhaled deeper into the lungs, and are more difficult for the body to expel than PM₁₀. Occasionally, one may see reference to PM₄. This

is particulate matter 4 microns or less in diameter, it is commonly discussed in occupational health literature and standards, but rarely used in the wildland fire or regulatory communities.

Respirable: Capable of being taken in by breathing.

Silicosis: A form of lung disease resulting from long-term (years) exposure to respirable silica dust. Silicosis gradually impairs lung function.

Ultramafic: A geology term describing volcanically-derived rocks containing small quantities of silica and large quantities of magnesium and iron. Altered ultramafic rocks can be a source of naturally occurring asbestos.

Volatile Organic Compounds (VOCs): Gaseous chemical compounds which contain, among other constituents, carbon molecules. VOCs can react with other compounds to form ozone.

SiO₂: Crystalline Silica.

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