Respiratory protection for wildland firefighters – Much ado about nothing or time to revisit accepted thinking?

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Abstract

Respiratory protection for wildland firefighters is a complex issue and the subject of heated debate and diverging opinions. Sampling has shown that wildland firefighters are exposed to a complex mixture of combustion products including carbon monoxide, irritant gases and vapours, carcinogens and ultra fine respirable particles. While some studies have been interpreted to show that exposure levels, when averaged over a firefighter's work week or career, are below 8-hr time weighted average occupational exposure limits, others have demonstrated that exposures to some toxic combustion products far exceed occupational short term exposure limits at least some of the time. The U.S. National Fire Protection Association has recently announced that it is proceeding with the development of a new wildland firefighting respiratory protection Standard, but it will be some time before respirators certified for wildland firefighting will become available. In the meantime, if administrative controls are unsuccessful in reducing exposures to acceptable levels, wildland firefighters should be provided with air purifying respirators for ultrafine particulate matter, organic vapours and acids, acrolein and formaldehyde. However, wildland firefighters should be cautioned that at high work levels the effectivness and duration of air purifying cartridges is unknown. There is also a concern that firefighters using air purifying respirators may unknowingly expose themselves to higher levels of contaminants not removed by their respirator than they would otherwise. Until a respirator is developed for wildland firefighters that effectively removes carbon monoxide, air purifying respirators should be used in conjuction with a carbon monoxide alarm. If it can be shown that other toxic contaminants are below short-term occupational exposure limits at the CO alarm set point, the use of a certified disposable dust mask in conjunction with a CO alarm may be sufficient.

Introduction

The wildland firefighting community has voiced its concerns since the 1980's about the short-term and long-term health risks of exposure to smoke. The Western Forestry Conservation Association (WFCA) adopted a resolution at its 1990 annual meeting urging, "*continuation and completion of studies that will scientifically quantify wildland smoke exposure risks and identify appropriate and acceptable protective measures* (U.S. Department of Agriculture Forest Service, 1991)." A survey of 300 Federal and State agency employees revealed that 82.2% of respondents thought that the hazards of smoke warranted respiratory protection, especially during direct attack (70.4%), line holding (79.8%) and mop-up (64.8%) (Driessen, et al., 1992).

Standards pertaining to wildland firefighting are generally silent concerning the use of respiratory protection (Canadian General Standards Board, 1997; National Fire

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Protection Association, 2005). One exception in this regard is the current edition of the ISO Standard on wildland firefighting personal protective equipment which states that wildland firefighters *may* use a disposable dust mask certified to EN149 with a minimum rating of FFP2 (corresponding to N95) (International Standards Organization, 2002). In Western Australia, FESA career firefighters are issued negative pressure half-face masks with particulate/formaldehyde air purifying cartridges (Fire and Emergency Services Authority Western Australia, 2003; De Vos, et al., 2006; Parlour, 2007). The Lawrence Livermore Laboratory in California issues negative pressure full-face and half-face air purifying respirators with HEPA/P100 filters and acid gas/organic vapour cartridges and a pre-filter for wildland firefighting, but most of the agencies responsible for wildland firefighting in North America generally do not issue respirators or recommend that they be used. Nonetheless, some forest firefighters are known to cover their face with a bandanna in a futile attempt to reduce smoke exposure (Reh, et al., 1994).

Unlike their municipal counterparts, there currently exists no respiratory protection Standard for wildland firefighting and no respirator certified for use by wildland firefighters. In the absence of a wildland firefighter respirator Standard, a number of uncertified and unapproved devices are currently being marketed to and used by some wildland firefighters. On February 27, 2007, the U.S. National Institute for Occupational Safety and Health (NIOSH) submitted a Comment Letter to the National Fire Protection Association (NFPA) Standards Council supporting the development of a respiratory protection standard for wildland firefighters (Boord, 2007). The author pointed out that there have been numerous studies in the past and that there are other ongoing studies investigating expected inhalation hazards and health consequences associated with wildland firefighting. He concluded that, "*There seems to be little debate the hazards are present and can for some period of time and under certain situations exceed limits requiring respiratory protection for the time that they are encountered*". On March 20, 2007, the NFPA Standards Council announced that it has decided to proceed with the development of a new respiratory Standard for wildland firefighting (National Fire Protection Standards Council, 2007a,b).

It is important to make the distinction between the need for a respirator performance Standard and the need for wildland firefighter respiratory protection. A respirator performance Standard would not mandate the use of a respirator by wildland firefighters. However, in the event that a wildland firefighter or the authority having jurisdiction were to determine that respiratory protection was necessary in any particular circumstance, then the respirator selected would need to meet the minimum specifications established by a future performance Standard and it would need to be certified as having met those performance criteria.

Exposure Assessments

Wildland firefighters experience multiple chemical exposures from smoke. Since there are currently no exposure limits for smoke from fires, it is necessary to measure firefighter exposures to the each component of the smoke having a toxic effect and to compare the results to the respective threshold limit values (TLVs). Smoke from wildland fires is comprised of a mixture of gases, organic compounds and particles, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), aldehydes, volatile organic compounds, free radicals and respirable particulate matter (RPM). If measured concentrations of toxic substances to which wildland firefighters are exposed are averaged over a shift, a

season or an entire career, and compared to time-weighted-average threshold limit value (TLV_{TWA}), the exposures can appear to be quite low. However, given typical intermittently high exposure patterns, that type of data manipulation may not be the most appropriate risk assessment technique for many of the toxic substances of concern to wildland firefighters that have acute and chronic effects. It is also necessary to measure short term exposures and compare the results to threshold limit value (TLV) 15-minute short term exposure limit (TLV_{STEL}) or ceiling values, when available, or to excursion limits (three times the TLV_{TWA}). Where task specific monitoring has been undertaken for a group of wildland firefighters, it is likely that the data is log normally distributed. However, when evaluating the chronic health risks the arithmetic mean (not the geometric mean) of the sample should be compared to the TLV. When evaluating acute health risks, the upper limit of the 95% confidence interval should be compared to the TLV. Where a simple mixture of two or more substances have similar effects on the same target organ, assuming that the health effects are additive, the threshold limit of the mixture is considered to have been exceeded when the following equation exceeds unity: $C_1/TLV_1 + C_2/TLV_2 + \ldots C_n/TLV_n$. Unfortunately, it is not known whether the combined effects of the components of smoke are additive, antagonistic, or synergistic. Also, smoke is a complex mixture and it is unknown to what extent the mixture equation is valid.

There are a number of studies of wildland firefighter exposures to smoke where exposure levels found were reported as being low. It is true that exposure levels may be very low for long periods of time in many cases. However, a study conducted by the National Wildfire Coordinating Group (NWCG) and U.S. Forest Service has found that some firefighters were exposed to levels of smoke far exceeding American Conference of Government Industrial Hygienists (ACGIH) threshold limit values (TLV) or ceiling limits (C) for selected substances sampled at prescribed burns for 20-32 minutes (Reinhardt and Ottmar, 2004): 37 mg/m^3 respirable particles (TLV_{TWA} 3 mg/m^3), 179 ppm carbon monoxide (TLV_{TWA} 25 ppm), 1.460 ppm formaldehyde (C 0.3 ppm), 0.129 ppm acrolein (C 0.1 ppm), and 0.277 ppm benzene (TLV_{TWA} 0.5 ppm). These exposures were 3 to 6 times higher than the levels estimated to have prevailed while holding a fire line at a large project fire where a firefighter suffered from nausea as a result of his exposure to "very heavy" smoke conditions. The NWCG/U.S. Forest Service study also found that at least one third of peak exposures during initial attack, project wildfires and prescribed burns exceeded 10 times the ACGIH STELs in some cases. While smoke levels at the fire line and during mop-up are highly variable, medium to heavy smoke conditions are not infrequent occurrences.

The NWCG and the U.S. Forest Service studies of the health hazards of smoke conducted from 1989 to 1997 were reviewed at an NWCG/U.S. Forest Service Consensus Conference in 1997 where participants voted on a list of recommendations (U.S. Department of Agriculture Forest Service, 1997). The results of these studies have also been published in various reports and journal articles (Driessen, et al. 1992; Sharkey 1994; Betchley, et al. 1997; Reinhardt and Ottmar 1997; Reinhardt, et al. 1999; Reinhardt and Ottmar 2000; Reinhardt, et al. 2000; Ruby, et al. 2002; Ruby, et al. 2003; Booze, et al. 2004; Reinhardt and Ottmar 2004; Slaughter, et al. 2004; Sharkey 2005). The NWCG/U.S. Forest Service 1997 Consensus Conference report noted that, "*exposure studies show that firefighters are sometimes exposed to levels of smoke that exceed OSHA (U.S. Occupational Safety and Health Administration) permissible exposure limits*" (U.S. Department of Agriculture Forest Service, 1997). The consensus report recommended that performance criteria and tests be established

for air-purifying respirators for use on prescribed and wildland fires. It refrained from concluding that respiratory protection is or is not required, preferring instead to state that, "*the need for respiratory protection will require further study and development*." However, recognizing the need to reduce wildland firefighter exposures to smoke, the NWCG/U.S. Forest Service 1997 Consensus Report also recommended that there be "*changes in training and tactics to further minimize exposure,*" and that a model respiratory protection program be developed where 95N/multi-gas respirators would be used at field study sites at prescribed fires. A follow-up NIOSH study of the firefighter exposure management program found that wildland firefighters may be exposed to CO levels in excess of ceiling or excursion limits during as much as 25% of their time fighting fires (McCammon and McKenzie, 2000).

The most frequently reported symptoms in a NIOSH study of wildland firefighters at the Arch Rock Fire in Yosemite National Park were nose irritation and headache (Reh, et al., 1994). In a study of 94 firefighters at the Klamath National Forest fires, 76% reported respiratory symptoms (cough, wheezing, or shortness of breath) and 70% reported at least one neurological symptom (dizziness, light-headedness, headache, loss of consciousness, diminished concentration, confusion, or visual disturbances) (California Department of Health Services, 1990). The most frequent cross shift symptoms reported by Type II crews (n=10) were nose irritation and headache but these did not correlate with self-reported exposure levels (Reh, et al., 1994). In a study of all California fire fighters, smoke inhalation accounted for 38% of all reported injuries and illnesses (U.S. Department of Agriculture Forest Service, 1989). During the 1988 Yellowstone fires, forest firefighters made 30,000 medical visits of which 40% were for respiratory problems (U.S. Department of Agriculture Forest Service, 1989). Forest firefighters have been reported to experience cross-seasonal increases in the prevalence of eye and nose irritation, cough, phlegm production, and wheezing (Rothman, et al., 1991).

The NWCG/U.S. Forest Service 1997 Consensus Conference concluded that, "*medical surveillance is needed to track exposures and further research is necessary to fill gaps in our understanding of emissions, exposure, and health effects*" (U.S. Department of Agriculture Forest Service, 1997). A more recent medical surveillance study by NIOSH has concluded that, "*Wildland firefighters are at risk for acute respiratory effects, apparently associated with fighting wildfires"* (Gaughan, et al., 2005). This is consistent with other studies of wildland firefighters that have found cross-shift and cross-seasonal decrements in pulmonary function (Rosado, et al., 1990; Letts, et al., 1991; Liu, et al., 1992; Reh, et al., 1994; Betchley, et al., 1997; Slaughter, et al., 2004). It is not known if relief from exposure during the off-season may allow for recovery and reversibility of health effects in wildland firefighters. Although medical surveillance of wildland firefighters has thus far focused almost exclusively on respiratory effects, it must be emphasized that smoke is a complex mixture of toxic substances (respirable particles, irritant gases, and toxic substances having both acute and chronic effects) having both acute and chronic effects on multiple organ systems. Respiratory health hazards are not the only health risks to which wildland firefighters are exposed. There have been no epidemiological studies conducted of forest firefighters.

Exposure to wood smoke has been shown to result in increased serum amyloid A and plasma factors in humans and changes in general indicators of toxicity in rodents: increased blood platelet number, circulating white blood cells and spleen

weight, and decreased blood urea nitrogen, serum alanine, aminotransferase and liver weight (Barregard, et al., 2006; Reed, et al., 2006). Aldehydes and acids reduce ciliary activity, reducing the ability of the respiratory tract to remove particles and micro-organisms (Dost, 1991). It has been demonstrated that immunotoxicity results from exposure to low doses of wood smoke (Fick, et al., 1984; Thomas and Zelikoff, 1999; Zelikoff, et al., 2002a; Zelikoff, et al., 2002b; Reed, et al., 2006). This may explain, at least in part, an NWCG/U.S. Forest Service observation that 30-50% of visits to field first aid stations were for upper respiratory problems (cold, cough, sore throat) (U.S. Department of Agriculture Forest Service, 1997).

Respiratory Protection

A NIOSH study of old bandana samples demonstrated that the pore size of the bandana was approximately 200 µm x 200 µm, roughly 500 to 2000 times larger than smoke particles (0.100-0.400 µm) (Reh, et al., 1994). Gases, vapours, and respirable and inhalable particulate matter would pass through the fabric as readily as a mosquito through an open door. There was no indication that frequent washing and hot air drying significantly reduced the pore size of the fabric.

The only NIOSH-approved respirators currently available that might be considered for use by wildland firefighters are air purifying respirators (APR) or powered air purifying (PAPR) respirators. However, none of these will remove carbon monoxide (CO) and none is approved for use under firefighting conditions. Under controlled conditions, it has been found that half-face air purifying respirators with particulate (P) filter cartridges do not protect firefighters from cough, wheezing and shortness of breath following 15-minute exposures under “light” smoke conditions (De Vos, et al., 2006). While particulate/organic vapour (POV) cartridges were more protective, particulate/organic vapour/ formaldehyde cartridges provided better protection. Anthony et al. also found that formaldehyde present in smoke from fires penetrated multi-gas and CBRN air purifying respirators (Anthony, et al., 2007).

Wildland firefighting is a physically demanding occupation conducted under adverse conditions. In the U.S.A., wildland firefighters may experience work shifts up to 24 hours, sleep deprivation, high altitude, poor diet, heat stress, and exposure to smoke (Ruby, et al., 2002). Tasks such as hiking, fire-line construction, chain-saw work, and brush removal requires approximately 7.5 kcal/min (Budd, et al., 1997; Ruby, et al., 2002). Total energy expenditure (TEE) of hot shot crew members engaged in fire suppression activities over five days is approximately 20 MJ/day for men, comparable to 21 MJ/day for simulated military combat training (Hoyt, et al., 1991; Ruby, et al., 2002). The maximum total energy expenditure for humans is approximately 29-37 MJ/day (Westerterp, et al., 1986). Physical activity (EEA) is approximately 4-12 MJ/day for hot shot crew members and is affected by work assignment, self-selected work intensity and fire location (Ruby, et al., 2002). The ISO technical committee has concluded that wildland firefighting personal protective equipment (PPE) needs to achieve an acceptable compromise between increasing the protection from flames and elevated temperatures, and reducing the build-up of metabolic heat and heat stress (International Standards Organization, 2006). In addition to providing PPE that enables wildland firefighters to work for extended durations it must also be sufficiently rugged for use under extreme conditions. Work levels and heat stress are high in the case of wildland firefighting. A respiratory protection program and realistic respirator performance criteria need to be developed that strike a balance between the need for respiratory protection from intermittently high levels of smoke, the need for a reasonable degree of comfort while working in a

hot environment for extended periods in remote areas performing physically demanding tasks, and the need to control and extinguish wildland fires.

Conclusion

Exposure assessments have not been conducted for all toxic substances of concern that are known to be emitted at wildland fires, comprehensive health evaluations of wildland firefighters have not been done, and there are no epidemiological studies that have evaluated the long term health effects of occupational exposures to smoke at wildland fires. However, sampling has demonstrated that some wildland firefighters are at times excessively exposed to a complex mixture of combustion products including acutely toxic carbon monoxide, irritant gases and vapours such as acrolein, carcinogens such as formaldehyde and benzene, and ultra fine respirable particles (<1 μm), and that occupational exposure to smoke causes decrements in pulmonary function. Wildland firefighter smoke exposures are variable and depend on the strategies and tactics employed by different wildfire fighting agencies, the threat level to populated areas and economic interests, and other factors including the type of soil and vegetation, fuel moisture, fire intensity, and wind. Unexpected exposures may also occur as a result of unpredictable events. If exposure levels of wildland firefighters working for different agencies are similar to those measured in studies conducted in the United States, it is probable that these exposures exceed short term occupational exposure limits at least some of the time. However, given the many differences in actual working conditions, especially differences in tactics, unless field studies are conducted one cannot predict what the exposure levels would be for wildland firefighters working in different jurisdictions.

Outstanding issues concerning respiratory protection for wildland firefighters include the quality and completeness of the wildland firefighter exposure assessment databases, methods used to summarize exposure data, possible synergistic effects between toxic substances present in smoke, higher work levels and pulmonary ventilation rates and longer work shifts that result in higher internal doses than assumed when establishing occupational exposure limits, toxicological significance of intermittent exposures to high concentrations, exposure to soil and ash particles kicked up while working, difficulties in monitoring the exposure and the health of a transient and seasonal workforce, identification of tasks and situations where respirators are and are not needed, shortcomings of respirators that are currently available, management of a respiratory protection program for a diverse and mobile workforce operating in a rapidly changing and sometimes unpredictable environment in remote areas for extended periods of time, and cost.

Recent studies have demonstrated large differences in the effectiveness of various respirators certified for industrial use in removing the toxic components of smoke. The multi-gas air purifying respirators are not effective against all of the toxic vapours, especially the aldehydes. None of the filtering respirators remove carbon monoxide (CO). All of the currently available respirators have serious shortcomings for use in a wildland fire situation. Even if they were effective, many wildland firefighters are understandably reluctant to accept negative pressure air purifying face masks for use at high work levels for long periods of time. There is also a legitimate concern that firefighters wearing air purifying respirators might unknowingly expose themselves to higher levels of toxic contaminants not removed by their respirator than they would otherwise.

Recommendation

If administrative controls are unsuccessful in reducing exposures to acceptable levels, wildland firefighters should be provided with a respirator to be used during the times that they are excessively exposed to smoke. In such cases, it is recommended that a certified air purifying respirator (APR) be used for respirable particles, organic vapours and acids, acrolein, and formaldehyde. However, since none of the currently available air purifying respirators effectively remove carbon monoxide, firefighters using these devices might unknowingly expose themselves to higher levels of carbon monoxide than they would otherwise. Carbon monoxide is a colorless, tasteless, odorless, highly toxic gas. Until a respirator is developed for wildland firefighting that effectively removes carbon monoxide, air purifying respirators should always be used in conjunction with a carbon monoxide monitor that sounds an audible vibrating alarm at 25 ppm CO. Wildland firefighters should retreat from areas where CO levels exceed 25 ppm.

At this time, there are too many unknown factors to make a definitive recommendation concerning the type of respirator that wildland firefighters should use. A negative pressure half-face mask APR offers an assigned protection factor (APF) of 10, while the full-face mask offers an APF of 50 and also protects the eyes. Powered air purifying respirators (PAPR) are positive pressure devices offering increased protection factors (an APF of 50 for half-face, and an APF of 1000 for full-face respirators), and reduced breathing resistance which is especially important at high work levels. If it can be demonstrated that when CO exposures levels are less than 25 ppm at wildland fires concomitant exposures to other toxic combustion products are also consistently below short term occupational exposure limits, then it may be sufficient to use certified disposable particulate respirators having an exhalation valve, in conjunction with a CO monitor and alarm. Use of these respirators would require a formal respiratory protection program, including fit testing, and beards will be prohibited. The use of a PAPR-helmet-face shield system (a loose fitting positive pressure device) would provide an APF of 25. The principle advantages of this type of system are comfort, the fact that fit testing would not be required, and beards would be permitted. Some models employing a hood can be demonstrated to have an APF up to 1000.

Regardless of the type of respiratory protection used, wildland firefighters should also be warned that none of the currently available respirators protect against all of the toxic components present in smoke. They should also be cautioned that, given the complex mixture of smoke components and the high work levels typical of wildland firefighting, the effectiveness and duration of air purifying cartridges is unknown.

To better manage wildland firefighter smoke exposures, either by administrative controls or by the use of respiratory protection, it is recommended that comprehensive task-specific exposure studies be conducted. Such field studies should measure exposures to toxic smoke components in relation to visual assessments of smoke, perform chemical characterization of particulate matter, conduct medical surveillance (eg. cross-shift and cross-season pulmonary function tests, prevalence of respiratory and neurological symptoms), and conduct pilot studies of respirator performance under realistic field conditions.

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