Assessing firefighters' exposure to air toxics in bushfire smoke

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Abstract

During the fire season firefighters are likely to be exposed on a regular basis to bushfire smoke, a complex mixture of potentially toxic gases and particles, but whether these exposures could cause health problems needs to be determined. There are a number of factors that determine whether exposure to smoke results in health problems, both short-term and long-term, including the concentrations of air pollutants within the breathing zone of the firefighters, the exposure duration, the ventilation rates and exertion levels, individual susceptibility as well as pre-existing lung or heart disease.

The research presented in this paper focuses on environmental monitoring, the first step within the risk management framework and provides crucial information on magnitude, extent and frequency of personal exposure levels. The environmental assessment shows that the primary air toxics of concern are carbon monoxide (CO) and respiratory irritants. Work activity is a major factor influencing exposure levels. Situations that currently often result in exceedances of existing occupational exposure standards (both average and short-term exposure limits) include suppression of spotfires, holding the fireline, and patrolling at the edge of a burn area in the urban interface.

The paper discusses the adequacy of the existing exposure standards for the bushfire fighting work environment and shows how the information on personal exposure levels will be used to develop methods for minimising potential negative health implications that may arise from exposure to bushfire smoke.

Introduction

Bush fire fighters face a range of hazards in their occupation, and procedures are generally in place to manage many of the hazards. However, one hazard for which there is currently little control is their exposure to bushfire smoke. Bushfire smoke is a complex mixture of gases and particles (Brauer, 1999; Ward, 1999), and when inhaled has the potential to cause adverse health effects. These health effects can be acute, resulting from short-term (usually high) exposure, or chronic, resulting from long term (often low level) exposure over a period of time (Dost, 1991; Larson & Koenig, 1994). Some of the short term health effects that firefighters may experience on the fire ground include respiratory or eye irritation, nausea, headaches, dizziness, or reduced work capacity. Those symptoms generally disappear once the hazard is removed. Chronic effects such as lung damage, heart disease or cancer may not occur for many years and causes of such diseases are often hard to identify.

The aim of the Bushfire CRC Project D 2.2 on Air Toxics Exposure and Management is to provide the best possible scientific information to feed into the development of a risk management strategy to mitigate the impact of smoke on firefighters. The present study focused on environmental monitoring, leading to a better characterisation of the bushfire firefighting work environment, in particular understanding and quantifying exposure levels to toxic air pollutants in bushfire smoke. The dose ingested by firefighters can then be determined by combining physiology data, such as ventilation rates and work activity levels with environmental monitoring of atmospheric composition. Further toxicological input is then necessary to assess potential adverse health effects as a result of exposure to bushfire smoke.

The goal is to create a safe and healthy work environment for firefighters which will be done by developing a strategy for controlling firefighter exposure to bushfire smoke to safe/acceptable levels. The findings from this study along with a better understanding of the bushfire scenario will allow us to review accepted exposure indices such as those presented by the Australian Safety and Compensation Council, in light of the bushfire environment and establish a work code for bushfire firefighting in Australia.

Occupational exposure standards

Fire fighting is an occupational activity and therefore is covered by Occupational Health and Safety regulations relevant to any other workplace. However, there are specific features of firefighting that differentiate it from most other workplaces, and so the Australian legislative requirements need to be reviewed in light of these features.

Existing occupational exposure standards (OES) relevant to the bushfire air toxics research are presented in Table 1 (NOHSC, 1995). They are presented as (1) time-weighted average (TWA) concentration, which is the average airborne concentration of a particular substance calculated over a normal eight hour working day for a five day working week for a sedentary work activity and (2) short-term exposure limit (STEL) which is a 15 minute average exposure. Neither STEL nor TWA should be exceeded.

Table 1 Occupational exposure standards (NOHSC, 1995)

Air Toxic	TWA	STEL	Carcinogen Category [1]
Carbon monoxide (CO)	30 ppm	400 ppm (0 min) 200 ppm (15 min) 100 ppm (30 min) 60 ppm (60 min)	
Formaldehyde (HCHO) [2]	1 ppm 0.3 ppm (proposed)	2 ppm 0.6 ppm (proposed)	2
Acrolein	0.1 ppm	0.3 ppm	
Acetaldehyde	20 ppm	50 ppm	
Benzene	1 ppm / 3.2 mg/m^3	-	1
Respirable particles: Carbon black Graphite dust Wood dust (hardwood) Wood dust (softwood) Fumed silica Talc dust	 3 mg/m^3 3 mg/m^3 1 mg/m^3 5 mg/m^3 2 mg/m^3 2.5 mg/m^3		

[1] Category 1 Carcinogens – established human carcinogens; there is sufficient evidence of a causal association between human exposure and development of cancer
Category 2 Carcinogens – probable human carcinogen; there is sufficient evidence to provide a strong presumption that human exposure might result in development of cancer

[2] The exposure level of 1 ppm should prevent any acute symptoms (eye & respiratory tract irritation). The recommended standard of 0.3 ppm will provide adequate protection against discomfort of sensory irritation and also provides a high level of protection for cancer

The standards need to be adjusted to take into account the different work environment of bushfire firefighters, eg longer and irregular work shifts, heavier workload, exposure to a mixture of air toxics that may have interactive health impacts. While the list of occupational exposure standards (OES,

Table 1) is extensive and identifies several types of respirable particles, it does not provide OES for smoke particles from any source. Since biological effects of particles are dependent upon the chemical composition and physical characteristics of particles, a better characterization of bushfire smoke particles is essential to determine a suitable exposure standard.

Environmental monitoring

A good understanding of the bushfire work environment is required to identify potential influences on contaminant concentrations, operational or environmental factors. Over the last 3 years, monitoring has been carried out at prescribed burns in Victoria, South Australia, Tasmania, Queensland and the Northern Territory and included fuel reduction burns, experimental burns and slash or heap burns in eucalypt or pine plantations. Monitoring was also done at bushfires in Victoria for the 2005/2006 and 2006/2007 bushfire season. All data collected during the field monitoring program are combined to estimate personal exposures and risk potentials to firefighters for different tasks and fire types as a result of exposure to bushfire air toxics.

Methodology

At each site, the aim was to monitor the personal exposure of 3 to 6 firefighters according to their tasks. Firefighters selected usually included those who volunteered to participate in the research study. The selection was also made to ensure that different work activities were represented. No differentiation was made based on age, sex, work experience on the fire ground or smoking habits. Some of the recruited firefighters may endure higher smoke exposures or may alter their normal duties to gain maximum smoke exposure although this was not encouraged by researchers. The firefighters were asked to wear up to five sampling devices monitoring carbon monoxide (CO), respirable particles, aldehydes and volatile organic compounds (VOCs), such as benzene, for the full duration of their work shifts. The equipment consisted of a datalogging sensor for CO and a micropump with an adsorbent tube for collection of VOCs, both devices placed in the top pocket of the firefighter's personal protective clothing. Air monitoring devices for respirable particles and aldehydes were carried in a small 'camelpack' style backpack with an inlet tube placed on the harness within the breathing zone.

Results

Personal breathing zone measurements collected at burns and bushfires between 2005 and 2007 included 117 average and peak measurements of carbon monoxide, 63 average measurements of formaldehyde, acetaldehyde and acrolein, 40 average measurements of VOCs, 65 average and peak measurements of respirable particles and 23 gravimetric measurements of respirable particles.

The exposure assessment showed that the primary air toxics of concern are CO and respiratory irritants. Several air contaminants in bushfire smoke cause irritation to the respiratory tract and mucous membranes. For those pollutants it is necessary to consider not only the compliance of a single substance to the occupational exposure standards (OES), but also the potential for additive effects. The equivalent respiratory irritant index (E_m) takes into account exposure to respiratory irritants including formaldehyde, acrolein, acetaldehyde and respirable particles. Compliance is achieved if E_m is maintained below 1. The respiratory irritant index is calculated as follows:

$$E_m = \frac{C_{\text{formaldehyde}}}{L_{\text{formaldehyde}}} + \frac{C_{\text{acrolein}}}{L_{\text{acrolein}}} + \frac{C_{\text{acetaldehyde}}}{L_{\text{acetaldehyde}}} + \frac{C_{\text{respirable particles}}}{L_{\text{respirable particles}}}$$

where C is the measured concentration of the irritant and L is the selected exposure limit of the irritant (TWA).

The environmental monitoring has shown that the majority of exposures are below OES (Figure 1,) and that exceedances are only observed in a small percentage of cases and over a short fraction of time. The use of data-logging sampling devices enables a better assessment of the extent and frequency of short-term exposure peaks in addition to provide an overall average exposure level over the duration of the work shift. Figure 2 shows the data-logging records of firefighter's exposure to CO during fuel reduction burns. One of the records shows an overall average exposure level below 30 ppm but a few excursions above 400 ppm. Those short-term peaks were measured during fire suppression and usually lasted no longer than 1 minute. The other record displays an average exposure level largely exceeding the TWA exposure limit of 30 ppm, and the peak limit of 400 ppm has been exceeded over a 4-5 min exposure time and at several occasions during the duration of the work shift.

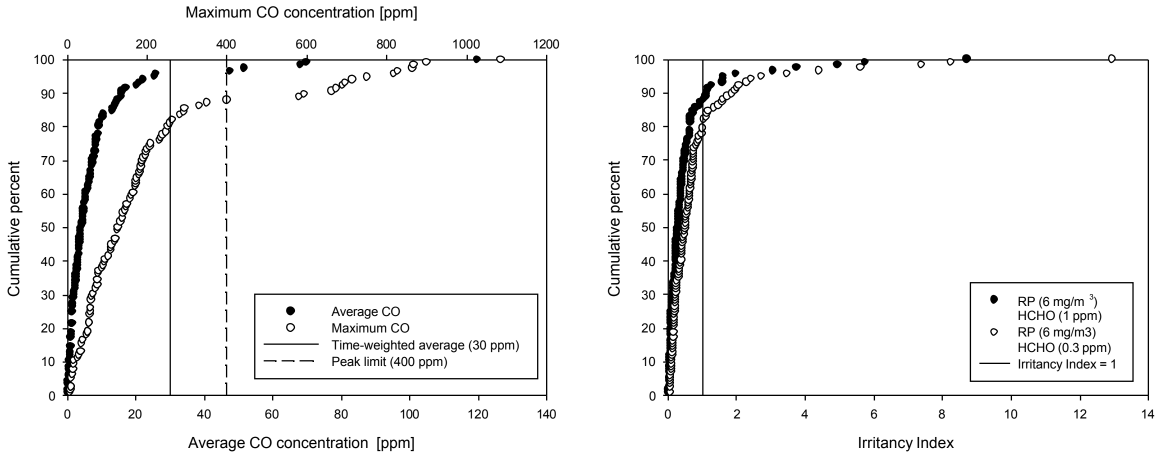

Figure 1 Distribution of exposure levels to carbon monoxide (average and peak) and respiratory irritants (expressed as irritancy index)

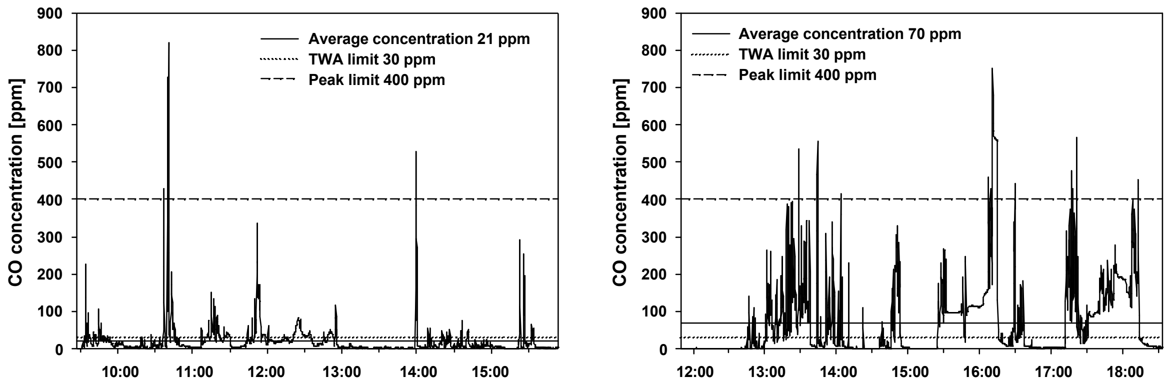

Figure 2 Data-logging records of firefighter's exposure to carbon monoxide

Work activity is a major factor influencing exposure levels. Exposure levels are highest for crews involved in patrol and suppression, with lowest levels observed for lighting crews, who are primarily working upwind of the smoke. Due to VOCs emitted from the drip torches, exposure levels to total VOCs are highest for lighting crews. Short-term peak exposures were observed during suppression of spotfires, and in general, high risk situations that lead to elevated exposures to air toxics include suppression of spotfires, holding the fireline, and patrolling at the edge of a burn area in the urban interface.

Potential health impacts and control strategies

The environmental monitoring provided essential information on magnitude, extent and frequency of personal exposure levels and identified a range of situations that may potentially cause exceedances of occupational standards. Primary air toxics of concern include CO and respiratory irritants.

Potential health impacts

Carbon monoxide (CO) is a colourless and odourless gas which when inhaled binds to haemoglobin in the blood. Carboxyhemoglobin (COHb) is produced leading to reduced transport, delivery and utilisation of oxygen. CO has a half life of about 4-5 hours, and COHb levels will return to background levels once CO exposures are eliminated. Exposure to elevated levels of CO can result in cognitive impairment, reduced work capacity, dizziness and nausea. The risk for CO induced symptoms depends on each individual. The question is whether ongoing exposure to low levels of CO with occasional exposure to elevated levels of CO is likely to cause headaches, dizziness or behavioural effects. In order to minimise potential symptoms from overexposure to CO, it is recommended to keep COHb levels below 5%. Regular monitoring of firefighters COHb levels in exhaled breath will provide a good indication whether it is safe to keep a firefighter on the fire ground or whether additional time in a low CO environment is necessary.

Acute effects that could arise from exposure to elevated levels of respiratory irritants include irritation to eyes and the respiratory tract, difficulty breathing and coughing. In general those symptoms are likely to disappear once the hazard is removed. Low concentrations of respiratory irritants in particular respirable particles and formaldehyde may also trigger asthmatic attacks in sensitised individuals.

Long term health effects that may possibly result from elevated exposure levels to respiratory irritants include permanent lung damage, reduced lung function. Exposure to sensitisers can cause increased symptoms on further contact. The risk for long-term health effects depends upon the magnitude and frequency of exposure, the duration exposure (in years), exposure to other pollutant sources (eg, vehicle exhaust, cigarette smoking), and the health status of the individual. Decrease in lung function could be assessed by measuring lung function at the beginning of the fire season and then again at the end of the fire season. In order to determine whether lung damage has been permanent, measuring lung function at the start of the next fire season will determine whether lung function has returned to initial value. It would be necessary to evaluate the individual's exposures to other pollutants potentially affecting the lung over the time period between fire seasons.

There is also a concern that some of the air toxics in bushfire smoke are carcinogenic. Formaldehyde has recently been classified by the International Agency for Research on Cancer (IARC) as a known human nasal carcinogen (Cogliano *et al*., 2005) and its exposure levels should be kept as low as feasible. For average exposure levels of 0.3 ppm formaldehyde, the occupational risk for respiratory tract cancers after repeated exposure to formaldehyde by inhalation is likely to be low (NICNAS, 2006).
Respirable particles may have adsorbed on their surfaces potentially carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs). Further analysis needs to be conducted to determine the chemical composition of bushfire smoke particles and assess their potential carcinogenicity. Classification as a carcinogen need not apply if it can be shown that the substance contains less than 0.005 % w/w benzo[a]pyrene (NOHSC, 2004).

Control strategies

The findings from the field monitoring program will help in developing control strategies to minimize potential health impacts. Potential control strategies include policies and procedures for safe work practices such as frequent rotations among lighting and patrol crews, reducing exposure time in dense smoke, and hazard awareness training. In case high exposure situations cannot be avoided, wearing of respiratory protection may be necessary. However, since CO is not filtered out by respiratory masks, it is recommended to limit the amount of time spent in dense smoke.

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