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COOPERATIVE RESEARCH CENTRE.

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FIRE NOTE

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FIREFIGHTER'S EXPOSURE TO AIR TOXICS DURING PRESCRIBED BURNS

SUMMARY

Bushfire fighting can be hazardous and in general control strategies are in place to minimize the hazards. However, Bushfire CRC partner agencies felt that there was little knowledge about firefighter's exposure to bushfire smoke, a complex mixture of toxic gases and particles.

The Bushfire CRC Project D 2.2 on *Air Toxics Exposure and Management* aims at developing a risk management strategy to mitigate the impact of smoke on firefighters. This will be done by limiting the exposure of fire-fighters according to a Bushfire Exposure Standard. The research undertaken for this purpose involves characterising the bushfire firefighting working environment, in particular understanding and quantifying exposure levels to toxic air pollutants in bushfire smoke.

Previous research on exposure levels is limited and has primarily been carried out in the US. In Australia, the composition of bushfire smoke, the factors that are likely to influence exposure levels and the impact of bushfire smoke on Australian firefighters is largely unknown.

BACKGROUND

Bushfire smoke is a complex mixture of toxic air contaminants that might be inhaled while fighting fires. These air toxics can be present as gases or as particulate matter.

Major air contaminants released in bushfire smoke include carbon monoxide, respiratory irritants (particles, formaldehyde, acrolein), volatile organic compounds (such as benzene) and potentially toxic compounds adsorbed to particles, such as polycyclic aromatic hydrocarbons (PAHs). If present at elevated levels, these compounds can potentially cause short-term health effects (headaches, dizziness, irritation, fatigue, lack of concentration) or long term health effects (cardio-respiratory health effects, reduced lung function, cancer).

Currently no formal standard of work practice for bushfire fighting exists, which specifies safe levels of exposure to air toxics.

To protect the short and long-term health of bushfire fighters it is important that there is measurement and evaluation of air toxics in both wild and prescribed fires in Australia so that exposure levels for specific conditions may be characterised.

Extensive personal exposure studies of bushfire firefighters have been carried out in the United States, but no other country.

In Australia there is little knowledge of firefighter's exposure to toxic air pollutants emitted during prescribed burn operations or bushfires.

Since vegetation types, fire characteristics and fire fighting operations are likely to differ from those in the US, it was considered necessary to carry out field measurements during Australian burns and bushfires to determine the magnitude of smoke exposure and related health risks.

DEFINITIONS

- **CO** is a colourless, odourless and non-irritating gas which is produced when carbon-containing compounds burn with insufficient air. When carbon monoxide is inhaled, it binds to hemoglobin, the red blood pigment that normally carries oxygen to all parts of the body. Carboxyhemoglobin (COHb) is produced inhibiting transport, delivery and utilisation of oxygen.
- **Respirable particles** are small particles that can settle deep within the lungs and that are not ejected by exhaling, coughing, or expulsion by mucus.
- **PAHs** are organic compounds consisting of at least two fused benzene rings. They are products of incomplete combustion of organic matter and can be present in the gas and particle phase. A number of these are classified as probable and possible human carcinogens.

LEFT: BUSHFIRE CRC RESEARCHER AND AIR SAMPLING DEVICES AT A PRESCRIBED BURN

BUSHFIRE CRC RESEARCH

A current constraint on how the fire agencies can manage their operations to comply with OHS regulations is the lack of air toxics exposure knowledge for Australian fire fighters and a lack of suitable Occupational Exposure Standards (OES).

In order to estimate the risk of exposure to potentially unhealthy levels of toxic air pollutants, the following are required:

a. Identification of primary air toxics present in bushfire smoke that could potentially cause adverse health effects;
b. A reliable estimate of exposure: How high? How variable? Key factors?; and
c. A compliance standard that can be used for risk management purposes.

KEY AIR TOXICS IN BUSHFIRE SMOKE

Key air toxics released during bushfires have been identified through review of Australian and international literature and through experimental burns of various Australian vegetation litter.

The key air toxics to be measured and their potential health effects are shown in Table 1.

EXPOSURE

To determine the exposure levels of firefighters to air toxics, quantitative samples were collected within the breathing zone of randomly selected firefighters. At each prescribed burn, up to four firefighters were asked to wear a sampling pack which included a range of sampling devices for monitoring different air toxics (Table 2). The sampling devices have been chosen based on a range of criteria:

- Comfort, weight
- robustness
- specificity to selected air toxic
- availability of reliable analysis method

To determine the variability of exposure levels, monitoring was conducted for key tasks involved at prescribed burns (supervision, ignition with hand-held drip torch, patrolling, fire suppression with hose or rake-hoe), different fuel types (eucalypt forest, grassland, mallee heath land, tropical forest, button grass) and different fire types (fuel reduction burns, slash or heap burns, experimental burns).

TABLE 1: AIR TOXICS IN BUSHFIRE SMOKE AND POTENTIAL HEALTH EFFECTS

AIR TOXICS	POTENTIAL HEALTH IMPACTS
Carbon monoxide (CO)	Headache, nausea, impaired exercise capability, impaired judgement, exacerbate respiratory & cardiac disease (angina), affects foetal development
Volatile Organic Compounds (VOCs) (eg: Benzene)	Headache, eye/nose/throat irritation, dizziness, fatigue Benzene – known human carcinogen
Aldehydes (eg: formaldehyde, acrolein)	Eye/nose/throat irritation, aggravation of existing respiratory conditions Formaldehyde - known human carcinogen
Respirable Particles (RP)	Impaired lung function, exacerbate cardiac and respiratory illnesses
Polycyclic aromatic hydrocarbons (PAHs)	Probable human carcinogens

TABLE 2: PERSONAL AIR SAMPLING DEVICES

AIR TOXICS	SAMPLING DEVICE
Carbon monoxide (CO)	Draeger Pac III data logging sensor measuring up to 2000 ppm CO in real time
Volatile Organic Compounds (VOCs)	Micro Air Sampler with a tube holder for Perkin-Elmer prepacked Air Toxics sorbent tubes
Aldehydes	UMEx100 passive sampler badge
Respirable Particles (RP)	Passive data-logging, light-scattering particle monitor (pDR) measuring up to 400 mg/m^3 in real time
Respirable Particles (gravimetric)	25 mm glass fibre filter loaded in a filter cassette and used with a conductive plastic cyclone

OCCUPATIONAL EXPOSURE STANDARDS

Since firefighting is an occupational activity, it is covered by Occupational Health & Safety (OHS) regulations relevant to any other workplace. Occupational exposure standards (OES) are provided in Australia by the National Occupational Health and Safety Commission (NOHSC) and ensure that "air inhaled at work should not contain chemical agents at concentrations that produce adverse effects on health, safety or well being". The OES do not represent 'no-effect' levels, but are best used to assess the quality of the working environment and identify areas of unacceptable risks for which control measures would be required.

The exposure standards are presented as

- time-weighted average (TWA) concentration which is the average airborne concentration of a particular substance when calculated over a normal 8-hour working day for a 5-day working week (sedentary work activity); and
- short-term exposure limit (STEL) which is a 15 minute average exposure which should not be exceeded more than 4 times a day, and be separated by at least 60 minutes.

The National Standard relevant to the bushfire air toxics research is "Exposure Standards for Atmospheric Contaminants in the Occupational Environment – Database [NOHSC:3008 (1995)]. Table 3 shows the major air contaminants present in bushfire smoke and their respective exposure standards. Note that there is no current standard available that is specific to bushfire smoke particles.

These exposure standards may need to be adjusted to take into account the different working environment of bushfire firefighting

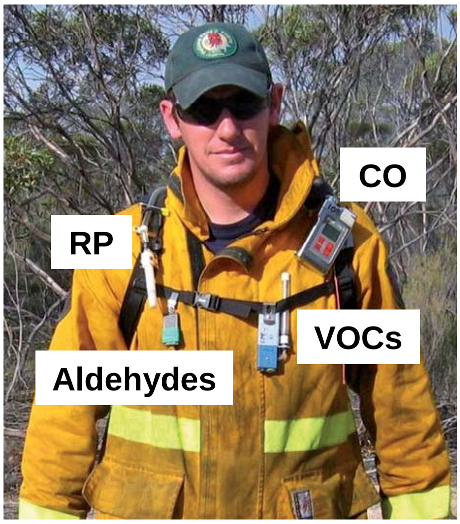
- adjustment for altered work shifts and heavier workloads. Heavy or strenuous work increases lung ventilation, thereby increasing the uptake of airborne contaminants; and
- complex nature of bushfire smoke. There is no current standard available that is specific to bushfire smoke particles and that addresses the potential for adverse health effects arising from interactive toxics.

RESEARCH OUTCOMES

Over the last two fire seasons, measurements were collected at 12 prescribed burns across Australia, five fuel reduction burns and two slash burns in Victoria, one fuel reduction burn and experimental burn in South Australia, experimental burns in the Northern Territory, one fuel reduction burn and one heap burn in Tasmania. Measurements were collected on 40 firefighters and 10 researchers working on the fire ground.

The results have shown that:

- According to the current OES relevant to bushfire air toxics, the majority of exposure levels are in compliance. However it should be noted that exposure standards may need to be adjusted to take into account the more strenuous workload firefighters are carrying out. Increased lung ventilation rate may lead to increased uptake of air contaminants.
- CO levels exceeded occupational exposure standards in a small number of cases, both from the averaged exposure limit of 30 ppm (2%) and the peak limit of 400 ppm (8%), which should never be exceeded. CO reduces the oxygen carrying capacity of the blood and therefore exposure to high levels of CO over an extended period of time may lead to impaired judgement and may have an effect on performing tasks that require vigilance. Elevated CO concentrations may also aggravate cardiac conditions especially for people with pre-existing heart disease, as the heart has to work harder with less oxygen available to help it. Regular monitoring of firefighter's carboxyhemoglobin (COHb) levels on the fire ground may be critical to ensure that no CO-induced symptoms are observed and that firefighters spend enough time in a CO-free environment to reduce their COHb levels in the blood.
- Other primary pollutants of concern include respiratory irritants. The equivalent irritant exposure index E_m takes into account the additive effects of respiratory irritants, including respirable particles, formaldehyde and acrolein. In order to be in compliance E_m has to be below 1.0, a level which was exceeded for 30% of the samples collected. High concentrations of these irritants are likely to cause eye watering and coughing, which were symptoms frequently reported by firefighters. Ongoing exposures to elevated levels of respirable particles may also lead to reduced lung function and potentially aggravation of pre-existing heart or respiratory disease.
- A large variability was observed among the samples collected. The type of work activity has been found to be a major factor influencing exposure risks. Crew members involved in patrolling and suppression have higher exposures to bushfire air toxics than those crew members involved in the ignition of burns. Drip torches however are an additional source of VOCs and inhalation of the fumes may lead to headaches.
- A good correlation was observed between pollutants in particular between CO, respirable particles and aldehydes. This shows that exposures will generally be to combined mixtures of these air toxics and that simplified measurement schemes may be possible in the future.
- So far measurements have focused primarily on prescribed burns; future work needs to include wildfires and burns and fires at the urban interface to complete the picture.



▲ **FIGURE 1:** FIRE FIGHTERS FITTED WITH PERSONAL SAMPLING DEVICES

TABLE 3: OCCUPATIONAL EXPOSURE STANDARDS RELEVANT TO BUSHFIRE SMOKE EXPOSURES (SOURCE: NATIONAL OCCUPATIONAL HEALTH AND SAFETY COMMISSION)

AIR TOXIC	TWA*	STEL**	CARCINOGEN CATEGORY[2]
Carbon monoxide[1]	**30 ppm**	400 ppm (0 min) 200 ppm (15 min) 100 ppm (30 min) 60 ppm (60 min)	
Formaldehyde	**1 ppm**	2 ppm	2
Acrolein	**0.1 ppm**	0.3 ppm	
Acetaldehyde	**20 ppm**	50 ppm-	
Benzene	**1 ppm or 3.2 mg/m^3**	-	1
Toluene	**50 ppm or 191 mg/m^3**	150 ppm	
Acetic acid	**10 ppm or 25 mg/m^3**	15 ppm	
Phenol	**1 ppm or 4 mg/m^3**	-	
Respirable particles - Wood dust, Coal dust, Graphite	 **1-5 mg/m^3** **3 mg/m^3**		

[1] Short-term excursions represent guidelines recommended by the Exposure Standards Expert Working Group

[2] 1 - Established human carcinogen; 2 – Probable human carcinogen

* TWA (Time-Weighted Average)

** STEL (Short-Term Exposure Limit)

FIGURE 2: DATA LOGGER RECORD

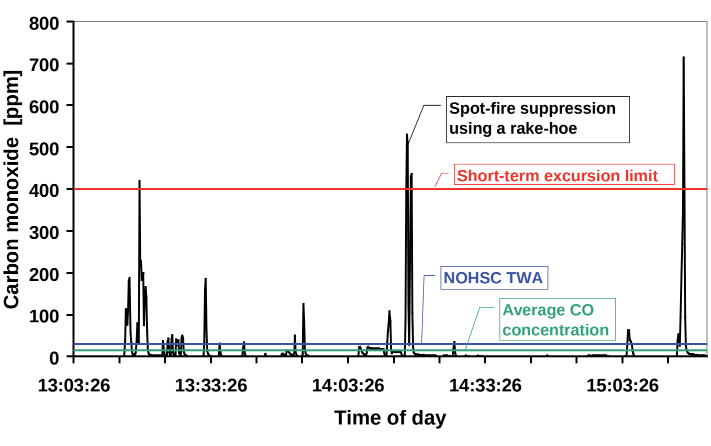
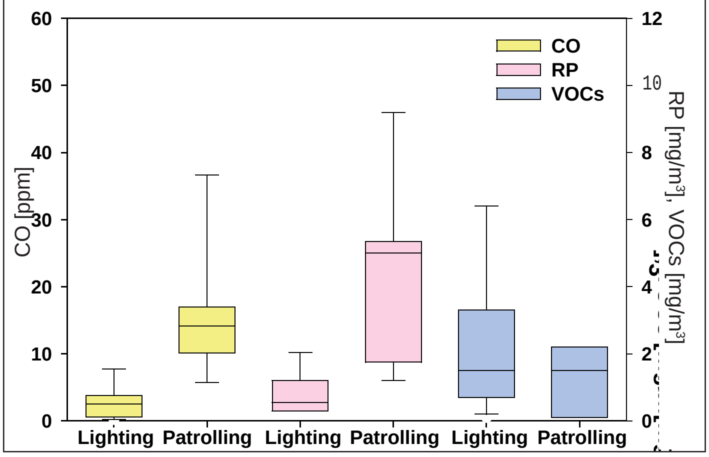


FIGURE 3: PERSONAL EXPOSURE RECORDS BY WORK ACTIVITY



▲ **FIGURE 2:** DATA LOGGER RECORD OF A FIREFIGHTER'S EXPOSURE TO CARBON MONOXIDE

▲ **FIGURE 3:** PERSONAL EXPOSURE LEVELS TO BUSHFIRE AIR TOXICS BY WORK ACTIVITY (Lighting – using a handheld drip torch; Patrolling- includes suppression with hose and/or rake-hoe) The boundary of the box indicates the 25th and 75th percentiles, a line within the box marks the median and error bars above and below the box indicate the 90th and 10th percentiles.

HOW IS BUSFHIRE CRC RESEARCH BEING USED

The outcomes of the research will aim at identifying those situations of unacceptable risk and develop risk management strategies to mitigate or minimize the risks.

Possibilities for control strategies include:

- At operational level: task assignment and rotation (mix high/low exposure tasks; assign firefighters to specific tasks;
- Hazard awareness training: explain situations where exposure to air toxics is likely to be high and how exposure risk can be minimized;
- Respiratory protection; and
- Use of personal exposure sensors – CO sensor to alert firefighters of high exposure risks and when the use of respiratory protection is recommended
- **Better understanding of the bushfire firefighting working environment**
    - » Understanding and quantifying any risks involved from air toxics and their potential magnitude.
    - » Identify whether there are any unacceptable risks, and how these can be mitigated or managed.
- **Enable agencies to develop protocols to:**
    - » Avoid injuries and fatalities resulting from impaired decision making,
    - » Retain staff and volunteers by reducing chronic impacts of smoke exposure

FUTURE DIRECTIONS

Over the next fire season, personal exposure monitoring will continue in order to increase the coverage of current monitoring to other states and vegetation classes, and also expand monitoring in bushfires as well as burns at the urban interface.

The analysis will be concentrated on personal exposures and risk potentials for different tasks, fire and fuel types. The exposure levels will also be linked to physiology assessment provided by Project D 2.1 *'Firefighter health and safety'*.

Future measurements will also expand on the characterization of particulate matter which has emerged as a pollutant of particular concern, looking particularly at size distribution, chemical composition and potential health impacts.

A risk management strategy and an associated draft Bushfire Exposure Standard will be developed. If additional funding can be secured, the risk associated with the application of the management strategy will be assessed.

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Bushfire CRC is a national research centre formed in partnership with fire and land management agencies in 2003 to undertake end-user focused research.

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