Background briefings on emerging issues for fire managers from AFAC and Bushfire CRC.

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FIRE NOTE

TOPICS IN THIS EDITION
- RISK
- HEALTH AND SAFETY

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# NEW MODELLING METHODS TO ESTIMATE SMOKE EXPOSURE


## SUMMARY

Toxic emissions from burning houses, cars and other household materials during bushfires may pose a range of health risks to communities and their firefighters.

The potential health effects range from relatively minor illnesses, such as nausea and respiratory irritation, to life threatening conditions, such as asphyxiation, as well as exposure to well-known cancer causing substances.

This *Fire Note* details research that estimates toxic emissions commonly encountered by firefighters extinguishing fires in semi-rural communities at the rural-urban interface.

The scientists developed laboratory-based simulations to burn samples of synthetic or constructed materials typically involved in property fires within these locations. These included materials such as particleboard, medium-density fibreboard, carpet and polyurethane foam, which all produce toxic chemical emissions when burnt.

Toxic emissions contained in smoke from burning building materials have been measured and characterised in previous laboratory tests (Reisen 2013). However, in this study, the researchers translated the modelled emissions into exposure estimates that could be compared with national occupational exposure standards. The study focused on fine particulate matter, gases such as hydrogen cyanide (HCN) and carbon monoxide (CO), as well as volatile or semi-volatile organic compounds (VOCs).

The researchers have developed new high resolution modelling techniques for both smoke dispersion and wind-behaviour to account for the chemical emissions from multiple and complex sources and to determine the zones of highest risk around burning properties.


▲ Researchers developed a new dispersion methodology to estimate exposure to smoke emissions.

## ABOUT THIS PROJECT

This *Fire Note* builds on the research outlined in *Fire Note* 114, and is part of the *Operational readiness of rural firefighters (air toxins)* project, within the Bushfire CRC *Managing the Threat* program. This is the final *Fire Note* from this project.

## AUTHORS

Dr Michael Borgas, CSIRO Oceans and Atmosphere Flagship and Dr Fabienne Reisen (right), CSIRO Oceans and Atmosphere Flagship and Bushfire CRC project leader. For more information contact michael.borgas@csiro.au or fabienne.reisen@csiro.au

## CONTEXT

**Exposure to smoke is one of the many risks faced by firefighters working at the front line. This research investigated the risks from smoke hazards to firefighters specifically working at the rural-urban interface, where typically they have been unlikely to wear breathing apparatus when responding to bushfires. The findings also have implications for community members who plan to stay and defend their homes.**

## INFORMING TACTICAL FIREFIGHTING

Firefighting at the rural-urban interface exposes firefighters to hazardous smoke from burning materials. This could involve exposure to high concentrations of chemical toxins. Exposures can be brief, lasting only seconds or minutes. However, a proper assessment of the risks is important for effective response management and planning in future. Unprotected exposure to high concentrations of toxic emissions could, in extreme conditions, result in firefighters being overcome by fumes. Repeated prolonged exposure could also potentially result in a range of chronic adverse health problems.

Decision making in the field is typically based on limited, uncertain information about wind conditions, building types and distributions of flammable materials. This research set out to develop a new model and approach to improve decision making and inform tactical firefighting decisions.

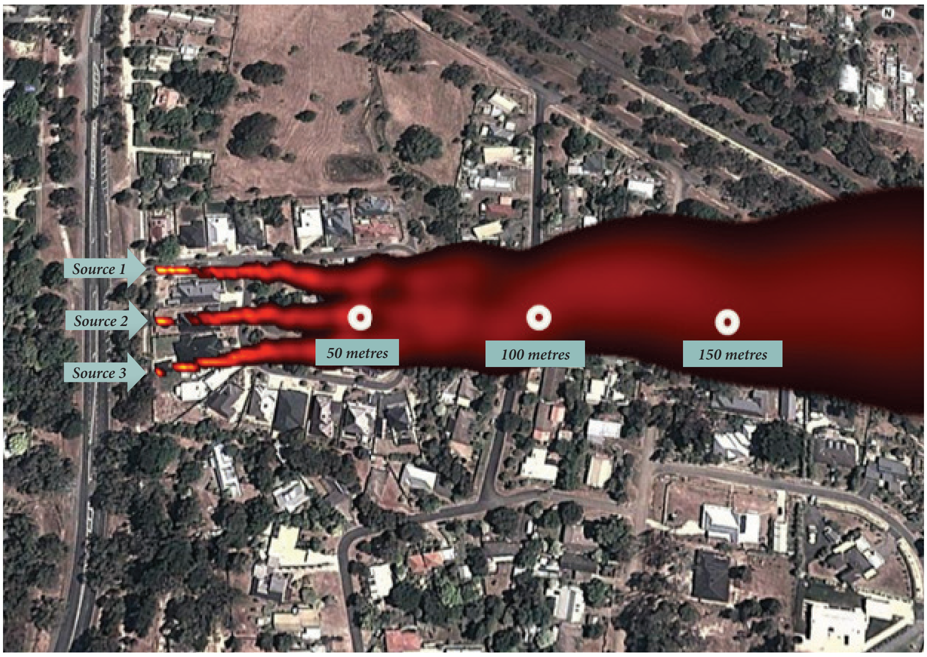
## NEW METHODOLOGY

This project developed a new dispersion methodology to estimate exposure to smoke emissions from burning buildings in a range of complex scenarios. The model applied set emission rates for chemicals at known points in a burning building. The model emissions were released as puffs of specific hazardous gases, second by second, into variable winds, but with known statistical characteristics of the atmospheric boundary layer. The statistical framework was necessary to account for fundamental uncertainty and a lack of precise information (which always accompany emergencies), together with the natural variability of wind. This technique allows more detailed plume modelling, including short-term resolution of fluctuating concentrations, merging of multiple plumes from multiple sources and the development of spatial characteristics downwind. The model provides estimates of concentrations averaged over short exposure times, as well as probability distributions estimating the frequency and likelihood of exposures exceeding safe occupational health and safety levels.

The model related to clusters of a few emission points and a simple (e.g. constant) emission rate. A house could be burning from many points internally, but from modest distances (e.g. 50 metres) downwind it was sensible to consider the house as a single source point.

The model relies on a range of information: databases of houses (types and locations), knowledge of materials in houses, sheds and associated vehicles, as well as known wind conditions.

The smoke emissions data contained data from published literature as well as from additional experimental testing. This testing was conducted using a cone calorimeter on selected structural and furnishing materials (Reisen, 2013).




▲ Figure 1: Three separate plumes in the small correlated wind field from a cluster of point sources. Yellow is high concentrations, bright red is intermediate concentrations and the darker colours are low concentrations at the plume edge.

## EXAMINING THE PLUMES

A system of plumes from a three point source cluster is shown in Figure 1 (above). There is a steady wind of four metres per second (approximately 15kph) blowing left to right, with turbulent deviations of the wind at one metre per second (approximately 3.6kph) causing undulations of the plume downwind. In this case, each source is a separate house with a distinct smoke plume emerging from each. Further downwind these three separate smoke plumes merge into one (after about 40-50 metres for smoke emitted 40 seconds earlier). Concentrations of pollutants within the plume decrease by dilution when moving further away from the source and further away from the plume centreline.

The concentration time series within the plume is shown in Figure 2 (page 3) for three downwind distances (represented by the dots in Figure 1). This figure clearly shows large fluctuations in concentrations, particularly at a short distance from the source (e.g. 50 metres). Further away from the source (at 100 and 150 metres), both the fluctuations and the overall concentration levels were significantly reduced. For this particular scenario, it was assumed

▲ Firefighter and community situational awareness in rural-urban interface bushfire exposures is a key element of personal safety.

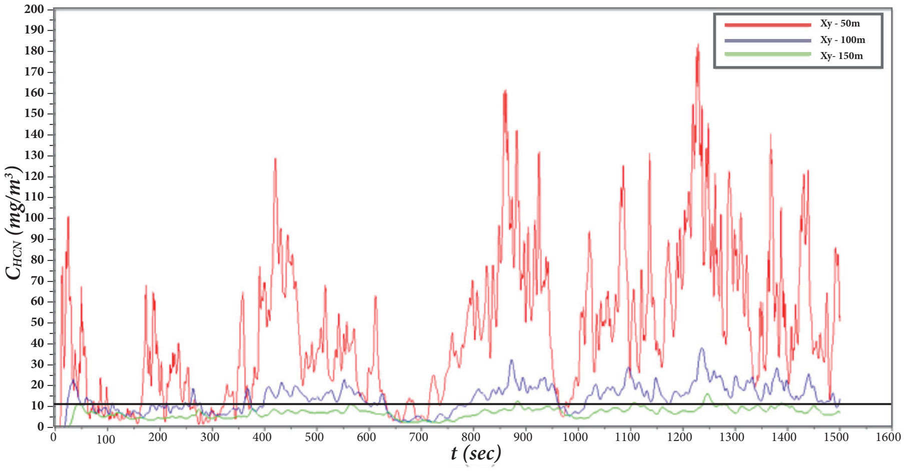
## END USER STATEMENT

Firefighter and community situational awareness in rural-urban interface bushfire exposures is a key element of personal safety. This project research provides new insight into risk of smoke exposures from structures and environmental conditions in interface bushfires.

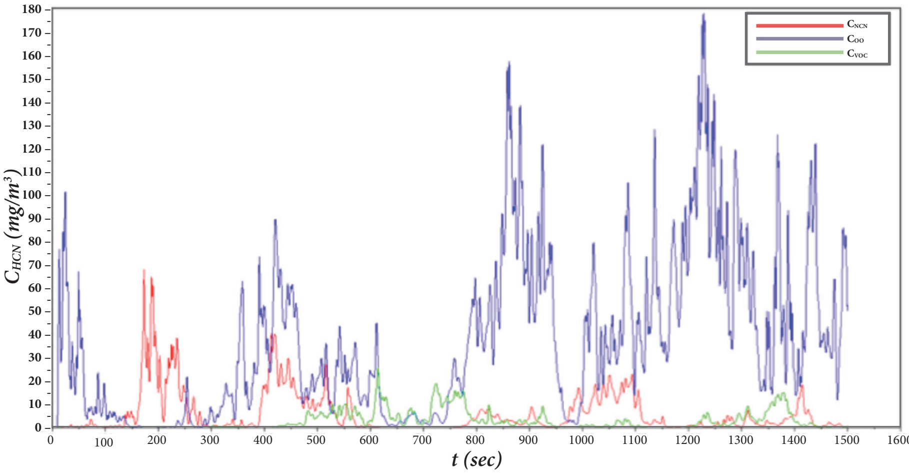
The research provides a detailed picture of the toxic risks faced by firefighters and community members endangered by bushfires in rural-urban interface communities. By using the new dispersion methodology, firefighters and the community can determine strategies to mitigate risk of bushfire toxic exposures and estimate the frequency and likelihood of exposures exceeding safe levels.

The project findings will assist fire and emergency management agencies in making tactical firefighting and occupational health and safety decisions. It will also assist in the development of bushfire education and community safety campaigns.

– Mr David Nichols
Manager, Research and Innovation,
Country Fire Authority, Victoria




▲ Figure 2: Hydrogen cyanide (HCN) concentrations directly downwind of the sources at three different distances (as shown in the legend). The black line represents the peak occupational exposure limit for HCN of 11 mg/m³.




▲ Figure 3: Combinations of chemicals at 50m downwind with different emissions from each source in the cluster (of three houses), i.e. different materials burning at the same time in each of the houses.

emission rates of 100, 200 and 500 micrograms of hydrogen cyanide (HCN) were emitted per second from sources one, two and three respectively. The emission rates were chosen to show exceeded threshold risks at 50 and 100 metres from the source. The exposure estimates shown in Figure 2 also display multiple 60 second periods at exposure concentrations exceeding the peak occupational exposure limit for HCN of 11 mg/m³ at both 50 metres and 100 metres from the source. Highest concentrations were at 50 metres downwind. The peak concentrations, which were 10-15 times higher than the occupational exposure peak limits, persisted for five to 10 seconds. The exposure risk became progressively lower further downwind. At 150 metres from the sources, HCN concentrations were mostly below the peak limit.

The scenario for a cluster of sources emitting different air toxics is shown in Figure 3 (page 4). This scenario assumes that HCN, CO and VOCs are emitted from source 1, 2 and 3 respectively at varying emission rates. Highest emissions were recorded for CO from source 2, with lower emissions of HCN from source 1 and lowest emissions of VOCs from source 3. The CO plume is sampled directly downwind but the HCN and VOC plume sampling differ because of lateral displacement (10 metres to either side). The peaks of HCN and VOCs are significant, but occur infrequently, due to the large lateral movements.

Figure 3 also shows a short-term hazard from HCN exposure at around 200 seconds, even when not directly downwind of the source. This shows that even though average concentrations decrease when moving away from the centreline of the plume, peak concentrations can still be elevated at the edge of a plume.

## RESEARCH OUTCOMES

The new modelling techniques detailed in this research combine correlated time-series of turbulent winds at the emission source with Lagrangian dispersion models downwind. This approach accounts for dispersion of toxic emissions over shorter time frames, as well as from multiple point sources.

Traditional dispersion models have typically been based on the application of averaging techniques for longer time scales (e.g. one hour) or over larger areas (e.g. average emissions for a whole suburb). These averaging methods do not provide reliable assessments of acute short-term exposure. The new model provides a better understanding and more precise estimates of the potential exposure risks. This information will, in turn, assist emergency management professionals make informed decisions about protecting their firefighters, as well as in developing future community safety education.

Exposure estimates from seconds to minutes can be developed with local averages and variability of wind and source characteristics on site during an incident.

The cluster approach also allows assessment of scenarios of multiple houses burning at the urban fringe. Such assessments of interacting urban smoke sources and plumes are new.

Full details of this study can be found in Borgas and Reisen (2014).

▲ The research findings will assist fire and emergency management agencies in making tactical firefighting and occupational health and safety decisions.

## HOW COULD IT BE USED?

An Inverse Modelling Workshop held at CSIRO (Borgas 2013) involved many agencies, such as the Country Fire Authority, Australian Radiation Protection and Nuclear Safety Agency, Bureau of Meteorology, Defence Science and Technology Organisation and Geoscience Australia. Feedback at the workshop indicated support for and interest in the new dispersion models.

In future, modern and commonly used GIS mapping tools would make ideal platforms for merging dispersion modelling with emergency response decision making in-the-field. In addition, the use of sensors to measure toxic exposure and the integration of chemical sensor data with dispersion models as (inverse) decision support systems could be adopted by agencies.

## FUTURE DIRECTIONS

The future needs of a technologically advanced emergency management sector will include 'inverse problems' where models capable of short time-scale resolution are used to understand real-time sensor measurements of chemical concentrations and wind. This real-time situational awareness, with model parameter and emissions estimates, provides for estimation of safe zones and exposure to hazards than scenario planning approaches.

## REFERENCES/ FURTHER READING


Borgas M and Reisen F, 2014, Bushfires extending into the rural-urban interface: final report for the *Operational readiness of rural firefighters (air toxins)* project, Bushfire CRC.

Borgas M, 2013, Moving Forward on Inverse Modelling: CMAR Inverse Modelling Workshop, Report to CMAR Capability Development Program.

Reisen F, 2011, Identifying smoke impacts from bushfires extending into the rural-urban interface, Bushfire CRC *Fire Note* 83.

Reisen F, 2011, Inventory of major materials present in and around houses and their combustion emission products, Bushfire CRC.

Reisen F, 2013, Assessing toxic emissions at the rural-urban interface, Bushfire CRC *Fire Note* 114.


## NOW WHAT?

What three things stand out for you about the research covered in this *Fire Note*? What information can you actively use, and how? Tools are available at www.bushfirecrc.com/firenotes to help, along with activities you can run within your team.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ACTIVITY SHEET 1

ONE KEY ACTION

PURPOSE

This activity sheet is designed for you to lead a discussion with your team to consider the key issues raised by a *Fire Note*, and the impacts these may have on your team.

OUTCOME

Leading this discussion will enable consideration and agreement on:

- 'What' i.e. the key issues raised by the *Fire Note*
- 'So what' i.e. the impacts this might have on the team
- 'Now what' i.e. what could the team do in the future to deal with these impacts?

SUITABILITY OF ACTIVITY

This is a good activity for downtime during a shift or for fire brigade meetings. It has greater value when the theme of the *Fire Note* relates to a topical/current experience for your team.

It can be


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**Bushfire Cooperative Research Centre**
Level 5/340 Albert Street
East Melbourne VIC 3002
Telephone: 03 9412 9600
www.bushfirecrc.com

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Bushfire CRC Limited ABN: 71 103 943 755

**Australasian Fire and Emergency Service Authorities Council**
Level 5/340 Albert Street
East Melbourne VIC 3002
Telephone: 03 9419 2388
www.afac.com.au

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