Respiratory Health of Fire Fighters

Bushfire CRC Project D4

Final Report

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Executive Summary

The Bushfire Cooperative Research Centre commissioned the project 'Respiratory Health of Fire Fighters' to the School of Population Health, The University of Western Australia.

The basis for the research was to assess the effectiveness of protective filters, at the request of Fire and Emergency Services Authority (FESA) of Western Australia. The FESA career fire fighters have - over the years - expressed their concern about the respiratory health effects from inhalation of bushfire smoke compounds, and the effectiveness of the protective filters on their masks. The protective filters issued to the FESA career fire fighters are the particulate filters, which are designed to be used against both mechanically and thermally generated particulates.

There is evidence available that the presence of toxic compounds, e.g. formaldehyde, acrolein, and carbon monoxide, in bushfire smoke may pose occupational risks for fire fighters. In particular, acute and chronic lung function impairment after exposure to bushfire smoke in the United States and Europe has been documented in the literature.

The study involved six controlled bushfire smoke exposure trials in a smoke chamber, followed by four validation trials in the field during prescribed burns. A total of 131 FESA career fire fighters participated in these study trials.

Thirty-seven particulate filters, 50 particulate/organic vapour filters, and 44 particulate/organic vapour/formaldehyde filters were tested and compared. Respiratory health symptoms were assessed by a self-completed respiratory health questionnaire, FEV_1 and SaO_2 measurements. In addition, personal air sampling inside the masks was conducted with each of the different filter types tested.

The results indicate that the particulate/organic vapour/formaldehyde filter provides clinically and statistically significant better protection for fire fighters' airways while fighting bushfires. Further research is needed to determine the breakthrough times of

the filters and the effectiveness of the filters over longer periods, such as a work shift or a bushfire season.

Based on the findings of this study the following recommendations are made:

- The strongest commendation is offered to FESA for commissioning this work with the full knowledge that the findings could point to a possible need for reviewing current best practice. It is acknowledged that the recommendations are based solely on the findings of this study, and that many other factors (including practicality, costs, and acceptability issues) will need to be taken into consideration before a decision can be made on implementation or otherwise.

- In keeping with the current FESA practice, the recommendation to wear a mask and protective filter during bushfire fighting is strongly supported, as particulate levels in the smoke chamber exceeded Time Weighted Average standards for both inspirable and respirable particulates.

- The particulate filter (3M™ 5925) was found to be ineffective in removing the main organic compounds, formaldehyde and acrolein, which are found in bushfire smoke in Western Australia. Given that formaldehyde is a human carcinogen, the use of a filter which removes these compounds is essential in protecting the respiratory health of FESA career fire fighters.

- Based on the overall health outcomes reported by the participants, the particulate/organic vapour/formaldehyde filter (3M™ 6075A1) performed to a significantly higher level than the particulate/organic vapour filter, and is therefore considered the most appropriate filter of the three tested, to protect the respiratory health of FESA career fire fighters in bushfire fighting.

  NOTE: In 2005 FESA implemented the recommendations from the *"Filter Study Phase 1 Preliminary Report March 2005"* by providing the option for

career fire fighters of using the particulate/organic vapour/formaldehyde filter pending the finalisation of this study.

- Consideration should be given to the development of a respiratory trainings program for fire fighters. Key elements in such a program may include:

    - Appropriate use, maintenance, service life, and limits of the respiratory protective equipment;
    - Fit testing procedures in accordance with Australian/New Zealand Standard 1715:1994 (Standards Australia 1994); and
    - Training of the fire fighters in the respiratory hazards to which they are potentially exposed during bushfire fighting.

- Consideration should be given to further research to determine the service life of the particulate/organic vapour/formaldehyde filter. This study did not test the filters for service life or breakthrough time. However, as a 'rule of thumb' filters should be replaced when fire fighters can detect the odour of smoke compounds penetrating through the filter.

- Until the research or the evidence on the service life is determined as indicated in Recommendation 6, a review of the Bush Fire Smoke Management Standard Operational Procedures 51 should be considered as to the most appropriately wording to be used to indicate service life of the filter. The current wording 'Extended periods' and 'Short duration' may need to be changed and substituted with the 'rule of thumb' approach.

- Consideration should be given to the provision of a suitable bag/container for the storage of the particulate/organic vapour/formaldehyde filter when not in use to ensure the filter does not further deteriorate and reduce service life due to exposure to ambient contaminants.

- A follow-up questionnaire survey should be considered at the end of the 2007 summer bushfire season to ascertain fire fighters' usage of the particulate/organic vapour/formaldehyde filter, its effectiveness, and any indications of service life, e.g. breakthrough of smoke sensation.

- FESA may wish to consider further research work into:

    - The correlation between carbon monoxide and formaldehyde, given that research in the USA has shown strong correlations between levels of carbon monoxide, formaldehyde, acrolein, and respirable particulate in smoke samples from prescribed burns (Reinhardt et al. 2000).
    - The use of CO alarm dosimeters to warn of concomitant CO overexposure. This will greatly increase hazard awareness because it provides the crews and managers with feedback about the hazards of smoke.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

BTPS	Body temperature and barometric pressure
CALM[1]	Department of Conservation and Land Management
CRC	Cooperative Research Centre
DEC	Department of Environment and Conservation
FDI	Fire Danger Index
FEF_{25-75}	Forced Expired Flow over the middle half of the FVC manoeuvre
FESA	Fire and Emergency Services Authority of Western Australia
FEV_1	Forced Expired Volume in one second
FVC	Forced Vital Capacity
OR	Odds Ratio
SaO_2	Arterial Oxygen Saturation
SMC	Surface Moisture Content
SOP 51	Bush Fire Smoke Management Standard Operational Procedures 51
STEL	Short Term Exposure Limit
TWA	Time Weighted Average
USA	Unites States of America
UWA	The University of Western Australia

[1] On 1 July 2006 the Department of Conservation and Land Management and the Department of the Environment was amalgamated to form the Department of Environment and Conservation (DEC).

Chapter 1: Introduction

This report presents the results of a two year research project undertaken to investigate the effectiveness of three types of filters to protect the respiratory health of fire fighters working in bushfires. The research project was funded by the Bushfire Cooperative Research Centre, and forms part of the Bushfire CRC Program D 'Protection of People and Property', as project D4 'Respiratory Health of Fire Fighters'.

This chapter describes the background and the rationale for the project, followed by a review of national and international literature with regard to respiratory health effects of occupational exposure to bushfire smoke.

1.1 Background

Fire fighting is amongst the most dangerous and hazardous occupations. Apart from enduring heat, noise and extreme difficulty in doing precise and physically demanding tasks, fire fighters are often exposed to smoke containing high concentrations of irritating and toxic gases. In addition, fire fighters frequently encounter situations in which they have little or no knowledge of what chemicals are present. The hazardous nature of bushfires is usually underestimated compared to urban and structural fires. Although toxic exposures are generally higher among structural fire fighters, bushfire fighters have potentially longer periods of exposure to bushfire smoke, which can range from hours to several days with limited respite periods (Betchley et al. 1997). Given the high annual frequency of bushfires in Western Australia - Fire and Emergency Services Authority of Western Australia (FESA) reports 8,925 attended bushfires in the period 2004-2005 - there is considerable risk of exposure to bushfire smoke and inhalation injury among the fire fighters.

Bushfire fighters have limited options for controlling their exposure to smoke constituents particularly in emergency fire situations. They can step back from the flames and smoke, or they can be rotated through the tasks by the fire managers to minimise long-lasting exposure to the dense smoke (Smith, R. & Sneeuwjagt, R.,

pers. comm. 2005). However, opportunities to rotate crews may be limited during bushfire emergencies in rural urban interface locations, where fire fighters are often protecting structures from fire impact in heavy smoke (Stevens, R., pers. comm. 2006). Suitable respiratory protection, such as the self contained breathing apparatus is available to simultaneously control exposures to carbon monoxide, formaldehyde, particulates, and other possible contaminants. However, its use is not feasible under the conditions of bushfire fighting, as the volume of air in the cylinders usually does not last for sufficiently long periods to fight bushfires in an effective manner. Moreover, the cylinders are too heavy for prolonged use in high temperatures with a heavy workload (Gorman 2004).

Under the Bush Fire Smoke Management Standard Operational Procedures 51 (SOP 51) (Fire and Emergency Services Authority Western Australia 2003), FESA career fire fighters in Western Australia are issued 3M™[2] half face piece masks fitted with particulate filters intended for use against both mechanically and thermally generated particulates. However, an unknown number of FESA career fire fighters have elected to purchase their own 3M™ particulate/organic vapour filters, as they perceived the particulate filter to be ineffective in protecting their airways while fighting bushfires.

The performance of the protective filters is tested by the manufacturer in order to comply with Australian/New Zealand Standard 1715:1994 (Standards Australia 1994) and Australian/New Zealand Standard 1716:2003 (Standards Australia 2003). However, there is no published evidence available on the effectiveness of particulate filters or whether they adequately protect the fire fighters' airways from combustion products generated during bushfires. In an experimental study, in which toxic penetrations using a combined carbon cartridge/particulate pre-filter was compared to a simple cloth bandana, it was concluded that neither filter performed well (Foote 1994). Although the performance of the respirators and their effects on the fire fighters' physical and mental performance have been widely discussed (Jaraiedi et al. 1994; Johnston et al. 1992; Nelson and Colton 2000), the various types of filters have never been rigorously compared with regard to respiratory health outcomes.

[2] The use of trade names in this report is for reader information only and does not imply endorsement by the authors of any product.

1.2 Previous Studies

A number of studies have suggested that the presence of toxic smoke compounds in bushfire smoke - such as carbon monoxide, formaldehyde, acrolein, and hydrocarbons - may pose occupational risks for bushfire fighters (Serra et al. 1996; Materna et al. 1992; Dost 1991; Reinhardt and Ottmar 2000; Reinhardt et al. 2000). However, little is known about the synergistic effects between different chemicals and the degree to which agents present at "safe levels" individually may synergistically produce adverse health impacts.

Previous studies of pulmonary function in fire fighters have demonstrated that their exposures to smoke may result in both acute and more chronic lung function impairment. For example, transient declines in Forced Vital Capacity (FVC), Forced Expiratory Volume after 1 second (FEV_1) and Forced Expiratory Flow $(FEF)_{25-75}$ have been documented in fire fighters after exposure to smoke (Musk et al. 1979; Large et al. 1990; Sheppard et al. 1986). An acute increase in airway reactivity has been observed after experimental exposure of fire fighters in a smoke chamber. Duration of service as a fire fighter was identified as a major contributing factor to airway reactivity (Chia et al. 1990). In addition, cross-shift and cross-seasonal studies on wildland fire fighters in the USA have shown significant acute decrements in respiratory functions associated with increasing exposure (Slaughter et al. 2004; Liu et al. 1992; Rothman et al. 1991; Betchley et al. 1997). There is conflicting evidence about the contribution of cigarette smoking to airways obstruction in fire fighters (Loke et al. 1980; Liu et al. 1992; Brotherhood et al. 1990; Young et al. 1980). Finally, it has been suggested that fire fighters may eventually progress to the development of chronic lung disease following acute exposures (Unger et al. 1980).

1.3 Project Scope

This project was specifically designed to assess the 'Respiratory Health of Fire Fighters when exposed to Bushfires', as applicable to FESA career fire fighters. The study was commissioned by FESA in the interest of providing an evidence base for best practice aimed at protecting the respiratory health of its career fire fighters. The standard filter issued to FESA career fire fighters is the 3M™ particulate filter.

However, a number of FESA career fire fighters considered the issued particulate filters to be ineffective and have elected to purchase their own 3M™ particulate/organic vapour filters. These fire fighters have advocated the use of these filters within FESA, as they perceived they experienced considerably less respiratory symptoms following bushfire fighting emergencies. In order to establish scientific evidence for these perceptions and thus to determine which filter is more effective in protecting the fire fighters' respiratory health, this project investigates and compares the effectiveness of the following filters:

1. Particulate[3] (P) filter (3M™ 5925)

There are three classes of particulate filter suitable for filtering finely divided solid or liquid particles, or both, from the inhaled air[4]. These are classified, in accordance with the tests in Australian/New Zealand Standard 1716: 2003 (Standards Australia 2003), as follows:

a) Class P1 – intended for use against mechanically generated particulates, e.g. silica, asbestos.
b) Class P2 – intended for use against both mechanically and thermally generated particulates, e.g. metal fumes.
c) Class P3 – intended for use against all particulates including high toxic materials, e.g. beryllium.

The Class P2 particulate filter was selected for the trials, because these filters are issued to FESA career fire fighters in Western Australia. It was also decided to utilise the fire fighters' own 3M™ 6000 half face piece mask for the trials, as the fire fighters are familiar with its use and fitting. The cost for the P2 particulate filter is $8.51 per set.

[3] For readers' convenience, the following abbreviations will be used throughout the report:
P for particulate filter, P/OV for particulate/organic vapour filter, and P/OV/F for particulate/organic vapour/formaldehyde filter.
[4] These classes do not take into account the size of the particulates.

Figure 1 Mask with Organic Vapour Filter and Attached Particulate Filter

2. Particulate/organic vapour (P/OV) filter (3M™ 6057ABE1)

This filter has a gas filter with a separate P filter attached to it on the inlet side (Figure 1). The gas filter has a limited useful life which varies with the volume of sorbent and the conditions under which it is used. The filters are affected by factors such as the concentration of the contaminant in the atmosphere, the humidity, and the breathing rate of the wearer. The filters are designated by a letter or chemical abbreviation indicative of the substance or group of substances against which protection is intended. In the case of the 6057ABE1 filter, the letters ABE indicate that this filter complies with the following:

- Type A – For use against certain organic gases and vapours (as specified by the manufacturer).
- Type B – For use against certain inorganic gases and vapours (as specified by the manufacturer).
- Type E – For use against sulphur dioxide and other acid gases and vapours (as specified by the manufacturer).

The number 1 in 6057ABE1 indicates the level absorption capacity. The higher the number, the longer the filter will last for a given concentration of gas where other factors remain constant. The classes are:

- Class AUS – Low capacity filter with shorter life than Class 1;
- Class 1 – Low absorption capacity filters;
- Class 2 - Medium absorption capacity filters; and
- Class 3 – High absorption capacity filters.

The 6057ABE1 is the type of filter that a number of FESA fire fighters have elected to purchase for reasons stated previously. The cost for the organic vapour cartridge is $22.00 per set (excl. $8.51 for the particulate filter).

3. Particulate/organic vapour/formaldehyde (P/OV/F) filter (3M™ 6075A1)

The P/OV/F filter looks similar to the P/OV filter. It also consists of a gas filter with a separate P filter attached to it on the inlet side (Figure 1). The P/OV/F filter protects the wearer against organic gases and formaldehyde vapour, and against particulates when combined with a particulate filter. The cost for the organic vapour/formaldehyde cartridge is $21.69 per set (excl. $8.51 for the particulate filter).

While carbon monoxide is a major compound found in bushfire smoke, it is important to emphasise that none of these types of filters are effective in its removal. The most effective in this regard is the self contained breathing apparatus.

At the outset of the project it was intended to assess and compare the difference in respiratory health outcomes between participants wearing:

- No respiratory protection;
- P filter; and
- P/OV filter as referred to above.

However, air sampling inside the smoke chamber during experimental burns had indicated the presence of high levels of particulates (See Section 4.3). Therefore, it was decided, for safety and ethical reasons, not to proceed with testing without some form of respiratory protection. In addition, the P/OV/F filter was added to the study, because the air sampling indicated the presence of formaldehyde levels in the smoke. Although levels detected in the experimental burns were within Short Term Exposure

Limits (STELs) formaldehyde is a compound of concern as it is a known carcinogen to humans (International Agency for Research on Cancer 2004a). It was therefore considered significant to include the P/OV/F filter in the project to be tested against the particulate and the P/OV filter.

Therefore, the three filters tested in the project were:

- Particulate filter (3M™ 5925);
- Particulate/organic vapour filter (3M™ 6057ABE1); and
- Particulate/organic vapour/formaldehyde filter (3M™ 6075A1).

The project was set up as an experimental design in two Phases:

1. Phase 1 - controlled exposure trials in a smoke chamber;
2. Phase 2 - to validate the Phase 1 findings in the field during prescribed burns.

1.4 Bushfire CRC Linkage

This project D4 Respiratory Health of Fire Fighters is part of the Bushfire CRC - Program D 'Protection of People and Property'. The project links to Project D 2.2 'Air Toxics Exposure and Management', which aims to measure, evaluate, and control the personal exposure of Australian fire fighters to air toxics in bushfire smoke under various conditions.

As part of the Project D 2.2 experimental burns with five Australian fuel samples, including Western Australian coastal scrub, were undertaken in a smoke chamber. The smoke analysis demonstrated the presence of formaldehyde, acetaldehyde, acrolein, respirable dust, and carbon monoxide in the Western Australian vegetation (Reisen et al. 2006). These findings supported the USA literature (Reinhardt and Ottmar 2000; Reinhardt et al. 2000), which demonstrated that these compounds are the major inhalation hazards for bushfire fighters. Following these findings, it was decided to focus on these compounds in this research project.

In addition, the Project D 2.2 also monitored personal exposures of fire fighters - according to their tasks - during prescribed burns. These measurements showed that

the primary pollutants of concern that are likely to exceed occupational exposure limits are carbon monoxide and respiratory irritants, including respirable particulates, formaldehyde, acrolein, and acetaldehyde. Furthermore, different exposure levels were observed according to tasks (Reisen 2006). These findings suggest that effective respiratory protection is essential to protect fire fighters' health while fighting bushfires.

1.5 Report Overview

The remainder of this report is organised in four chapters. Chapter 2 provides an overview of the regulation and current application with respect to personal protective equipment for FESA career fire fighters in Western Australia. Chapter 3 describes the study design and the methodology developed for this project. It also details the recruitment process, the data collection, the exposure process, and the conditions at the test sites. Chapter 4 presents the key results from both the smoke chamber trials and the field validation trials during the prescribed burns. Chapter 5 discusses in detail the findings from the project and Chapter 6 presents recommendations based on the findings of this project, which may contribute to improved respiratory health outcomes for the FESA career fire fighters and may also assist other fire fighting groups.

Chapter 2: Personal Protective Equipment

2.1 Regulation in Western Australia

In Western Australia, the management of bushfire smoke exposure for FESA career fire fighters is regulated by the Bush Fire Smoke Management Standard Operational Procedures 51 (SOP 51) (Fire and Emergency Services Authority Western Australia 2003) which are based on the *Occupational Safety and Health Act 1984*, the *Occupational Safety and Health Regulations 1996*, and the Australian/New Zealand Standard 1715: 1994 (Standards Australia 1994). The SOP 51 provides a tool to determine the most appropriate method to manage bushfire smoke exposure for fire fighters by:

- Raising awareness about the hazards of smoke inhalation;
- Detailing procedures for smoke management in the field, including particulate filter use (Table 1);
- Providing fire fighting strategies aimed at minimising smoke exposure.

Table 1 Current FESA Advice for Particulate Filter and Mask Use

Grass – Scrub – Bushfires		
Smoke Type	**Smoke Description**	**Service Life Particulate Filter**
Light	White to light grey colour Moist fuels Mild behaviour Reasonable visibility (15 plus metres)	Extended periods
Medium	Dark grey to black colour Moist to dry fuels Moderate behaviour Moderate visibility (8 to 15 metres)	Short duration
Heavy	Black to copper-bronze colour Very dry fuels Severe behaviour Poor visibility (5-8 metres)	Breathing apparatus

Although the smoke type is described in the SOP 51 as light, medium, and heavy, it would undoubtedly benefit from a photo series displaying a range of smoke conditions and corresponding levels of carbon monoxide as described in (Reinhardt and Ottmar 2000).

2.2 Current Applications

In accordance with the SOP 51 FESA career fire fighters in Western Australia are issued with 3M™ half face-piece masks with particulate filters to be used during grass, scrub and bushfires. The effective service life of the filters is affected by many factors, including the concentration and the nature of the contaminant, breathing rate, exposure time, humidity levels, ventilation, and temperature. Therefore, it is nearly impossible to indicate a specific timeline for the effective service life of the filters. The manufacturer 3M™ recommends that:

> *"The end of service life of gas/vapour filters is indicated by the wearer smelling or tasting traces of the contaminant inside the face piece".*

And

> *"Particulate filters must be changed when breathing resistance becomes unacceptable".*

While these recommendations are very subjective and depend on the observational capacities of the individual fire fighter, they do however provide a 'rule of thumb' approach that is a very practical measure. To determine the effective service life, given the many variables as mentioned above, would require extensive laboratory or field testing, which was not part of this project.

According to the manufacturers 3M™, the filters should be stored in the packaging provided in dry, clean conditions away from direct sunlight, sources of high temperature, petrol and solvent vapours. The filters should also not be stored outside the temperature range of -10°C to +50°C or with humidity above 90%. It is not known however, whether FESA career fire fighters are aware of these recommendations, and store their filters accordingly.

2.3 Respiratory Health Steering Group

The Respiratory Health Steering Group was established by FESA to provide support, guidance, and technical advice to the execution of this research project. Regular meetings were held at the FESA House, Hay Street, Perth to discuss the progress of the various stages of the project. The Steering Group provided an opportunity to liaise

with representatives from FESA, and facilitated a transparent communication process between the UWA researchers and FESA officers regarding the project.

The Respiratory Health Steering Group comprised the following representatives from FESA:

- Mr. Russell Stevens;
- Mr. Dave Wright;
- Mr. Kevin Foreman;
- Mr. Iain Agnew (United Firefighters Union of Western Australia);
- Mr. Barry Jenkins;
- Mr. John Chatfield; and
- Mr. Peter Thomas.

The researchers from the School of Population Health, The University of Western Australia involved in the Steering Group were:

- Professor Philip Weinstein;
- Dr. Angus Cook;
- Mr. Brian Devine; and
- Mrs. Annemarie De Vos.

In close collaboration with the members of the Steering Group, four information sessions were given at FESA House to raise awareness and inform FESA career fire fighters about the study. Visits to the FESA Training Centre at Forrestfield were undertaken to view and assess the study facilities and equipment for the Phase 1 smoke chamber trials.

The recruitment of the study participants took place in collaboration with Mr. Dave Wright and Mr. Kevin Foreman. Finally, meetings with CALM Perth District Fire Coordinator Mr. Mike Cantelo and District Operations Officer Mr. Brian Inglis and members of the Steering Group were convened to discuss opportunities for collaboration and management of the Phase 2 field trials during prescribed burns.

Chapter 3: Methodology

3.1 Study Design

The study has an experimental design in which the effectiveness of three protective filters were tested and compared under controlled and semi-controlled conditions. The controlled exposure trials took place in a smoke chamber at FESA Training Centre, Forrestfield, Western Australia. The field trials were conducted during prescribed burns in the Yanchep and Two Rocks area, which is located about 70 kilometres north of Perth CBD, Western Australia.

In order to test the effectiveness of the three filters, the participants were randomly allocated one of the three types of study filters:

1. P filter (3M™ 5925);
2. P/OV filter (3M™ 6057ABE1); and
3. P/OV/F filter (3M™ 6075A1).

During the Phase 1 trials in the smoke chamber 24 P, 23 P/OV, and 17 P/OV/F filters were tested. As the preliminary findings of the smoke chamber trials showed that the P filter was the least effective in filtering out bushfire smoke components, it was decided to under-sample this type of filter in the following field validation trials. Therefore, a total of 13 P, 27 P/OV filters, and 27 P/OV/F filters were tested in the Phase 2 field trials during the prescribed burns.

The three types of filters were as similar in appearance as possible, in order to blind the participants with respect to the type of filter they used. This ensured that the measured health outcomes were not affected by the participants' perception of wearing a particular type of filter. Table 2 shows the number of participants and the number of filters for each trial.

Table 2 Details Exposure Trials

	Participants (n)	P (n)	P/OV (n)	P/OV/F (n)
Smoke Chamber				
20 October 2004	8	4	4	*
6 December 2004	8	3	3	2
9 December 2004	10	4	3	3
10 December 2004	10	3	3	4
13 December 2004	5	2	2	1
14 December 2004	13	5	4	4
15 December 2004	10	3	4	3
Total	64	24	23	17
Prescribed Burns				
17 October 2005	25	5	10	10
20 October 2005	13	3	5	5
10 November 2005	12	2	5	5
24 November 2005	17	3	7	7
Total	67	13	27	27
Grand Total	**131**	**37**	**50**	**44**

* Not tested

Following the Phase 1 controlled exposure trials in the smoke chamber a report "*Filter Study Phase 1 Preliminary Report March 2005"* (Appendix 1) was presented to FESA for their consideration in March 2005. Subsequently FESA has acted upon the recommendations in the Report and has issued the FESA career fire fighters with the recommended P/OV/F filter for use in bushfire situations.

3.2 Recruitment

In order to raise awareness about the study, the investigators arranged four information sessions at FESA House, Perth, at which 80 fire fighters attended. Posters were also designed and circulated around the fire stations and FESA released an Intranet Circular detailing the study purpose and recruitment procedures.

The source population from which the study samples were drawn consisted of the group of approximately 800 male and female FESA career fire fighters in Western Australia. The study subjects were defined as currently active career fire fighters based in fire stations in the Perth Metropolitan Area. The most significant determinant

of respiratory health outcomes was likely to be the frequency of exposures. Therefore, two stratified random samples were taken from fire stations in areas experiencing high versus low bushfire frequencies (i.e. Balcatta, Canning Vale, Joondalup, and Malaga fire stations versus 16 remaining fire stations).

The fire fighters were enrolled for the study depending on their availability during the trials and participated on a voluntary basis. The investigators recruited the fire fighters by telephoning them at their fire station. They were informed about the study and asked whether they wished to participate. Individuals with self-reported unstable asthma, current acute or chronic respiratory illness, or any other chronic or severe illness were excluded. The investigators approached approximately 200 fire fighters initially, but due to non-availabilities, emergencies, and transport issues, a total of 131 fire fighters eventually participated in the study (64 in Phase 1 and 67 in Phase 2).

3.3 Data Collection

The respiratory health outcomes were measured before (baseline) and after the exposure to the combustion products by use of a respiratory symptom questionnaire, spirometry, and pulse oximetry.

The respiratory symptom questionnaire (Appendix 2 and 3) was a standardised self-completed form, primarily designed to obtain information about the participants' health status and their perception of the acute respiratory health effects of the exposure to the bushfire smoke. The questionnaires were administered at two separate times, i.e. before and immediately after the bushfire smoke exposure.

Spirometry was performed by a single trained individual according to the guidelines for manoeuvre performance provided by the American Thoracic Society (ATS) (American Thoracic Society 1995). FEV_1 was the primary lung function measure used, which is an extensively used index with good reproducibility (Pierce and Johns 1995). Changes across a work shift in FEV_1 have been described as useful response indices to measure acute airways' narrowing (Venables 1994). A single Welch Allyn PneumoCheck™ spirometer was used in all tests to ensure standardisation of the measurements. Calibration of the equipment was performed with a 3L syringe before

each testing session, and readings were automatically corrected to BTPS (Body temperature and barometric pressure). All subjects were tested sitting straight up with their feet firmly on the ground, and without a nose clip (Figure 2). A minimum of three manoeuvres was undertaken to meet the ATS criteria for collection and to obtain reproducible tracings with the two highest FEV_1 within 5% of each other. Spirometric data were collected before entering and immediately after exiting the smoke. The change in FEV_1 (ΔFEV_1) for each participant was measured by subtracting the FEV_1 obtained after the exposure from the baseline FEV_1 measured before the exposure.

Figure 2 Spirometry Measurement during Field Trials

Arterial oxygen saturation of haemoglobin was measured in percentages (%) using a Datex-Ohmeda TuffSat™ pulse oximeter. A decline in SaO_2 may indicate the presence of high levels of carbon monoxide in the bushfire smoke. The change in SaO_2 (ΔSaO_2) for each participant was measured by subtracting the SaO_2 obtained after the exposure from the baseline SaO_2 measured before the exposure.

In order to obtain preliminary data about individual exposures, personal sampling with organic vapour monitors (Figure 3) was undertaken during the first smoke chamber trial on 20 October 2004. The monitors were clipped on the fire fighters' jackets and sampling lasted for 15 minutes, the minimal required period to obtain sufficient air sample material for analysis.

Figure 3 3M™ Organic Vapour Monitors

Personal air samples from inside the masks were collected via sampling ports. In order to facilitate the inside the mask sampling, the masks were drilled and fitted with 60 cm Tygon tubing (6mm ID). The tubing was connected to the air sampling pumps attached to the waist belts worn by the participants (Figure 4). Air sampled from inside the mask was passed through a pre-weighed filter in a cassette and a carbonyl compound sorption tube connected in series using a calibrated air sampling pump (set at 1 litre/minute). Sampling lasted for the duration of the exposure period, i.e. in the smoke chamber for 15 minutes and in the prescribed burns for 120 minutes, broken into two periods of 60 minutes.

Figure 4 Study Participant with Sampling Equipment

Positional air samples both inside the smoke chamber (Figure 5) and in the prescribed burns were collected as controls. The monitoring for toxic gases in the smoke chamber was conducted using portable gas analysers with data logging capacities. Dust was measured using a Dustrak™ monitor. In addition, the Hapsite™ was used in the smoke chamber which is a portable gas chromatograph/mass spectrometer for analysis of volatile organic compounds.

Figure 5 Positional Sampling inside Smoke Chamber

Note: In background white circle markers used for visual assessment of the smoke density

Particulate matter on the sample filters was analysed gravimetrically as per Australian Standard AS 3640: 2004 (Standards Australia 2004). Formaldehyde and acrolein were analysed by high performance liquid chromatography according to the National Institute for Occupational Safety and Health method 2016 (The National Institute for Occupational Safety and Health 2003). Samples were stored under refrigeration and transported in accordance with established procedures to prevent sample degradation. Electronic monitor data for oxygen, toxic gases and particulate matter were downloaded and printed out with summary results. The Chemistry Centre (WA), Perth, Western Australia performed all sampling procedures and laboratory analyses.

3.4 Exposure Process

Controlled and semi-controlled exposure trials were conducted with a total of 131 FESA career fire fighters who volunteered to participate in the study. Seven controlled exposure trials took place in a smoke chamber at FESA Forrestfield Training Centre. The findings from these trials were validated in the field during four prescribed burns.

Both trials were conducted under similar circumstances. On arrival the participants were informed about the details of the study, the procedures, and safety issues during the trials. All participants were asked to read an information sheet and to sign a consent form, and complete the first part of the questionnaire. Before entering the

smoke environment the participants were required to wear their full fire-fighting gear, i.e. uniform, helmet, protective goggles, and mask. The investigators then attached the randomly allocated study filters to the participants' mask, and the participants were asked to perform a Positive Pressure Fit Check in accordance with Australian/New Zealand Standard 1715:1994 (Standards Australia 1994) to ensure an appropriate seal of the mask (3M™ 6000 Series Standard Half Face Respirator).

In the smoke chamber trials the participants were asked to remain inside for 15 minutes to ensure that sufficient air sample material could be acquired for analysis. During the prescribed burn trials the participants were required to stay in the field for two subsequent periods of 60 minutes. They were asked to move around in the field to ensure exposure to a representative sample of the smoke. After the exposure period of 60 minutes the fire fighters were brought out of the smoke and taken to base where measurements (FEV_1 and SaO_2) were taken. After approximately 10 minutes break they were returned to the smoke zone for a further 60 minutes, after which they returned to base where final measurements (FEV_1 and SaO_2) were taken.

During the trials the participants were assured that they could remove themselves from the smoke at any time if they experienced any adverse health effects both physically (i.e. shortness of breath/wheezing/dizziness) and/or psychologically (anxiety/distress). In addition, the participants were under the observation of a Registered Nurse in order to ensure their safety. First aid facilities were available at both test-sites, and an emergency protocol was in place.

3.5 Test Site and Conditions

3.5.1 Phase 1 Controlled Exposure Trials - Smoke Chamber

Phase 1 of the study was conducted over seven trial sessions in a controlled environment at the FESA Training Centre at Forrestfield in October and December 2004. The smoke chamber used for the study was a modified sea container (12.2m x 2.4m x 2.4m), which is commonly used by FESA for training purposes. The container had a door completely open for the fire fighters to exit at all times (Figure 6 and 7).

Figure 6 Smoke Chamber

Figure 7 Study Participants inside Smoke Chamber

A light smoke situation was produced, determined as a density of smoke producing a white to light grey colour with reasonable visibility of at least 15 metres (Fire and Emergency Services Authority Western Australia 2003). Visual assessment of the smoke was undertaken by one single observer, using the visual smoke exposure classification as described by (Reinhardt and Ottmar 2000). The painted white dots inside the smoke chamber served as indicators for the smoke density (Figure 7).

The smoke was generated in a standardised way from a small incinerator to ensure that the smoke characteristics were reproducible throughout all trial sessions. The environment inside the smoke chamber was controlled as far as practicable to ensure an even distribution and density of the smoke at all times.

The vegetation used in the smoke chamber trials was a mixture of banksia and coastal heath (Figure 8) collected in the Gingin and Eglington area, which was typical of the material fire fighters would encounter in a bushfire situation. These vegetation types were selected because, based on workplace reports, these are known to create substantial smoke levels during bushfires. The collected vegetation was stockpiled at the FESA Training Centre, Forrestfield and was analysed for moisture content, which was recorded at nine percent during the smoke chamber trials.

Figure 8 Vegetation used in Smoke Chamber

3.5.2 Phase 2 Field Trials - Prescribed Burns

Prescribed burns are low intensity fires used to reduce the build up of leaves and twigs on the forest floor. This procedure has proven to be an effective and environmentally sound way of combating destructive, high intensity bushfires. The frequency of prescribed burns in a given area is variable, with intervals between burns typically ranging from five to 15 years. The preferred seasons are usually during spring and autumn months. Only 60 to 80 per cent of each burn area is burnt and many areas remain unburnt for several decades. Fire is also used to promote the biological diversity of the forest, to regenerate habitat for native fauna and to restore areas cut for timber.

The Department of Conservation and Land Management (CALM) in Western Australia undertakes the prescribed burns as part of their *"Indicative Prescribed Burning Plan South-West Western Australia, Spring 2005 to Autumn 2008"*. These prescribed burns are designed to meet either a primary purpose, or a combination of purposes that include:

- Biodiversity conservation, i.e. through application of scientifically based fire regimes to maintain and protect native flora and fauna communities and/or habitats;
- Community protection, including the protection of human life, property, public assets, parks, timber values and plantations; and

- Silvicultural burns for regeneration of native forests following timber harvesting.

The Phase 2 exposure trials were conducted during four prescribed burns in the Yanchep and Two Rocks area, which is on the outer fringe of the Perth Metropolitan area. The prescribed burns were managed and controlled by CALM officers. Table 3 shows the collected field data and predicted conditions for these days.

Table 3 Details of the Prescribed Burns
(From Sage, L., pers. comm. 2006)

	17 and 20 October 2005	**10 and 24 November 2005**
Location	Caraban State Forest Block Prescribed Burn (415 057A) - approx. 10 km NE of Two Rocks/Yanchep (Figure 10)	Caraban State Forest Block Prescribed Burn (415 055) - approx. 5 km E of Yanchep
Area burnt	20 to 30 hectares per day were burnt to provide smoke for the trial Total burn area - 418 hectares	20 to 30 hectares per day were burnt to provide smoke for the trial Total burn area - 210 hectares
Vegetation Type	Predominantly Banksia Low Forest A (LAc) with small areas of Dryandra sessilis Dense Heath A (Figure 9)	Predominantly Banksia Dense Low Forest A (LAd) with some emergent Eucalyptus marginata and E.gomphocephala
Associated Plant Species	Banksia grandis, Banksia menziesii, Acacia pulchella, Xanthorrhoea preissii, Dryandra sessilis, Scaevola repens, Scaevola canescens, Conostylis aculeate, Dampiera linearis, Hakea prostrata, Hakea lissocarpha, Melaleuca spp., Eucalyptus todtiana	Eucalyptus marginate, E. gomphocephala, Eucalyptus todtiana, Banksia grandis, B. menziesii, Xanthorrhoea preissii, Allocasurina fraseriana, Carprobrotus sp., Conostylis aculeate, Hakea prostrata, Hakea lissocarpha, Scaevola repens, S. canescens
Fire Behaviour	Surface Moisture Content (SMC) 8 - 12% Rate of Spread ~ 35m/hr Fire intensity - low to medium	SMC 10 - 12% Rate of Spread ~ 35m/hr Fire Intensity - low to medium
Predicted Conditions	<u>17 October 2005</u> Min SMC for pine 10% Fire Danger Index (FDI) 441m/hr and extreme Winds mostly SW to 35 km/hr Temp 21 °C and fine <u>20 October 2005</u> Min SMC for pine 7% FDI 414m/hr and extreme Winds mostly W to 25 km/hr Temp 21 °C and fine	<u>10 November 2005</u> Min SMC for pine 8% FDI 181m/hr and very high Winds W to 20 km/hr Temp 24 °C and fine <u>24 November</u> 2005 Min SMC for pine 6% FDI 370m/hr and extreme Winds mostly SW to 28 km/hr Temp 23 °C and fine Windy and then showers

Figure 9 Vegetation Types in Prescribed Burns

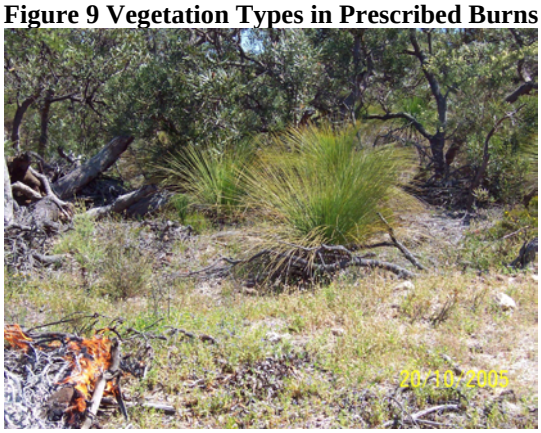


Figure 10 Location of Prescribed Burns
(From CALM Map 17 October 2005; Map Overlay by Yih Pyng Lee)

For the purpose of the study, a consistent light smoke situation was required comparable to the smoke produced in the smoke chamber. In order to monitor the smoke pattern during the prescribed burns a number of fire fighters observed and were asked to complete an observation sheet with respect to vegetation, terrain, wind, and smoke behaviour (Figure 11). Table 4 summarises these recordings.

Figure 11 Fire Fighters in the Field during Prescribed Burns

Table 4 Smoke Behaviour during Prescribed Burns

Smoke Behaviour Indicator	Observation
Vegetation type	Scrubland, banksias, grass trees, coastal heath
Vegetation height	1 - 4 meter
Vegetation dryness	Moderate - dry - very dry
Slope terrain	Level - gentle slope - 5°
Wind direction	South - South-West
Wind speed	15 - 20 km/hour
Smoke density	Light - moderate
Smoke behaviour	Consistent, stable, drifting slightly, swirling
Fire fighters' position in the smoke	Downwind - peripheral - central
Other observations	Light smoke, not from an intense hot fire, thick smoke at the end

Chapter 4: Results

4.1 Phase 1 Controlled Exposure Trials - Smoke Chamber

Sixty-four (64) healthy career fire fighters from 20 fire stations in the Perth Metropolitan area participated in the six controlled exposure trials (Table 5). Nearly half of the participants (47%) were in the age group 40-49 years. The mean years of service in FESA in this study population was 13.

Table 5 Demographics

	n	%
Gender		
Male	60	94
Female	4	6
Age group		
20-29	4	6
30-39	25	39
40-49	30	47
50-59	4	6
60+	1	2
FESA years (mean)	13	

The analysis demonstrated no significant association between the demographic variables, such as gender, age group, FESA years, current fire station and the observed differences in pre and post-exposure FEV_1/SaO_2 measurements, self-reported respiratory health symptoms, and exposure time.

Previous occupational exposures of relevance were measured by recording the frequency of past attendances of bushfires and self-reported associated symptoms for each individual. These were evaluated in relation to self-reported associated symptoms from past bushfire exposures, including coughing, wheezing, and shortness of breath. Fifty percent of the participants (n=32) reported to have symptoms after previous attendances at bushfires, with 29 indicating symptoms of coughing, wheezing, and shortness of breath. However, no consistent relationship between previous exposures to bushfires or past symptoms and the Phase 1 measured differences in FEV_1/SaO_2, respiratory health outcomes, or exposure time could be demonstrated.

Pre-existing medical conditions as reported in the questionnaire - including perceived overall health, self reported asthma, allergies, sputum, and use of bronchodilators (Table 6) - could not be related to the Phase 1 measured differences in FEV_1/SaO_2, respiratory health outcomes, or exposure time. However, the majority of the participants (54%) who reported an increase in coughing, wheezing, tightness, shortness of breath after the exposure in the smoke chamber indicated that they also suffered from hay fever.

Table 6 Pre-existing Medical Conditions

	n	%
Overall health		
Good	12	19
Very good	37	58
Excellent	15	23
Asthma		
Yes	6	9
No	58	91
Don't know	0	0
Hay fever		
Yes	24	38
No	37	58
Don't know	3	4
Allergies		
Yes	3	5
No	54	84
Don't know	7	11
Current use of bronchodilators (puffers)		
Yes	6	9
No	58	91

Reported symptoms in the last 12 months (such as coughing wheezing, tightness, shortness of breath, and respiratory tract infections) could also not be related to any differences in the FEV_1/SaO_2, respiratory health outcomes, sputum, or exposure time in the Phase 1 trial.

There were no current smokers among the participants. Twenty-two participants were identified as past smokers, and 42 participants reported to have never smoked. Neither smoking status nor total pack years (packs/day/year) were related to differences in self-reported and measured respiratory health outcomes in the Phase 1 trial.

Fire fighter utilisation of the currently issued filter was measured by variables assessing the frequency of use and the perceived effectiveness (Table 7). The majority

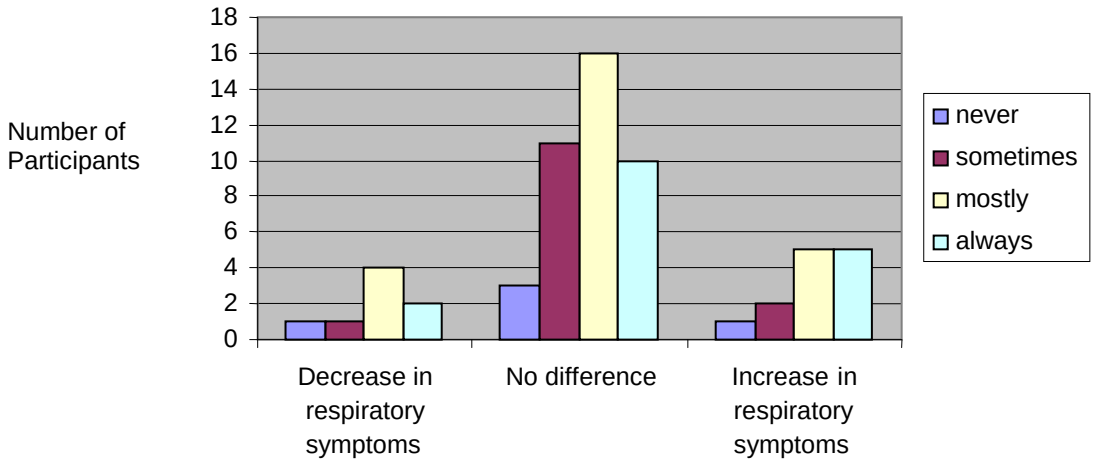
of the participants (69%, n=44) reported to 'mostly' or 'always' wearing a mask while fighting bushfires, and a small majority (52%) believed that use of the mask had a positive effect on their breathing.

Table 7 Current Mask Use by FESA Fire Fighters

	n	%
Routinely wear a mask		
Never	5	8
Sometimes	14	22
Mostly	27	42
Always	17	27
Effect of mask on breathing		
Not different	11	17
Worse	19	30
Better	33	52
Usefulness of mask		
Don't know	12	19
Disagree	24	38
Agree	27	42
Comparability of smoke to real bushfire smoke		
Different	20	31
Similar	42	66

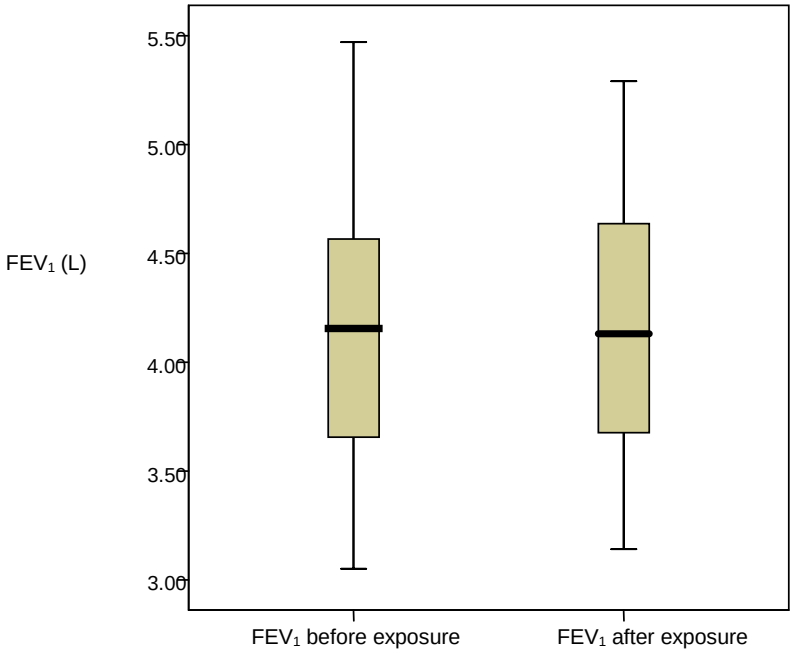
There was an apparent trend for a greater proportion of participants who reported an increase in coughing, wheezing, and shortness of breath following the smoke exposure in fire fighters who were more likely to routinely wear a mask during bushfires - never (7.7%, n=1), sometimes (15.4%, n=2), mostly (38.5%, n=5), and always (38.5%, n=5) - but these trends were not statistically significant (Figure 12).

Figure 12 Relationship between Routine Mask Use and Difference in Respiratory Symptoms following Exposure



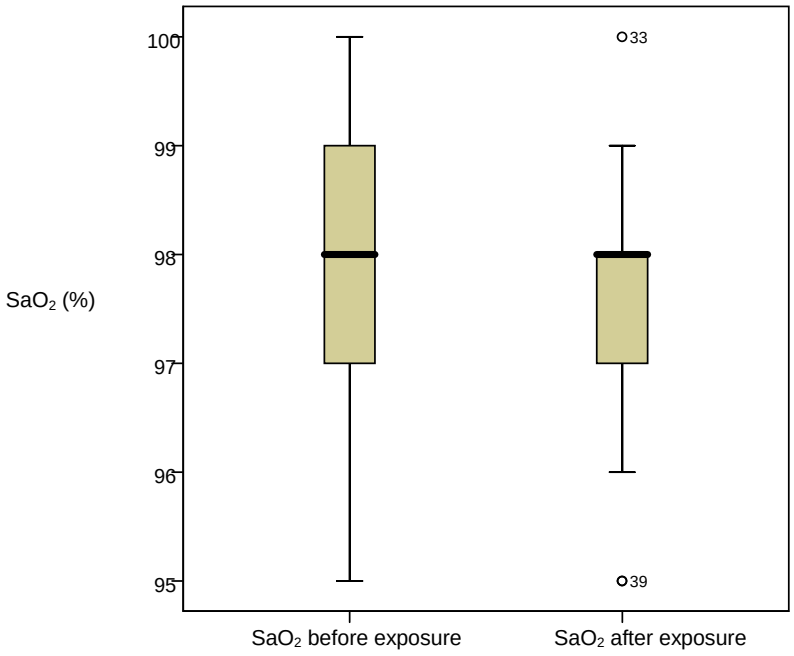
A small mean decline in FEV_1 (0.01L) was observed between the pre and post exposure measurements (Figure 13). Linear regression analysis demonstrated that the declining trend in FEV_1 could not be predicted from the type of filter used, after controlling for age, years in FESA, and smoking status.

Figure 13 Mean FEV_1 Measurements (Before - After 15 min Smoke Exposure)



Across the study population a small but statistically significant decline (0.5%, $p < 0.05$) was observed between the mean pre and post exposure SaO_2 measurements (Figure 14). The analysis indicated that this decline was not related to any of the previously reported variables.

Figure 14 Mean SaO_2 Measurements (Before - After 15 min Smoke Exposure)

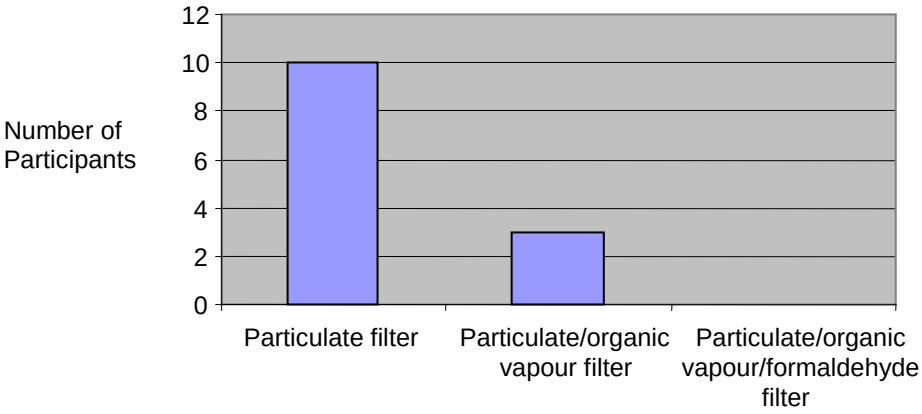


Although a significant relationship could be demonstrated within the pre and post exposure SaO_2 differences, there was no observable association between these differences and the three types of filters.

Acute respiratory health effects were measured by self-reported symptoms of coughing, wheezing, and shortness of breath. After the 15-minute exposure to bushfire smoke 40 participants (63%) reported no difference in these symptoms, with 13 participants (20%) reporting an increase in coughing, wheezing, and shortness of breath. After 30 minutes recovery time however, most of these symptoms had resolved, with 6 participants (9%) still experiencing an increase in coughing, wheezing, or shortness of breath compared to before the exposure. Although these observations are important, a statistical significant difference could not be established between the respiratory symptoms at baseline and after 15 minutes smoke exposure.
A significant association was observed in the number of participants (Figure 15) reporting an increase in coughing, wheezing, and shortness of breath between:

- P and P/OV/F filter;
- P/OV and P/OV/F filter.

Figure 15 Number of Participants with Increase in Coughing, Wheezing, Shortness of Breath immediately after Exposure



Statistically significant differences however, were not observed between the P and P/OV filter. Within the group of participants who reported an increase in coughing, wheezing, and shortness of breath immediately after the smoke exposure, 10 (77%) used a P filter and 3 (23%) used a P/OV filter. There were no (0%) reports on such symptomatology from those wearing a P/OV/F filter. Similar outcomes were observed after 30 minutes recovery time (Table 8).

Table 8 Distribution of Filter Use in Participants with Increase in Respiratory Symptoms following Exposure

	P filter	P/OV filter	P/OV/F filter
Immediately after exposure	10 (77%)	3 (23.1%)	0 (0%)
After 30 mins. recovery time	5 (84%)	1 (16%)	0 (0%)

Odds ratios comparing the effectiveness of the P filter with the P/OV/F filter showed a statistically significant 12-fold reduction in the number of participants with respiratory symptoms, who used the P/OV/F filter (ie OR 0.082., 95% CI 0.009 – 0.775, $p < 0.05$). In addition, results showed a statistically significant 5-fold reduction in the number of participants with respiratory symptoms who had used the P/OV versus P filter (OR 0.191, 95% CI 0.039 – 0.931, $p < 0.05$).

The distribution of the three types of filters used in the smoke chamber trials were P filter (n=24); P/OV filter (n=23); and P/OV/F filter (n=17). Levels of dust, formaldehyde, and acrolein were measured by air sampling inside 18 masks using the protocol described in Section 3.3. Table 9 shows that both the formaldehyde and the

acrolein levels in masks fitted with the P filter were higher than in masks fitted with the other two types of filters.

Table 9 Filter Types and Air Sampling Results

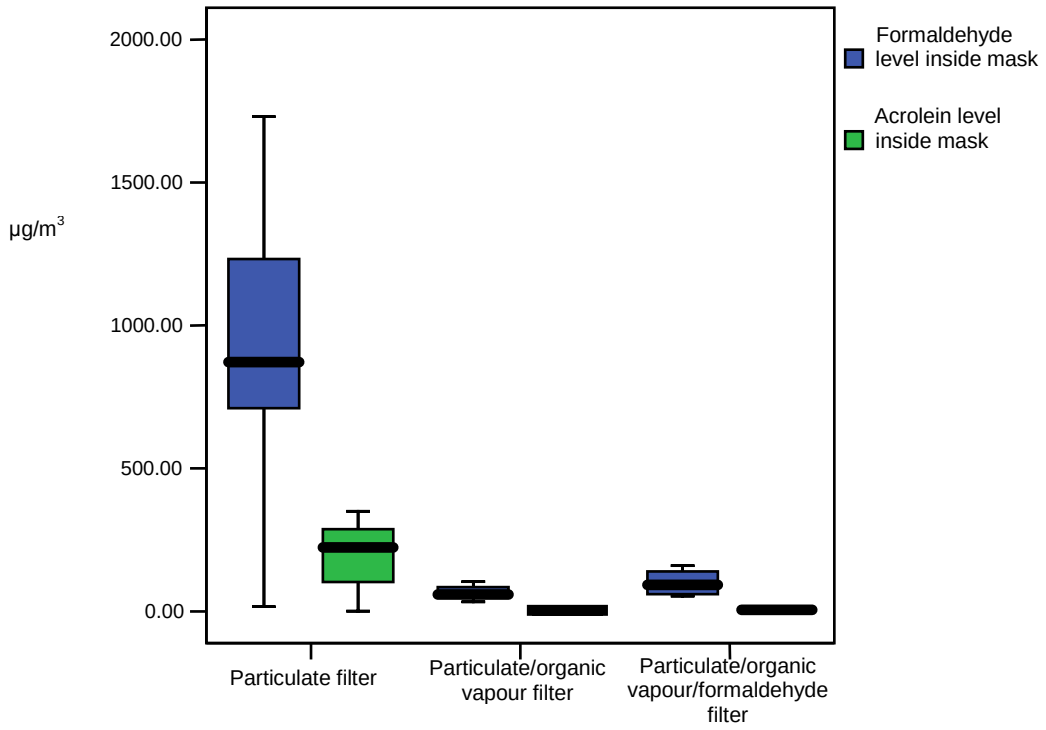
Filter Type	n	Dust mg/m^3+	Formaldehyde µg/m^3 (STEL° 2500 µg/m^3)	Acrolein µg/m^3 (STEL° 687 µg/m^3)
P filter	7	0.7	598	224
		0.3	1062	350
		0.1	824	284
		5.1	872	290
			1731	109
			17	1
			1402	96
P/OV filter	7	2.2	73	4
		2.1	58	5
		1.0	97	5
		0.7	33	0
			59	1
			104	10
			37	1
P/OV/F filter	4	*	160	10
			119	10
			53	1
			67	1

° STEL (Short Term Exposure Limit): a maximal concentration to which workers can be continuously exposed for up to 15 minutes without adverse effect
+ STEL for toxic dust is not available (STEL non-toxic particulates: 5-10 mg/m3)
***** Not available

Statistical analysis confirmed that the difference in formaldehyde and acrolein levels inside the masks was significantly different between:

- P and P/OV filters (p = 0.001); and
- P and P/OV/F filters (p = 0.006).

Figure 16 Air Sampling Results inside the Masks



No statistically significant difference was found for formaldehyde and acrolein levels between the P/OV and the P/OV/F filters (Figure 16).

Although dust levels inside the masks were also measured, these results were not significantly different between the P and the P/OV filter (dust results for the P/OV/F filter were not available).

4.2 Phase 2 Field Trials - Prescribed Burns

Sixty-seven (67) career fire fighters from Perth Metropolitan fire stations participated in the four subsequent field trials during prescribed burns. The largest proportion of this group (45%, n=30) was in the in the 30-39 age group. Sixty-four (64) were male, and 3 were female (Table 10). The analysis demonstrated no association between the demographic variables, (including gender, age group, and FESA years) and the observed differences in baseline and follow-up FEV_1/ SaO_2 measurements and self reported respiratory health symptoms.

Table 10 Demographics

	n	%
Gender		
Male	64	96
Female	3	4
Age group		
20-29	7	10
30-39	30	45
40-49	24	36
50-59	4	6
60+	2	3
FESA years (mean)	11	

Eighty-five per cent of the participants (n=57) reported to be in very good to excellent health; 15% (n=10) stated that they were in good health (Table 11). Three per cent (n=2) of the participants reported suffering from asthma, and 25% (n=17) reported having hay fever. At baseline, 22% of the participants (n=15) reported to have slight to moderate coughing, wheezing, shortness of breath, with 16% (n=11) reporting to have had a cold, influenza or chest infection less than two weeks ago. Pre-existing medical conditions including perceived overall health, self reported asthma, allergies, and upper respiratory tract infections were not associated with the observed differences in FEV_1/SaO_2 measurements, or with respiratory health symptoms.

Table 11 Pre-existing Medical Conditions

	n	%
Overall health		
Good	10	15
Very good	40	60
Excellent	17	25
Asthma		
Yes	2	3
No	64	96
Don't know	1	1
Hay fever		
Yes	17	25
No	44	66
Don't know	6	9
Allergies		
Yes	2	3
No	64	96
Don't know	1	1
Current use of bronchodilators(puffers)		
Yes	1	1
No	66	99

Approximately 40% of the subjects (n=26) reported experiencing respiratory symptoms after bushfires, such as coughing, wheezing, shortness of breath, and one participant reported having watery eyes after bushfire fighting. Previous exposure-

related respiratory symptoms were not associated with the declines in FEV_1/ SaO_2 measurements, or with self reported respiratory health symptoms.

Seventy per cent (n=47) had never smoked, 25% (n= 17) were past smokers, and 5% (n=3) were current smokers. The statistical analysis demonstrated no association between smoking history and respiratory outcomes. However, it must be noted that the two participants who both exited the smoke early before completion of the first and the second hour (i.e. after 45 and 47 minutes) were a past and a current smoker.

Twenty-five per cent (n=17) reported to 'always' wearing a mask while fighting bushfires, while the remaining 75% reported to 'sometimes' or 'mostly' wearing a mask during bushfire fighting activities. Figure 17 shows the types of filter that are normally used by the subject FESA career fire fighters at the time of the study. The P filter was mostly used (72%, n=48), followed by the P/OV filter (9%, n=6), while 3% (n=2) reported to use another unspecified type of filter, and 16% (n=11) of the participants could not recall what they used.

Figure 17 Type of Filter used by FESA Fire Fighters

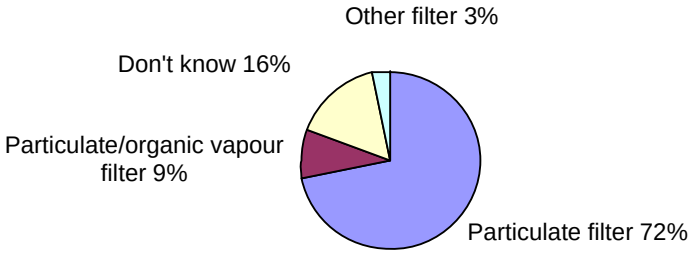


Table 12 illustrates the current mask/filter use by the study FESA fire fighters. Forty-three per cent (n=29) stated that they agreed that their current mask/filter was useful, in contrast, 36% of the participants (n=24) disagreed that the mask/filter they were currently issued was useful. Of the 29 participants who agreed with the usefulness of their mask/filter, 65% (n=19) reported to 'sometimes' or 'mostly' wear a mask/filter, and 35% (n=10) reported to 'always' wear a mask/filter. Of the 24 participants who

disagreed with the usefulness of the mask/filter 79% (n=19) reported to 'sometimes' or 'mostly' use it, and 21% (n=5) reported to 'always' wear it despite their negative perception of its usefulness. Nearly half of the participants (46%, n=11) who disagreed with the usefulness of the current mask/filter, indicated that the mask/filter made breathing more difficult, while the other 54% (n=13) reported that the mask/filter made no difference or improved their breathing.

Table 12 Current Mask Use by FESA Fire Fighters

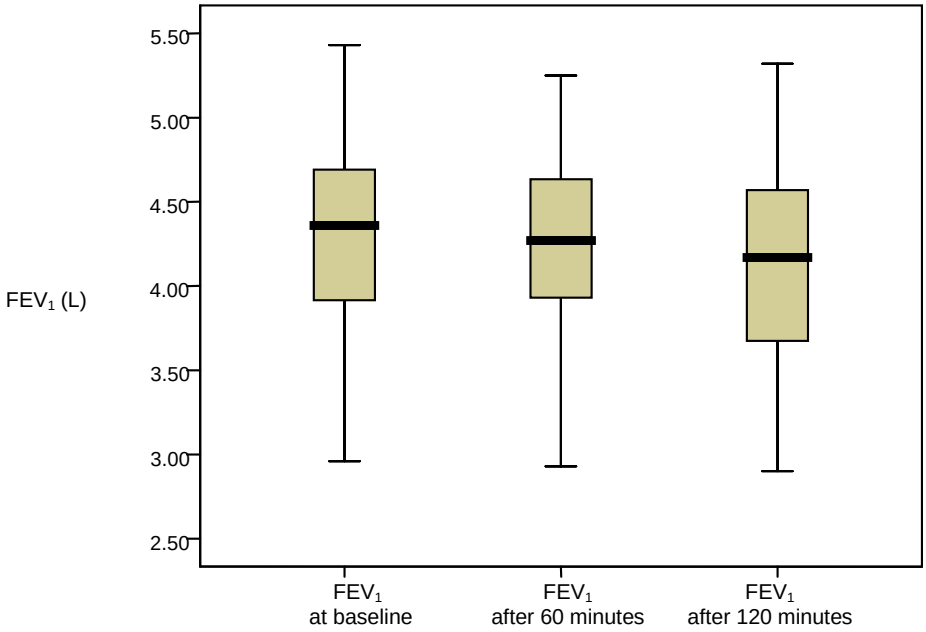
	n	%
Routinely wear a mask/filter		
Always	17	25
Sometimes, mostly	50	75
Never	0	0
Type of usual filter		
Particulate filter	48	72
Particulate/organic vapour filter	6	9
Don't know	11	16
Other	2	3
Usefulness of mask/filter in protecting health		
Strongly agree/agree	29	43
Strongly disagree/disagree	24	36
Don't know	14	21
Effect of mask/filter on breathing		
Much/slightly worse	24	36
Not different	17	25
Slightly/much better	26	39

After the first 60 minutes exposure to smoke in the prescribed burn 15% per cent of the participants (n=10) reported to be 'quite a bit' to 'extremely' thirsty, 63% (n=42) reported to be 'slightly' to 'moderately' thirsty, and 22% (n=15) was 'not thirsty at all'. After 120 minutes 13% (n=9) reported to be 'quite a bit' to 'extremely' thirsty, and 58% (n=39) reported to be 'slightly' to 'moderately' thirsty.

Sixteen percent of the participants (n=11) reported experiencing headaches after the first 60 minutes; five (45%) of these were allocated a P filter. After 120 minutes the majority of this group (n=6) still reported experiencing headaches. Four of these (67%) were allocated a P filter.

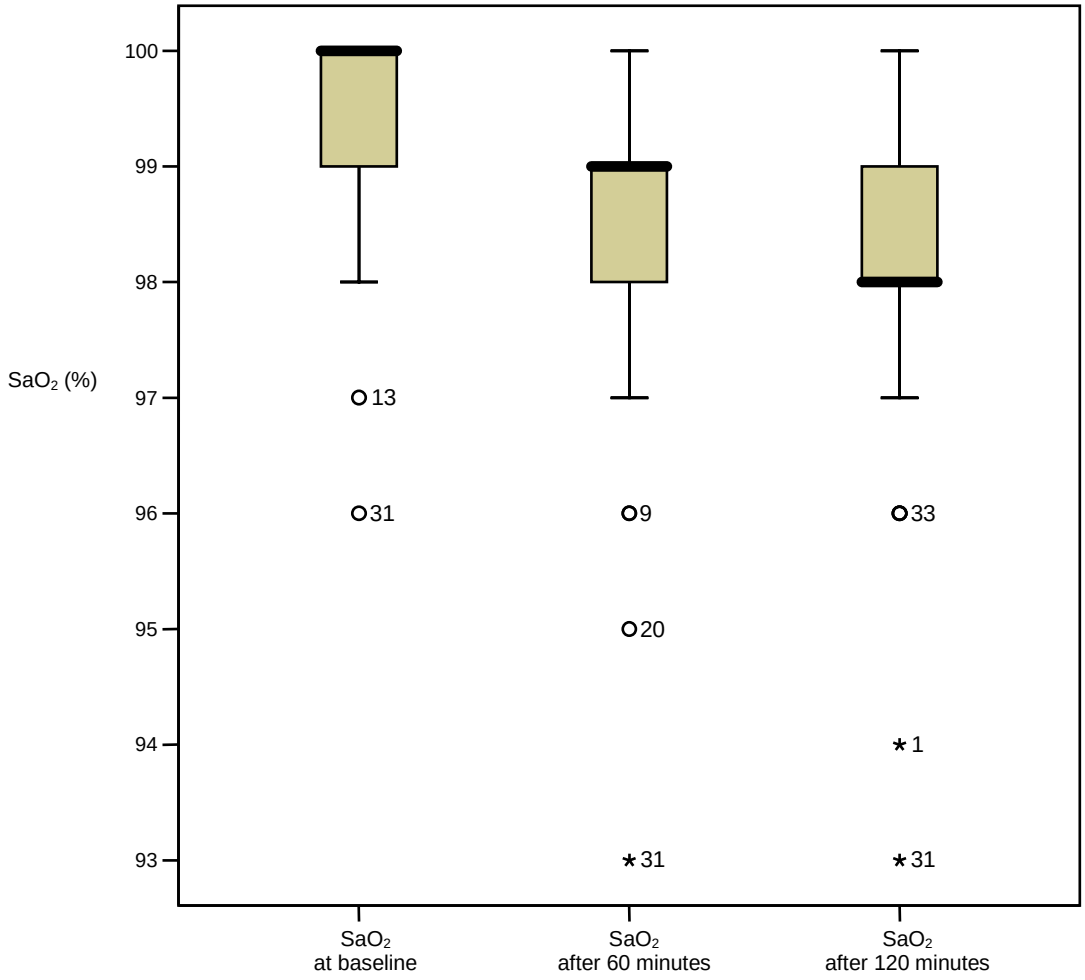
Across the study population there was a significant decline in FEV_1 both after 60 minutes (0.08L, $p < 0.05$), and 120 minutes (0.15L, $p < 0.05$) compared to the baseline measurements (Figure 18). These declines however, were not associated with the type of filter used during the trials.

Figure 18 Mean FEV_1 Measurements (Baseline - After 60 min - After 120 min)



In addition, a decline in SaO_2 was measured across the study population both after 60 minutes (1.2%, $p < 0.05$) and 120 minutes (1%, $p < 0.05$) compared to baseline measurements (Figure 19). Although the SaO_2 declines were statistically significant, the effect is small in clinical terms, and was not associated with the type of study filter.

Figure 19 Mean SaO_2 Measurements (Baseline - After 60 min - After 120 min)



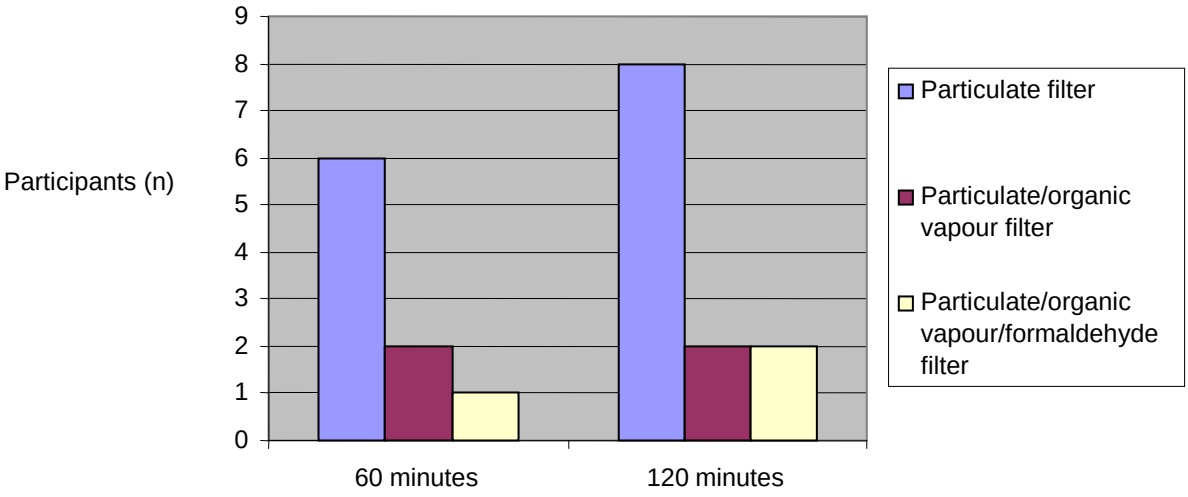
During the field validation trials a total of 13 P filters, 27 P/OV filters, and 27 P/OV/F filters were tested. After 60 minutes smoke exposure 13% of the participants (n=9) reported increased coughing, wheezing, and/or shortness of breath (Figure 20).

A significant difference in the number of participants was seen between:

- The P filter and the P/OV filter group (67% (n=6) vs. 22% (n=2)) ($p < 0.05$);
- The P filter and the P/OV/F filter group (67% (n=6) vs. 11% (n=1)) ($p < 0.05$).

Potential confounders such as years in FESA, gender, smoking history, and asthma did not significantly contribute to the model.

Figure 20 Number of Participants with Increase in Coughing, Wheezing, Shortness of Breath following 60-120 min Exposure



These findings were relatively comparable after 120 minutes. Eighteen per cent of the total study population (n=12) reported increased coughing, wheezing and shortness of breath following exposure. A significantly higher proportion of this group was allocated the P filter (64%, n=8) compared to the P/OV filter (18%, n=2), and the P/OV/F filter (18%, n=2) ($p < 0.05$).

Following the 60-minute exposure period, there was a statistically significant 20-fold reduction in the number of participants - with increased respiratory symptoms for the P/OV filter compared to the P filter (OR 0.050, 95% CI 0.004 – 0.597, *p* 0.02), and a four-fold reduction in the number of participants - with increased respiratory symptoms for the P filter group compared to the P/OV/F filter group (OR 0.234, 95% CI 0.068 – 0.797, *p* 0.02). These findings were comparable after 120 minutes exposure (Table 13).

Table 13 Odds Ratios for Increases in Respiratory Symptoms across the Three Types of Filters

Filters	Adj. OR*	*p*	95% CI
0-60 Minutes			
P filter vs. P/OV filter	0.050	0.02	0.004 – 0.597
P filter vs. P/OV/F filter	0.234	0.02	0.068 – 0.797
P/OV filter vs. P/OV/F filter	0.484	ns	0.034 – 6.802
0-120 Minutes			
P filter vs. P/OV filter	0.048	0.00	0.006 – 0.358
P filter vs. P/OV/F filter	0.237	0.00	0.092 – 0.613
P/OV filter vs. P/OV/F filter	1.300	ns	0.149 – 11.359

*OR adjusted for FESA years, age group, pack years
°ns = Difference statistically not significant

Although not a statistically significant outcome, it is notable that the only two participants who exited the smoke early (after 45 and 47 minutes) in the first as well as in the second hour were both issued a P filter during the trials. These two participants also reported to be a past and a current smoker, suggesting that tobacco use may be a risk factor in terms of health-related responses to bushfires.

Formaldehyde levels were significantly higher in the P filter group compared to the P/OV and the P/OV/F filter group both in the first and second hour of smoke exposure (both $p < 0.05$). No significant difference could be demonstrated between the P/OV filter group and the P/OV/F filter group with regard to formaldehyde levels (Table 14).

Table 14 Formaldehyde Levels inside Three Filter Types

Filter Type		Formaldehyde µg/m³ (STEL 2500 µg/m³)	
	n	60 minutes	120 minutes
P filter	2	440	260
		440	230
P/OV filter	6	10	10
		30	10
		80	70
		20	20
		10	10
		10	10
P/OV/F filter	5	10	50
		10	10
		10	10
		40	10
		10	10

4.3 Ambient Air Sampling Phase 1 and Phase 2

Personal sampling with 3M™ Organic Vapour Monitors was undertaken on the first smoke chamber trial on 20 October 2004 to obtain preliminary data about personal exposure to organic vapours. In comparison to the occupational standards (National Occupational Health and Safety Commission 1995) the measured organic vapours were well below STELs. Table 15 shows the values for the measured organic vapours in the smoke chamber.

Table 15 Results from Personal Sampling 3M™ Organic Vapour Monitors

Smoke chamber 20 October 2004	N-hexane mg/m³	Benzene mg/m³	Toluene mg/m³	Ethyl benzene mg/m³	M&P xylenes mg/m³	O-xylenes mg/m³	Total C2 benzenes mg/m³
TWA* (8hr)	176	16	377	434	350	350	-
STEL° (15mins)	-	-	565	543	655	655	-
Personal	1.90	0.19	39.27	0.15	0.15	0.25	0.56
sampling	1.69	0.14	40.97	0.15	0.15	0.10	0.41
15 minutes	1.20	0.19	24.17	0.15	0.17	0.25	0.57
3M™ Organic	2.08	1.91	78.95	0.17	0.22	0.25	0.65
Vapour Monitors	1.62	0.19	34.44	0.14	0.15	0.25	0.54
	2.01	0.22	53.20	0.25	0.13	0.25	0.63
	4.14	0.77	103.96	0.25	0.26	0.10	0.61
	2.26	0.23	56.35	0.25	0.20	0.25	0.70

*TWA: Eight-hour Time Weighted Average Concentration
° STEL (Short Term Exposure Limit): a maximal concentration to which workers can be continuously exposed for up to 15 minutes without adverse effect

In both the smoke chamber and during the field trials, positional sampling was undertaken to measure ambient levels of air pollutants. Levels of formaldehyde,

acrolein, particulates and carbon monoxide were measured during the exposure periods of 15 minutes in the smoke chamber. Only formaldehyde was measured during 120 minutes exposure in the field (Table 16).

During the smoke chamber burn in October 2004, the levels of particulates exceeded the TWA both for respirable and inspirable particulates. STELs for toxic particulates are not available due to the complex mixture, synergistic and cumulative effects of the individual compounds. Based on these findings, it was decided for safety and ethical reasons not to conduct the smoke exposure trials without personal respiratory protection, as was proposed in the initial stages of the study.

Formaldehyde levels in the smoke chamber were up to five times higher than formaldehyde levels measured in the field. On one occasion the formaldehyde level in the smoke chamber exceeded the STEL slightly. Unfortunately acrolein, particulate, and carbon monoxide levels were not available for the field trials. Carbon monoxide levels in the smoke chamber exceeded the STEL considerably on two occasions.

Table 16 Results from Positional Sampling

	Formaldehyde µg/m^3	**Acrolein µg/m^3**	**Particulates mg/m^3**	**Carbon Monoxide ppm**
TWA* (8hr)	1200	230	Respirable 5+ Inspirable 10+	30
STEL° (15 mins)	2500	690	n/a	200
Smoke chamber (Sept 2004)				
15 mins	1160	210	n/a	130 (peak)
	1220	90		70 (mean)
	1840			
	1910			
Smoke chamber (Oct 2004)				
15 mins	1747	697	3.9	742 (peak)
	1874	565	11.3	131 (mean)
	1654	480	11.7	
	1704	581	13.1	
Smoke chamber (Dec 2004)				
15 mins	2542	151	n/a	932 (peak)
	1955	101		257 (mean)
Prescribed burns (Oct 2005)	600	n/a	n/a	n/a
2 hrs	710			
	750			
	490			
	530			
	630			

*TWA: Eight-hour Time Weighted Average Concentration
° STEL: Maximal concentration to which workers can be continuously exposed for up to 15 minutes without adverse effect
+Exposure limits for non-toxic particulates only. No exposure limits available for toxic particulates

The Hapsite™ was used on one occasion in the smoke chamber in order to analyse the levels of volatile organic compounds. Although a complex mixture of compounds was demonstrated, it was not possible to determine the levels, as many of the compounds were present only in trace amounts and were poorly resolved by the gas chromatograph. The major compounds present in the smoke were benzene, toluene, ethylbenzene, xylenes, styrene, benzaldehyde, benzonitrile, phenol, benzofuran, alkanes, indene, and naphthalene (Wilkinson, S., pers. comm. 2005).

Chapter 5: Discussion

This report presents the results of a two year project investigating the effectiveness of three types of protective filters on fire fighters' masks.

The study was specific to the mask/filter use by FESA career fire fighters in Western Australia in bushfire situations.

The project was designed in two Phases, i.e.: Phase 1 involved controlled exposure trials in a smoke chamber, and in Phase 2 these findings were validated in the field under prescribed burn conditions.

During the controlled exposure trials 64 FESA career fire fighters were subjected to a light smoke situation in a smoke chamber. Smoke was generated by controlled combustion of a representative mixture of Western Australian native vegetation with low moisture content. To manage the smoke density and behaviour continuous visual assessment of the smoke was undertaken. In addition, air monitoring and sampling was conducted to determine the levels of the smoke compounds. During an experimental smoke chamber burn, levels of particulates exceeded the TWA, and it was therefore considered not safe to test without respiratory protection, as was initially proposed.

Twenty-four particulate filters, 23 particulate/organic vapour filters, and 17 particulate/organic vapour/formaldehyde filters were tested and compared. Respiratory health symptoms were assessed by a self-completed respiratory health questionnaire, FEV_1 and SaO_2 measurements. In addition, personal air sampling inside the masks was conducted with each of the different filter types fitted.

Both the measured and self reported respiratory health outcomes demonstrated that fire fighters exposed to a light bushfire smoke for 15 minutes, while using a particulate filter as the minimum respiratory protection, may experience minimal transient respiratory health effects, ranging from a slight cough to marginal declines in FEV_1 and SaO_2. It is likely that accumulation of carbon monoxide may play a role

in the SaO_2 decline. This is important, given that prolonged exposure to high carbon monoxide concentrations may affect fire fighters' safety and cognitive functioning. However, the adverse effects of carbon monoxide were not specifically examined in this project.

Testing the efficacy of the three types of filters under controlled conditions indicated that the particulate filter was only effective in filtering out particulates, and was ineffective in filtering out other bushfire smoke components, particularly respiratory irritants such as formaldehyde and acrolein. Although the particulate/organic vapour filter was effective in filtering out these compounds, the number of participants with an increase in self reported respiratory health symptoms clearly indicated that the particulate/organic vapour/formaldehyde filter was most effective in preventing acute respiratory health symptoms.

After adjusting for possible confounders such as FESA service years, age, and history of tobacco smoking, a significant 12-fold reduction was found in the number of participants with increased respiratory symptoms following the smoke exposure with the particulate/organic vapour/formaldehyde filter compared with the particulate filter. In addition, a 5-fold reduction was found in the number of participants with increased respiratory symptoms following the smoke exposure who used the particulate/organic vapour versus the particulate filter.

Anecdotal evidence showed that the particulate/organic vapour and the particulate/organic vapour/formaldehyde filter noticeably gave the wearer a sensation of not smelling anything resembling smoke during the exposure period. This observation was confirmed by feedback received from a FESA career fire fighter:

> *"On 10 Feb 2006 we were at a bush fire, this being the first opportunity I have had to use the new filters. In my 16 odd years with FRS and years previously with a Bush Fire Brigade I have never worn a more effective mask. I couldn't even smell the smoke I was standing in which was very heavy at times.*
>
> *I had made this comment to numerous people at the fire as I really couldn't believe that a mask could achieve this. For the first time I went home with my lungs not reeking of smoke (a comment often made by my wife and kids).*

> *I believe this type of filter is the minimum we should be using as fire fighters to protect our health. I hope this assists in making the above-mentioned filter standard issue to all staff for the protection of our health regardless of cost."*

The field trials during prescribed burns were undertaken to validate the findings from the controlled exposure trials. Sixty-seven (67) FESA career fire fighters participated in the field trials, with 13 particulate, 27 particulate/organic vapour, and 27 particulate/organic vapour/formaldehyde filters tested and compared. Repeated measurements were conducted at baseline, after 60 and 120 minutes exposure, including self-reported respiratory health symptoms, FEV_1 and SaO_2 measurements, and personal air sampling inside the masks.

These measurements during the prescribed burns demonstrated that after 60 and 120 minutes smoke exposure, a significantly higher number of participants in the particulate filter group - compared to the other two filter groups - reported an increase in respiratory symptoms (such coughing, wheezing and shortness of breath). Although declines in both FEV_1 and SaO_2 were observed after 60 and 120 minutes, these were not statistically associated with a particular type of filter. After adjusting for possible confounders such as FESA service years, age, and history of tobacco smoking, a significant four-fold reduction was found in the number of participants reporting an increase in respiratory symptoms following smoke exposure, in the particulate/organic vapour/formaldehyde filter group compared to the particulate filter group ($p = 0.02$). In addition, a twenty-fold reduction was found in the number of participants reporting an increase in respiratory symptoms following smoke exposure, in the particulate/organic vapour filter group compared to the particulate filter group ($p = 0.02$). Air sampling inside the masks demonstrated a significantly higher mean level of formaldehyde inside the particulate filters compared to the other two filters both after 60 and 120 minutes ($p < 0.05$).

The study revealed an apparent discrepancy between the chemical analysis of agents in the mask and the reported respiratory health outcomes. Results indicated that measured levels of particulates, formaldehyde and acrolein were comparable in masks fitted with particulate/organic vapour and particulate/organic vapour/formaldehyde

filters, yet a significantly lower proportion of the participants in the particulate/organic vapour/formaldehyde filter group reported an increase in respiratory symptoms after the exposure. At least two possible explanations may be presented to explain this apparent anomaly between the similarity of measured chemicals and difference in respiratory effects across the two filters. Firstly, a number of volatile organic compounds were detected in the smoke, e.g. terpenes, xylenes and other organic by-products of vegetation smoke. Although many of these compounds were present at levels below STEL, such individual components of the smoke - many of which are known respiratory irritants - may have exerted a synergistic effect on the respiratory health of the participants. Therefore, although not specifically examined in the chemical analysis within the masks (which focussed on the most "common" compounds: particulates, formaldehyde and acrolein), the particulate/organic vapour/formaldehyde filter may in fact have been more effective in removing many other volatile compounds, thereby reducing the possibility of synergistic toxic effects and consequently the rate of reported respiratory symptoms. Such combined irritant effects are poorly recognised in the literature and existing standards, and it is acknowledged that the full synergistic toxicity is probably impossible to measure due to the complexity of the smoke composition.

Another explanation for the discrepancy relates to inadequate seals of the masks. Inadequate sealing of the mask against the user's face may, in some cases, have resulted in the leaking of toxic compounds into the masks, thereby causing adverse respiratory health effects. Although the fire fighters were instructed to perform a Positive Pressure Fit Check in accordance with Australian/New Zealand Standard 1715:1994 (Standards Australia 1994) to ensure an appropriate seal, leakage may have occurred due to perspiration, helmets pushing the masks downwards, and movements of the head and neck by participants unintentionally causing displacement.

The study also showed a discrepancy between some of the results from the smoke chamber compared to the field trials. In the smoke chamber the number of participants reporting an increase in respiratory symptoms was significantly lower in the particulate/organic vapour/formaldehyde filter group. Yet in the field trials the number of participants reporting an increase in symptoms was comparable in the

particulate/organic vapour and the particulate/organic vapour/formaldehyde filter group. A possible explanation for the variation in these findings may be presented by the apparent dilution of the smoke in the field trials. Our data suggest that the formaldehyde levels were three to five times lower during the prescribed burns compared to the formaldehyde levels in the smoke chamber. In addition, carbon monoxide levels in the smoke chamber exceeded the STEL considerably during two trials. The reason for the high levels recorded in the smoke chamber is no doubt due to the confined space in the chamber where pathways for ventilation were reduced, thus concentrating the various compounds. In the field trials the dilution effect due to wind would account for lower values. This variability may in turn have resulted in smaller differences in respiratory outcomes between the particulate/organic vapour and the particulate/organic vapour/formaldehyde filter group in the field trials.

A potential impact on the validity of our reported results is the influence of self-reporting bias. Although self-reporting on occupational exposures is generally valid, Teschke et al. (2002) found that validity and reliability estimates with regard to self-reporting may vary greatly from study to study, and also within studies. In this project, the participants may have inaccurately reported information regarding their health, either intentionally or unintentionally. For example, the occurrence of asthma may have been under-reported given that not all fire fighters either admit to having asthma or seek medical attention for asthma symptoms, perhaps from self-denial or fear of job loss.

Bias may also arise from fire fighters pre-conceptions regarding the efficiency of particular filters. In order to minimise potential self-reporting bias caused by the participants' prior perceptions of the superiority of one of the three filters, the study filters were as similar in appearance as possible, thereby effectively blinding the participants to the type of filter used. This strategy of blinding the participants and investigators at the time of allocation was aimed at preventing the fire fighters from identifying the different filters, thereby ensuring that the health outcomes were not affected by the participants' perception of wearing a particular type of filter.

Another limitation of the study was the initial selection of the most appropriate filters for comparison. Defining an optimal filter may be problematic, if not impossible, due

to the complex and variable mixture of the products of combustion present in bushfire smoke. In this study, it was decided to use the particulate and the particulate/organic vapour filter, because these were the two types of filter that were currently used among FESA career fire fighters in Western Australia. A particulate/organic vapour/formaldehyde filter was added to the study after smoke analysis during preliminary burns demonstrated elevated levels of formaldehyde - a Class 1 carcinogen (International Agency for Research on Cancer 2004b) - in the smoke. It must be noted however that levels of formaldehyde were measured within STELs (National Occupational Health and Safety Commission 1995), ensuring that none of the participating fire fighters - with or without formaldehyde filters - were exposed to unacceptably high levels of formaldehyde during the course of this study.

Finally, the present study attempted to compare three types of filters in an experimental setting and did not incorporate the impact of the stresses and strains on the masks of the fire fighters, as described for example by Sharkey (1997). The study did not address work load factors such as job tasks, heat and physical exertion, which will be explored by other collaborative partners in the Bushfire CRC.

Although the study design and methodology can be applied for similar purposes elsewhere, the findings of this study should be considered specific in regard to exposure to Western Australian bushfire smoke. The respiratory health effects are highly dependent on the composition of the bushfire smoke, which is in turn determined by the fuel properties, such as the type and amount of vegetation, and the meteorological conditions (e.g. presence of clearing winds or inversions) (Gill et al. 1981; Beer and Meyer 1999; Luke and McArthur 1978). Therefore, it is important that the findings from this study be considered within an appropriate context. Nevertheless, it is the author's opinions that the recommendations that follow from this work (Chapter 6) are likely to be protective of fire fighters' respiratory health generally.

In conclusion, testing the effectiveness of 37 particulate, 50 particulate/organic vapour, and 44 particulate/organic vapour/formaldehyde filters under controlled and semi-controlled bushfire smoke conditions from 15 minutes up to 2 hours demonstrated that the particulate/organic vapour/formaldehyde filter provides

clinically and statistically significant better protection for the fire fighters' airways. These findings suggest that the FESA career fire fighters' respiratory health would be best protected by the provision of the particulate/organic vapour/formaldehyde filter. Further research is needed to determine the breakthrough times of the filters and the effectiveness of the filters over longer time periods, such as a work shift or a bushfire season.

The cost of the particulate/organic vapour/formaldehyde filter is approximately 3 ½ times more expensive ($30.20) than that of the particulate filter ($8.51). However, the provision of the particulate/organic vapour/formaldehyde filter, in providing a significantly more effective outcome for the respiratory health of fire fighters, would indicate that the additional expenditure is justified.

Chapter 6: Recommendations

Based on the findings of this study the following recommendations are made:

1. The strongest commendation is offered to FESA for commissioning this work with the full knowledge that the findings could point to a possible need for reviewing current best practice. It is acknowledged that the recommendations are based solely on the findings of this study, and that many other factors (including practicality, costs, and acceptability issues) will need to be taken into consideration before a decision can be made on implementation or otherwise.

2. In keeping with the current FESA practice, the recommendation to wear a mask and protective filter during bushfire fighting is strongly supported, as particulate levels in the smoke chamber exceeded Time Weighted Average standards for both inspirable and respirable particulates.

3. The particulate filter (3M™ 5925) was found to be ineffective in removing the main organic compounds, formaldehyde and acrolein, which are found in bushfire smoke in Western Australia. Given that formaldehyde is a human carcinogen, the use of a filter which removes these compounds is essential in protecting the respiratory health of FESA career fire fighters.

4. Based on the overall health outcomes reported by the participants, the particulate/organic vapour/formaldehyde filter (3M™ 6075A1) performed to a significantly higher level than the particulate/organic vapour filter, and is therefore considered the most appropriate filter of the three tested, to protect the respiratory health of FESA career fire fighters in bushfire fighting.

   NOTE: In 2005 FESA implemented the recommendations from the *"Filter Study Phase 1 Preliminary Report March 2005"* by providing the option for career fire fighters of using the particulate/organic vapour/formaldehyde filter pending the finalisation of this study.

5. Consideration should be given to the development of a respiratory trainings program for fire fighters. Key elements in such a program may include:
   - Appropriate use, maintenance, service life, and limits of the respiratory protective equipment;
   - Fit testing procedures in accordance with Australian/New Zealand Standard 1715:1994 (Standards Australia 1994); and
   - Training of the fire fighters in the respiratory hazards to which they are potentially exposed during bushfire fighting.

6. Consideration should be given to further research to determine the service life of the particulate/organic vapour/formaldehyde filter. This study did not test the filters for service life or breakthrough time. However, as a 'rule of thumb' filters should be replaced when fire fighters can detect the odour of smoke compounds penetrating through the filter.

7. Until the research or the evidence on the service life is determined as indicated in Recommendation 6, a review of the Bush Fire Smoke Management Standard Operational Procedures 51 should be considered as to the most appropriately wording to be used to indicate service life of the filter. The current wording 'Extended periods' and 'Short duration' may need to be changed and substituted with the 'rule of thumb' approach.

8. Consideration should be given to the provision of a suitable bag/container for the storage of the particulate/organic vapour/formaldehyde filter when not in use to ensure the filter does not further deteriorate and reduce service life due to exposure to ambient contaminants.

9. A follow-up questionnaire survey should be considered at the end of the 2007 summer bushfire season to ascertain fire fighters' usage of the particulate/organic vapour/formaldehyde filter, its effectiveness, and any indications of service life, e.g. breakthrough of smoke sensation.

10. FESA may wish to consider further research work into:

- The correlation between carbon monoxide and formaldehyde, given that research in the USA has shown strong correlations between levels of carbon monoxide, formaldehyde, acrolein, and respirable particulate in smoke samples from prescribed burns (Reinhardt et al. 2000).
- The use of CO alarm dosimeters to warn of concomitant CO overexposure. This will greatly increase hazard awareness because it provides the crews and managers with feedback about the hazards of smoke.

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Appendix 1

FILTER STUDY

Phase 1

PRELIMINARY REPORT

March 2005

A BUSHFIRE CRC/UNIVERSITY OF WESTERN AUSTRALIA/FESA COLLABORATIVE STUDY INTO THE RESPIRATORY HEALTH EFFECTS OF OCCUPATIONAL EXPOSURE TO WESTERN AUSTRALIAN BUSHFIRE SMOKE AND THE EFFECTIVENESS OF WEARING PROTECTIVE FILTERS FOR FIRE FIGHTERS

1.0 Introduction

Fire fighting is amongst the most dangerous and hazardous occupations. Apart from enduring heat, noise and extreme difficulty in doing precise and physically demanding tasks, fire fighters are often exposed to smoke containing high concentrations of irritating and toxic gases. To exacerbate the problem, fire fighters are frequently confronted with situations in which they have little or no knowledge of what chemicals are present. Although exposures are generally higher among structural fire fighters, bushfire fighters have the potential for longer periods of exposure to bushfire smoke with few or no respite periods. Given the high annual frequency of bushfires in Western Australia, there is considerable risk of exposure to bushfire smoke and inhalation injury among the fire fighters.

This report presents the findings of Phase 1 of the Filter Study. This study investigates the respiratory health effects of occupational exposure to Western Australian bushfire smoke and the effectiveness of the protective filters on the fire fighters' masks while fighting bushfires. Phase 1 of the study involved exposure trials under controlled conditions, which will then be followed by the field validation in Phase 2 during prescribed burns and bushfires (late 2005 - early 2006).

2.0 Background

The Fire and Emergency Services Authority of Western Australia (FESA) has indicated that fire fighters are increasingly concerned about the health risk of exposure to combustion products from bushfires. Furthermore, there is insufficient evidence available to determine if the commonly provided filters protect the fire fighters' respiratory health from exposure to bushfire smoke.

In Western Australia, the two currently available filters are the Class P2, intended for use against both mechanically and thermally generated particulates, and the Class P2 + organic, intended to use against particulates and organic volatiles. Although the performance of the filters is tested by the manufacturer, in order to comply with the Australian and New Zealand Standard 1715/1716, it remains unclear whether the provision of the P2 filter, the P2 + organic filter, or no filter differ in their

effectiveness to protect the fire fighters' airways from combustion products from Western Australian bushfires (Picture 1).

Picture 1: Masks with Protective Filters

Picture 2: Inside the Mask Sampling

Therefore, in order to address this lack of information, the Filter Study investigates the effectiveness of the filters by means of (a) measurement of lung function and respiratory symptoms; (b) air sampling inside the masks to determine fire fighters' exposure levels (Picture 2); (c) comparison of the exposure levels to Short Term Exposure Limits (STEL)[5].

3.0 Aims

The specific aims of the Filter Study are:

1. To determine whether wearing protective filters affects the acute respiratory health of Western Australian fire fighters under controlled conditions;
2. To validate these findings in the field during prescribed burn-offs and real bushfires.

4.0 Methodology

4.1 Test-site and Conditions

The exposure trials were conducted in the controlled environment of the FESA Training Centre at Forrestfield. The smoke chamber used for the study (Picture 3) was

[5] Short Term Exposure Limit: a maximal concentration to which workers can be continuously exposed for up to 15 minutes without adverse effect.

a modified sea container (12.2m x 2.4m x 2.4m), which had one end completely open for people to enter and exit at all times.

Picture 3: Smoke Chamber

The smoke was produced by controlled combustion of a set quantity of dried Western Australian native vegetation in a custom-built incinerator. The environment was controlled for temperature and wind as far as practicable, to ensure that the only variable possibly affecting the outcomes was the type of filter worn. For the purpose of the study a light smoke situation was utilized, determined as a white to light grey color with reasonable visibility (15 plus metres)[6]. The smoke was generated in a standard way to ensure that the smoke characteristics were reproducible.

The study vegetation included a mixture of banksia, coastal heath, and kikuya grass collected in the Gingin and Eglington area (Picture 4). These vegetation types were selected because, based on workplace reports, they are known to create substantial smoke levels during bushfires. The collected vegetation was stockpiled at the FESA Training Centre, Forrestfield and had a moisture content of 9 per cent during the trial burns.

[6] Fire and Emergency Services Authority Western Australia 2003, *Bush Fire Smoke Management SOP 51*, Version – 28 May 2003.

Picture 4: Vegetation Sample

4.2 Exposure Trials

A pilot study and five exposure trials (6 sessions in all) were conducted with 64 career fire fighters who volunteered to participate in the study. On arrival at Forrestfield the participants were re-informed about the study and updated about the procedures of the exposure trials. Then they were asked to:

- Read the Information Sheet
- Sign the Consent Form;
- Fill out the Respiratory Symptom Questionnaire Part 1;
- Undergo FEV_1[7] and SaO_2[8] measurements;
- Wear full fire-fighting gear, i.e. uniform, helmet, protective goggles, and mask, before entering the smoke chamber.

Next the investigators attached the randomly allocated study filters to the participants' mask, and the participants were asked to perform a positive pressure test, to ensure an adequate seal was achieved. The participants were asked to remain in the smoke chamber for 15 minutes to ensure that sufficient air samples could be acquired for analysis. Before the participants entered the smoke chamber, they were reassured that they were free to step out of the smoke chamber whenever they experienced shortness of breath, coughing or otherwise felt anxious, stressed or generally unwell. Activities in the smoke chamber were limited to walking around. The participants were

[7] Forced Expiratory Volume after 1 second.
[8] Oxygen saturation.

observed continuously by a Registered Nurse in order to ensure their safety. Full first aid facilities were available at the test-site, and an emergency protocol was in place.

After the 15 minute exposure period, the participants were asked to exit the smoke chamber, and to:

- Repeat the FEV_1 and SaO_2 measurements;
- Fill out the Respiratory Symptom Questionnaire Part 2.

After 30 minutes recovery time, the participants were asked to fill out the Respiratory Symptom Questionnaire Part 3. This concluded the exposure trial.

4.3 Data Collection

The respiratory health outcomes were measured before (baseline) and after the exposure to the combustion products by use of a respiratory symptom questionnaire, spirometry, and pulse oximetry.

The respiratory symptom questionnaire is a standardised self-completed form, primarily designed to obtain information about the participants' health status and their perception of the acute respiratory health effects of the exposure to the controlled bushfire smoke. The questionnaires were administered in three separate times, i.e. before, immediately after the exposure and after 30 minutes recovery time.
Spirometry was performed before and immediately after the bushfire smoke exposure. The FEV_1 was obtained which is an extensively used index, and provides a useful tool to measure the functional state of the lung.

Pulse oximetry was performed prior to entering and after exiting the smoke chambers. This is a simple non-invasive method of monitoring the arterial oxygen saturation (SaO_2) of haemoglobin.

4.4 Field Validation

The findings of the controlled exposure trials will be validated in the field during the controlled burn-offs and actual bushfire events. Measurements will be made of the terrain, climate or other variables pertaining to the environmental context of the fire

5.0 Results

5.1 Acute respiratory Health Effects of occupational Exposure to Bushfire Smoke

Sixty-four healthy career fire fighters from 20 fire stations in the Perth Metropolitan area participated in the six controlled exposure trials. They were randomly selected after stratification by location of fire station, as according to workplace reports, fire fighters from Balcatta, Canning Vale, Joondalup, and Malaga fire stations are likely to be more frequently exposed to bushfire smoke (Table 5.1).

5.1.1 Demographics

The analysis demonstrated no significant association between the demographic variables, (including gender, age group, FESA years, current fire station) and the observed differences in pre and post exposure FEV_1/ SaO_2 measurements, self reported respiratory health symptoms, sputum, and exposure time.

Table 5.1: Demographics

Demographics	*N=*
Gender	
➢ Male	60
➢ Female	4
Age group	
➢ 20-29	4
➢ 30-39	25
➢ 40-49	30
➢ 50-59	4
➢ 60+	1
FESA years (mean)	13.16
Current fire station	
➢ Balcatta, Canning Vale, Joondalup, Malaga	30
➢ Remaining stations	34

5.1.2 Previous Exposures

Previous exposures to bushfires were measured by attendances of bushfires. These were evaluated in relation to self-reported associated symptoms from past bushfire exposures, including coughing, wheezing, and shortness of breath. Thirty-two participants reported to have symptoms after previous attendances at bushfires, with 29 indicating symptoms of coughing, wheezing, and shortness of breath. However, no consistent relationship between previous exposures to bushfires or past symptoms and the Phase 1 observed differences in FEV_1/ SaO_2, respiratory health outcomes, sputum, or exposure time could be demonstrated.

5*.1.3 Pre-existing Medical Conditions*

Pre-existing medical conditions including perceived overall health, self reported asthma, allergies, sputum, and use of bronchodilators (Table 5.2) could not be related to the Phase 1 observed differences in FEV_1/SaO_2, respiratory health outcomes, sputum or exposure time. However, the majority of the participants (53.8%) who reported an increase in coughing, wheezing, tightness, shortness of breath after the exposure indicated that they suffered from hay fever.

Table 5.2: Pre-existing Medical Conditions

Pre-existing medical conditions	*N=*	*%*
Overall health		
➢ Good	12	18.8
➢ Very good	37	57.8
➢ Excellent	15	23.4
Asthma		
➢ Yes	6	9.4
➢ No	58	90.6
Hay fever		
➢ Yes	24	37.5
➢ No	37	57.8
➢ Don't know	3	4.7
Allergies		
➢ Yes	3	4.7
➢ No	54	84.4
➢ Don't know	7	10.9
Sputum		
➢ Yes	5	7.8
➢ No	57	89.1
➢ Don't know	2	3.1
Current use of bronchodilators (puffers)		
➢ Yes	6	9.4
➢ No	58	90.6

5.1.4 Recent Symptoms

Recent symptoms in the last 12 months, such as coughing wheezing, tightness, shortness of breath, and respiratory tract infections (cold, flu, throat or chest infection) could also not be related to any differences in the FEV_1/SaO_2, respiratory health outcomes, sputum, or exposure time in Phase 1.

5.1.5 Smoking History

There were no current smokers among the participants. Twenty-two participants were identified as past smokers, and 42 participants reported to have never smoked. Neither smoking status nor pack years (packs/day/year) were related to differences in self-reported and measured respiratory health outcomes in Phase 1.

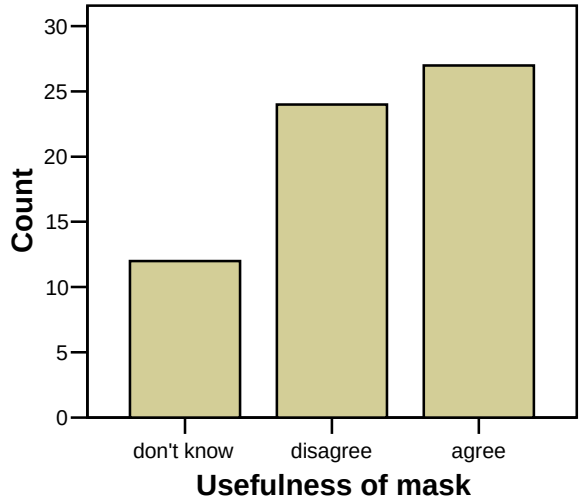
5.1.6 Perception of Risk

The perception of risk (Table 5.3) was measured by variables assessing the perceived protection of wearing masks while fighting bushfires.

Table 5.3: Perception of Risk

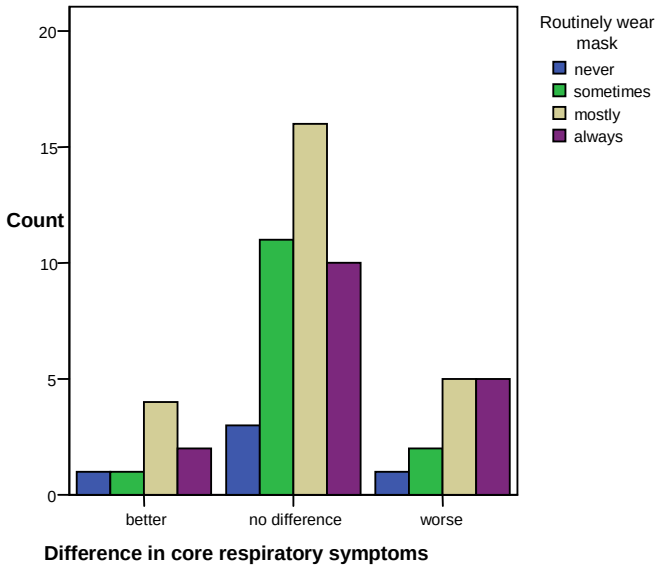
Perception of Risk	*N=*	*%*
Routinely wear a mask		
➢ Never	5	7.8
➢ Sometimes	14	21.9
➢ Mostly	27	42.2
➢ Always	17	26.6
Mask effect on breathing		
➢ Not different	11	17.2
➢ Worse	19	29.7
➢ Better	33	51.6
Usefulness of mask		
➢ Don't know	12	18.8
➢ Disagree	24	37.5
➢ Agree	27	42.2
Comparability of smoke to real bushfire smoke		
➢ Different	20	31.3
➢ Similar	42	65.6

Figure 5.1: Usefulness of Mask



There was a suggestion of a possible trend for a greater proportion of participants who reported an increase in coughing, wheezing, tightness, and shortness of breath after the exposure in fire fighters who were more likely to routinely wear a mask during bushfires (never wore a mask 7.7%, sometimes wore a mask 15.4%, mostly wore a mask 38.5%, and always wore a mask 38.5%), but these trends were not statistically significant (Figure 5.2).

Figure 5.2: Difference in core respiratory symptoms and routinely wearing a mask



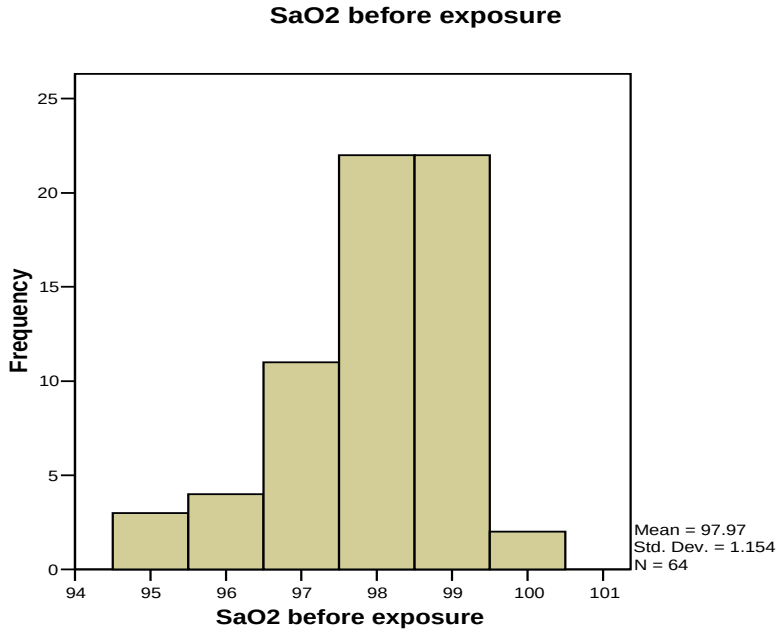
5.1.7 Spirometry and Oximetry

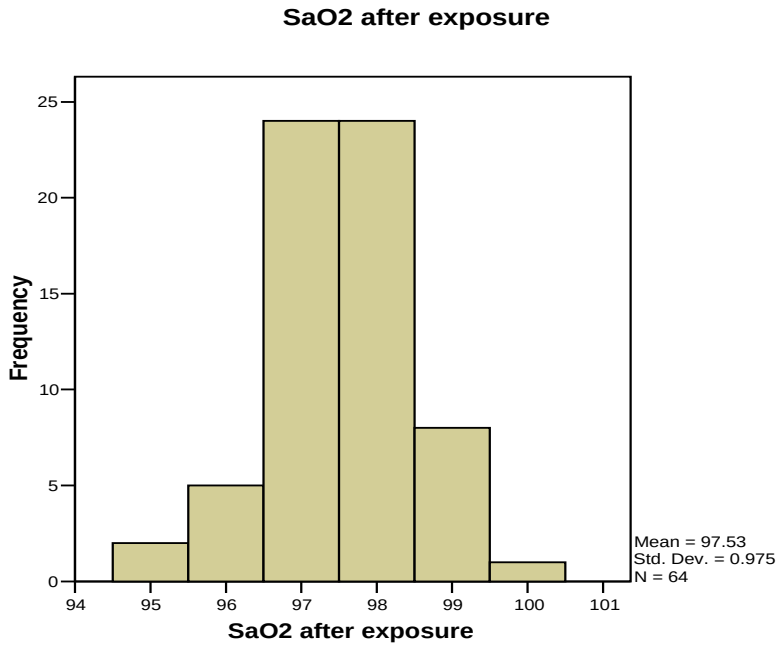
The observed decline between the pre and post exposure FEV_1 measurements (Table 5.4) was not statistically significant. In addition, multiple linear regressions analysis demonstrated that the declining trend in FEV_1 could not be predicted from the type of filter used, after controlling for age, years in FESA, and smoking status.

Table 5.4 Spirometry and Oximetry

Pre and Post FEV_1/ SaO_2	*Mean L for FEV_1 % for SaO_2*
➢ Pre FEV_1	4.16
➢ Pre SaO_2	97.97
➢ Post FEV_1	4.15
➢ Post SaO_2	97.53
➢ **Difference pre and post FEV_1**	**0.01**
➢ **Difference pre and post SaO_2**	**0.44**

Figure 5.3: SaO_2 before and after Exposure





Although a statistically significant decline was observed between the pre and post exposure SaO_2 measurements (Figure 5.3), this could also not be related to any of the previously reported variables.

5.1.8 Difference pre and post Exposure Respiratory Outcomes

Acute respiratory health effects were measured by self-reported symptoms of coughing, wheezing, and shortness of breath. After the 15-minute exposure to bushfire smoke 40 participants (62.5%) reported no difference in these symptoms, with 13 participants (20.3%) reporting an increase in coughing, wheezing, and shortness of breath.

After 30 minutes recovery time however, most of these symptoms had resolved, with 6 participants (9.4%) still experiencing a slight increase in coughing, wheezing, or shortness of breath compared to before the exposure. Although these observations are important respiratory outcomes, a statistical significance could not be established.

5.2 Effectiveness of wearing protective filters under controlled conditions

5.2.1 Results Air Sampling inside the Masks

The testing of the protective filters involved the particulate filter (n=24), the particulate/organic vapour filter (n=23), and the particulate/organic vapour/formaldehyde filter (n=17). Levels of dust, formaldehyde, and acrolein were measured by air sampling inside the masks (Table 5.5). A significant difference was found in both formaldehyde and acrolein levels inside the masks between:

- Particulate and the particulate/organic vapour filters, and
- Particulate and the particulate/organic vapour/formaldehyde filters (Figure 5.4).

No statistical difference was found in formaldehyde and acrolein levels between particulate/organic vapour and particulate/organic vapour/formaldehyde filters.

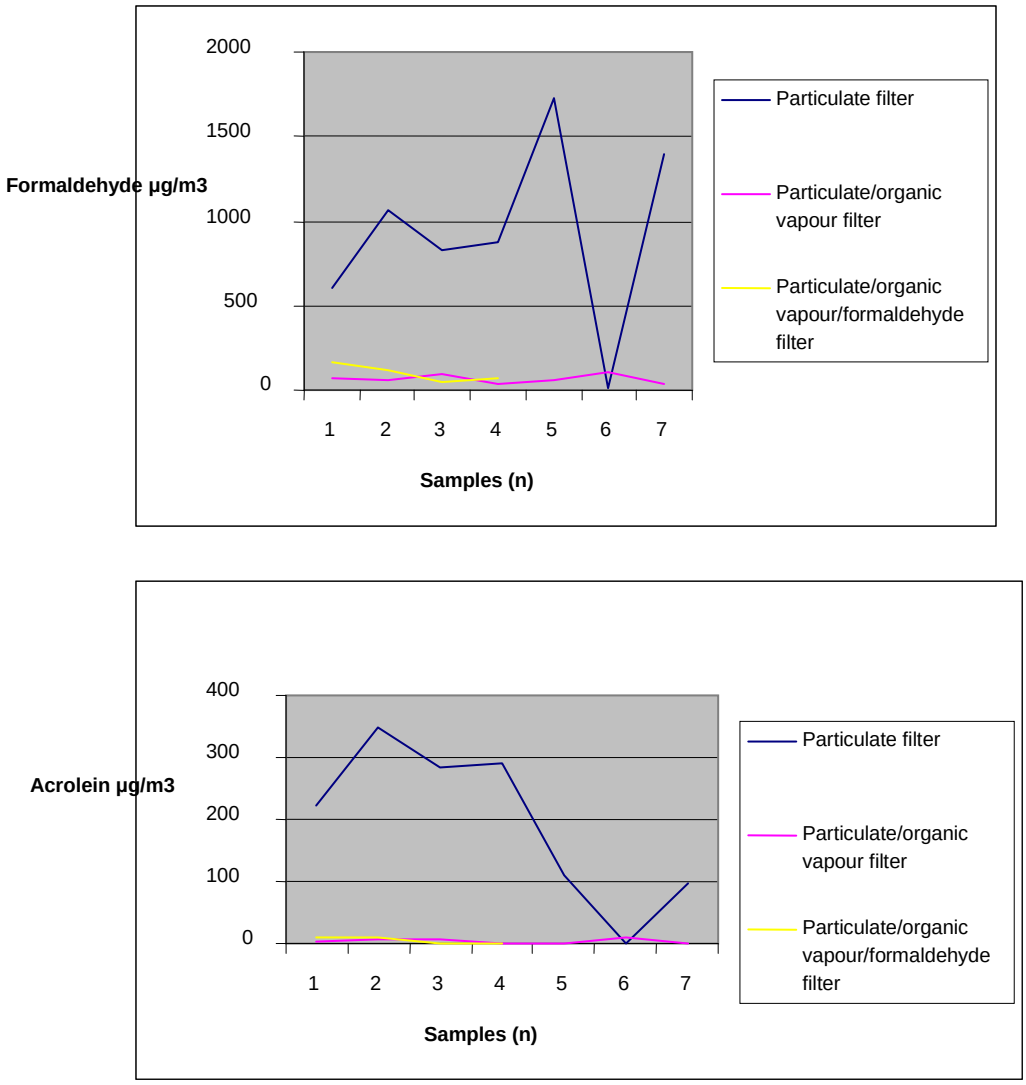
Although dust levels inside the masks were also measured, these results were not significantly different across the two types of filters (dust results for the particulate/organic vapour/formaldehyde filter were not available).

Table 5.5: Filter Types and Air Sampling Results

FilterType	*N=*	*Dust mg/m3+*	*Formaldehyde µg/m3 (STEL 2500 µg/m3)*	*Acrolein µg/m3 (STEL 687 µg/m3)*
➢ Particulate filter	24	0.7 0.3 0.1 5.1	598 1062 824 872 1731 17 1402	224 350 284 290 109 1 96
➢ Particulate/organic vapour filter	23	2.2 2.1 1.0 0.7	73 58 97 33 59 104 37	4 5 5 0 1 10 1
➢ Particulate/organic vapour/formaldehyde filter	17	*	160 119 53 67	10 10 1 1

+STEL for toxic dust is not available (STEL non-toxic particulates: 5-10 mg/m3)
***** Not available

Figure 5.4: Air Sampling Results inside the Masks

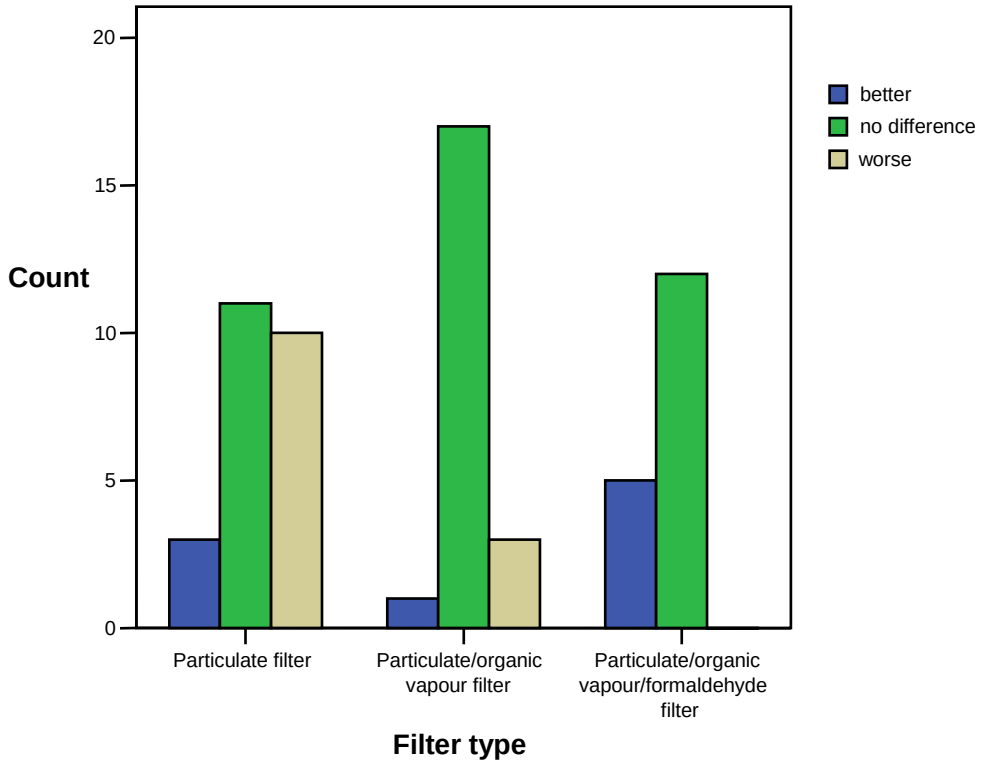


5.2.2 Pre and post Exposure Respiratory Outcomes

A significant association was observed in the reported difference in coughing, wheezing, tightness, and shortness of breath between:

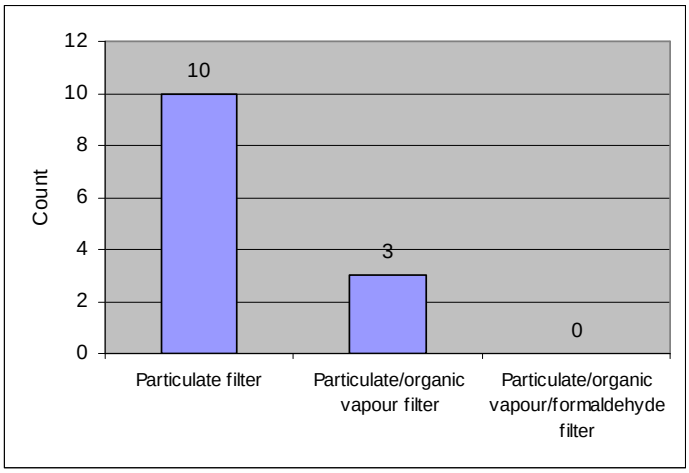
- Particulate and the particulate/organic vapour/formaldehyde filter;
- Particulate/organic vapour and particulate/organic vapour/formaldehyde filter (Figure 5.5 and 5.6).

Figure 5.5: Difference in Coughing, Wheezing, Shortness of Breath across three Filter Types



Such differences however, were not observed between the particulate and particulate/organic vapour filter. Within the group of participants who reported the highest increase in coughing, wheezing, and shortness of breath after the exposure, 10 (76.9%) used a particulate filter and 3 (23.1%) used a particulate/organic vapour filter (0% used a particulate/organic vapour/formaldehyde filter).

Figure 5.6: Participants with increased Symptoms of Coughing, Wheezing, Shortness of Breath following Exposure



5.2.3 Pre and post FEV_1 and SaO_2

Although a significant relationship could be demonstrated within the pre and post exposure SaO_2 differences, a significant association between these differences and the three types of filters could not be established.

The observed decline between the pre and post exposure FEV_1 measurements across the three types of filters was not statistically significant.

6.0 Discussion

During controlled exposure trials 64 healthy career fire fighters were subjected to a light smoke situation in a smoke chamber. Smoke was generated by controlled combustion of a representative mixture of Western Australian native vegetation with low moisture content. To ensure that smoke components would not exceed STEL levels during the trials, continuous visual assessment of the smoke and ambient air sampling was undertaken.

Before and after the exposure, the acute respiratory health outcomes were assessed by a self-completed respiratory health questionnaire, and FEV_1 and SaO_2 measurements. Concurrently, three types of protective filters were tested for their efficacy by 'inside the masks' air sampling and self reported respiratory health symptoms.

Both the measured and self reported respiratory health outcomes demonstrate that fire fighters exposed to a light bushfire smoke for 15 minutes, while using a particulate filter as the minimum respiratory protection, may experience minimal transient respiratory health effects, ranging from a slight cough to marginal declines in FEV_1 and SaO_2.

Testing the efficacy of the three types of filters clearly indicate that the particulate filter is ineffective in filtering out bushfire smoke components, including respiratory irritants such as acrolein and formaldehyde. Although the particulate/organic vapour filter was effective in filtering out the measured components, the self reported respiratory health symptoms indicate that the particulate/organic vapour/formaldehyde filter is most effective in preventing acute respiratory health symptoms, such as coughing, wheezing, and shortness of breath.

In conclusion, the testing of the effectiveness of 24 particulate, 23 particulate/organic vapour, and 17 particulate/organic vapour/formaldehyde filters has demonstrated that the particulate/organic vapour/formaldehyde filter provides statistically significant better protection for the fire fighters' airways under controlled conditions.

7.0 Recommendations

The findings of the controlled exposure trials indicate that the fire fighters' respiratory health and perception of respiratory health would be best protected by the provision of the particulate/organic vapour/formaldehyde filter. It must be acknowledged however that recommendations can only be based on the findings of the exposure trials under controlled conditions.

Therefore, further research is needed to determine the efficacy of the filters over longer time periods under field conditions. It is anticipated, that some of these issues can be addressed in the Phase 2 of the Filter Study during prescribed burns and real bushfire situations.

Appendix 2

MASK STUDY

QUESTIONNAIRE

Part 1: Before contact with smoke

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|
Date: day |__|__| month |__|__| year |__|__|__|__|
Time: hour |__|__| minutes |__|__|

1.1 How many years have you been working as a career firefighter with FESA?

|_|_| Years

1.2 At which station are you currently working?

_____

1.3 Are you male or female?

- ❑ Male
- ❑ Female

1.4 In which age group are you?

- ❑ 20 to 29 years
- ❑ 30 to 39 years
- ❑ 40 to 49 years
- ❑ 50 to 59 years
- ❑ 60+ years

1.5 In general, would you say your health is:

(Please tick one)

Excellent	Very good	Good	Fair	Poor
❑	❑	❑	❑	❑

1.6 Are you a current smoker or have you ever smoked in the past?

- ❑ Never smoked
- ❑ Current smoker→ what do you mainly smoke? (tick all that apply)
  - ❑ cigarettes → How old were you when you started smoking? **|_|_| years**
    On average how many cigarettes per day? **|_|_|**
  - ❑ other forms of smoking→ specify _____
    For how many years? **|_|_| years**
    How many times do you smoke per day? **|_|_|**
- ❑ Past smoker → what did you mainly smoke? (tick all that apply)
  - ❑ cigarettes → How old were you when you started smoking? **|_|_| years**
    How many cigarettes per day? **|_|_|**
    How old were you when you stopped smoking? **|_|_| years**
  - ❑ other → specify _____
    For how many years? **|_|_| years**
    How many per day? **|_|_|**
    How many years ago did you stop? **|_|_| years**

1.7 Have you ever been diagnosed with:

Asthma?

- ❑ Yes → At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

Hay fever?

- ❑ Yes→ At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

Any type of allergies not already mentioned?

- ❑ Yes → Please, specify _____
  → At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

1.8 Do you regularly bring up phlegm (sputum) from your chest?

❑ Yes → Please specify: For how many years has this occurred? **|_|_| years**

Does it occur most years? ❑ Yes ❑ No

If yes → Please specify → For how many months of the year?
|_|_| months

❑ No

❑ Don't know

1.9 In the past 12 months, have you experienced any of the following on a regular basis?:	**(Please tick one of the answers)**				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Other symptoms affecting your chest or breathing? Please specify _____ _____	❑	❑	❑	❑	❑

1.10 Do you suffer from any of these symptoms after bushfires?

❑ I don't attend bushfires

❑ Yes → Please specify what symptoms: _____

_____

❑ No

❑ Don't know

1.11 Do you take any medicines (such as puffers, inhalers, tablets) to help with wheezing?

- ❑ Yes → If yes, what is the medicine? _____

  On average, how many times a WEEK do you take it?

  _____ a week

- ❑ No
- ❑ Don't know

1.12 During the past two weeks, have you suffered from any of the following: cold, flu, throat or chest infection?

- ❑ Yes
- ❑ No
- ❑ Don't know

1.13 During the past two weeks, have you suffered from any other type of infections?

- ❑ Yes → If yes, please describe: _____
- ❑ No
- ❑ Don't know

1.14 Apart from any already mentioned, have you been treated for any medical conditions in the last year?

- ❑ Yes → If yes, what was the condition?: _____

  Are you taking any medications for this condition?

  - ❑ Yes → If yes, what are the the medicines?

    _____

  - ❑ No
  - ❑ Don't know

MASK STUDY

QUESTIONNAIRE

Part 2: After contact with smoke

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|
Date: day |__|__| month |__|__| year |__|__|__|__|
Time: hour |__|__| minutes |__|__|

2.1 After the exposure do you experience any of the following:	**(Please tick one of the answers)**				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Choking	❑	❑	❑	❑	❑
Thirst	❑	❑	❑	❑	❑
Blocked nose	❑	❑	❑	❑	❑
Throat pain	❑	❑	❑	❑	❑
Hoarseness	❑	❑	❑	❑	❑
Nausea/ want to vomit or have vomited	❑	❑	❑	❑	❑
Light headed or dizzy	❑	❑	❑	❑	❑
Headache	❑	❑	❑	❑	❑
Racing or irregular heartbeat	❑	❑	❑	❑	❑
Other symptoms not listed above, please specify _____ _____	❑	❑	❑	❑	❑

2.2 After your time in the smoke chamber, are you bringing up phlegm (sputum) from your chest?

❑ Yes

❑ No (Please go to 2.4)

Fill out this table ONLY if you are bringing up phlegm or sputum:

2.3 Which of the following statements about the aspect of your phlegm (sputum) from your chest is true or false?	(Please tick true or false)	
	True	False
<u>Colour</u> ➢ Transparent ➢ White ➢ Yellow ➢ Green ➢ Blood stained ➢ Black/soot stained	❑ ❑ ❑ ❑ ❑ ❑	❑ ❑ ❑ ❑ ❑ ❑
<u>Taste/smell</u> ➢ No taste or smell ➢ Faint taste or smell ➢ Strong taste or smell	❑ ❑ ❑	❑ ❑ ❑
<u>Amount of phlegm/sputum</u> ➢ Small (less than ½ a teaspoon) ➢ Moderate (½ to 1 teaspoon) ➢ Large (over 1 teaspoon)	❑ ❑ ❑	❑ ❑ ❑
<u>Texture</u> ➢ Thin ➢ Thick (hard to cough up)	❑ ❑	❑ ❑

2.4 Do you routinely wear a mask when fighting bushfires?

(Please tick one)

Always	Mostly	Sometimes	Never
❑	❑	❑	❑

2.5 Do you think wearing your usual mask has any effect on your breathing when fighting a real bushfire?

When wearing a mask, my breathing is :

(Tick the box closest to your opinions)

MUCH WORSE	SLIGHTLY WORSE	NOT DIFFERENT	SLIGHTLY BETTER	MUCH BETTER
❑	❑	❑	❑	❑

2.6 To what extent do you agree or disagree that your usual mask is useful in protecting your health?

(Tick the box closest to your opinions)

STRONGLY AGREE	AGREE	DON'T KNOW	DISAGREE	STRONGLY DISAGREE
❑	❑	❑	❑	❑

2.7 Was the smoke in the smoke chamber similar compared to smoke of a real bushfire?

(Tick the box closest to your opinions)

VERY SIMILAR	SIMILAR	QUITE SIMILAR	QUITE DIFFERENT	DIFFERENT	VERY DIFFERENT
❑	❑	❑	❑	❑	❑

Appendix 3

MASK STUDY

QUESTIONNAIRE

Part 3: After Recovery

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|

Date: day |__|__| month |__|__| year |__|__|__|__|

Time: hour |__|__| minutes |__|__|

3.1 At this point in time after the exposure are you experiencing any of the following:	**(Please tick one of the answers)**				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Choking	❑	❑	❑	❑	❑
Thirst	❑	❑	❑	❑	❑
Blocked nose	❑	❑	❑	❑	❑
Throat pain	❑	❑	❑	❑	❑
Hoarseness	❑	❑	❑	❑	❑
Nauseated / want to vomit or have vomited	❑	❑	❑	❑	❑
Light headed or dizzy	❑	❑	❑	❑	❑
Headache	❑	❑	❑	❑	❑
Racing or irregular heartbeat	❑	❑	❑	❑	❑
Other symptoms not listed above, please specify _____ _____	❑	❑	❑	❑	❑

3.2 After the 30 minute recovery period, are you bringing up phlegm (sputum) from your chest?

❑ Yes

❑ No *(Please go to next page)*

Fill out this table ONLY if you are bringing up phlegm or sputum:

3.3 Which of the following statements about the aspect of your phlegm (sputum) from your chest is true or false?	**(Please tick true or false)**	
	True	False
<u>Colour</u> ➢ Transparent ➢ White ➢ Yellow ➢ Green ➢ Blood stained ➢ Black/soot stained	❑ ❑ ❑ ❑ ❑ ❑	❑ ❑ ❑ ❑ ❑ ❑
<u>Taste/smell</u> ➢ No taste or smell ➢ Faint taste or smell ➢ Strong taste or smell	❑ ❑ ❑	❑ ❑ ❑
<u>Amount of phlegm/sputum</u> ➢ Small (less than ½ a teaspoon) ➢ Moderate (½ to 1 teaspoon) ➢ Large (over 1 teaspoon)	❑ ❑ ❑	❑ ❑ ❑
<u>Texture</u> ➢ Thin ➢ Thick (hard to cough up)	❑ ❑	❑ ❑

This is the end of the questionnaire. Thank you very much for your time and effort in answering these questions.

Is there any comment you would like to make or any information that you think is relevant?

_____

_____

_____

_____

_____

Appendix 3

FILTER STUDY

Phase 2

QUESTIONNAIRE

Baseline

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|
Date: day |__|__| month |__|__| year |__|__|__|__|
Time: hour |__|__| minutes |__|__|

1.1 How many years have you been working as a career fire fighter with FESA?

|_|_| Years

1.2 At which station are you currently working?

_____

1.3 Are you male or female?

- ❑ Male
- ❑ Female

1.4 In which age group are you?

- ❑ 20 to 29 years
- ❑ 30 to 39 years
- ❑ 40 to 49 years
- ❑ 50 to 59 years
- ❑ 60+ years

1.5 In general, would you say your health is:

(Please tick one)

Excellent	Very good	Good	Fair	Poor
❑	❑	❑	❑	❑

1.6 Are you a current smoker or have you ever smoked in the past?

- ❑ Never smoked

- ❑ Current smoker → What do you mainly smoke? (Tick all that apply)

  ❑ Cigarettes → How old were you when you started smoking? **|_|_| years**

  On average how many cigarettes per day? **|_|_|**

  ❑ Other forms of smoking→ Specify _____

  For how many years? **|_|_| years**

  How many times per day do you smoke? **|_|_|**

- ❑ Past smoker (stopped more than 12 months ago)

  → What did you mainly smoke? (Tick all that apply)

  ❑ Cigarettes → For how many years? **|_|_| years**

  How many cigarettes per day? **|_|_|**

  ❑ Other forms of smoking → Specify _____

  For how many years? **|_|_| years**

  How many per day? **|_|_|**

1.7 Have you ever been diagnosed with:

Asthma

- ❑ Yes → At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

Hay fever

- ❑ Yes→ At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

Any type of allergies not already mentioned

- ❑ Yes → Please, specify _____

  → At what age were you diagnosed? **|_|_| years**
- ❑ No
- ❑ Don't know

1.8 Do you regularly bring up phlegm (sputum) from your chest?

- ❑ Yes → Please specify:

  For how many years has this occurred? **|_|_| years**

  Does it occur most years? ❑ Yes ❑ No

  If yes → Please specify → For how many months of the year?

  |_|_| months

- ❑ No
- ❑ Don't know

1.9 In the past 12 months, have you experienced any of the following on a regular basis?	Please tick one of the answers				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Other symptoms affecting your chest or breathing? Please specify _____ _____	❑	❑	❑	❑	❑

1.10 Do you suffer from any of these symptoms after bushfires?

- ❑ I don't attend bushfires
- ❑ Yes → Please specify what symptoms: _____ _____
- ❑ No
- ❑ Don't know

1.11 Do you take any medicines (such as puffers, inhalers, tablets) to help with wheezing?

- ❑ Yes → If yes, what is the medicine? _____

  On average, how many times a WEEK do you take it?

  _____ a week
- ❑ No
- ❑ Don't know

1.12 During the past two weeks, have you suffered from any of the following: cold, flu, throat or chest infection?

- ❑ Yes
- ❑ No
- ❑ Don't know

1.13 During the past two weeks, have you suffered from any other type of infections?

- ❑ Yes → If yes, please describe: _____
- ❑ No
- ❑ Don't know

1.14 Apart from any already mentioned, have you been treated for any medical conditions in the last year?

- ❑ Yes → If yes, what was the condition?: _____

  Are you taking any medications for this condition?

  - ❑ Yes → If yes, what are the medicines?

    _____
  - ❑ No
  - ❑ Don't know

1.15 Do you routinely wear a mask when fighting bushfires?

(Please tick one)

Always	Mostly	Sometimes	Never
❑	❑	❑	❑

1.16 When wearing a mask, what type of filter do you use on your mask?

(Please tick one)

Particulate filter	Particulate/ organic vapour filter	Don't know	Other, please specify
❑	❑	❑	----------

1.17 To what extent do you agree or disagree that your usual mask is useful in protecting your health?

(Tick the box closest to your opinion)

Strongly agree	Agree	Don't know	Disagree	Strongly disagree
❑	❑	❑	❑	❑

1.18 Do you think wearing your usual mask has any effect on your breathing when fighting a real bushfire?

When wearing a mask, my breathing is:

(**Tick the box closest to your opinion)**

Much worse	Slightly worse	Not different	Slightly better	Much better
❑	❑	❑	❑	❑

FILTER STUDY

Phase 2

QUESTIONNAIRE

After 60 minutes

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|
Date: day |__|__| month |__|__| year |__|__|__|__|
Time: hour |__|__| minutes |__|__|

2.1 After 60 minutes exposure to the smoke do you experience any of the following?	**(Please tick one of the answers)**				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Choking	❑	❑	❑	❑	❑
Thirst	❑	❑	❑	❑	❑
Blocked nose	❑	❑	❑	❑	❑
Throat pain	❑	❑	❑	❑	❑
Hoarseness	❑	❑	❑	❑	❑
Nausea/ want to vomit or have vomited	❑	❑	❑	❑	❑
Light headed or dizzy	❑	❑	❑	❑	❑
Headache	❑	❑	❑	❑	❑
Racing or irregular heartbeat	❑	❑	❑	❑	❑
Other symptoms not listed above, please specify _____	❑	❑	❑	❑	❑

2.2 At this point in time, are you bringing up phlegm (sputum) from your chest?

❑ Yes

❑ No *(Please go to 2.4)*

Fill out this table ONLY if you are bringing up phlegm or sputum:

2.3 Which of the following statements about the aspect of your phlegm (sputum) from your chest is true or false?	**(Please tick true or false)**	
	True	False
<u>Colour</u> ➢ Transparent ➢ White ➢ Yellow ➢ Green ➢ Blood stained ➢ Black/soot stained	❑ ❑ ❑ ❑ ❑ ❑	❑ ❑ ❑ ❑ ❑ ❑
<u>Taste/smell</u> ➢ No taste or smell ➢ Faint taste or smell ➢ Strong taste or smell	❑ ❑ ❑	❑ ❑ ❑
<u>Amount of phlegm/sputum</u> ➢ Small (less than ½ a teaspoon) ➢ Moderate (½ to 1 teaspoon) ➢ Large (over 1 teaspoon)	❑ ❑ ❑	❑ ❑ ❑
<u>Texture</u> ➢ Thin ➢ Thick (hard to cough up)	❑ ❑	❑ ❑

FILTER STUDY

Phase 2

QUESTIONNAIRE

After 120 minutes

Study Identification Number: |_|_|-|_|-|_|-|_|_|-|_|_|_|_|
Date: day |__|__| month |__|__| year |__|__|__|__|
Time: hour |__|__| minutes |__|__|

3.1 After 120 minutes exposure to the smoke do you experience any of the following?	**(Please tick one of the answers)**				
	Not at all	Slightly	Moderately	Quite a bit	Extremely
Coughing	❑	❑	❑	❑	❑
Wheezing or whistling in your chest	❑	❑	❑	❑	❑
Tightness in your chest	❑	❑	❑	❑	❑
Shortness of breath	❑	❑	❑	❑	❑
Choking	❑	❑	❑	❑	❑
Thirst	❑	❑	❑	❑	❑
Blocked nose	❑	❑	❑	❑	❑
Throat pain	❑	❑	❑	❑	❑
Hoarseness	❑	❑	❑	❑	❑
Nausea/ want to vomit or have vomited	❑	❑	❑	❑	❑
Light headed or dizzy	❑	❑	❑	❑	❑
Headache	❑	❑	❑	❑	❑
Racing or irregular heartbeat	❑	❑	❑	❑	❑
Other symptoms not listed above, please specify _____	❑	❑	❑	❑	❑

3.2 At this point in time, are you bringing up phlegm (sputum) from your chest?

❑ Yes

❑ No *(Please go to 2.4)*

Fill out this table ONLY if you are bringing up phlegm or sputum:

2.3 Which of the following statements about the aspect of your phlegm (sputum) from your chest is true or false?	**(Please tick true or false)**	
	True	False
<u>Colour</u> ➢ Transparent ➢ White ➢ Yellow ➢ Green ➢ Blood stained ➢ Black/soot stained	❑ ❑ ❑ ❑ ❑ ❑	❑ ❑ ❑ ❑ ❑ ❑
<u>Taste/smell</u> ➢ No taste or smell ➢ Faint taste or smell ➢ Strong taste or smell	❑ ❑ ❑	❑ ❑ ❑
<u>Amount of phlegm/sputum</u> ➢ Small (less than ½ a teaspoon) ➢ Moderate (½ to 1 teaspoon) ➢ Large (over 1 teaspoon)	❑ ❑ ❑	❑ ❑ ❑
<u>Texture</u> ➢ Thin ➢ Thick (hard to cough up)	❑ ❑	❑ ❑

3.3 What work activity were you doing during the exposure in the field?	**Please tick one of the answers**
Supervisor	❑
Lighting	❑
Holding	❑
Attack	❑
Mop-up	❑
Pump Operator	❑
Other work activity, please specify _____	❑

This is the end of the questionnaire. Thank you very much for your time and effort in answering these questions.

Is there any comment you would like to make or any information that you think is relevant?

_____

_____

_____

_____

_____