

PERSONAL PM<sub>2.5</sub> EXPOSURES FOR FIREFIGHTERS DOING PRESCRIBED FOREST  
BURNS IN THE SOUTHEASTERN UNITED STATES

by

CAMERON S. CARLTON

(Under the Direction of Luke Naeher)

ABSTRACT

Exposure to PM<sub>2.5</sub> during prescribed forest burn operations was studied in winter 2003 in a cohort of 10 forest fighters over a five-week study in the Southeastern United States. Individual work shift samples (n=54) were collected during burn activities and 5 during non-burn activities (controls). Over the five-week study, there were 10 days of prescribed burn activity when fire fighters were sampled, with 5-7 (Avg=5.4) monitored per burn, and burn sizes ranged from 1 to 2042 acres. Average PM<sub>2.5</sub> concentration from the 54 samples was 0.36 mg/m<sup>3</sup> (range 0.006-1.7 mg/m<sup>3</sup>). A daily exposure questionnaire and time-activity log was administered daily post-shift to qualitatively assess worker exposure to smoke and to inquire regarding daily respiratory health symptoms (e.g., cough, phlegm). The results of this study are consistent with earlier studies demonstrating prescribed forest burn-related occupational exposures to PM<sub>2.5</sub> are of concern for firefighters and warrant further exposure and health effects studies.

INDEX WORDS: PM<sub>2.5</sub>, Smoke Exposure, Firefighter Health

PERSONAL PM<sub>2.5</sub> EXPOSURES FOR FIREFIGHTERS DOING PRESCRIBED FOREST  
BURNS IN THE SOUTHEASTERN UNITED STATES

by

CAMERON S. CARLTON

B.S., The University of Georgia, 2002

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment  
of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2004

© 2004

Cameron S. Carlton

All Rights Reserved

PERSONAL PM<sub>2.5</sub> EXPOSURES FOR FIREFIGHTERS DOING PRESCRIBED FOREST  
BURNS IN THE SOUTHEASTERN UNITED STATES

by

CAMERON S. CARLTON

Major Professor: Luke Naeher

Committee: Phil Williams  
Jeff Fisher

Electronic Version Approved:

Maureen Grasso  
Dean of the Graduate School  
The University of Georgia  
May 2004

## DEDICATION

I want to dedicate this to my grandfather, a man I greatly admire for always being a wonderful Christian role model in my life. I also want to dedicate this to my family for their prayers, support and always having faith in me. Most importantly I want to dedicate this to my Lord, Jesus Christ, for never leaving my side.

## ACKNOWLEDGEMENTS

Funding from the United States Department of Agriculture Forest Service supported this research. The study protocol was reviewed and approved by the University of Georgia Institutional Review Board for the inclusion of human subjects.

Special thanks goes to Maggie Crowe, Rob Robinson, Tara Almekinder and Meagan Kane for their help in conducting the study and analyzing the data. Thank you to Dan Shea and his crew of firefighters for participating in this study. Thanks to my major professor, Luke Naeher, to my committee members, Phil Williams and Jeff Fisher for their input and guidance that went into this project. Finally, I would like to thank all who were involved with making this possible, and those who have helped me make this far in life.

## TABLE OF CONTENTS

|  | Page |
|--|------|
| ACKNOWLEDGEMENTS .....                         | v    |
| LIST OF TABLES .....                           | viii |
| LIST OF FIGURES .....                          | ix   |
| CHAPTER  |      |
| 1 INTRODUCTION .....                           | 1    |
| Purpose of the Study.....                      | 1    |
| This Study Differs from Previous Research..... | 1    |
| Literature Review .....                        | 2    |
| References for Chapter 1 .....                 | 2    |
| 2 INTRODUCTION AND LITERATURE REVIEW .....     | 3    |
| Air Pollution is Bad for Your Health .....     | 3    |
| Particulate Matter.....                        | 3    |
| PM <sub>2.5</sub> .....                        | 4    |
| Particulate Matter Standards.....              | 5    |
| Sources of PM <sub>2.5</sub> .....             | 6    |
| Sources of Woodsmoke.....                      | 6    |
| Wildfire and Prescribed Burns in the U.S.....  | 8    |
| Firefighter Exposure Assessment.....           | 9    |
| Firefighter Health Assessment.....             | 14   |

|   |   |    |
|---|---|----|
|   | Strengths and Weaknesses of Firefighter Health Assessment.....  | 16 |
|   | Gaps in Smoke Exposure Assessment.....  | 17 |
|   | This Study.....   | 17 |
|   | References for Chapter 2.....   | 19 |
| 3 | PERSONAL PM <sub>2.5</sub> EXPOSURES FOR FIREFIGHTERS DOING PRESCRIBED<br>FOREST BURNS IN THE SOUTHEASTERN UNITED STATES..... | 22 |
|   | Abstract .....  | 23 |
|   | Introduction .....  | 24 |
|   | Methods.....  | 28 |
|   | Results.....  | 32 |
|   | Discussion and Conclusion.....  | 36 |
|   | Acknowledgements.....   | 42 |
|   | References for Chapter 3.....   | 43 |
| 4 | SUMMARY .....   | 58 |
|   | References for Chapter 4.....   | 59 |

## LIST OF TABLES

|   | Page |
|---|------|
| Table 1: Study population and data collected from each firefighter.....       | 46   |
| Table 2: The average PM <sub>2.5</sub> personal exposures from each burn..... | 47   |
| Table 3: Control PM <sub>2.5</sub> exposure samples from non-burn days.....   | 48   |
| Table 4: FRM background samples on burn and non-burn days.....                | 49   |
| Table 5: Highest corporate time-activity diary task percentages.....          | 50   |
| Table 6: Individual time-activity diary task percentages.....                 | 50   |
| Table 7: Reference chart for previous studies of firefighter exposure.....    | 51   |

## LIST OF FIGURES

|  | Page |
|--|------|
| Figure 1: PM <sub>2.5</sub> personal exposure for firefighters on days they are working a prescribed burn ..                                       | 52   |
| Figure 2: A comparison of PM <sub>2.5</sub> exposure concentrations collected in the study from<br>background, control, and personal sampling..... | 53   |
| Figure 3: Inter-subject PM <sub>2.5</sub> personal exposure during prescribed burn activity over duration of<br>study .....                        | 54   |
| Figure 4: Relationship between personal PM <sub>2.5</sub> exposure during burn activity and the amount of<br>acres burned.....                     | 55   |
| Figure 5: Questionnaire as a predictor of personal PM <sub>2.5</sub> exposure measured by pump and filter  | 56   |
| Figure 6: The amount of acres burned and its effect on PM <sub>2.5</sub> personal sample concentrations...   | 57   |

# CHAPTER 1

## INTRODUCTION

### *Purpose of the Study*

This study will seek to determine the PM<sub>2.5</sub> personal exposures of firefighters working on prescribed burns in the Southeastern United States. The study is the exposure assessment part of a larger epidemiological health study. By looking at firefighter tasks and individual characteristics of each burn, this study seeks to determine different factors that cause the PM<sub>2.5</sub> exposure levels sampled. Background and control sampling are incorporated into the study to compare levels of exposure when burns are not taking place.

### *This Study Differs From Previous Research*

In previous studies the focus seems to be on firefighter exposures at the fire (Reinhardt, Ottmar, 2000). This study looks at firefighter exposure over their entire workday. When sampling only at the fire, exposures will be much higher because it does not account for down time before or after the burn. Previous studies like Materna (1992) do not include the most intense stage of flaming. This study is unique because it involves a firefighters exposure for the full workday, during all stages of the burn and all tasks the subject was involved with. Instead of randomly selecting firefighters to monitor (Yanosky, 2001) this study follows 10 firefighters for the full 5-week study. By following these same subjects for 5-weeks the study provides representative data of exposure levels a typical firefighter crew may experience during a given 5-week span of their burn season. Because questionnaires and time-activity diaries were used in the study some relationship was determined between the amount of smoke the worker predicted they encountered (questionnaire) on a burn day and the actual exposure sampled (pump and filter). A

comparison between the amount of acres burned and exposure levels indicated a relationship between the two, though it was not as strong as we had suspected.

### *Literature Review*

The literature review will go into further detail on what PM<sub>2.5</sub> is and where it comes from. The exposure standards for different particle size exposures will be compared. The review will demonstrate the prevalence of wildfire and prescribed burning in the U.S. This review will then look at adverse health effects as a result of PM<sub>2.5</sub> exposures to firefighters and it will highlight exposure assessment studies similar to this study.

### References for Chapter 1

Materna, B. L., J. R. Jones, et al. (1992). "Occupational Exposures in California Wildland Fire Fighting." American Industrial Hygiene Association Journal **53**(1): 69-76.

Reinhardt, T. E. and R. D. Ottmar (2000). "Smoke Exposures at Western Wildfires." United States Dept. of Agriculture Research Paper.

Yanosky, J.D., D.L. MacIntosh. (2001). "Fine Particle Exposure of Prescribed Fire Workers in the Southeastern United States and a Comparison of Several Particulate Matter Sampling Methods." A Master Thesis Submitted to the Graduate Faculty of the University of Georgia in Partial Fulfillment of the Requirements for the Degree. Athens, Georgia, 2001.

## CHAPTER 2

### INTRODUCTION AND LITERATURE REVIEW

Firefighters are exposed to high levels of air pollutants found in woodsmoke from forest fires. The job involves working in close proximity to intense flames that give off high levels of air pollutants from vegetative burning. When a wildland or prescribed burn takes place, burning could continue for days, with thousands of acres being burned. The firefighters working these burns often work long shifts of 10-12 hours and could be working a burn for multiple days. Because of the nature of the job these workers are at risk for serious acute and chronic health affects.

#### *Air Pollution is Bad For Your Health*

Air pollution is a major health concern. In recent years numerous studies have been done to look at the adverse health effects from various air pollutants. Some of the leading pollutants of concern are particulate matter (PM), carbon monoxide (CO), ozone, and polynuclear aromatic hydrocarbons (PAHs). Studies have shown such adverse health affects to increased levels of particle air pollution as decreases in lung function, increases in respiratory symptoms including cough, wheezing, exacerbation, and increase in respiratory-related diseases, including chronic obstructive pulmonary disease, cardiovascular diseases and lung cancer ( Mitra et. Al., 2002). Heart rate variability has also been linked to exposure to particulate air pollution (Magari et. al., 2001).

#### *Particulate Matter*

The U.S. Environmental Protection Agency (EPA) defines particle air pollutants or particulate matter as solid particles and liquid droplets found in the air. These particles vary in

composition, size and origin. Total Suspended Particulates (TSP) incorporates all particulate matter with some particles so large and dark that they can be seen by the naked eye in soot and smoke. The smaller particles are so fine that they cannot be detected without the use of an electron microscope. Fine particles consist of those that are 2.5 micrometers or less in diameter ( $PM_{2.5}$ ). These finer particles come from combustion sources like motor vehicles, power generation, industrial facilities and woodsmoke from stoves, fireplaces, and forest fires. Gases like Sulfur Dioxide ( $SO_2$ ), Nitrous Oxides ( $NO_x$ ) and Volatile Organic Compounds (VOCs) can also come together to form these fine particles. Coarser particles consist of those that are larger than 2.5 micrometer in diameter ( $PM_{10}$ ,  $PM_{3.5}$ ). The sources of the coarser particles are material handling, road dust, crushing or grinding operations, and wind dust. The U.S. EPA also defines inhalable or respirable particulates as both fine and coarse particles. The coarse particles cause respiratory aggravation such as asthma but its the fine particles that are able to penetrate deeply into the lung tissue and cause increased hospital visits for heart and lung disease, decreased lung function and even premature death (U.S. EPA, 1997).

#### *PM<sub>2.5</sub>*

In a prospective 16-year cohort study known as the Harvard Six City Study by Dockery et al. (1993), the main objective was to estimate the effects of air pollution on mortality. The study began in 1974 sampling for TSP but growing research indicated that the fine particulates were a greater risk to health. The study found that levels of fine particles were more strongly associated with mortality than TSP levels, sulfur dioxide levels, nitrogen dioxide levels, or the acidity of aerosol (Dockery et. al., 1993). Before 1987, EPA's National Ambient Air Quality Standard (NAAQS) focused on "Total Suspended Particles". However, due to new research showing that the smaller particles are the ones that penetrate deeply and cause the greatest health concern, the

EPA revised its NAAQS standard for TSP and developed a PM<sub>10</sub> standard in 1987 (Federal Register, 1987). Since then, increasing health studies of particulate matter called for a need to better address the “fine” particulate standard. This Harvard Six Cities Study was one of the major research pieces that led to the U.S. EPA’s revision of the NAAQS for PM<sub>2.5</sub> and ozone. In 1994 the Health Effects Institute began the Particle Epidemiology Evaluation Project, looked for evidence of a relation between daily mortality and particulate matter. Studies were showing that daily mortality rates were growing in association with particulate matter at levels lower than the NAAQS. This study could not establish the extent of mortality due to particulate matter exposure but did conclude that it plays a role (Health Effects Institute, 1995). In 1997 the EPA set a new PM<sub>2.5</sub> standard to protect human health with an adequate margin of safety. This standard was set at 65 ug/m<sup>3</sup> for a 24hr period and 15 ug/m<sup>3</sup> annually of PM<sub>2.5</sub> exposure (U.S. EPA, 1997).

#### *Particulate Matter Standards*

The American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Value (TLV) for respirable and inhalable particles (3 mg/m<sup>3</sup>, 8h, 10 mg/m<sup>3</sup>, 8h) is a recommended standard for dust exposure in an occupational workplace setting and not necessarily for respirable particulates found in woodsmoke (ACGIH, 2003). The Occupational Safety and Health Administration (OSHA) is the regulatory agency that enforces its standards in an occupational setting. The OSHA Permissible Exposure Limit (PEL) for respirable dust is 5mg/m<sup>3</sup> (Federal Register, 1997). OSHA also has a PEL of 2.4 mg/m<sup>3</sup> for respirable coal dust (Federal Register, 1997). On April 23, 1998, the EPA came out with the Interim Air Quality Policy on Wildland and Prescribed Fires. Because of the fact that recent studies have shown evidence of serious health effects (mortality, exacerbation of chronic disease, increased hospital visits, etc.) are due to exposure of “fine” fraction particles-PM<sub>2.5</sub>, the EPA set the new NAAQS

24h average for PM<sub>2.5</sub> (U.S. EPA, 1998). This new standard is designed to protect public health from smoke exposure and this standard should also be used for the health of firefighters.

#### *Sources of PM<sub>2.5</sub>*

There are many sources of combustion that produce PM<sub>2.5</sub>. Outdoor sources include both mobile and stationary sources. There are mobile sources such as vehicles, planes and boats. There are also stationary sources such as industrial facilities, refineries, power plants, environmental tobacco smoke, and vegetative burning. The major indoor combustion sources are cooking, heating, and tobacco smoke (Mitra et. al., 2002).

#### *Sources of Woodsmoke:*

##### *Wood Burning Stoves*

Biomass fuels (wood, charcoal, agricultural residues, animal dung) make up about half of the world's primary source of energy (Barnes et. Al., 1994). Wood burning in the home is used for both a source of heat and a way of cooking. The World Health Organization (WHO) estimates that about half the world's population relies on biomass fuels for their energy needs (Bruce, 2002). Studies have looked at the health effects caused from exposure to indoor woodsmoke.

In 1999 one study took place in southern India looking at indoor exposure, in 436 rural homes, to different fuel sources. The study found levels of respirable particulates among those cooking with wood (Avg=226 ug/m<sup>3</sup>, St Error=7 ug/m<sup>3</sup>, n=226), wood chips (Avg=285 ug/m<sup>3</sup>, St Error=42 ug/m<sup>3</sup>, n=7), and agricultural produce (Avg=262 ug/m<sup>3</sup>, St Error=16 ug/m<sup>3</sup>, n=34) to be higher than those cooking with clean burning fuels like Kerosene (Avg=83 ug/m<sup>3</sup>, St Error=7 ug/m<sup>3</sup>, n=34) and Gas (Avg=79 ug/m<sup>3</sup>, St Error=4 ug/m<sup>3</sup>, n=8) (Kalpana et. Al., 2002). This is an exposure assessment study, which is valuable information needed for future studies to look at exposure-response relationships. In an epidemiological study that took place in Honduras in

1995 a total of 366 women were enrolled to determine if burning wood in the kitchen increased the risk of cervical neoplasia. The data from this study suggested that there was a significant linear dose-response relationship between woodsmoke and risk of cervical neoplasia (Velema et.al, 2002). Though they are different these two studies help to provide substantial evidence that there is a health risk involved with woodsmoke in the indoor environment. The first study (Kalpana et. Al., 2002) shows the levels of respirable particulates that come from woodsmoke in the indoor environment and the second study (Velema et.al, 2002) shows that an increase in cervical neoplasia can be traced back to wood burning in the homes. More laboratory studies need to be conducted to determine the mechanism of woodsmoke and how it effects those most at risk, so regulatory standards can be set for indoor exposures (Zelikoff et.al., 2002).

#### *Forest and Agricultural Fires*

Exceeded only by a violent volcanic eruption, forest fires are the most frequent source of widespread atmospheric pollution (Ward, 1991). Vegetative fires from wildfires and prescribed burns are a serious contributor of woodsmoke. One study conducted to observe the particulate content of savannah fire emissions on the Ivory Coast of Africa found that aerosols from savannah biomass burning are primarily (90-95%) made up of fine particles or those in the submicrometer size range (Cachier et. Al, 1995). A study done in 1998, smoke monitoring was conducted in Brunei Darussalam from fires taking place in Southeast Asia. The study found that only particulate matter was a significant pollutant, finding that  $PM_{10}$  levels exceeded the WHO guidelines of  $70 \text{ ug/m}^3$  (24 h average) on 54 days of the two-month haze period (Radojevic et.al., 1999). With the absence of precipitation these large burns are not only a threat to the surrounding community but  $PM_{2.5}$  is very capable of long distance transport (hundreds or even thousands of km). In 1998 during Mexico's drought periods many forest fires broke out forcing high levels of

PM<sub>2.5</sub> into the atmosphere. It was determined that this long range transport of particulates increased the monthly averages of PM<sub>2.5</sub> in the Tennessee Valley and southeastern United States as much as 50% (Tanner et. al., 2001). In 1995 monitoring was done for one week of the burn period in the Amazon basin of Brazil. Outdoor samples of respirable levels of PM<sub>3.5</sub> (particles with an aerodynamic diameter of 3.5 um or less) showed an average of 191 ug/m<sup>3</sup> well above the 1995 U.S. National Ambient Air Quality Standards (NAAQS) for PM<sub>10</sub> (24 h average) and proposed standards for PM<sub>2.5</sub> (24 h average) (Reinhardt et.al, 2001). These exposure assessment studies prove that fine particulates are present in potentially hazardous levels from forest and agricultural burns. Epidemiological studies have shown an increase in adverse health effects as a result of this forest smoke.

In 1997 fires from Indonesia caused thick smoke over Malaysia. This study showed an increase in mortality as a result of PM<sub>10</sub> concentrations found in smoke haze (Sastry, 2002). In Singapore, 1997, severe smoke haze from forest fires caused a 30% increase in outpatient attendance for haze related conditions. An increase of 100ug/m<sup>3</sup> in PM<sub>10</sub> levels was associated with increases of 12% for upper respiratory infections, 26% for rhinitis, and 19% for asthma. By using electron microscopic sizing it was determined that approximately 94% of the smoke haze consisted of PM<sub>2.5</sub> (Emmanuel, 2000). The constituents found in woodsmoke from these fires can pose serious health risk to those exposed.

#### *Wildfire and Prescribed Burns in the U.S.*

Prescribed forest burning is a common practice used throughout the United States to maintain both government and state forests. Prescribed burns have been found to be a beneficial tool for improving forage value of the forests, for reducing wildfire hazard and competing vegetation (Reinhardt, 1991). They have become such a mandatory land management practice that in a

given burn season as much as 70,000 burns take place each year burning approximately two million acres and an estimated 80,000 firefighters per year in the United States are included in these burns (Ward et. al., 1989). Fire has long been a valuable management tool in the southeastern states on both public and private land (McMahon, 1999). However with this abundant burning comes large amounts of particulates. In Texas, from the years 1996-1997, it is estimated that fires produced 40,000 tons/yr of fine particulates, representing a significant amount of the state's emission inventory (Dennis, 2002). Epidemiological studies show the adverse health affects that communities suffer as a result of this forest burning.

A study by the Center for Disease Control and Prevention (CDC) was conducted on a reservation in Hoopa, California in 1999. The study population consisted of 289 participants of the 385 residents on the reservation. By looking at medical records the study found that during the weeks of the fire medical visits for respiratory illness increased by 52% from the previous year (Mott et. al., 2002). From previous research it is an established fact that wildland fires give off large amounts of particulates and other harmful contaminants at high enough levels to be a health risk to surrounding communities. However, those closest to the source of exposure are the firefighters. It was not until after the 1988 Yellowstone fires when thousands of firefighters experienced respiratory problems, that concern about the occupational health of the firefighters increased. After this event a series of studies were brought about to look at fire worker's exposures and monitor their health (McMahon, 1999).

### *Firefighter Exposure Assessment*

One the earliest studies found on firefighter exposure was conducted in Northern California at wildland and prescribed fires during three burn seasons from 1987 to 1989 (Materna et. al., 1992). This study involved personal time-weighted average monitoring of

firefighter exposure to various chemicals including total and respirable particulates. Results are posted by the actual sampling time without adjustment for an 8 hr average. None of the sampling was done during the most intense stage of the fire or “direct attack” and the majority of the firefighters were engaged in “mop-up” activities. It focused on the difference between those located on the fireline-conducting mop up and those firefighters involved in prescribed burning. For total particulates taken from the base camp of those waiting in the staging area the mean was 3.27 mg/m<sup>3</sup> (n=3) with a range of 1.80-4.40 mg/m<sup>3</sup>. For those located on the fire line, conducting mop-up, the total particulate mean was 9.46 mg/m<sup>3</sup> (n=22) with a range of 2.70-37.4 mg/m<sup>3</sup>. The respirable particulate mean for prescribed burning was found to be 1.15 mg/m<sup>3</sup> (n=22) and the respirable particulate mean for those located on the fire line conducting mop-up was found to be 1.75 mg/m<sup>3</sup> (n=20). Of the 22 total particulate samples taken on the fire line during mop-up three (14%) exceeded the OSHA (Occupational Safety and Health Administration) PEL (Permissible Exposure Limit) of 15 mg/m<sup>3</sup> and 7(32%) exceeded the ACGIH TLV (Threshold Limit Value) of 10 mg/m<sup>3</sup>. Ground dust was a major contribution to these exposure levels. Of the respirable particulate samples only one exceeded the PEL of 5 mg/m<sup>3</sup>. The firefighters chosen do not necessarily represent those with highest exposures because the workers had either been previously contacted by the team or were easily accessible. In future monitoring silica content of the sample should be checked to determine the amount of ground dust in the sample. According to Materna, when choosing the workers to monitor, random selection should be used to obtain a statistically representative estimate of the distribution of exposures over a wide range of job classifications and fire conditions (Materna et. al., 1992). In 1990 a study of firefighter exposure at prescribed burns in Yosemite National Park was conducted by NIOSH and found similar exposure levels of RPM but the sample size was

small (Avg=1.22 mg/m<sup>3</sup>, n=6). There are further studies that have been conducted on firefighter exposure.

In the Pacific Northwest from 1991 to 1994 (Reinhardt et. al, 2000) looked at the exposure potential from each job task conducted at a prescribed burn, to identify if one job may be the cause of higher exposures. Another goal of this study was to determine if exposure to multiple pollutants could be estimated from the measurement of a single pollutant. The study measured the smoke exposure among over 200 firefighters, at 52 prescribed burns, with six firefighters randomly chosen to monitor per day and work shifts averaging 11.5 hours. The cut point for the respirable particulate sampling was 3.5 um. This study found that among all the firefighters sampled 14% of the exposures to respiratory irritants exceeded the recommended limits set by the occupational health advisory organization and about 5% of respiratory irritant exposures exceeded the OSHA exposure limit of 5 mg/m<sup>3</sup>. Over the work shift the average exposure to PM<sub>3.5</sub> was 0.63 mg/m<sup>3</sup> and 1 mg/m<sup>3</sup> while at the burns. The maximum exposure over the work shift was 6.9 mg/m<sup>3</sup> and 10.5 mg/m<sup>3</sup> during the burn. The highest levels of smoke exposure were found among those workers who were line holding, line supervision or direct attack on the fires. Also a direct correlation was found between CO levels and those of respirable particulates. One bias determined from this study was the fact that the sampling strategy did not include every moment the firefighters were in smoke and this could introduce some error into the overall TWA (time weighted average). This study also points out the fact that wind speed has an effect on exposures (Reinhardt et. al., 2000). The results of this study show that there is a direct correlation between CO levels and respirable particulates, so studies that include only CO monitoring are beneficial to this review.

In Wenatchee National Forest in central Washington CO and Formaldehyde exposures were monitored during 4 prescribed forests burns (Reinhardt, 1991). These were burns made up of logging debris from clear-cutting in mixed conifers; the burns are referred to as broadcast burns. Each burn involved 20-30 workers with 5 fitted with smoke sampling packs. From the sampling 49 samples of CO were taken with 3 exceeding the ACGIH limit of 35 ppm. Direct Attack and mop-up of spot fires particularly downwind of the fire showed the highest levels of exposure to CO. Due to favorable winds and good burn practices the fire managers agreed that smoke exposure during this study seemed to be less than is often encountered (Reinhardt, 1991). Another study that shows that respirable particulate matter can be predicted from measurements of CO is one that took place from 1992 to 1995.

Air monitoring was conducted on 129 firefighters at wildfires in the western United States; measurements were taken at 13 initial attack wildfires in California and at 8-multiday wildfires in Idaho, California, Montana, and Washington (Reinhardt, Ottmar, 2000). The particulate samples that were taken included TSP and PM<sub>3.5</sub>. Hand crews were measured at the multiday wildfires (project wildfires) and engine crews were monitored at the initial attack fires. Between 2 and 6 workers were chosen for sampling each day and these were volunteers from a single fire crew. Each sample taken lasted the full time period of the individual's task. Sampling usually started with an STEL (short-term exposure limit) and switch to a 1 to 2 hour sample as the fire was controlled. No sampling was done until smoke reached the worker and during breaks in clean air conditions, sampling was stopped. The clean air conditions were estimated from background levels for TWA calculations. The data was analyzed separately because the exposures of these two crews are very different. Workers at a multiday fire had a shift average time of 14 hours and usually spend more time at the fire than initial attack crews do. None of the

TSP samples exceeded the PELs but there were relatively few of these samples taken and none from the higher smoke conditions. It was found that between 3 and 5% of exposures to CO and respiratory irritants exceeded the occupational exposure limits. Results from respirable particulate and TSP sampling can be seen in Table 1. Though most of the smoke exposures found was not considered hazardous, a small percentage of the workers at the project wildfires regularly exceeded recommended exposure limits and none of the smoke exposures exceeded the recommended exposure limit at initial attack wildfires. Smoke exposure was found to be highest among those who were line holding or involved with direct attack. This study also proved a strong correlation between CO and respirable particulates. One bias mentioned is the fact that the firefighters sampled were volunteers and may not be those with the highest exposures. Also the additional weight of the sampling apparatus may have affected the task or the amount of work the firefighter conducted (Reinhardt, Ottmar, 2000). Firefighter tasks and the corresponding personal exposure were observed in a recent study.

In the Southeastern United States sampling was conducted on 9 burn days between January 25 and March 14, 2001. This study took 48 personal air samples from 27 individual prescribed firefighters during 8 prescribed burns. The study included a questionnaire and a daily-activity log for each subject that a sample was taken from. The study found comparable exposure results with that of previous studies. Of the 41 samples that were included in the data analysis 4.9% exceeded the ACGIH TLV of  $3.0 \text{ mg/m}^3$ . With only one of the 41 samples exceeding the OSHA PEL of  $5.0 \text{ mg/m}^3$ . The results found no clear correlation between firefighter task and exposure, possibly due to the fact that the firefighters were involved in multiple activities throughout the day. From the questionnaire a sample size of 18 fire workers were asked, "How much wood smoke do you feel that you encountered today?" The possible answers ranged from

“very little” to “a high level”. With the responses to this question compared to the exposures from pump and filter, a generalized linear model was able to account for 65% ( $R^2=0.649$ ) of the variance in personal  $PM_{2.5}$  concentrations (Yanosky et. al., 2001) These studies have found that exposure levels of CO and respirable particulates from smoke can be a concern for firefighters health.

### *Firefighter Health Assessment*

Because firefighters are exposed to potentially dangerous levels of respirable particulates as seen by the exposure assessment studies, it is important to review the epidemiological health studies available for firefighters. One such study looked at the mortality experience of 1,867 municipal firefighters employed by the City of Buffalo, New York (Vena, 1987). The study consisted of full time employees employed between January 1, 1950 and October 1, 1979. The study consisted of 890 (48%) currently employed workers, 740 retirees (40%), 65 employees who resigned (3%), and 172 employees (9%) who died while in service. Workers employed at least one year in the fire department were included in this study. As of October 1, 1979 vital status was determined for 99% of the fire fighters resulting in 470 observed deaths. The study found that mortality for those employed less than ten years was slightly lower than expected but it there was a slight trend of increasing mortality with the number of years worked. An increased risk of mortality from colon and bladder cancer was strongly associated with 40 years duration of employment and a very long latency period (Vena, 1987). Municipal and wildland firefighters are exposed to different compounds from the smoke they encounter. Municipal fire fighters are exposed to both natural and synthetic materials like asbestos, hydrogen cyanide, acrolein and ammonia (Harrison et. al., 1995). Wildland fire fighters are exposed to natural products of combustion from wood burning like aldehydes, ozone, and particulates (Harrison et. al., 1995).

The United States Department of Agriculture and Forest Services (USDAFS) has been involved with studies on the health effects of firefighters.

In the 1989 burn season, the smoke exposure of five USDAFS full-time, wildland firefighter, Hotshot crews, in Northern California and Montana participated in a pulmonary testing study (Liu, 1992). Pulmonary function testing, Methacholine Challenge (MCh) testing and questionnaires were administered to the firefighters at the beginning of the fire season (May). The same tests, along with a questionnaire, were administered in the post-season after the last burn (late September, October). The study population consisted of 63 firefighters, 55 (87%) were male and 8 (13%) were female. Spirometry from pre-season to post-season showed a mean individual decline 0.09, 0.15, and 0.44 L/s in the Forced Vital Capacity (FVC), Forced Expiratory Volume (FEV<sub>1</sub>) and Forced Expiratory Flow (FEF<sub>25-75</sub>) the maximal midexpiratory flow rate values. The MCh testing showed a significant increase in the mean individual dose response slope (DRS) at (p=0.02) in post-season testing versus pre-season testing suggesting that smoke exposure might have an effect on lung function. The study design and lower number of individuals sampled do not allow the changes in lung function to be attributed specifically to the woodsmoke, but other studies have shown similar results (Liu, 1992). In a similar study conducted in the 1992 fire season, fire workers from Region 6 of the USDA Forest Service and the Bureau of Land Management in Salem, Oregon were observed (Betchley et. al., 1997). This study focuses on both cross-season and cross-shift spirometry of firefighters. The study population consisted of 76 subjects studied for cross-shift and 53 for cross-season analysis. For cross-shift testing a questionnaire was administered to the worker and spirometry testing conducted both before the shift began and after the shift was over. For the cross-season analysis, baseline values for spirometry were taken in March and a questionnaire was administered. Post-

season testing was conducted in the same manner in late November, early December and a questionnaire was administered. The study showed a decline in cross-shift spirometry measures. From pre-shift to post-shift the decreases were 0.065 L, 0.150 L and 0.496 L/sec in FVC, FEV<sub>1</sub> and FEF<sub>25-75</sub>. For the cross-season spirometry mean FVC, FEV<sub>1</sub>, and FEF<sub>25-75</sub> decreases were 0.033 L, 0.104 L, 0.275 L/sec. When increased respiratory symptoms were reported they could be associated with decreases in the lung function across the work shift (Betchley et. al., 1997).

### *Strength and Weaknesses of Firefighter Health Assessments*

Studies have supported the fact that respirable particulates in the ambient air can cause serious health effects from cardiovascular disease, respiratory disease, and even mortality ( Dockery et. al., 1993, Magari et. al., 2001). It has also been established from previous research that woodsmoke contains high levels of these respirable particulates (Tanner et. al.,2001, Cachier et. al., 1995). Studies on the exposures of firefighters have proven that at least some of the exposure levels of particulate matter and CO exceed occupational health standards (Materna et. al., 1992, Reinhardt et. al, 2000).

From the health studies conducted on firefighters short-term exposure is documented (Liu et. al., 1992, Betchley et. al. 1997). Short-term exposure health effects and intermediate exposure (days and weeks) health effects have been clearly documented. However, firefighter health studies have not been able to adequately address long-term exposure. It is a known fact that smokers suffer from many health risks such as asthma, heart disease and cancers but smokers reach this after decades of daily smoke exposure. Urban air pollution suggests the potential for long-term health effects from fine particulates. However, these studies include the entire population both young and old (Sharkey, 1997). Wildland firefighters are a unique population because of the fact that they, for the most part, are healthy adults, with seasonal exposures. Their respiratory systems

have the opportunity to recover during the off-season. Long-term exposure to wildland firefighters is one area of the health assessment field that could use more data.

### *Gaps in Smoke Exposure Assessment*

One bias in most of the exposure assessment of firefighters is that the individuals with the highest exposures may not have been monitored. Instead of using random selection, workers that were monitored, had either previously contacted the team or were easily accessible (Materna et. al., 1992). Also, the individuals that were monitored may have changed their routine due to the additional weight of the sampling apparatus and the individual may have volunteered because they were assigned a less stressful task during the burn. Exposure monitoring did not include the full time the worker was exposed to smoke and this could affect the TWA (Reinhardt et. al., 2000)<sup>1</sup> (Reinhardt, Ottmar, 2000). One of the key differences in all of the studies is the size of the particulate studied and what exposure limit to compare to. If the latest U.S. EPA PM<sub>2.5</sub> (24h average) standard of 65 ug/m<sup>3</sup> were compared to the findings of previous exposure assessment studies, there would be a much larger percentage of overexposures.

### *This Study*

We conducted a study in the Southeastern United States in 2003. This study was part of a larger epidemiological woodsmoke and respiratory function and health study in which exposure to PM<sub>2.5</sub> and spirometry testing were done. From our study we collected 55 PM<sub>2.5</sub> samples from a cohort of 10 fire workers during a five-week span. Questionnaires and time-activity diaries were administered to the firefighters at the end of every day. In addition to this data we conducted spirometry before and after every individual's shift. From this study we hope to first determine the exposures of the fire workers that conducted the burn. Once these exposures have been analyzed we would like to look at any correlations between firefighter tasks and the exposures

measured. In our questionnaire we asked the question, “ How much wood smoke do you feel you encountered today? ”. We narrowed the answers to this question into 3 different categories, low, medium and high. From these answers in comparison to the exposures of the 55 samples taken we hope to build a stronger correlation between fire worker predicted exposures and actual (pump and filter) sampled exposure. If a strong correlation could be established this could provide a cost effective way to quickly sample a fire worker’s exposure for future studies. Another aspect that this research will focus on is the number of acres burned in comparison to the individual’s exposure. From previous studies we have seen that the duration of the burn makes a difference in the individuals exposure but we would like to further probe this and analyze the number of acres burned. If a strong correlation is found between the number of acres burned and the exposures measured it may be possible to determine which firefighters will have the highest exposures by simply determining the number of acres that will be burned. Another unique aspect of this research is that for 5 of the fire workers we have 7-8 days of sampling. These same firefighters were monitored throughout the season for their full shifts, involved with various size burns, and with various tasks. This would give some indication of the exposure levels a firefighter might experience in a given five-week span of the burn season or their average exposure levels after 7-8 burns. This helps to avoid some of the bias involved with random sampling of individuals involved with a burn. In previous studies volunteers were sampled at each burn and it is possible that these volunteers would be the firefighters least affected by the smoke. By following these particular firefighters for five-weeks the subject could be sampled in all situations that are normal to prescribed forest burn workers. Instead of sampling for a broad class of respirable particulates we sampled for PM<sub>2.5</sub> and compared the results to the EPA PM<sub>2.5</sub> NAAQS. Other studies have shown that wind speed is significant

contributor to exposure on these prescribed burn situations but very little wind speed was tolerable or the burn would not take place, however, this could be a factor in the exposure concentrations. The samples will not be analyzed for silica content from road or ground dust because it is unlikely this was a significant contributor to PM<sub>2.5</sub> exposure concentrations. The spirometry data that was conducted will be analyzed and included in future writings.

## References for Chapter 2

- American Conference of Governmental Industrial Hygienists. Online Threshold Limit Values. Last Updated 10/1/03. <http://www.acgih.org/Products/tlvintro.htm>.
- Barnes, D.F., K. Openshaw, et al. (1994). "What Makes People Cook with Improved Biomass Stoves?" A Comparative International Review of Stove Programs. Washington, DC: The World Bank.
- Betchley, C., J. Q. Koenig, et al. (1997). "Pulmonary Function and Respiratory Symptoms in Forest Fighters." American Journal of Industrial Medicine 31: 503-509.
- Bruce, N., R., Perez-Padilla. (2002). "The health effects of indoor air pollution exposure in developing countries." World Health Organization Protection of the Human Environment, Geneva, 2002. WHO/SDE/OEH/02.05.
- Cachier, H., C. Liousse, et al. (1995). "Particulate Content of Savannah Fire Emissions." Journal of Atmospheric Chemistry 22: 123-148.
- Dennis, A., M. Fraser, et al. (2002). "Air pollutant emissions associated with forest, grassland, and agricultural burning in Texas." Atmospheric Environment 36(23): 3779-3792.
- Dockery, D. W., C. A. I. Pope, et al. (1993). "An Association between Air Pollution and Mortality in Six U.S. Cities." The New England Journal of Medicine 329(24): 1753-1759.
- Emmanuel, S. C. (2000). "Impact to Lung Health of Haze from Forest Fires: The Singapore Experience." Respirology 5: 175-182.
- Federal Register. (1987). "Revisions to the national ambient air quality standards for particulate matter. F.R. (July 1) 52: 24634-24669.
- Federal Register. (1997). 29CFR1910.1000 Tables Z-1 through Z-3. Vol. 62. 42018, August 4, 1997. [http://www.osha-slc.gov/SLTC/respiratory\\_advisor\\_genius\\_nrdl/z\\_tables.html](http://www.osha-slc.gov/SLTC/respiratory_advisor_genius_nrdl/z_tables.html).

Harrison, R., B. Materna, et. al. (1995). "Respiratory Health Hazards and Lung Function in Wildland Firefighters." *Occupational Medicine: State of the Art Reviews*-Vol. 10, No. 4, Oct-Dec 1995. Philadelphia, Hanley & Belfus, Inc.

Health Effects Institute, (2003). "Statement: Particulate Air Pollution and Daily Mortality: Analysis of the Effects of Weather and Multiple Air Pollutants." The Phase I.B Report of the Particle Epidemiology Evaluation Project. <http://www.healtheffects.org/Pubs/peepib.htm>. Last updated 2/23/2003.

Kalpana, B., J. Parikh, et, al. (2002). "Daily Average Exposures to Respirable Particulate Matter from Combustion of Biomass Fuels in Rural Households of Southern India." *Environmental Health Perspectives* vol. 110, no. 11: 1069-1075.

Liu, D., I. B. Tager, et al. (1992). "The Effect of Smoke Inhalation on Lung Function and Airway Responsiveness in Wildland Fire Fighters." *Am. Rev. Respir. Dis.* 146: 1459-1473.

Magari, S. R., R. Hauser, et al. (2001). "Association of Heart Rate Variability with Occupational and Environmental Exposure to Particulate Air Pollution." *Circulation* 104: 986-991.

Materna, B. L., J. R. Jones, et al. (1992). "Occupational Exposures in California Wildland Fire Fighting." *American Industrial Hygiene Association Journal* 53(1): 69-76.

McMahon, C. K. (1999). "Forest Fires and Smoke- Impacts on Air Quality and Human Health in the USA." *TAPPI International Environmental Conference*; 1999 April, Nashville, TN: TAPPI Press; 2: 443-453.

Mitra, A. P., L. Morawska, et al. (2002). "Chapter 2: Methodologies for Characterization of Combustion Sources and for Quantification of Their Emissions." *Chemosphere* 49: 903-922.

Mott, J.A., P. Meyer, et. al. (2002). "Wildland forest fire smoke: health effects and intervention evaluation, Hoopa, California, 1999." *Western Journal of Medicine* 2002; 176: 157-162.

NIOSH, (1994). "NIOSH Health Hazard Evaluation Report: U.S. Department of the Interior National Park Service Yosemite National Park, California." U.S. Department of Health and Human Services Public Health Service; Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health. HETA 90-0365-2415.

Radojevic, M. and H. Hassan (1999). "Air Quality in Brunei Darussalam During the 1998 Haze Episode." *Atmospheric Environment* 33: 3651-3658.

Reinhardt, T. E. (1991). "Monitoring Firefighter Exposure to Air Toxins at Prescribed Burns of Forest and Range Biomass." *United States Dept. of Agriculture Research Paper*.

Reinhardt, T. E. and R. D. Ottmar (2000). "Smoke Exposures at Western Wildfires." *United States Dept. of Agriculture Research Paper*.

Reinhardt, T. E., R. D. Ottmar, et al. (2000). "Smoke Exposure Among Firefighters at Prescribed Burns in the Pacific Northwest." United States Dept. of Agriculture Research Paper.

Reinhardt, T. E., R. D. Ottmar, et al. (2001). "Smoke Impacts from Agricultural Burning in a Rural Brazilian Town." Journal of the Air & Waste Management Association 51: 443-450.

Sastry, N. (2002). "Forest Fires, Air Pollution, and Mortality in Southeast Asia." Demography 39(1): 1-23.

Sharkey, B. (1997). "Health Hazards of Smoke; Recommendations of the Consensus Conference April 1997." United States Department of Agriculture Forest Service. Technology & Development Program Missoula, Montana 5100 Fire, 9751-2836-MTDC, Nov. 1997.

Tanner, R. L., W. J. Parkhurst, et al. (2001). "Impact of the 1998 Central American Fires on PM<sub>2.5</sub> Mass and Composition in the Southeastern United States." Atmospheric Environment 35(36): 6539-6547.

U.S. EPA (1997). "National Ambient Air Quality Standards for Particulate Matter; Final Rule." Federal Register 2.

U.S. EPA (1997). "1997 Summary Report: Particulate Matter (PM-10)." [<http://www.epa.gov/oar/aqtrnd97/brochure/pm10.html>]. 3 pp, last updated April 9<sup>th</sup>, 2002.

U.S. EPA (1998). "Interim Air Quality Policy on Wildland and Prescribed Fires" [<http://www.epa.gov/ttn/orapg>]. 38 pp, April 23, 1998.

Velema, J. P., A. Ferrera, et al. (2002). "Burning Wood in the Kitchen Increases the Risk of Cervical Neoplasia in HPV-Infected Women in Honduras." International Union Against Cancer 97: 536-541.

Vena, J.E., R.C. Fielder. (1987). "Mortality of a Municipal-Worker Cohort: IV. Fire Fighters." American Journal of Industrial Medicine 11; 671-684.

Ward, D. E. and C. C. Hardy (1991). "Smoke Emissions form Wildland Fires." Environment International 17: 117-134.

Yanosky, J.D., D.L. MacIntosh. (2001). "Fine Particle Exposure of Prescribed Fire Workers in the Southeastern United States and a Comparison of Several Particulate Matter Sampling Methods." A Master Thesis Submitted to the Graduate Faculty of the University fo Georgia in Partial Fulfillment of the Requirements for the Degree. Athens, Georgia, 2001.

Zelikoff, J. T., L. C. Chen, et al. (2002). "The Toxicology of Inhaled Woodsmoke." Journal of Toxicology and Environmental Health 5: 269-282.

## CHAPTER 3

# PERSONAL PM<sub>2.5</sub> EXPOSURES FOR FIREFIGHTERS DOING PRESCRIBED FOREST BURNS IN THE SOUTHEASTERN UNITED STATES

---

<sup>1</sup>Carlton, C.S. and Naeher, L.P. To be submitted to the Journal of Occupational and Environmental Hygiene.

## Abstract

Exposure to PM<sub>2.5</sub> during prescribed forest burn operations was studied in winter 2003 in a cohort of 10 forest fighters over a five-week study at the Savannah River Site in South Carolina. Fifty-four individual work shift samples were collected during burn activities and 9 during non-burn activities (controls). Over the five-week study, there were 9 days of prescribed burn activity when fire fighters were sampled, with an average of 5.4 fire fighters monitored per burn. Burn sizes ranged from 1 to 2042 acres, with an average of 613.1 acres. Workers were studied for an average duration of 7.85 hrs. Samples were collected using an SKC pump at 4.0 L/min with a BGI KTL cyclone and 2.0 micron pore size glass-fiber Teflon-coated filters. The overall average PM<sub>2.5</sub> concentration for the 54 burn activity samples was 385.5 ug/m<sup>3</sup> (range 21.3-2462 ug/m<sup>3</sup>). Daily PM<sub>2.5</sub> 24 hr. measures were taken during the study period as a measure of background PM<sub>2.5</sub> exposures in the area. A daily exposure questionnaire and time-activity log was administered daily post-shift to qualitatively assess worker exposure to smoke and to inquire regarding daily respiratory health symptoms (e.g., cough, phlegm). The questionnaire will also be used to compare the amount of smoke the worker felt they encountered during the burn to their actual exposure sampled. The time activity log will be used to determine if there are any correlation between the worker's activity (e.g., lighting, holding) and their sampled exposure. The size of each burn will be taken into account by comparing the number of acres burned to each individual's exposure. Results of the exposure assessment component of this study are consistent with earlier studies that demonstrate prescribed forest burn-related occupational exposures to PM<sub>2.5</sub> are of concern for forest fighters and warrant further exposure and health effects studies.

## Introduction

Firefighters are exposed to high levels of air pollutants found in woodsmoke from forest fires. The job involves working in close proximity to intense flames that give off high levels of air pollutants from vegetative burning. When a wildland or prescribed burn takes place, burning could continue for days, with thousands of acres being burned. The firefighters working these burns often work long shifts of 10-12 hours and could be working a burn for multiple days. Because of the nature of the job these workers are at risk for serious acute and chronic health affects.

### *Air Pollution is Bad For Your Health*

In recent years numerous studies have been done to look at the adverse health effects from various air pollutants. Some of the leading pollutants of concern are particulate matter (PM), carbon monoxide (CO), ozone, and polynuclear aromatic hydrocarbons (PAHs). Studies have shown such adverse health affects to increased levels of particle air pollution as decreases in lung function, increases in respiratory symptoms including cough, wheezing, exacerbation, and increase in respiratory-related diseases, including chronic obstructive pulmonary disease, cardiovascular diseases and lung cancer ( Mitra et. al., 2002).

### *Particulate Matter*

The U.S. Environmental Protection Agency (EPA) defines particle air pollutants or particulate matter as solid particles and liquid droplets found in the air. These particles vary in composition, size and origin. Total Suspended Particulates (TSP) incorporates all particulate matter. Fine particles consist of those that are 2.5 micrometers or less in diameter (PM<sub>2.5</sub>) and they cannot be detected without the use of an electron microscope. Coarser particles consist of those that are larger than 2.5 micrometer in diameter (PM<sub>10</sub>, PM<sub>3.5</sub>). The U.S. EPA also defines

inhalable or respirable particulate matter (RPM) as both fine and coarse particles. The coarse particles cause respiratory aggravation such as asthma but it's the fine particles (PM<sub>2.5</sub>) that are able to penetrate deeply into the lung tissue and cause increased hospital visits for heart and lung disease, decreased lung function and even premature death (U.S. EPA, 1997). Gases like Sulfer Dioxide (SO<sub>2</sub>), Nitrous Oxides (NO<sub>x</sub>) and Volatile Organic Compounds (VOCs) can come together to form these fine particles. These finer particles also come from combustion sources like motor vehicles, power generation, industrial facilities and woodsmoke from stoves, fireplaces, and forest fires (U.S. EPA, 1997).

#### *Wildfire and Prescribed Burns in the U.S.*

Prescribed burns are a beneficial tool for improving forage value of the forests, for reducing wildfire hazard and competing vegetation (Reinhardt, 1991). They have become such a mandatory land management practice that in a given burn season as much as 70,000 burns take place each year burning approximately two million acres and an estimated 80,000 firefighters per year in the United States are included in these burns (Ward et. al., 1991). Epidemiological studies have shown increases of 52% in medical visits for respiratory illness as a result of community smoke exposure from forest burning (Mott et. al., 2002). Those closest to the source of exposure are the firefighters and it was not until after the 1988 Yellowstone fires, when thousands of firefighters experienced respiratory problems, that concern about the occupational health of the firefighters increased (McMahon, 1999).

#### *Firefighter Exposure Assessment*

A study of respirable particulate exposures to firefighters from both wildland and prescribed fires found only one sample exceeding the Permissible Exposure Limit (PEL) of 5mg/m<sup>3</sup> (Materna et. al., 1992). Further studies like two from the United States Department of

Agriculture and Forestry Service (USDAFS) conducted on firefighter exposure have found similar results. In the Pacific Northwest smoke exposure among over 200 firefighters, at 52 prescribed burns, was monitored, finding that among all the firefighters sampled 5% of respiratory irritant exposures exceeded the Occupational Safety and Health Administration (OSHA) exposure limit of  $5 \text{ mg/m}^3$  (Reinhardt et. al., 2000). Air monitoring of 129 firefighters at wildfires in the Western United States from 13 initial attack wildfires and 8-multiday wildfires included TSP and  $\text{PM}_{3.5}$  samples. None of the TSP samples exceeded the PELs but between 3-5% of exposures to CO and respiratory irritants exceeded the occupational exposure limits (Reinhardt, Ottmar, 2000). Firefighter tasks and the corresponding personal  $\text{PM}_{2.5}$  exposures were monitored in a recent study conducted on 9 burn days in the Southeastern United States. The study found that 4.9% of the samples ( $n=41$ ) exceeded the ACGIH TLV ( $3.0 \text{ mg/m}^3$  for 8 hr) (Yanosky et. al., 2001). These studies have found that exposure levels of CO and respirable particulates from smoke can be a concern for firefighters health.

### *Firefighter Health Assessment*

The United States Department of Agriculture and Forest Services (USDAFS) has been involved with epidemiological studies on the health effects of firefighters. In the 1989 burn season Hotshot crews, in Northern California and Montana participated in a pulmonary testing study (Liu, 1992). Spirometry from pre-season to post-season showed a mean individual decline 0.09, 0.15, and 0.44 L/s in the Forced Vital Capacity (FVC), Forced Expiratory Volume ( $\text{FEV}_1$ ) and Forced Expiratory Flow ( $\text{FEF}_{25-75}$ ) the maximal midexpiratory flow rate values (Liu, 1992). In a similar study conducted in the 1992 fire season, firefighters from Region 6 of the USDA Forest Service and the Bureau of Land Management in Salem, Oregon were observed for both cross-season and cross-shift spirometry. The study showed a decline in cross-shift spirometry

measures. From pre-shift to post-shift the decreases were 0.065 L, 0.150 L and 0.496 L/sec in FVC, FEV<sub>1</sub> and FEF<sub>25-75</sub>. For the cross-season spirometry mean FVC, FEV<sub>1</sub>, and FEF<sub>25-75</sub> decreases were 0.033 L, 0.104 L, 0.275 L/sec (Betchley et. al., 1997).

### *Strength and Weaknesses of Firefighter Health Assessments*

Studies have supported the fact that respirable particulates in the ambient air can cause serious health effects from cardiovascular disease, respiratory disease, and even mortality ( Dockery et. al., 1993, Magari et. al., 2001). It has also been established from previous research that woodsmoke contains high levels of these respirable particulates (Tanner et. al.,2001, Cachier et. al., 1995). Studies on the exposures of firefighters have proven that at least some of the exposure levels of particulate matter and CO exceed occupational health standards (Materna et. al., 1992, Reinhardt et. al, 2000).

From the health studies conducted on firefighters, short-term exposure health effects are documented (Liu et. al., 1992, Betchley et. al. 1997). However, firefighter health studies have not been able to adequately address long-term exposure. Urban air pollution suggests the potential for long-term health effects from fine particulates. These studies include the entire population both young and old (Sharkey, 1997). Wildland firefighters are a unique population because of the fact that they, for the most part, are healthy adults, with seasonal exposures. Their respiratory systems have the opportunity to recover during the off-season. Long-term exposure to wildland firefighters is one area of the health assessment field that could use more data.

### *Gaps in Smoke Exposure Assessment*

One bias in most of the exposure assessment of firefighters is that the individuals with the highest exposures may not have been monitored. Instead of using random selection, workers that were monitored, had either previously contacted the team or were easily accessible (Materna et.

al., 1992). Also, the individuals that were monitored may have changed their routine due to the additional weight of the sampling apparatus and the individual may have volunteered because they were assigned a less stressful task during the burn. Exposure monitoring did not include the full time the worker was exposed to smoke and this could affect the Time Weighted Average (TWA) (Reinhardt et. al., 2000) (Reinhardt, Ottmar, 2000).

### *This Study*

We conducted a study of PM<sub>2.5</sub> exposure to firefighters in the Southeastern United States in 2003. This study was part of a larger epidemiological woodsmoke and respiratory function and health study in which exposure to PM<sub>2.5</sub> and spirometry testing were done. Questionnaires and time-activity diaries were administered to the firefighters at the end of every day. From this study we hope to first determine the exposures of the fire workers that conducted the burn. We would like to look at any correlations between firefighter tasks and the exposures measured. We hope to build a stronger correlation between fire worker predicted exposures from the questionnaire and actual (pump and filter) sampled exposure. Another aspect that this research will focus on is the number of acres burned in comparison to the individual's exposure. A unique aspect of this research is that for 5 of the firefighters we have 7-8 days of sampling during the season for their full shifts, involved with various size burns, and with various tasks. The spirometry data that was conducted will be analyzed and included in future writings.

### Methods

#### *Study Population*

From February 5<sup>th</sup> to March 12<sup>th</sup> 2003 a cohort of 10 forest service workers participated in an epidemiological health study conducted at a southeastern United States forest. This was a 5- week study design that incorporated administering a daily post-shift exposure and respiratory

health symptoms questionnaire along with a time-activity diary, daily pre- and post-shift spirometry testing, and PM<sub>2.5</sub> sampling on select days. The cohort of forest service workers selected for the study included 11 men and one woman and ranged in ages from 23-37 (Table 1). Participation in the study was voluntary. Each subject had the study explained to them and was invited to participate. If they wanted to participate they were asked to sign a consent form to be in the study. The study protocol was reviewed and approved by the University of Georgia Institutional Review Board for the inclusion of human subjects.

*Exposure Assessment: Questionnaire and time-activity diary*

A daily post-shift questionnaire was administered to all workers every day that they worked, to determine if the worker assisted in a prescribed burn and if there were any other possible air pollution or smoke exposures other than from a prescribed burn. If a burn took place the questionnaire addressed such issues as, if the worker was involved in the burn, how many acres was the burn, whether respiratory protective equipment was worn, how much smoke the worker felt they encountered that day, any symptoms felt as a result of the burn, and if the worker smoked or was around anyone smoking. The questionnaire was teamed with a daily activity diary to provide an account for the different tasks the worker conducted and the time spent on each task. The possible worker tasks on the time-activity diary included, holding: on foot, Mule, 4-wheeler, vehicle, dozer, other, direct attack, lighting: drip torch, ATV, other, mop-up: on foot, Mule, 4-wheeler, vehicle, dozer, other, other (Outside) on site: truck, dozer, other, inside, and off site.

*Exposure Assessment: Personal PM<sub>2.5</sub> Sampling*

Personal levels of PM<sub>2.5</sub> were measured on fire fighters on days that they worked on a prescribed burn (burn day) and on several control days when they were not working a prescribed

burn. If a prescribed burn or mop-up took place, 5 to 7 workers would wear the PM<sub>2.5</sub> sampling equipment for their full work shift. For the personal sampling of PM<sub>2.5</sub> an SKC Air Check pump was attached to a BGI, GK2.05 (KTL) Respirable/Thoracic cyclone (BGI, Inc. Waltham, MA, USA) via tygon tubing( Kenny and Gussman, 1997). The KTL cyclone housed a Gelman 37 mm Teflo filter (Pall Corp., Ann Arbor, MI, USA). This filter has a PTFE (PolyTetraFloralEthylene) 100% Teflon membrane, a 2.0 um pore size, and a polymethylpentene support ring. Pre and post-flows of the pump and filter sampling apparatus were measured with a Bios Dry Cal DC-Lite Model DCL20K (Bios International, Butler, NJ, USA). The flow rate for the sampling unit was set at 4.0 L/min. Shift times ranged from 4.2 to 10.5 hours (avg = 7.7 hrs, std dev =1.7 hr ). A field blank was taken on all sampling days. During a burn day background/ambient PM<sub>2.5</sub> concentrations were sampled at the Forest Service Station. This was conducted with a BGI PQ-200 (BGI, Inc. Waltham, MA, USA) using 47 mm Teflo filters (Pall Corp., Ann Arbor, MI). This is an EPA Federal Reference Method (FRM) (US EPA, 1997c). At the end of the burn day, all personal sampling equipment was removed from each worker and the filters were unloaded from both the KTLs and the PQ-200. All filters were placed in a cassette and put into an anti static bag that was put on ice. Filters were kept cool until they were returned to the lab, where they were kept frozen until further analysis. Sampling was conducted following EPA Standard Operating Procedures (SOP) (U.S. EPA, 1998).

#### *PM<sub>2.5</sub> Gravimetric Analysis*

Filters were stored in a partially climate-controlled lab for a minimum of 48 hours before they were pre- and post- weighed. Minor variations in temperature, barometric pressure and humidity were accounted for in all pre- and post-weights by using the equations referenced in (Koistinen et al., 1999). Field Blank adjustments were made to all samples by taking the field

blank concentrations from the sample day and subtracting this concentration from the exposure samples on this day. Filters were weighed with a Cahn C-35 microbalance with a sensitivity of +/- 1 ug following guidelines in US EPA's Standard Operating Procedures (1998). Filters were weighed twice for each pre- and post-weight.

### *Data Analysis*

For analysis, the PM<sub>2.5</sub> exposure concentrations were paired with the questionnaire and the time activity diary for each worker, each day. Once all data was together on one spreadsheet every fifth row of the spreadsheet was checked to make sure all inputs were correct, this was done as part of the QA/QC (Quality Assurance/Quality Control). Before any comparisons or trends could be obtained from the data all outliers and invalid samples must be removed. Four samples were declared invalid due to equipment, operator or worker error. Two samples were declared invalid by the operator due to the fact that the cyclone twisted loose or fell apart during sampling (worker 12 on 2/21/03, worker 02 on 2/25/03). One sample was declared invalid by the operator because the worker reported the cyclone falling off and taking in sand (worker 04 on 2/21/03). One sample was declared invalid by the operator because the worker reported and the pump showed that the pump had stopped at 10 am with only about 2 hours of sampling time (worker 12 on 3/10/03). The other type of samples that are invalid for this analysis are those that reflected pre and post flows above or below + or - 5% of 4.0 L/min. this according to standards set forth by OSHA (OSHA, 2001). The post-flows on two of the samples were below 5% of 4.0 L/min., one being 7.5% below and the other more significantly below. One sample showed a post-flow higher than 5% of 4.0 L/min. The FRM background samples yielded 21 samples, 16 on non-burn days, 5 on burn days and 4 ruled invalid. During the study 5 samples were taken as controls in order to compare personal exposure levels between burn and non-burn days. With all

invalid samples removed, the clean data set (n=48) was used for further comparisons between exposure and acreage, questionnaire responses and worker tasks. For the study 200 time-activity diaries were collected from the 10 individuals who participated in the study. The time-activity diary was expected to add some meaning to the exposures collected during the burn days and determine if there were any exposure concerns on non-burn days. For all statistical analysis of relationships between variables a Tukey test was applied to the data using SAS 8.2 in Windows (SAS Institute, Cary, NC). A significance level of 0.05 was used for all statistical tests. Trends and regression lines were also found using the SAS program. All averages are arithmetic means unless otherwise noted.

## Results

### *Fire fighter personal exposure to PM<sub>2.5</sub> while working a prescribed burn*

This study collected 48 valid samples with exposure levels ranging from 6.4-1690.9 ug/m<sup>3</sup> with an average and standard deviation of (Avg=362.8 ug/m<sup>3</sup>; St Dev=372.7 ug/m<sup>3</sup>). Each of the 48 samples are presented as points with their corresponding PM<sub>2.5</sub> exposure concentrations. These results can be seen in Figure 1. Each burn and the characteristics of it were analyzed. The number of acres and fire fighter personal PM<sub>2.5</sub> exposures were compared for all burns. An average, minimum and maximum PM<sub>2.5</sub> concentration from those that worked the burn, were calculated. This included all burns ranging in sizes from 1-1900 acres. These results are presented in Table 2.

### *Controls*

Five PM<sub>2.5</sub> personal exposure samples were collected as control samples on days when the fire fighters were not working a prescribed burn. Four of these samples were taken on a day when no burn was being conducted. The fifth sample was taken on a day when a burn was

conducted but the worker did not participate and did not work in proximity to the burn. The  $PM_{2.5}$  concentrations from the control days are presented in Table 3.

#### *Background Samples*

FRM background sampling resulted in 21 samples, 16 from days when there was no burn (non-burn days) and 5 from days when burning took place (burn days). The flow rates (Avg=16.72 L/min; St Dev=0.01 L/min) and sampling time (Avg=20.5 hrs; St Dev=3.65 hrs) stayed consistent throughout the study. The concentrations and averages from burn days (Avg=16.5  $\mu\text{g}/\text{m}^3$ ; St Dev=6.1  $\mu\text{g}/\text{m}^3$ ) were compared to those of non-burn days (Avg=12.5  $\mu\text{g}/\text{m}^3$ ; St Dev=6.2  $\mu\text{g}/\text{m}^3$ ). The statistical test showed that background on non-burn day samples are not significantly different from background on burn day samples ( $p=0.22$ ). These results are presented in Table 4.

#### *Background Samples and Their Comparison to Control, and Personal $PM_{2.5}$ Exposures*

A comparison was made between the average  $PM_{2.5}$  concentrations for, background on non-burn days, background on burn days, all background samples (burn and non-burn days), controls and personal  $PM_{2.5}$  on burn days. Statistical analysis was conducted to look at the relationship between each of these groups. All background samples combined (Avg=13.4  $\mu\text{g}/\text{m}^3$ ; St Dev=6.3  $\mu\text{g}/\text{m}^3$ ) were compared to the control samples (Avg=23.1  $\mu\text{g}/\text{m}^3$ ; St Dev=8.7  $\mu\text{g}/\text{m}^3$ ) and it was determined that the two groups are significantly different ( $p=0.008$ ). A further comparison was made between all background samples combined and personal  $PM_{2.5}$  exposures from burn days. The two groups are significantly different from each other ( $p<0.0001$ ). All group averages were compared with their standard errors. These results are presented in Figure 2.

### *Worker-specific PM<sub>2.5</sub> Exposure Over 5 Weeks*

Five of the fire fighters were monitored for personal PM<sub>2.5</sub> exposure on all days that they worked a prescribed burn during the study, each of which ended up with 7 or 8 person-days of sampling. The average PM<sub>2.5</sub> exposure concentration for each fire fighter from the 7 to 8 burns they participated in was calculated. A standard error was applied to the five subject samples. Over 7 burns, fire fighter 12 (subject ID) had the highest personal PM<sub>2.5</sub> exposure average (Avg=505.8 ug/m<sup>3</sup>; St Dev=490.2 ug/m<sup>3</sup>). The lowest personal PM<sub>2.5</sub> exposure average was from fire fighter 19 (Avg=131.7 ug/m<sup>3</sup>; St Dev=128.8 ug/m<sup>3</sup>). The statistical results showed that all subjects are not significantly different from each other (p=0.48). These results are presented in Figure 3.

### *PM<sub>2.5</sub> exposure concentrations in comparison to the amount of acres burned*

The burns were put into 3 groups by the amount of acres burned on each and the 3 groups consisted of different acreage ranges. Each group could be compared to all fire fighter person-days (personal PM<sub>2.5</sub> exposure) that were collected within that burn category. The first group was the burns in the 1-30 acre range, which consisted of 4 burns with a total of 20 personal PM<sub>2.5</sub> samples (Avg=218.9 ug/m<sup>3</sup>; St Dev=208.9 ug/m<sup>3</sup>). The next group was the >30-600 acre range and this group consisted of 3 burns with a total of 14 personal PM<sub>2.5</sub> samples (Avg= 333.1 ug/m<sup>3</sup>; St Dev=430.6 ug/m<sup>3</sup>). The final group was >600 acre range and this group consisted of 3 burns with a total of 13 personal PM<sub>2.5</sub> samples (Avg=613.6 ug/m<sup>3</sup>; St Dev=426.4 ug/m<sup>3</sup>). By taking the overall average of all person-day exposure concentrations from burns within the acreage range an average and standard error were calculated. The results of the statistical test show that the 0-30 acre category and the >600 acre category are significantly different from each other but the >30-600 acre category is not significantly different from the other two categories

( $p=0.012$ ). The results are presented in Figure 4. Each individual sample concentration ( $PM_{2.5}$ ) was compared to the amount of acres burned during the time that sample was taken. A significant relationship was found between amount of acres and concentration ( $p=0.0006$ ) with some variance around the regression line ( $R^2=0.162$ ). The results are presented in Figure 6.

#### *Questionnaire as a Predictor of Personal $PM_{2.5}$ Exposure*

In the questionnaire, administered to all fire workers each day during the 5 week study, the question was asked “How much smoke do you feel you encountered today?” with the possible answers of “low, medium or high”. The exposure concentrations from  $PM_{2.5}$  sampling were compared to the individual’s response on the questionnaire of the predicted amount of smoke the worker felt they encountered that day. An average concentration was taken from all the individuals that answered “low” on the questionnaire question with a total of 28 personal  $PM_{2.5}$  samples (Avg=192.9  $ug/m^3$ ; St Dev=181.9  $ug/m^3$ ). A total of 17 personal  $PM_{2.5}$  samples were taken from those that answered “medium” (Avg=522.1  $ug/m^3$ ; St Dev=429.4  $ug/m^3$ ). Of those that answered “high” a total of 3 personal  $PM_{2.5}$  samples were taken (Avg=1045.6  $ug/m^3$ ; St Dev=303.7  $ug/m^3$ ). The statistical test showed that all three data sets from those that answered either “low”, “medium”, or “high” are significantly different from one another ( $p<0.0001$ ). These results are presented in Figure 5.

#### *Time-Activity Diary and Worker Tasks*

The time-activity diary was broken into two groups according to whether the employee participated in a burn that day (burn day group) or not (non-burn day group)-the controls were included in the non-burn day group. To compile the tasks of the overall study population, total hours from each task were calculated from both the burn and non-burn data sets. The highest percentage work activities of the entire group on all burn days included holding on foot, holding

in the vehicle, lighting with a drip torch and other activities outside but on site. On non-burn days the highest percentage work activities included being either inside or outside but on site.

This data is presented in Table 5.

For the individual worker tasks, the burn day sample set was broken down to include just 6 individuals who had 4 days of sampling or more. All of the individual's personal PM<sub>2.5</sub> exposures, from the burns they participated in, were compiled to come up with an exposure average to be compared to the total hours they spent at each task during the study. The hours were converted to percentages with the higher percentage work activities being, lighting with a drip torch, holding on foot, and outside on site. The data is presented in Table 6.

### *Discussion*

The results of this study provide a close look at 10 firefighters during 5-weeks of their burn season. The sample media for this study was PM<sub>2.5</sub> because of the health impacts due to this fine particle exposure but other studies on firefighter exposure have included different sizes of particulate matter to sample. This study and its results are comparable to other studies of this nature. The PM<sub>2.5</sub> exposures found are below regulatory standards but could cause health impacts even at low levels. The present study adds to the research that is available for firefighter exposures but it is not without limitations. The limitations of this study are aspects that should be included in future research.

Previous studies have shown that fine particles ( $\leq 2.5$   $\mu\text{m}$ ) are directly related to excess mortality due to lung cancer and cardiopulmonary disease. The Harvard Six City Study found a strong association between excess mortality and fine particle exposure ( $p < 0.005$ ) at averages ranging from 11.0-29.6  $\mu\text{g}/\text{m}^3$  (Dockery et. al., 1993). When characterizing woodsmoke it has been found to be 94% PM<sub>2.5</sub> (Emmanuel, 2000). Because of the prevalence of fine particles and

the health risks involved with smoke exposure, the present study focused on sampling PM<sub>2.5</sub>. Two studies conducted by NIOSH (NIOSH, 1994) and Materna (Materna et.al., 1992) both sample for RPM (PM<sub>10</sub>). Two USDA studies involve sampling for PM<sub>3,5</sub> which is a very similar particle size cut to that of PM<sub>2,5</sub> but one of the USDA studies included TSP which incorporates all particulate matter present (Reinhardt, Ottmar, July, 2000) (Reinhardt et. al., Oct, 2000). The study that most closely relates to the present study was one conducted in the Southeastern United States that sampled for PM<sub>2.5</sub>. The overview of sample media and results from these studies are presented in Table 7.

The NIOSH (National Institute of Occupational Safety and Health) study in 1990 (NIOSH, 1994) of a prescribed burn in Yosemite National Park, found the average exposure to RPM (Respirable Particulate Matter) to be 1.2 mg/m<sup>3</sup> among the six firefighters sampled (n=6) from two Type 1 Hot Shot Crews. Sampling was done during the 9-10 hour period the firefighter was at the burn and not during the full work-shift. This is one major reason that our results show lower respirable particulate matter exposures. In the present study sample monitoring began as soon as the firefighter arrived at the site, hours prior to the burn and was not stopped until the firefighter was about to leave the site. The time involved with getting to the burn and leaving the burn results in lower overall averages for the full workday. The small sample size and sampling for RPM (PM<sub>2.5</sub> and PM<sub>10</sub>) would help to explain the higher concentrations between this NIOSH study and the present study. A more extensive study was conducted in Northern California and contained a larger sample size of RPM.

In a study, conducted in Northern California firefighter exposure was monitored for three successive burn seasons from 1987-1989 on wildland and prescribed burns. This study looked at both TSP and RPM. There were 22 RPM samples taken at the fireline during mop-up

(wildfires), with an average exposure of 1.75 mg/m<sup>3</sup> and 20 RPM samples were taken during prescribed burns, with an average of 1.15 mg/m<sup>3</sup>. Of the RPM samples only one exceeded the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 5 mg/m<sup>3</sup> at 5.14 mg/m<sup>3</sup> on a 229 min. sample, however the average sampling time for the 42 RPM samples was 274min. Sampling was not conducted during “direct attack” or the most intense flaming stage of the burn, when fire fighters are most closely in contact with the flames (Materna et. al., 1992). The present study had a longer sampling time (Avg= 459 min.) and involved all stages of the burn from lighting to mop-up, including the most intense flaming stages. Two of the largest studies conducted on firefighter smoke exposure included PM<sub>3,5</sub>, which closely compares to the size cut of particles sampled in the present study.

Both USDAFS (United States Department of Agriculture and Forest Service) studies, in the Pacific Northwest and in the Western United States conducted PM<sub>3.5</sub> sampling on firefighters involved with prescribed burns and wildfires (Reinhardt, Oct. 2000, July 2000). Sampling did not begin until smoke actually reached the worker and sampling was turned off during break periods. The overall TWA of the firefighter’s exposure was calculated by taking the exposure samples and using background levels as an estimate of the workers break period exposures.

During sampling firefighters were followed by an observer from the study team and this could have resulted in limited access to the exposures the firefighter could encounter or the task the firefighter could conduct (Reinhardt, Oct. 2000). In the current study, other than the onset of equipment failure, the sampling equipment was not turned off during any part of the firefighter’s day. The concentrations have not been adjusted to an 8 hr average but reflect exposure from actual sampling time and are compared to 8 hr standards. There were no restraints from

observers for the individual firefighter and they were allowed to perform normal tasks, under normal situations on the burns.

During the 2001 late winter to early spring burn season Yanosky conducted a study on firefighter exposure in the Southeastern United States, to PM<sub>2.5</sub> that closely relates to this study. Monitoring was done on 8 burn days and the study includes 27 firefighters. Of the 41 samples taken 7% of the samples exceeded the flow rate but were not excluded from the data analysis. The exposure concentrations from this study ranged from 64.3-5354.9 ug/m<sup>3</sup> with a mean of 1156.1 ug/m<sup>3</sup> (Yanosky, 2001). The concentrations from the Yanosky study are considerably higher than the ones from the current study but the size of the burn and the process of choosing the individual to monitor are not stated, so it is difficult to make a true comparison. In the current study all samples that exceeded the flow rates were excluded from data analysis.

In all of the previous studies it has been unclear which occupational particle standard to compare too. The regulatory agency OSHA has set the standard for respirable dust at 5 mg/m<sup>3</sup> for 8 hours, however OSHA has adopted the 1968 ACGIH TLVs and are the most lenient of all standards (Federal Register, 1997). Respirable dust includes particulate matter 10 ug or smaller in aerodynamic diameter. NIOSH, the research arm of OSHA, has set a standard of 3 mg/m<sup>3</sup> for respirable dust over 8 hours. The ACGIH TLV standard is 3mg/m<sup>3</sup> for respirable dust over 8 hours and these standards are thought to be the most up to date (ACGIH, 2003). Due to the fact that previous studies like the Harvard Six City Study have shown strong associations between mortality and fine particle exposure at much lower levels (11.0-29.6 ug/m<sup>3</sup>) it is appropriate to compare the exposures to the EPA standard. The overwhelming amount of literature on health effects at low levels of fine particles caused the EPA to establish a PM<sub>2.5</sub> standard of 65 ug/m<sup>3</sup> for a 24 hour period and 15 ug/m<sup>3</sup> annually (U.S. EPA, 1997). EPA's standard does not

necessarily apply to the occupational setting but instead focuses on public health. These standards must be this restrictive to account for the health risk of the elderly and young children. However, firefighters are exposed to levels of woodsmoke well above  $65 \text{ ug/m}^3$  on a regular basis and often for long periods on larger burns.

In the present study subjects were monitored for their full workday when a prescribed burn was conducted. Random selection or choosing those firefighters with highest exposures to monitor, might have shown different values but the 10 firefighters followed during this study, performed various tasks and at times were some of the highest exposed. By looking at the time-activity diary and the questionnaire it is believed that the tasks were no different between firefighters who wore monitoring equipment and those who did not. A higher mean was seen from the background burn days in comparison to the background non-burn days. This is probably due to the fact that two of the burns were in close proximity to the background sampler causing slightly higher concentrations ( $24.2 \text{ ug/m}^3$ ,  $21.2 \text{ ug/m}^3$ ) and the sample size is small ( $n=5$ ). The group of all combined background samples were compared to the control group and they were proven significantly different ( $p=0.008$ ). The higher concentrations from control days are most likely due to road dust from the trucks or dust from worker activities out in the forests. Personal samples were found to also be significantly different from all combined background samples ( $p<0.0001$ ) because the samples were worn during heavy smoke conditions. The amount of acres burned was shown to have some effect on the personal exposures ( $R^2=0.162$ ). This effect is not due to sample time because sample times are similar and all firefighters were sampled for their full workday, not just time spent at the fire. The samples were not analyzed for silica content from road or ground dust because it is unlikely this was a significant contributor to  $\text{PM}_{2.5}$  exposure concentrations.

Further research should be conducted on firefighter exposure to fine particles because of the health affects that can take place at low levels. It has been proven that mortality, morbidity, altered lung function, increased respiratory symptoms and cardiovascular disease are associated with fine particle exposure (U.S. EPA, 1998). These studies should follow firefighters for many years, looking at the chronic effects from PM<sub>2.5</sub> exposures. To look at exposures from different tasks during the burn, studies should incorporate real time monitoring of PM<sub>2.5</sub>, keeping a careful time-activity diary of the firefighter during the shift. It has been observed before in the Reinhardt studies but further research should look at CO exposure in comparison to PM<sub>2.5</sub> exposure because they are closely correlated. From both Tables 4 and 5 it can be seen that a high percentage of the firefighters time is spent outside on the site. For future studies, time-activity diaries should be more specific to incorporate the activities involved while the firefighter is outside or the questionnaire should ask exactly what tasks were conducted during the day. Holding on foot and lighting with a drip torch where the next highest percentages in both tables. By comparing the individual firefighter tasks to their exposures we can see that they are all very similar. However, one firefighter shows an average exposure lower than that of the others (131.7 ug/m<sup>3</sup>). The subject's task percentages are very similar to others for holding on foot and lighting with a drip torch. The big difference noticed is that the firefighter spent 45% of their time outside on site. The activities that were conducted while they were outside on site are not known but they could be the result of this lower exposure average. The only way to effectively determine what tasks cause higher exposure would be to conduct real-time PM<sub>2.5</sub> monitoring during these activities. This would allow researchers to look at the peaks during the day and compare them to the time-activity diary, showing what the individual was doing at that time.

## *Conclusion*

The present study showed a PM<sub>2.5</sub> average from 48 valid samples of 362.8 ug/m<sup>3</sup>. This is a considerably lower average than previous studies have shown but due to the more recent literature on health effects from levels much lower than this, it is no longer certain that these firefighters are not at risk. Our findings warrant future research on the long-term effects of PM<sub>2.5</sub> exposures. In the present study 10 firefighters were closely monitored for 5-weeks of the burn season providing a good picture of the exposure levels one firefighter could encounter during a given 5-week period of the burn season. The present study found a relationship between the number of acres burned and the exposure concentrations sampled from the workers on the burn. The study also showed a strong correlation between the amount of smoke the worker predicted they encountered in the questionnaire and the actual sampled exposure (pump and filter), during the burn day. This could be very beneficial and cost effective for future studies if exposures could be assessed by just the use of a questionnaire.

All particulate matter can cause some health risk but it's the fine particles or PM<sub>2.5</sub> that cause serious health effects by penetrating deep into the lung tissue. Previous studies have compared the concentrations found to either the OSHA or ACGIH standard and exposures as high as these standards will cause acute effects like watery eyes, headaches and nausea. However, it's the chronic effect, over many years, from exposure to much lower levels of fine particles that future research should be concerned with.

## *Acknowledgements*

Funding from the United States Department of Agriculture Forest Service supported this research. The study protocol was reviewed and approved by the University of Georgia Institutional Review Board for the inclusion of human subjects.

Special thanks goes to Maggie Crowe, Rob Robinson, Tara Almekinder and Meagan Kane for their help in conducting the study and analyzing the data. Thank you to Dan Shea and his crew of firefighters for participating in this study. Thanks to my major professor, Luke Naeher, to my committee members, Phil Williams and Jeff Fisher for their input and guidance that went into this project.

### References for Chapter 3

American Conference of Governmental Industrial Hygienists. Online Threshold Limit Values. Last Updated 10/1/03. <http://www.acgih.org/Products/tlvintro.htm>.

Betchley, C., J. Q. Koenig, et al. (1997). "Pulmonary Function and Respiratory Symptoms in Forest Firefighters." American Journal of Industrial Medicine 31: 503-509.

Cachier, H., C. Liousse, et al. (1995). "Particulate Content of Savannah Fire Emissions." Journal of Atmospheric Chemistry 22: 123-148.

Dennis, A., M. Fraser, et al. (2002). "Air pollutant emissions associated with forest, grassland, and agricultural burning in Texas." Atmospheric Environment 36(23): 3779-3792.

Dockery, D. W., C. A. I. Pope, et al. (1993). "An Association between Air Pollution and Mortality in Six U.S. Cities." The New England Journal of Medicine 329(24): 1753-1759.

Federal Register. (1997). 29CFR1910.1000 Tables Z-1 through Z-3. Vol. 62. 42018, August 4, 1997. [http://www.osha-slc.gov/SLTC/respiratory\\_advisor\\_genius\\_nrdl/z\\_tables.html](http://www.osha-slc.gov/SLTC/respiratory_advisor_genius_nrdl/z_tables.html).

Kenny, L.C., R.A. Gussman. (1997). "Characterization and Modeling of a Family of Cyclone Aerosol Preseparators." J. Aerosol Sci. Vol. 28, No. 4, pp. 677-688, 1997, Pergamon Press.

Koistinen, Kimmo, Kousa, Anu, Virpi, Tenhola, Hanninen, Otto, Jantunen, Matti. Fine Particulate (PM<sub>2.5</sub>) Measurement Methodology, Quality Assurance Procedures, and Pilot Results of the EXPOLIS Study. Air and Waste Management Association. Vol.49, 1212-1220. 1999.

Liu, D., I. B. Tager, et al. (1992). "The Effect of Smoke Inhalation on Lung Function and Airway Responsiveness in Wildland Fire Fighters." Am. Rev. Respir. Dis. 146: 1459-1473.

Materna, B. L., J. R. Jones, et al. (1992). "Occupational Exposures in California Wildland Fire Fighting." American Industrial Hygiene Association Journal 53(1): 69-76.

McMahon, C. K. (1999). "Forest Fires and Smoke- Impacts on Air Quality and Human Health in the USA." TAPPI International Environmental Conference; 1999 April, Nashville, TN: TAPPI Press; 2: 443-453.

Mitra, A. P., L. Morawska, et al. (2002). "Chapter 2: Methodologies for Characterization of Combustion Sources and for Quantification of Their Emissions." Chemosphere 49: 903-922.

Mott, J.A., P. Meyer, et. al. (2002). "Wildland forest fire smoke: health effects and intervention evaluation, Hoopa, California, 1999." Western Journal of Medicine 2002; 176: 157-162.

NIOSH, (1994). "NIOSH Health Hazard Evaluation Report: U.S. Department of the Interior National Park Service Yosemite National Park, California." U.S. Department of Health and Human Services Public Health Service; Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health. HETA 90-0365-2415.

Reinhardt, T. E. (1991). "Monitoring Firefighter Exposure to Air Toxins at Prescribed Burns of Forest and Range Biomass." United States Dept. of Agriculture Research Paper.

Reinhardt, T. E. and R. D. Ottmar (2000). "Smoke Exposures at Western Wildfires." United States Dept. of Agriculture Research Paper.

Reinhardt, T. E., R. D. Ottmar, et al. (2000). "Smoke Exposure Among Firefighters at Prescribed Burns in the Pacific Northwest." United States Dept. of Agriculture Research Paper.

Sharkey, B. (1997). "Health Hazards of Smoke; Recommendations of the Consensus Conference April 1997." United States Department of Agriculture Forest Service. Technology & Development Program Missoula, Montana 5100 Fire, 9751-2836-MTDC, Nov. 1997.

Tanner, R. L., W. J. Parkhurst, et al. (2001). "Impact of the 1998 Central American Fires on PM<sub>2.5</sub> Mass and Composition in the Southeastern United States." Atmospheric Environment 35(36): 6539-6547.

U.S. Department of Labor, OSHA, OSHA Technical Manual-Section II: Chapter 1 (sampling protocols). [http://www.osha.gov/dts/osta/otm/otm\\_ii/otm\\_ii\\_1.html#ii:1\\_6](http://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_1.html#ii:1_6). Current as of 10 Feb. 2004.

U.S. EPA (1997). "National Ambient Air Quality Standards for Particulate Matter; Final Rule." Federal Register 2.

U.S. EPA (1997). "Reference method for determination of fine particulate matter as PM<sub>2.5</sub> in the atmosphere." U.S. Environmental Protection Agency. 40 CFR Part 50, Appendix L. 1997c.

U.S. EPA (1997). "1997 Summary Report: Particulate Matter (PM-10)." [<http://www.epa.gov/oar/aqtrnd97/brochure/pm10.html>]. 3 pp, last updated April 9<sup>th</sup>, 2002.

U.S. EPA (1998). "Quality Assurance Guidance Document; Method Compendium; Field Standard Operating Procedures for the PM<sub>2.5</sub> Performance Evaluation Program." United States Environmental Protection Agency Office of Air Quality Planning and Standards. Nov 1998.

U.S. EPA (1998). "Interim Air Quality Policy on Wildland and Prescribed Fires"  
[<http://www.epa.gov/ttn/orapg>]. 38 pp, April 23, 1998.

Ward, D. E. and C. C. Hardy (1991). "Smoke Emissions form Wildland Fires." Environment International **17**: 117-134.

Yanosky, J.D., D.L. MacIntosh. (2001). "Fine Particle Exposure of Prescribed Fire Workers in the Southeastern United States and a Comparison of Several Particulate Matter Sampling Methods." A Master Thesis Submitted to the Graduate Faculty of the University fo Georgia in Partial Fulfillment of the Requirements for the Degree. Athens, Georgia, 2001.

Table 1. Study population and data collected from each firefighter.

| Subject ID | Sex | Age | Years of Fire Fighting | # of Personal Sampling Days<br>Questionnaire: PM2.5: |               | # of Control Days |
|------------|-----|-----|------------------------|--|---------------|-------------------|
| 12         | M   | 28  | 12                     | 27   | 9 (7 valid)*  | 1                 |
| 13         | M   | 37  | 14                     | 3  | 1             | 1                 |
| 6          | M   | 26  | 5                      | 23   | 8             |                   |
| 20         | M   | 29  | 9                      | 4  | 1             |                   |
| 7          | F   | 30  | 7                      | 10   | 3             |                   |
| 4          | M   | 33  | 9                      | 19   | 5 (4 valid)*  |                   |
| 5          | M   | 23  | 2                      | 3  | 2             |                   |
| 8          | M   | 24  | 2                      | 10   | 2             |                   |
| 2          | M   | 26  | 1                      | 25   | 9 (7 valid)*  | 1                 |
| 15         | M   | 35  | 15                     | 3  | 1             | 1                 |
| 19         | M   | 29  | 2                      | 22   | 7             | 1                 |
| 11         | M   | 33  | 8                      | 29   | 10 (8 valid)* |                   |
| Sum:       |     |     |                        | 178  | 58            | 5                 |

\*valid samples were those that were not thrown out for further analysis

Table 2. The average PM<sub>2.5</sub> personal exposures from each burn.

| Date of Burn | Number of Workers | Acres Burned | Average Time Sampled (min.) | Average Conc. (ug/m3) | Maximum Conc. (ug/m3) | Minimum Conc. (ug/m3) |
|--------------|-------------------|--------------|-----------------------------|-----------------------|-----------------------|-----------------------|
| 2/15/2003    | 4                 | 1900         | 563.5                       | 860.0                 | 1394.1                | 177.3                 |
| 2/24/2003    | 4                 | 980          | 513.5                       | 399.9                 | 737.7                 | 145.7                 |
| 3/11/2003    | 5                 | 650          | 538.0                       | 587.4                 | 904.1                 | 26.3                  |
| 2/25/2003    | 5                 | 597          | 522.6                       | 102.6                 | 166                   | 17.5                  |
| 3/10/2003    | 3                 | 400          | 397.0                       | 141.5                 | 222.4                 | 6.3                   |
| 2/14/2003    | 6                 | 190          | 487.5                       | 621.1                 | 1690.6                | 216.4                 |
| 3/12/2003    | 6                 | 30           | 389.8                       | 266.3                 | 525.3                 | 71.1                  |
| 2/20/2003    | 5                 | 20           | 516.0                       | 279.0                 | 736.1                 | 55.4                  |
| 2/21/2003    | 1                 | 2            | 422.0                       | 111.0                 | 110.8                 | 110.8                 |
| 2/7/2003     | 8                 | 1*           | 348.6                       | 159.2                 | 188.1                 | 14.3                  |
| Overall Avg: | 48 (sum)          |              | 459.0                       | 362.8                 |                       |                       |
| Overall Max: |                   |              | 628.0                       |                       | 1690.6                |                       |
| Overall Min: |                   |              | 253.0                       |                       |                       | 6.3                   |

\*pile burn-a small burn where large piles of brush and limbs are burnt  
 PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Table 3. Control PM<sub>2.5</sub> exposure samples from non-burn days.

| Subject ID | Date Sampled | Worker Task     | Time Sampled (min.) | PM <sub>2.5</sub> (ug/m <sup>3</sup> )* |
|------------|--------------|-----------------|---------------------|---|
| 15         | 2/5/2003     | Truck (9hrs.)   | 411                 | 15.9                                    |
| 12         | 2/5/2003     | Outside (9hrs.) | 253                 | 31.0                                    |
| 13         | 2/5/2003     | Outside (9hrs.) | 408                 | 32.5                                    |
| 2          | 2/5/2003     | Outside (9hrs.) | 398                 | 13.0                                    |
| 19         | 2/20/2003    | Outside (7hrs.) | 366                 | 23.2                                    |
| Average:   |              |                 | 367.2               | 23.1                                    |
| St Dev     |              |                 |                     | 8.7                                     |
| St Error   |              |                 |                     | 3.9                                     |

\*PM<sub>2.5</sub> is particulate matter 2.5ug in aerodynamic diameter or smaller

Table 4. FRM Background samples on burn and non-burn days.

| <b>Burn Day</b>     |   |
|---------------------|---|
| <b>Date</b>         | <b>PM<sub>2.5</sub> (ug/m<sup>3</sup>)*</b> |
| 02/20/03            | 21.2  |
| 02/21/03            | 24.2&                                       |
| 02/24/03            | 9.8   |
| 02/25/03            | 14.9  |
| 03/10/03            | 12.4  |
| Avg                 | 16.5  |
| St Dev              | 6.1   |
| <b>Non-Burn Day</b> |   |
| <b>Date</b>         | <b>PM<sub>2.5</sub> (ug/m<sup>3</sup>)*</b> |
| 02/17/03            | 16.7  |
| 02/18/03            | 10.4  |
| 02/19/03            | 17.7  |
| 02/20/03            | 21.2  |
| 02/21/03            | 24.2#                                       |
| 02/22/03            | 4.1   |
| 02/23/03            | 5.3   |
| 02/24/03            | 9.8   |
| 02/25/03            | 14.9  |
| 02/26/03            | 19.7  |
| 02/27/03            | 4.4   |
| 02/28/03            | 10.2  |
| 03/01/03            | 4.8   |
| 03/02/03            | 11.1  |
| 03/03/03            | 12.8<-                                      |
| 03/10/03            | 12.4  |
| Avg                 | 12.5  |
| St Dev              | 6.2   |

\*PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

# 2/21, duration=12.05 hrs

<- 3/03, duration=11.48 hrs

& 2/21, duration=12.05 hrs

Table 5. Highest corporate time-activity diary task percentages.

| Type of Day          | Holding On Foot | Holding Vehicle | Lighting With Drip Torch | Other (Outside) On Site | Inside On Site | All Other Combined** | TADs Completed* |
|----------------------|-----------------|-----------------|--------------------------|-------------------------|----------------|----------------------|-----------------|
| <b>Burn Days</b>     | 26%             | 5%              | 21%                      | 30%                     | 4%             | 14%                  | 48              |
| <b>Non-Burn Days</b> |                 |                 |                          | 40%                     | 51%            | 9%                   | 139             |

\*the number of time-activity diaries that were filled out

\*\*other task included: holding on mule, 4-wheeler, dozer, lighting on ATV, on-foot, mule, dozer

Table 6. Individual time-activity diary task percentages.

| Subject ID | Holding On Foot | Holding Mule | Holding Vehicle | Lighting With Drip Torch | Other (Outside) On Site | Other (Outside) Dozer | Inside On Site | All Other Combined* | # of samples | PM <sub>2.5</sub> (ug/m <sup>3</sup> )** |
|------------|-----------------|--------------|-----------------|--------------------------|-------------------------|-----------------------|----------------|---------------------|--------------|--|
| 19         | 28%             |              |                 | 20%                      | 45%                     |                       | 2%             | 5%                  | 7            | 131.7                                    |
| 2          | 29%             |              | 11%             | 14%                      | 27%                     |                       |                | 19%                 | 7            | 331.9                                    |
| 6          | 31%             |              |                 | 32%                      | 26%                     |                       | 4%             | 7%                  | 8            | 423.6                                    |
| 4          | 6%              |              | 19%             | 15%                      | 30%                     |                       | 21%            | 9%                  | 4            | 427.7                                    |
| 11         | 12%             | 15%          | 11%             | 16%                      | 31%                     | 6%                    | 3%             | 6%                  | 8            | 502.6                                    |
| 12         | 24%             | 3%           |                 | 34%                      | 28%                     |                       |                | 11%                 | 7            | 505.8                                    |

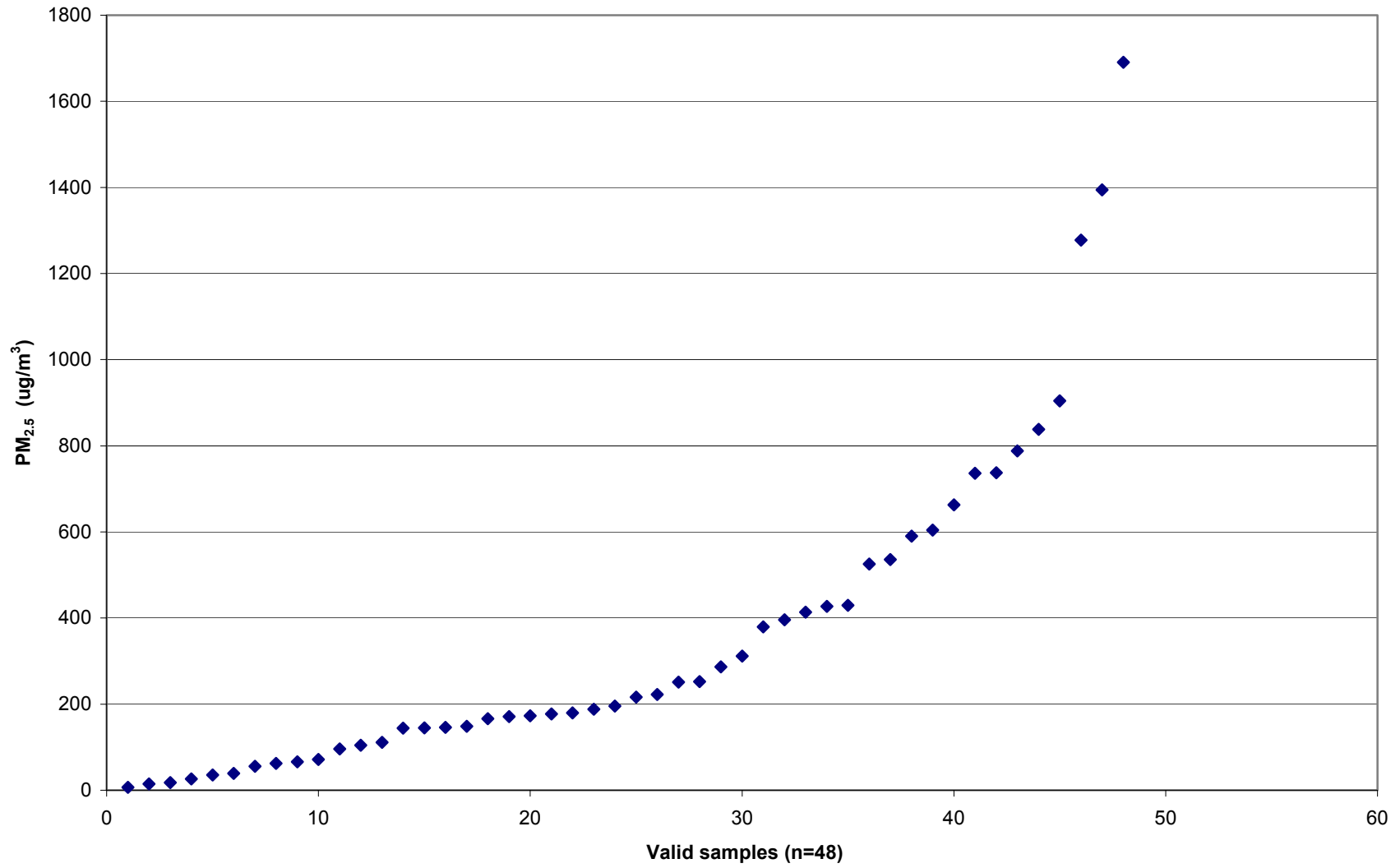
\*other task included: holding on mule, 4-wheeler, dozer, lighting on ATV, on-foot, mule, dozer

\*\*PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Table 7. Reference table of previous firefighter exposure studies in comparison to the present study.

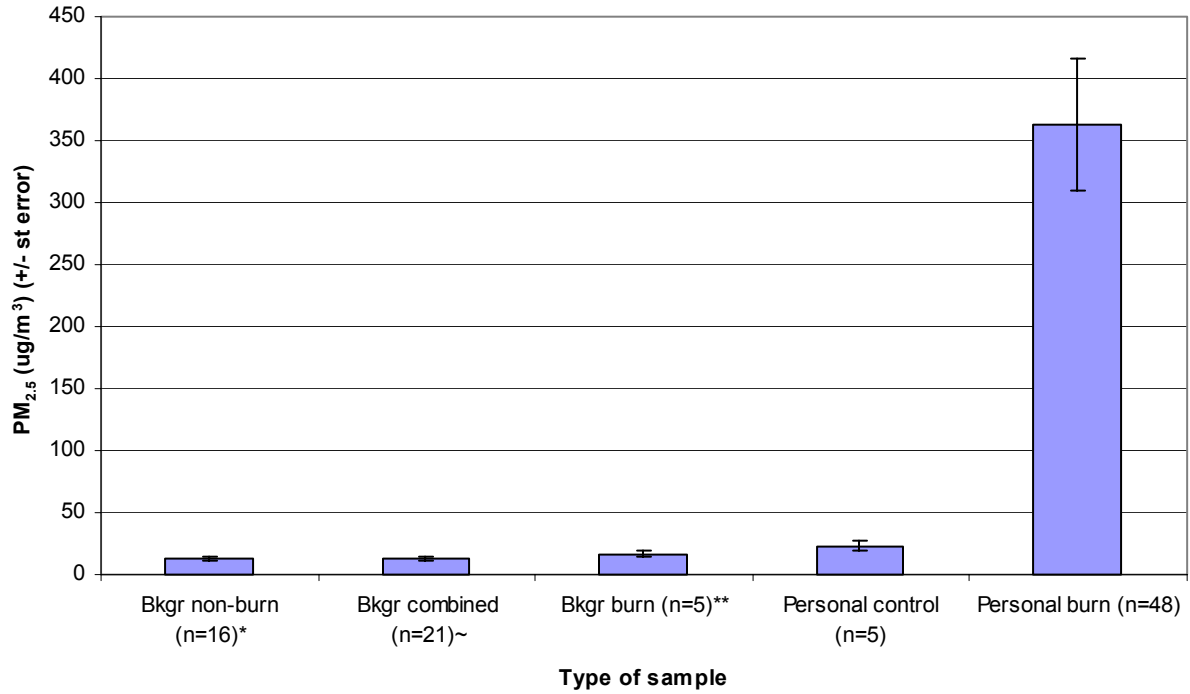
| Reference          | Location/Period   | Particulate Measure | # of Valid Samples | Mean Wkshft mg/m3 | Mean Burn mg/m3 | Range mg/m3 | Max Wkshft mg/m3 | Max Burn mg/m3 | Type of Burn                |
|--------------------|-------------------|---------------------|--------------------|-------------------|-----------------|-------------|------------------|----------------|-----------------------------|
| NIOSH              | Yosemite National | RPM                 | 6                  | 1.22              |                 | 0.6-1.7     | 1.7              |                | Prescribed Burn             |
| 1994               | Park, CA 1990     |                     |                    |                   |                 |             |                  |                |                             |
| Materna et. Al.,   | Northern, CA      | TSP                 | 22                 | 9.46              |                 | 2.70-37.4   |                  |                | Wildfires                   |
| 1992               | 1987-1989         | RPM                 | 22                 | 1.75              |                 | 0.327-5.14  |                  |                | Wildfires                   |
|                    |                   | RPM                 | 20                 | 1.15              |                 | 0.235-2.71  |                  |                | 3 Prescribed Burns          |
|                    |                   | TSP                 | 3                  | 3.27              |                 | 1.80-4.40   |                  |                | Waiting in Staging Area     |
| Reinhardt et. Al., | Northwestern U.S. | RPM (PM3.5)         | 338                | 0.63              | 1               |             | 6.9              | 10.5           | 52 Prescribed Burns         |
| 2000               | 1991-1994         |                     |                    |                   |                 |             |                  |                |                             |
| Reinhardt, Ottmar  | CA, ID, MT, WA    | TSP                 | 29                 | 1.47              | 1.72            |             | 4.38             | 4.17           | 8 Project Wildfires         |
| 2000               | 1992-1995         | RPM (PM3.5)         | 115                | 0.5               | 0.72            |             | 2.93             | 2.3            | Project Wildfires           |
|                    |                   | TSP                 |                    | 1.39              | 5.32            |             | 1.81             | 8.64           | 13 Initial Attack Wildfires |
|                    |                   | RPM (PM3.5)         |                    | 0.022             | 1.11            |             | 1.56             | 2.46           | Initial Attack Wildfires    |
| Yanosky, 2001      | SRS, Aiken, SC    | RPM (PM2.5)         | 38                 | 1.16              |                 | 0.06-5.35   |                  |                | 8 Prescribed Burns          |
|                    | 2001              |                     |                    |                   |                 |             |                  |                |                             |
| Carlton, 2004      | SRS, Aiken, SC    | RPM (PM2.5)         | 48                 | 0.36              |                 | 0.006-1.7   | 1.7              |                | 10 Prescribed Burns         |
|                    | 2003              |                     |                    |                   |                 |             |                  |                |                             |

Figure 1. PM<sub>2.5</sub> Personal exposure for firefighters on days they are working on a prescribed burn.



PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Figure 2. A comparison of PM<sub>2.5</sub> exposure concentrations collected in the study from background, control and personal sampling.



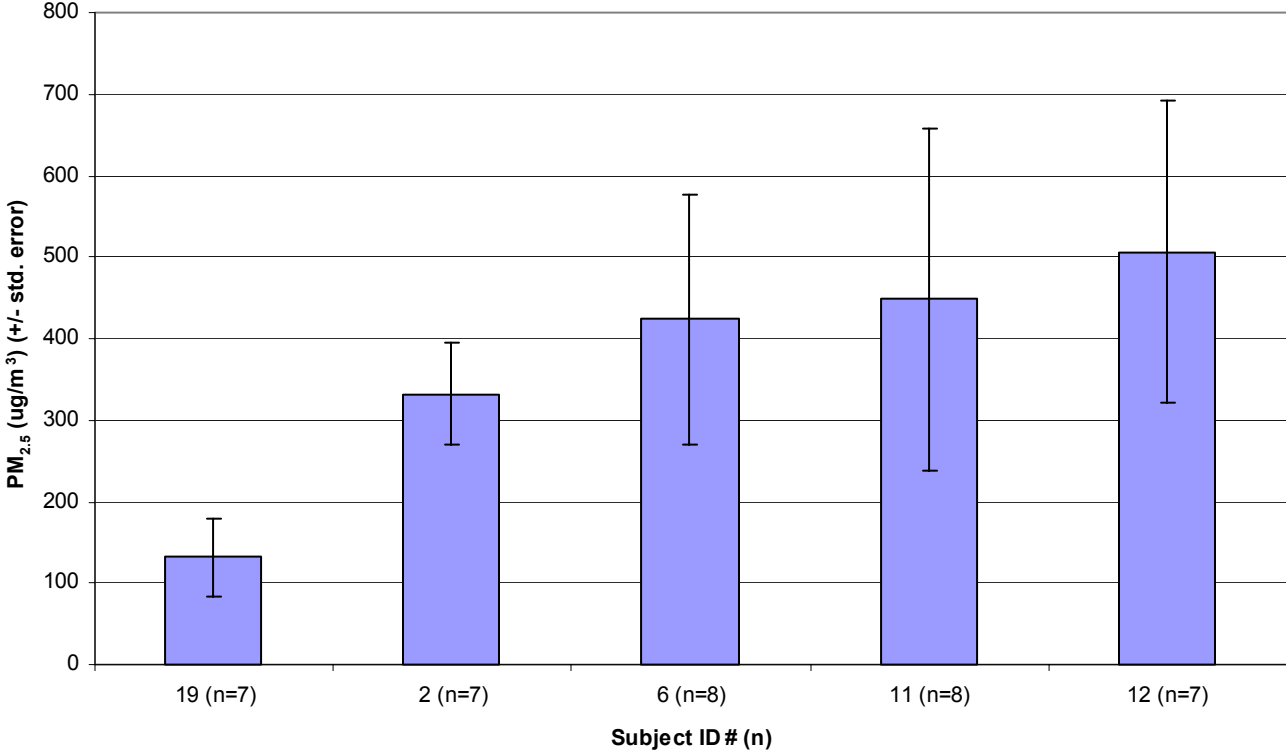
\*Background non-burn day samples

~Background, both non-burn and burn day samples

\*\*Background burn day samples

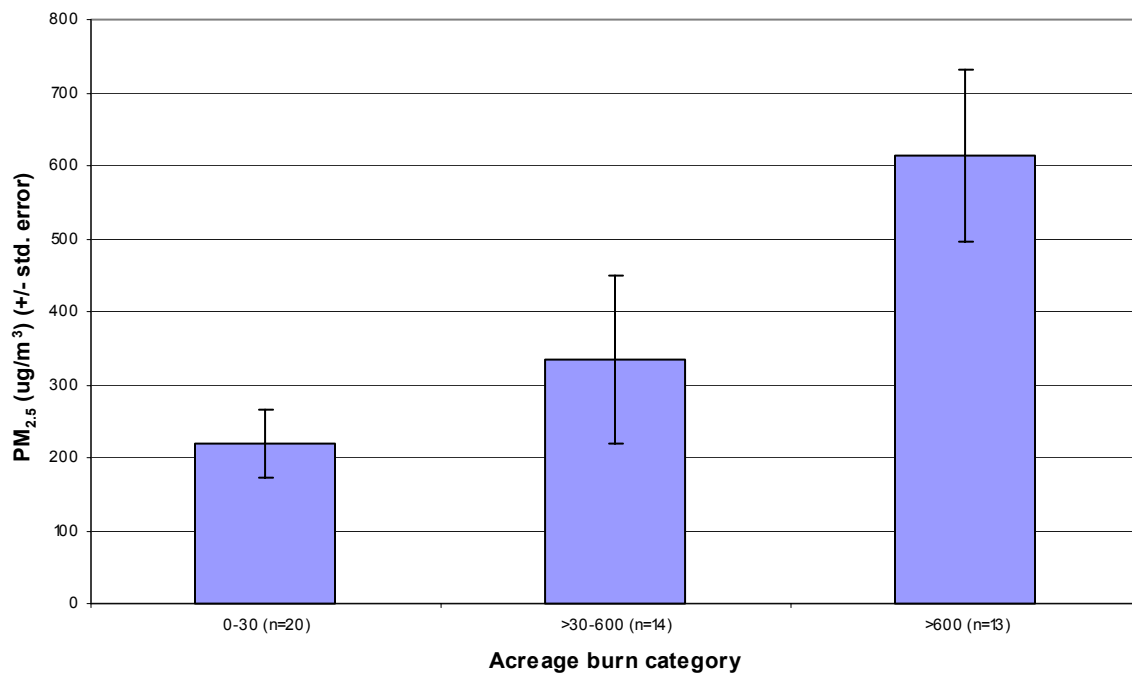
PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Figure 3. Inter-subject PM<sub>2.5</sub> personal exposure during prescribed burn activity over duration of study.



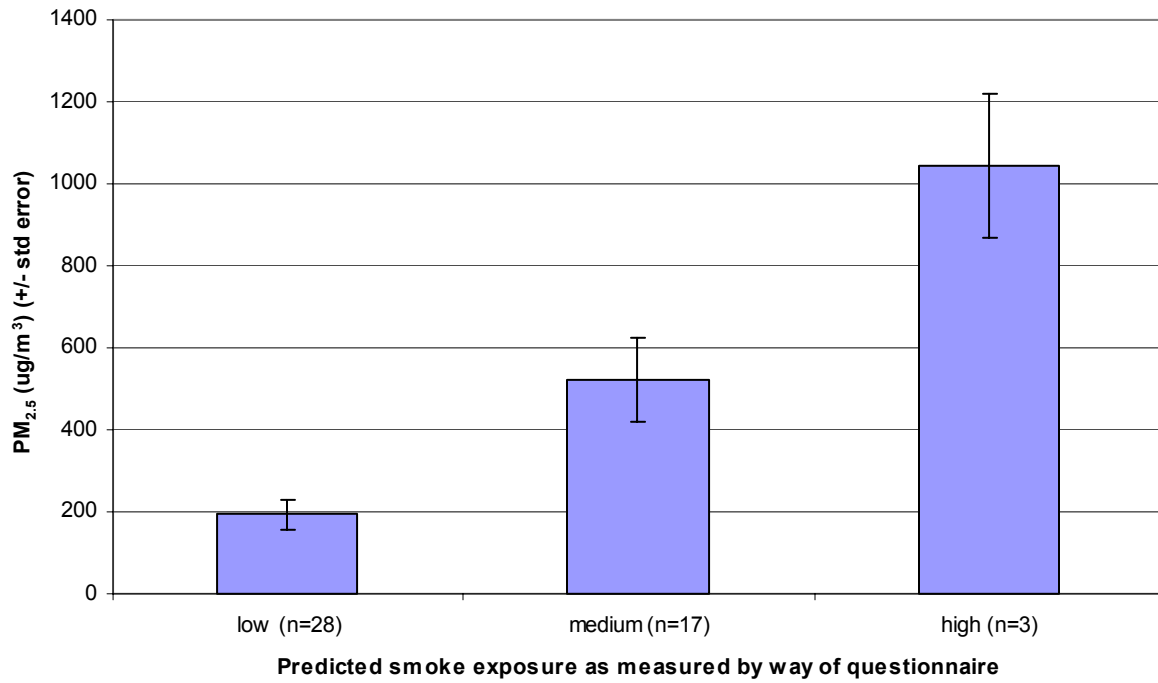
PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Figure 4. Relationship between personal PM<sub>2.5</sub> exposure during burn activity and the amount of acres burned.



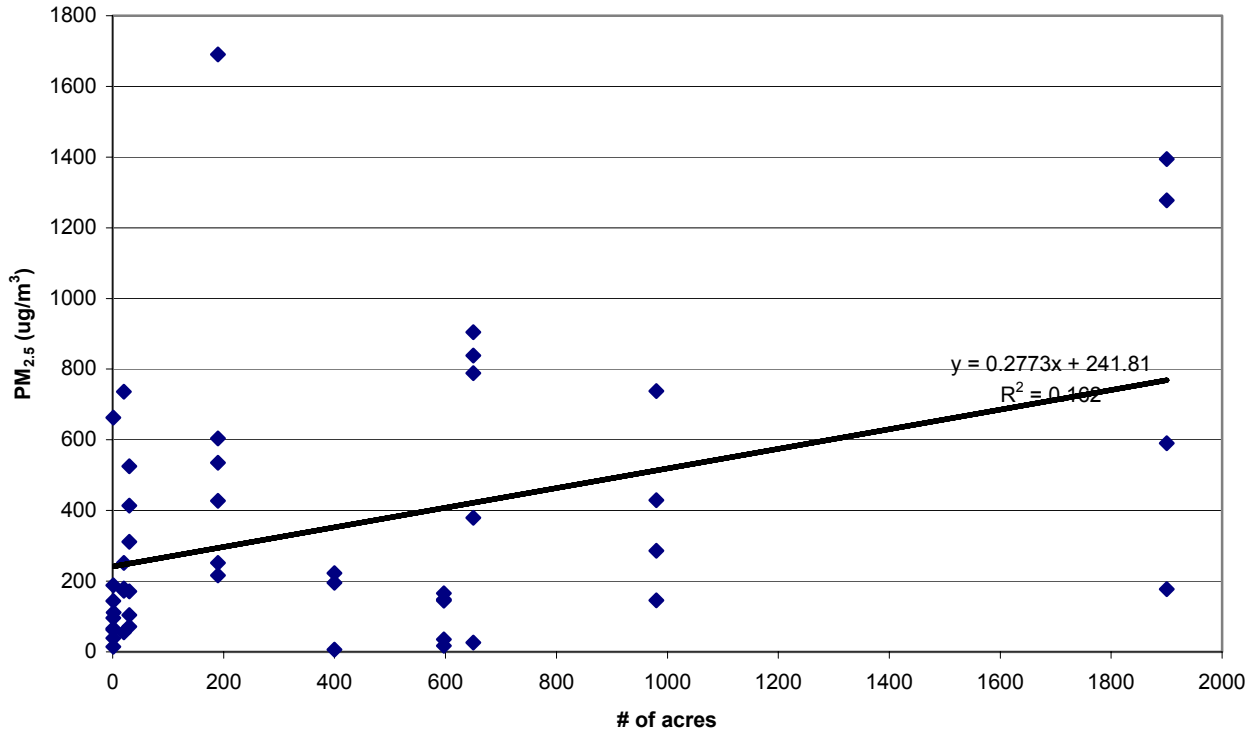
PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Figure 5. Questionnaire as a predictor of personal PM<sub>2.5</sub> exposure measured by pump and filter.



PM<sub>2.5</sub> is particulate matter 2.5um in aerodynamic diameter or smaller

Figure 6. The amount of acres burned and its effect on PM2.5 personal sample concentrations.



## CHAPTER 4

### SUMMARY

This document presents information on firefighter exposure to PM<sub>2.5</sub> (particulate matter 2.5 um in aerodynamic diameter or smaller) found in smoke from prescribed forest burns in the Southeastern United States. From February through March of 2003 a cohort of 10 firefighters were followed for 5 weeks during their burn season. The results from this study provide some insight to various factors that play a role in personal PM<sub>2.5</sub> concentrations.

This research has shown there is some relationship between the amount of acres burned and the personal exposures sampled ( $R^2=0.16$ ). This study has also shown a strong relationship between predicted exposures from the questionnaire and the actual exposure concentration, sampled by pump and filter. This would be beneficial, if future studies could get an idea of exposure levels by simply administering a questionnaire. This study is unique in the fact that it follows the same 10 firefighters for 5 weeks, providing a snapshot of what a typical firefighter may be exposed to in a 5-week period.

Previous studies have shown that a relatively small amount of firefighters sampled have exposure levels above occupational standards. Some studies sampled for Respirable Particulate Matter (RPM) (Materna, 1992) while others sampled for Total Suspended Particulates (TSP) and PM<sub>3.5</sub> (Reinhardt et. al., 2000, Reinhardt, Ottmar, 2000). Particulate matter comes in many different sizes (U.S. EPA, 1997) and previous studies vary in the particle size sampled. It has been proven that “fine particles” (2.5 um or smaller) are inhaled deep into the lung tissue and can cause serious adverse health effects (Mitra, 2002). Because it is these “fine particles” that cause the serious health effects, future studies should focus on PM<sub>2.5</sub> exposure levels. Also when comparing PM<sub>2.5</sub> exposure levels to a standard, it is important to look at all standards set forth for PM<sub>2.5</sub> and not different particle sizes. Occupational Safety and Health Administration (OSHA)

has a Permissible Exposure Limit (PEL) for respirable particulates of 5 mg/m<sup>3</sup> for 8 hr (Federal Register, 1997). This differs significantly from the EPA's PM<sub>2.5</sub> standard of 65 µg/m<sup>3</sup> for 24 hrs (U.S. EPA, 1997). When exposure levels are compared to the PEL, few are overexposed.

However, when data is compared to EPA's standard, most of the exposures exceed this limit. It is not clear as to what standard firefighter exposure levels should be compared to but it is clear that serious health effects have resulted from low levels (11-29 µg/m<sup>3</sup>) of PM<sub>2.5</sub> (Dockery, 1993).

Future research should conduct real-time monitoring for PM<sub>2.5</sub>. When paired with a time-activity diary this would provide exposure levels from each task conducted. Studies should also include CO monitoring because of the close relationship between CO and PM<sub>2.5</sub>. Time-activity diaries should be very detailed in order to represent all possible tasks a firefighter may be involved with. Future research should look at the chronic health effects of these firefighters after years of exposure.

#### References for Chapter 4

Dockery, D. W., C. A. I. Pope, et al. (1993). "An Association between Air Pollution and Mortality in Six U.S. Cities." The New England Journal of Medicine **329**(24): 1753-1759.

Federal Register. (1997). 29CFR1910.1000 Tables Z-1 through Z-3. Vol. 62. 42018, August 4, 1997. [http://www.osha-slc.gov/SLTC/respiratory\\_advisor\\_genius\\_nrdl/z\\_tables.html](http://www.osha-slc.gov/SLTC/respiratory_advisor_genius_nrdl/z_tables.html)

Materna, B. L., J. R. Jones, et al. (1992). "Occupational Exposures in California Wildland Fire Fighting." American Industrial Hygiene Association Journal **53**(1): 69-76.

Mitra, A. P., L. Morawska, et al. (2002). "Chapter 2: Methodologies for Characterization of Combustion Sources and for Quantification of Their Emissions." Chemosphere **49**: 903-922.

Reinhardt, T. E. and R. D. Ottmar (2000). "Smoke Exposures at Western Wildfires." United States Dept. of Agriculture Research Paper.

Reinhardt, T. E., R. D. Ottmar, et al. (2000). "Smoke Exposure Among Firefighters at Prescribed Burns in the Pacific Northwest." United States Dept. of Agriculture Research Paper.

U.S. EPA (1997). "National Ambient Air Quality Standards for Particulate Matter; Final Rule." Federal Register **2**.

U.S. EPA (1997). "1997 Summary Report: Particulate Matter (PM-10)."  
[<http://www.epa.gov/oar/aqtrnd97/brochure/pm10.html>]. 3 pp, last updated April 9<sup>th</sup>, 2002.