Evaluating the Use of Indoor Residential Wipe Samples Following a Wildfire

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Abstract

The Las Conchas wildfire that burned in New Mexico between 26 June and 3 August, 2011 was one of the largest in state history. In addition to burning nearly 160,000 acres, smoke from the fire significantly impacted downwind communities. In an effort to quantify the extent of smoke exposure to indoor environments, wipe samples were collected inside of 64 homes located throughout the north/central region of New Mexico. These wipe samples were analyzed for char and ash (indicators of biomass smoke) using Polarized Light Microscopy, with the results plotted in Google Maps. Out of the 64 residences that were investigated, char was detected from within 78% of the homes. Ash was not measured from any of the wipe samples. Mapping of these results demonstrates the far-reaching impact that smoke from the Las Conchas wildfire had on downwind communities, as indoor wipe samples from homes up to 50 kilometers from the fire tested positive for char. This project also demonstrated the usefulness of collecting wipe samples to retrospectively assess wildfire smoke impacts on indoor environments in lieu of expensive indoor air sampling campaigns.

Key Words: Wildfire smoke, Las Conchas wildfire, indoor air pollution, $PM_{2.5}$, air sampling.

Introduction

The primary goal of this research was to investigate the impact that wildfire smoke from the 2011 Las Conchas wildfire had on 64 residences downwind of the fire. A secondary goal was to evaluate the effectiveness of using wipe samples (in lieu of expensive sampling equipment) to serve as a surrogate for detecting forest fire smoke ($PM_{2.5}$) in indoor environments. In this manuscript, we present the results of a sampling, analytical and mapping program, which includes results of wipe sample evaluations.

On 26 June, 2011, the Las Conchas wildfire started in the Jemez Mountains located in the Santa Fe National Forest of north/central New Mexico (Fig. 1) when a tree fell on a power line. By the time the fire was 100% contained on 1 August, nearly 160,000 forested acres (~244 square miles) had burned, making it one of the largest wildfires in New Mexico state history. Not only were 63 residences and 49 outbuildings destroyed during the Las Conchas wildfire, smoke directly impacted areas downwind of the fire throughout the duration of the event.

Biomass combustion emissions can be transported over hundreds of kilometers, such that air quality is degraded even at great distances from forest fire locations (Gillies et al. 1996, Sapkota et al. 2005). The smoke that is transported during these episodes is primarily composed of $PM_{2.5}$ (airborne particulate matter with aerodynamic diameters of ≤2.5 microns). Larger particles (those >10 µm in aerodynamic diameter) tend to settle closer to their source due to gravitational settling, while ultrafine particles (those < 100 nm) tend to coagulate, leading to loss of particles in that size fraction (Hinds 1982, Zhu et al. 2002).

Forest fire smoke impacting downwind populations can be episodic, with elevated ambient $PM_{2.5}$ concentrations lasting from hours up to weeks at a time. If the downwind impacts are sustained, elevated $PM_{2.5}$ concentrations can result in exceedances of health based standards such

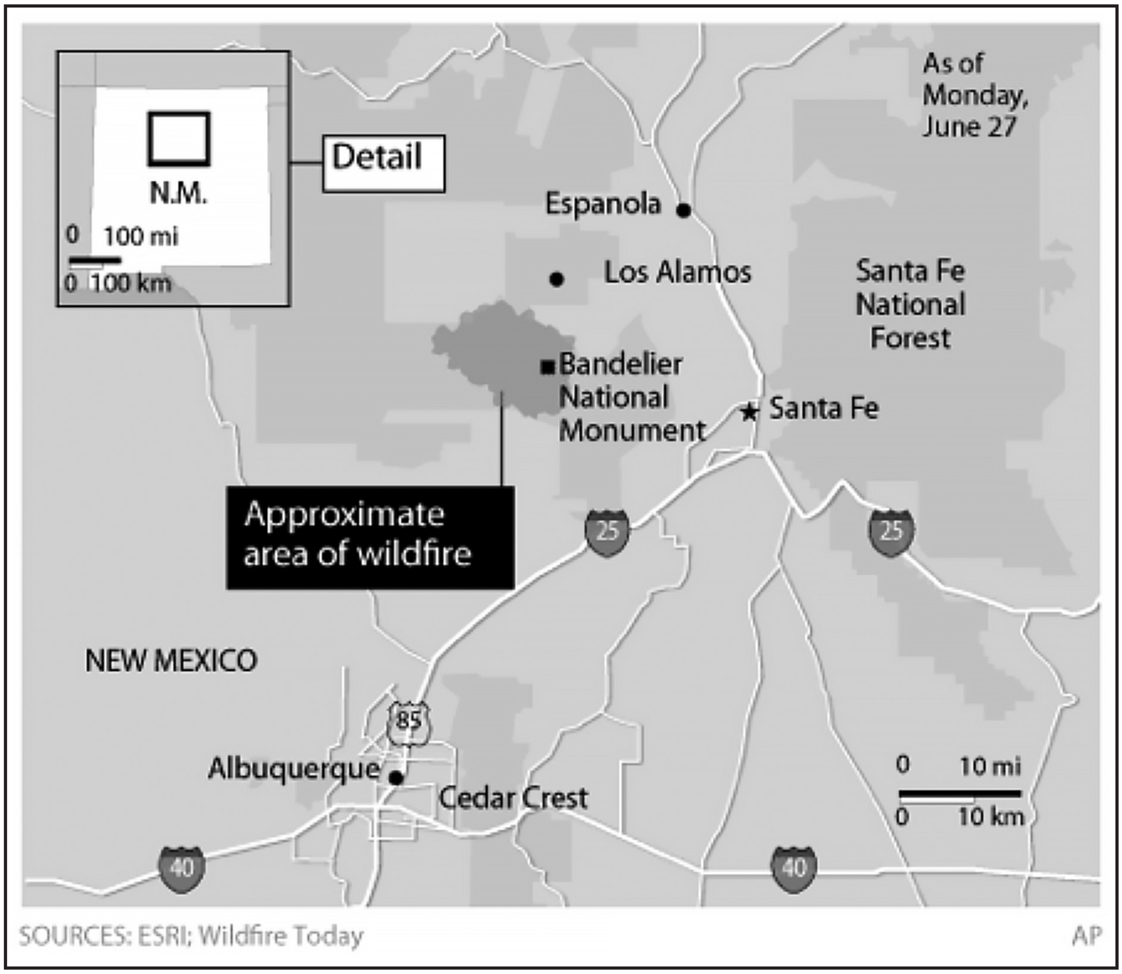


Figure 1. Location of the Las Conchas (New Mexico) wildfire and surrounding communities, summer 2011.

as the Environmental Protection Agency's (EPA) 24-hour National Ambient Air Quality Standard (NAAQS). During such events, source apportionment computer modeling research has shown that over 80 percent of the airborne $PM_{2.5}$ originates from wildfire smoke (Ward and Smith 2005). Less is known about the impact of forest fire smoke on indoor environments during such episodes. This indoor component is critically important, in that most people spend ~95 percent of their time indoors (Fishbein and Henry 1991, Jenkins et al. 1992).

Currently, the primary method of accurately determining the magnitude and duration of forest fire smoke exposures within homes is through indoor air sampling, consisting of expensive sampling equipment operated by trained personnel. However, this can be a challenge if there is a lack of sampling resources – especially if the goal is to simultaneously assess indoor exposures in a large number of homes over an extended period of time. Therefore it is of interest to identify an inexpensive, easy to use and accurate alternative to assessing the impact of forest fire smoke on indoor environments.

Methods and Materials

Sampling Program

Between November 2011 and April 2012, 64 homes were recruited for sampling in north/central New Mexico in areas downwind of the Las Conchas wildfire. Each of these homes had previously filed claims with their insurance companies, requesting that their homes be cleaned to remove forest fire smoke particles that had impacted the interior of their homes. Each home was within 100 km of the Las Conchas fire and was located in the following communities: Cordova, Espanola, Chimayo, Velarde, Los Alamos, Santa Cruz, Cuarteles, Alcalde, San Juan Pueblo, La Mesilla, Ojo Caliente, Rio Rancho, Chamita, Santa Fe, Fairview, Penasco and San Juan Pueblo (El Grique).

As this study aimed to qualitatively determine the presence of forest fire smoke by-products within the homes (weeks to months following the actual forest fire event), active air sampling was not conducted during the home visits. In lieu of air sampling, three individual surface wipe samples of visible dust were collected within each of the homes using pre-moistened 1 x 1" isopropyl alcohol pads. Sampling was conducted by wiping flat, horizontal, undisturbed surfaces (10 cm x 10 cm) such as windowsills, tops of fan blades, tops of shelves and door jambs, etc. For consistency within the homes, we focused our wipe sample collection efforts within the common areas and bedrooms of the residences. Once the samples were collected, the alcohol pads were placed in pre-labeled Ziplock baggies.

Analytical Program

All wipe samples were sent to LA Testing (South Pasadena, CA) where they were analyzed for wildfire combustion by-products (char and ash) using Polarized Light Microscopy (PLM) following the Visual Area Estimation Method (used in asbestos analysis for bulk samples EPA 600 method). Char is a solid decomposition product composed of particles that are larger than 1μm. Char may preserve the original form (including cellular morphology) of the material that was burned and is mostly composed of elemental carbon (with lesser concentrations of other elements). Ash is the mineral content of a product remaining after complete combustion of vegetation. The main difference between ash and char is that ash may not preserve any of the original morphology of the precursor and it may have a higher concentration of inorganic components (including calcium) due to the complete combustion of some of the organic matrix (Moffett, 2010).

Results

Ambient $PM_{2.5}$ Concentrations During the Wildfire

During the time period when the Las Conchas wildfire was burning (26 June-1 August, 2011), ambient $PM_{2.5}$ concentrations were elevated in locations downwind of the wildfire. In Los Alamos (located 20 kilometers northeast of the fire), the EPA's Air Quality Index (AQI) for $PM_{2.5}$ ranged from "Unhealthy" to "Hazardous", with elevated 24-hr concentrations measuring 68.2 $\mu g/m^3$ on 11 June and 258.9 $\mu g/m^3$ on 30 June (Resnick et al. 2013). Both of these samples from these days exceeded the 24-hr $PM_{2.5}$ NAAQS of 35 $\mu g/m^3$. Though we do not have measured ambient $PM_{2.5}$ concentrations from any of the other communities targeted in this study, many homeowners reported being in smoke for extended periods of time throughout the duration of the Las Conchas wildfire (personal communication).

Wipe Samples

Table 1 presents the results of the wipe samples. Importantly, ash was not found on any of the wipe samples collected within the 64 homes, likely due to the larger sizes of these particles (that deposited near the source) compared to the char. However, 50 of the 64 homes that were sampled contained measurable concentrations of char above the Limit of Quantitation (LOQ, ~1%, based on surface area). The majority of the homes that tested positive for char

Table 1. Char concentrations measured from wipe samples collected in 64 homes after the Las Conchas, New Mexico fire in 2011.

Char Concentrations	Number of Homes
<1% in all wipe samples (non detects)	14
1-2%	37
2-5%	10
>5%	3

had an average concentration between 1 and 2 percent (Table 1). Ten of the homes had average concentrations between 2 and 5 percent, while three homes had concentrations above 5 percent (9.7, 6.3 and 5.7%). The variability within the three samples per home ranged from 0 to 13.3 percent, with an overall standard deviation of 1.5 percent across all homes. The highest char concentrations from individual wipes were measured within a home ~42 km from the fire (25%) and a home ~60 km from the fire (15%).

Char Concentration Gradient Mapping

Using Google Maps, sampling points (addresses of the homes) were plotted on a satellite map of the north/central New Mexico region. Once points were plotted, a color was assigned to each respective point based on the concentrations of char measured from the wipe samples collected within the residences. For the purpose of mapping (e.g., to get a wider distribution of sample points), final concentrations (per home) were determined by summing the concentrations of each of the three individual wipe results collected. In presenting the different concentrations in the map (Fig. 2), the following color scheme was utilized: green (<1% char detected); blue (1-4% char detected); yellow (5-9% char detected); and red (10-30% char detected). The results in Figure 2 illustrate that char was consistently measured above the 1 percent LOQ within the majority of homes sampled in areas located to the northeast, east, southeast and south of the Las Conchas fire.

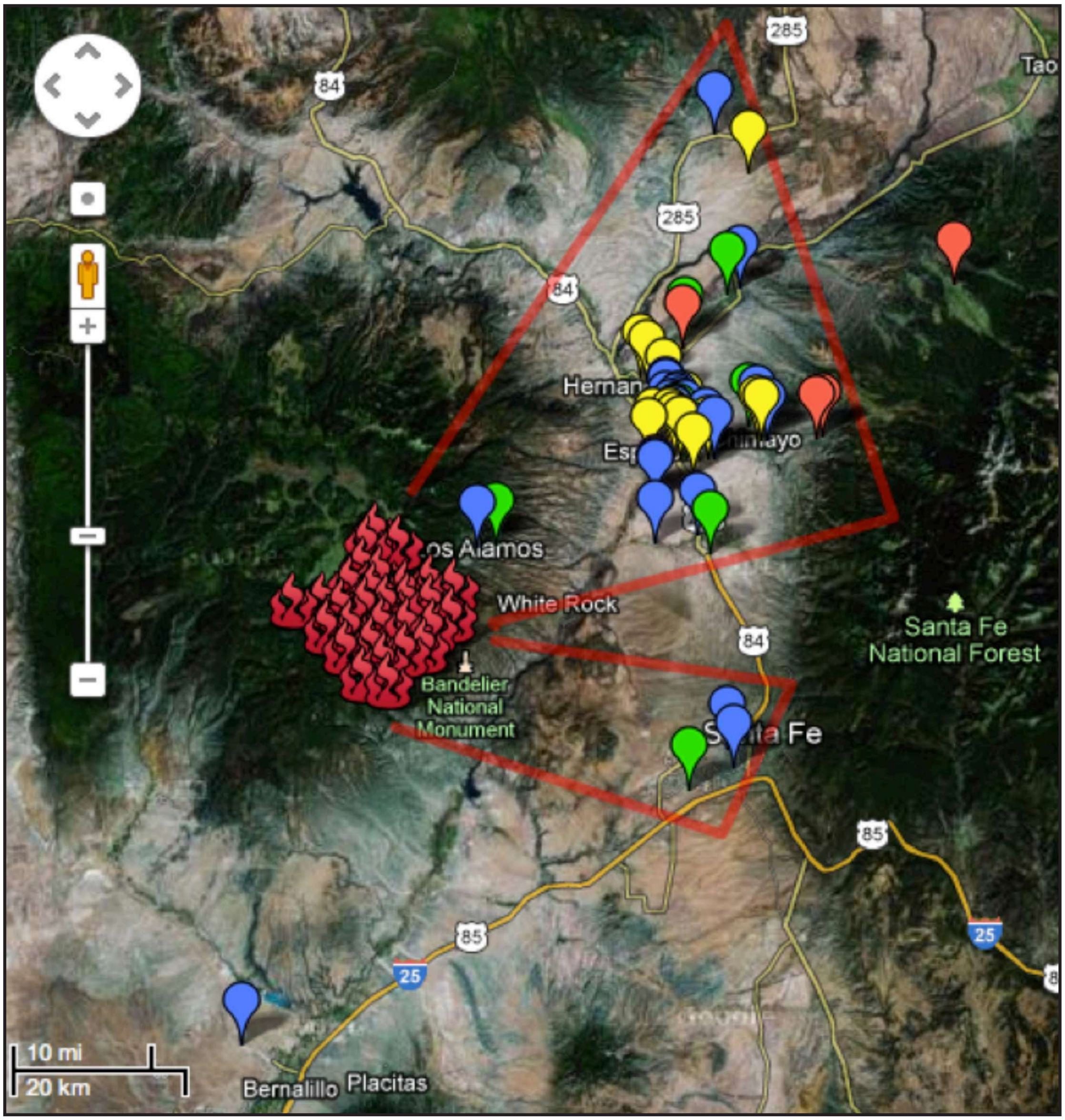
Discussions

The Impact of Smoke on Downwind Communities

Forest fire smoke is composed of a complex mixture of air pollutants in both particulate and gas-phases. Of the thousands of chemicals identified, many have well-documented adverse human health effects. Fine particulate matter ($PM_{2.5}$) is the largest pollutant in wood smoke and can travel hundreds of kilometers once emitted into the air, degrading local air quality even at great distances from forest fire locations (Gillies et al. 1996, Sapkota et al. 2005). During the summer months, the prevailing wind directions (direction with the highest percent of frequency) as measured by the Los Alamos meteorological monitoring site (near the Las Conchas fire) were from the south to the north (Western Regional Climate Center, 2012). The wind direction suggests that areas ranging from the west-northwest to the east-northeast of the fire were likely impacted by smoke at variable concentrations and frequency throughout the duration of the wildfire.

During forest fire events, smoke from the ambient air can penetrate the indoor environment, resulting in elevated, prolonged human exposures. Henderson et al. (2005) found that indoor $PM_{2.5}$ concentrations were 58–100% of the concentrations measured outdoors during one prescribed burn and three wildfires during the 2002 Colorado fire season. During 2002 Canadian forest fires, Sapkota et al. (2005) found that penetration of ambient $PM_{2.5}$ indoors during a smoke event was efficient (median indoor-to-outdoor ratio 0.91), such that the high ambient levels were similarly experienced indoors. Barn et al. (2008) measured infiltration rates in homes in British Columbia affected by summer forest fire smoke, concluding that a person remaining indoors gained little protection from outdoor smoke.

Prior to sample collection we hypothesized that the homes closest to the fire would have the greatest concentrations of char measured from the wipe samples compared to homes further from the fire. However, this was not the case (Fig. 2). Some of the homes closest to the fire (Los Alamos, ~10 km away) had minimal char measured within their homes (although one of these homes had already been cleaned by a restoration professional prior to sample collection), while homes furthest from the fire (>50 km) had elevated char concentrations. Statistically, there was not a



Note: green (<1% char detected); blue (1-4% char detected); yellow (5-9% char detected); and red (10-30% char detected).

Figure 2. Mapping of residential wipe sampling results.

strong correlation between distance from the wildfire and char concentrations measured within the homes. When comparing the two variables across all 64 homes, a correlation coefficient of 0.35 was calculated. Correlations between distance from the wildfire and char concentrations in homes within 30 km of the fire (n=38, communities of Los Alamos, La Mesilla, Espanola, Santa Cruz and Cuarteles) were small (correlation coefficient = 0.20). Statistically insignificant correlations occurred in homes greater than 30 km away from the fire (n=26, communities of San Juan Pueblo, Santa Fe, Fairview, Chimayo, Cordova, Chamita, Velarde, Alcalde, Rio Rancho, Penasco and Ojo Caliente), where a correlation coefficient of 0.25 was calculated.

A greater frequency of sampling was conducted in the Espanola area (~30 km from the fire) compared to the other communities. Results from the Espanola homes showed that the majority of residences tested positive for char. However, there were some homes in the vicinity that did not measure any char from the indoor wipe samples. This variability could be explained by residential behaviors within the homes. For example, some of the homeowners may have thoroughly cleaned or painted the indoor environment following the wildfire (and prior to wipe sample collection). In addition, physical building characteristics of the homes could explain some of the variability. This includes some homes being sealed tighter than others, preventing the penetration of ambient particles to the indoor environment. In addition, some of the homes could have utilized air filtration systems during the wildfire event. Unfortunately, none of these confounding variables were recorded during the wipe sampling program.

Effectiveness of Indoor Wipe Samples to Assess the Presence of Wildfire Smoke

In order to accurately assess indoor exposures, air sampling equipment is typically used by trained personnel to collect samples. To collect samples within a large number of homes, many sets of equipment would be needed, with a corresponding increase in equipment costs as well as the level of effort of sampling personnel. In addition, it is difficult to predict when and where a wildfire will occur and if smoke will be impacting indoor environments during the sampling program. Oftentimes the smoke plume passes directly over communities, while other times the communities and homes are directly impacted for extended periods of time. All of these factors underscore the difficulty in conducting wildfire smoke sampling in downwind communities and the need for a cheap, easy to use, reliable and efficient method of evaluating indoor smoke exposures.

In contrast to comprehensive air sampling programs, utilizing wipe samples (and analyzing for char and ash) is a simple and inexpensive way of determining if an indoor environment has been exposed to forest fire smoke. Wipe samples have been used in a variety of applications to measure contaminants from surfaces including those in buildings, homes, outdoor areas and hands (dermal wipes). Specifically, wipe samples have been used to test household surfaces for lead, airport luggage screening for explosives and post-remediation sampling of methamphetamine houses (USEPA 2007). However, there are some limitations to using this technique. Although wipe samples give a qualitative result indicating whether the indoor residence was infiltrated with forest fire smoke, it provides little information on actual human exposures that may have occurred within the homes. It also provides little information on actual exposure concentrations, length of exposures, etc. There are also other factors that can influence ash/char concentrations measured within a home, including home ventilation rates and surface cleaning activities.

Residential wood stoves or other combustion devices can also be a source of biomass smoke inside homes. During the routine operation of a wood stove, loading and stoking activities can release wood smoke particles inside the home (Ward et al. 2008). These residential heating wood smoke particles may be similar to those deposited (and subsequently measured) within the home during forest fire smoke events. Although wood stoves were present in a small number of homes (<5) sampled, their presence does not explain our overall findings of char in most houses.

Conclusions

There is a growing body of evidence from human and animal studies that suggest that exposure to wood smoke poses a risk to human health (Ezzati and Kammen 2002, Zelikoff et al. 2002, Lewtas 2007, Naeher et al. 2007). In addition to human health concerns, Moffett (2008) details the damaging impact that forest fire soot can have on the contents of a home. Suspended particles can penetrate upholstery, drapes and insulation and can also electrostatically adhere to electronic components. The chemical makeup (including acidity) of forest fire smoke particles can damage the contents of a home, causing discoloration, corrosion and overall damage (Moffett

2008). In addition to the corrosive properties of wood smoke, odors from forest fire smoke can also persist long after the smoke has cleared, causing an ongoing nuisance problem.

During the summer of 2011, smoke from the Las Conchas wildfire impacted downwind communities at varying frequencies and durations. Given that char was measured within 50 of the 64 homes that were investigated in this study, it is likely that additional homes in the surrounding areas were similarly impacted. As illustrated from the concentration gradient map we were unable to identify downwind areas that were completely free of smoke measured within homes (noted by the presence of char)(Fig. 2).

Although forest fires are a large source of $PM_{2.5}$ and other pollutants to the ambient environment, the impact on the indoor environment is often overlooked and misunderstood. This is concerning in that most people spend ~95 percent of their time indoors (Fishbein and Henry 1991, Jenkins et al. 1992). In homes impacted by smoke, there is also a concern about secondary and ongoing exposures within the home. Perhaps understated in previous reports, $PM_{2.5}$ that has settled indoors can be re-entrained into the air by even small disturbances, leading to continued human exposures inside the home. All of these factors suggest that in addition to concerns with smoke impacting the homes during the wildfire event, there are additional concerns regarding the indoor environment to consider even after the wildfire has been extinguished.

Assessing the impact of forest fire smoke on residential environments is important, whether it be in support of an insurance claim (to assess damages prior to restoration) or in estimating human wood smoke exposure and its effects on health. The use of wipe samples in this project demonstrated some of the advantages as well as the limitations of this technique. Wipe samples collected from areas downwind of the Las Conchas wildfire showed that the majority of the homes sampled measured char. However, results from this study cannot determine how much exposure each of the homes and residents received throughout the forest fire event. Given the practicality and lower expenses of the wipe sampling/analytical method, the findings from this project demonstrate that collecting wipe samples can be qualitatively used to assess $PM_{2.5}$ wildfire smoke impacts within homes in lieu of a more comprehensive and expensive residential air sampling program. In support of the wipe sampling program, an initial survey that controls for confounders (open burning outside the home, presence of wood stove or ventilation system, etc.) and an observational survey performed during wipe sampling to validate the lack or presence of confounders should be conducted in an effort to further explain overall findings.

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Literature Cited

Barn, P., Larson, T., Noullett, M., Kennedy, S., Copes, R., Brauer, M. 2008. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. Journal of Exposure Science and Environmental Epidemiology. 18(5): 503-511.

Ezzati, M. and D.M. Kammen. 2002. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps and data needs. Environmental Health Perspectives. 110(11): 1057-1068.

Fishbein, L. and C. Henry. 1991. Introduction: workshop on the methodology for assessing health risks from complex mixtures in indoor air. Environmental Health Perspectives. 95: 3–5.

Gillies, J.A., Nickling, W.G., Mctainsh, G.H., 1996. Dust concentrations and particle-size characteristics of an intense dust haze event: inland delta region, Mali, West Africa. Atmospheric Environment. 30(7): 1081-1090.

Henderson, D.E., Milford, J.B., Miller, S.L. 2005. Prescribed burns and wildfires in Colorado: Impacts of mitigation measures on indoor air particulate matter. Journal of the Air and Waste Management Association. 55(10): 1516-1526.

Hinds, W.C. 1982. Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles. John Wiley & Sons.New York.

Jenkins, P., Phillips, T., Mulberg, J., Hui, S. 1992. Activity patterns of Californians: use of and proximity to indoor pollutant sources. Atmospheric Research. 26A: 2141–2148.

Lewtas, J. 2007. Air pollution combustion emissions: characterization of causative agents and mechanisms associated with cancer, reproductive and cardiovascular effects. Mutation Research: Reviews in Mutation Research. 636(1-3): 95-133.

Moffett, P. 2008. Soot particles: A procedural guide for containing and removing wildfire - caused soot in buildings. Environmental Management & Engineering, Inc.

Moffett, P. 2010. Wildfire glossary of environmental, insurance and restoration terms and definitions: building assessment, cleaning, restoration and clearance, Version 5. http://www.scrt.org/free-reports/doc_view/127-wildfire-glossary-version-5.

Naeher, L.P., Brauer, M., Lipsett, M., Zelikoff, J., Simpson, C.D., Koenig, J.Q., Smith, K.R. 2007. Woodsmoke health effects: A review. Inhalation Toxicology. 19(1): 67-106.

Resnick, A., Woods, B., Krapfl, H. and Toth, B. 2013. Health outcomes associated with smoke exposure in Albuquerque, New Mexico during the 2011 Wallow Fire. New Mexico Epidemiology. 2013(6): 104.

Sapkota, A., Symons, J.M., Kleissl, J., Wang, L., Parlange, M.B., Ondov, J., Breysse, P.N, Diette, G.B., Eggleston, P.A., Buckley, T.J. 2005. Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore City. Environmental Science and Technology. 39(1): 24-32.

United States Environmental Protection Agency (USEPA). 2007. A literature review of wipe sampling methods FOR chemical warfare agents and toxic industrial chemicals. EPA/600/R-07/004, January 2007.

Ward, T.J., Smith, G.C. 2005. The 2000/2001 Missoula valley PM2.5 Chemical Mass Balance study, including the 2000 wildfire season – seasonal source apportionment. Atmospheric Environment. 39: 709-717.

Ward, T.J., Palmer, C., Bergauff, M., Hooper, K., Noonan, C. 2008. Results of a residential indoor PM2.5 sampling program before and after a woodstove changeout. Indoor Air. 18: 408–415.

Western Regional Climate Center. 2012. (http://www.wrcc.dri.edu/htmlfiles/westwinddir.html).

Zelikoff, J.T., Chen, L.C., Cohen, M., Schlesinger, R.B. 2002. The toxicology of inhaled woodsmoke. Journal of Toxicology and Environmental Health-Part B-Critical Reviews. 5(3): 269-282.

Zhu, Y., Hinds, W.C., Kim, S., Sioutas, C. 2002. Concentration and size distribution of ultrafine particles near a major highway. Journal of the Air and Waste Management Association. 52(9): 1032-1042.

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