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Monitoring Firefighter Exposure to Air Toxins at Prescribed Burns of Forest and Range Biomass

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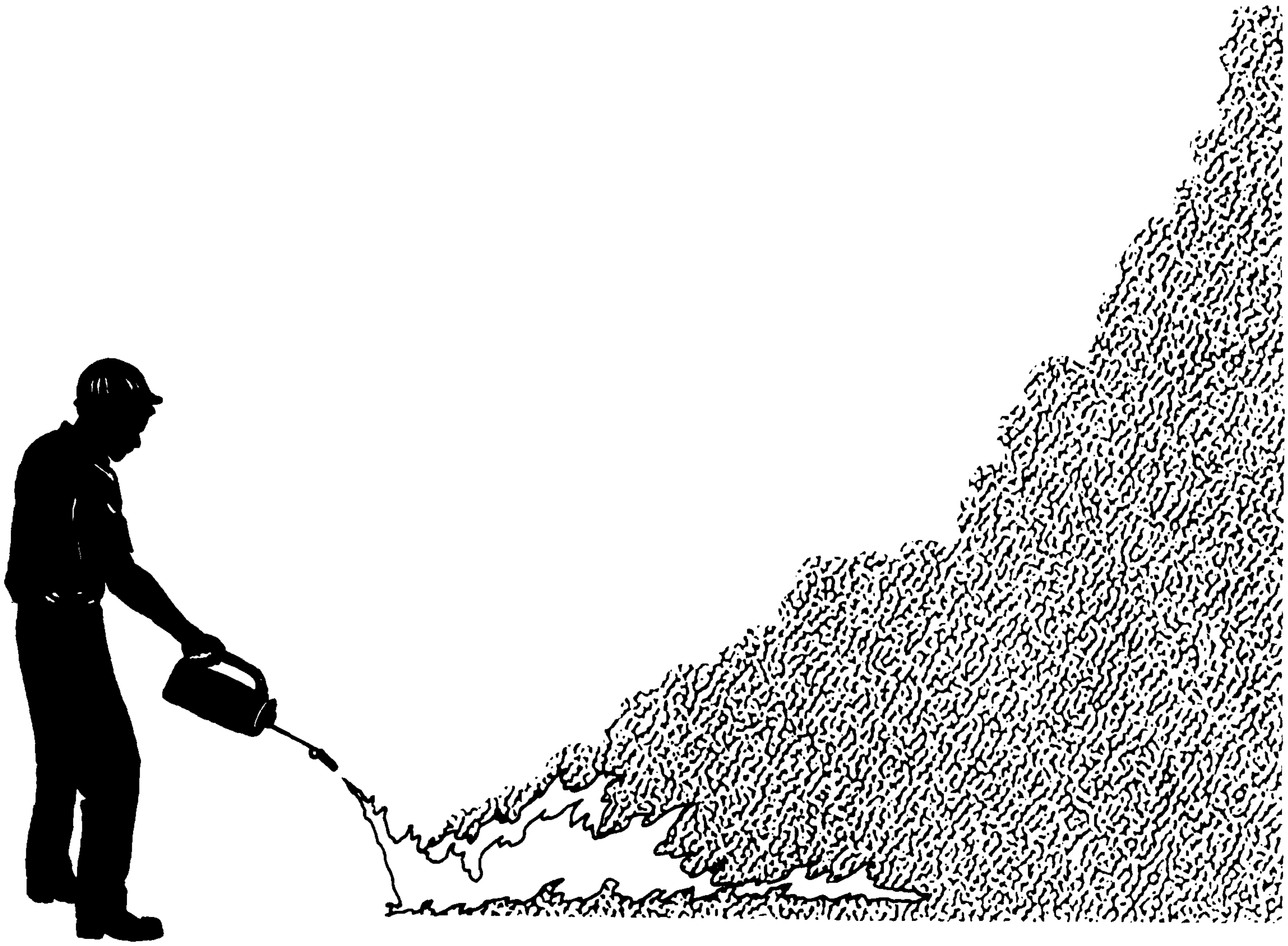

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Abstract

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A variety of potent air toxins are in the smoke produced by burning forest and range biomass. Preliminary data on firefighter exposures to carbon monoxide and formaldehyde at four prescribed burns of Western United States natural fuels are presented. Formaldehyde may be correlated to carbon monoxide emissions. The firefighters' exposures to these compounds relative to workplace standards are discussed.

Keywords: Firefighter health, air toxins, formaldehyde, carbon monoxide.

Summary

Many potent air toxins are in the smoke of burning forest and range biomass. Firefighters are exposed to the smoke of both wildfire and prescribed fire. A comprehensive assessment of these exposures is not yet possible due to insufficient data. Preliminary data on firefighter exposures to carbon monoxide and formaldehyde at four prescribed burns of Western United States natural fuels are presented. At these well-managed prescribed burns, occupational exposure limits for these compounds were not exceeded. In the exposure samples taken, formaldehyde was correlated to carbon monoxide emissions. The firefighters' exposures to these compounds relative to workplace standards are discussed.

Contents

Introduction

Because firefighter exposures to the air toxins in smoke from prescribed burns and wildfires are not adequately understood, we have begun a study to achieve the following goals:

(1) to obtain a first approximation of the exposures that firefighters face in different fire-control situations;

(2) to test the feasibility of personal monitoring methods, including passive dosimetry, in the complex fire environment; and

(3) to evaluate the correlation between carbon monoxide and other air toxins in smoke.

Prescribed fire is a tool commonly used by land managers today. Among its applications, fire is used to reduce wildfire hazard and competing vegetation in forested areas, as a site preparation before tree planting, and to improve forage value of range lands. The USDA Forest Service and other forest and rangeland managers employ many thousands of firefighters nationwide to manage these prescribed burns as well as to suppress wildfires. Firefighters can be exposed to several potent air toxins in the smoke from burning vegetative biomass.

The atmosphere near the fire is complex and prone to interferences in sample collection and analysis. In addition to the extremes of heat and humidity near a large fire, the smoke contains hundreds of organic and inorganic combustion products. Of those that are toxic or carcinogenic in humans, few are present in high enough concentrations to pose a potential health threat. Earlier work has identified carbon monoxide (CO) as a potential health threat to firefighters (Jackson and Tietz 1989). In addition to CO, we have identified low-molecular-weight aldehydes (including formaldehyde [HCHO], acrolein, and furfural), respirable particulate (PM2.5), and benzene as potential firefighter health threats. Many polycyclic aromatic hydrocarbons (PAH) are also common components of the particulate phase of smoke. For validation, workplace monitoring methods for these compounds must be tested in the conditions that they will be used in.

Experimental Methods

Monitoring of firefighter exposures to smoke was accomplished at four prescribed fires in October 1988 on the Lake Wenatchee District of the Wenatchee National Forest in central Washington. These were broadcast burns of debris (slash) left after clearcut logging in mixed-conifer stands ranging in size from 4 to 44 acres. The general burning plan for broadcast burns is to ignite the top and center of the unit to be burned, thereby forming a strong convection column that draws fresh air towards the center of the unit. The edges of the unit are then ignited, and the heat and smoke are carried towards the center, away from the firelines. About 20 to 30 firefighters, 5 fitted with smoke sampling packs, were involved in each burn.

The firefighters' activities include several tasks: (1) lighting, which involved igniting the area to be burned by walking through the slash while dripping a burning mixture of gasoline and diesel fuel; (2) line holding, which requires the firefighter to stand guard, often in smoke, to keep the fire within the boundaries of the burn area; (3) direct attack, which was a consequence of spot-fires ignited by sparks and brands blown across the fire line which the firefighter must then extinguish with a fire hose, axe, and shovel; and (4) mop-up, which occurs after the main burn is smoldering and involves extinguishing "hot spots." This work often continues for several days.

The smoke sampling packs were flameproof, lightweight, and designed not to catch in heavy brush. Each pack contained a personal air-sampling pump (Gilian Instruments[1]) which drew air at approximately 300 milliliters per minute through an inlet at the firefighters' breathing zone. A C-18 sample clean up cartridge (Waters Associates), at the inlet, was impregnated with 2,4-dinitrophenylhydrazine.

Aldehydes, including formaldehyde, were efficiently chemisorbed in this cartridge. At the laboratory, the cartridges were eluted with 2.0 milliliters acetonitrile and analyzed by liquid chromatography. Authentic aldehyde derivatives were prepared and recrystallized for use as standards (Hull 1985, Kuwata and others 1983).

A constant fraction of the exhaust of the pump was used to fill an inert gas bag (Calibrated Instruments) over the sample period. The integrated gas sample collected was analyzed for CO by nondispersive infrared spectroscopy (Wilson and others 1983) by using a standard CO mix traceable to the National Bureau of Standards. Carbon monoxide samples were obtained sequentially from a firefighter over 0.5 to 1.5 hours during the burns; the duration depended on logistics and our visual estimates of the homogeneity of the smoke exposures at the time. The individual CO samples collected from a given firefighter in a day were time-weighted and averaged to derive exposures over 1.5 to 3 hours, which was the total duration of the firefighters' exposures on this set of burns. The aldehyde samples were concurrently taken from each firefighter over 1.5 to 3 hours. Sampling was not meant to statistically describe the exposures of the firefighters, but to test method performance and obtain estimates of the concentration ranges to be expected.

In addition to the above two active sampling methods, two commercial dosimeters were compared for their performance at monitoring HCHO and CO on the same subjects and time periods. These were direct-reading passive diffusion tubes from Sensidyne and Draeger, respectively. These devices are sealed glass tubes filled with an indicator sorbent. The tube end is opened, the tube clipped to the firefighter, and the exposure estimated at the end of the sample period by reading a length-of-stain indicator scale. The exposure is then adjusted for temperature and pressure variation from the calibration conditions.

Results

A frequency distribution for all individual CO samples is shown in figure 1. The limit for worker exposure to CO recommended by the American Council of Government Industrial Hygienists (ACGIH) is 35 parts per million (ppm) by volume time-weighted over 8 hours. Additionally, a ceiling limit of 200 ppm is recommended. Only 3 of 49 samples were above 35 ppm by volume. The skewed nature of the graph suggests a "log-normal" distribution, typical of industrial hygiene measurements.

The time-weighted average (TWA) CO exposures are presented in figure 2, grouped by work activity. Samples divided over two activities have combined designations. Firefighters that were lighting the burn generally had low exposures to CO. Line-holding was variable in firefighter CO exposure, from 0 to 14.2 ppm by volume; the exposure depended on whether one was upwind or downwind of the burn. Direct attack activity around small spotfires downwind of the burn produced the highest exposures. Mop-up activites did not occur on the sampled days.

[1] Mention of a commercial or proprietary product in this publication does not constitute endorsement by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

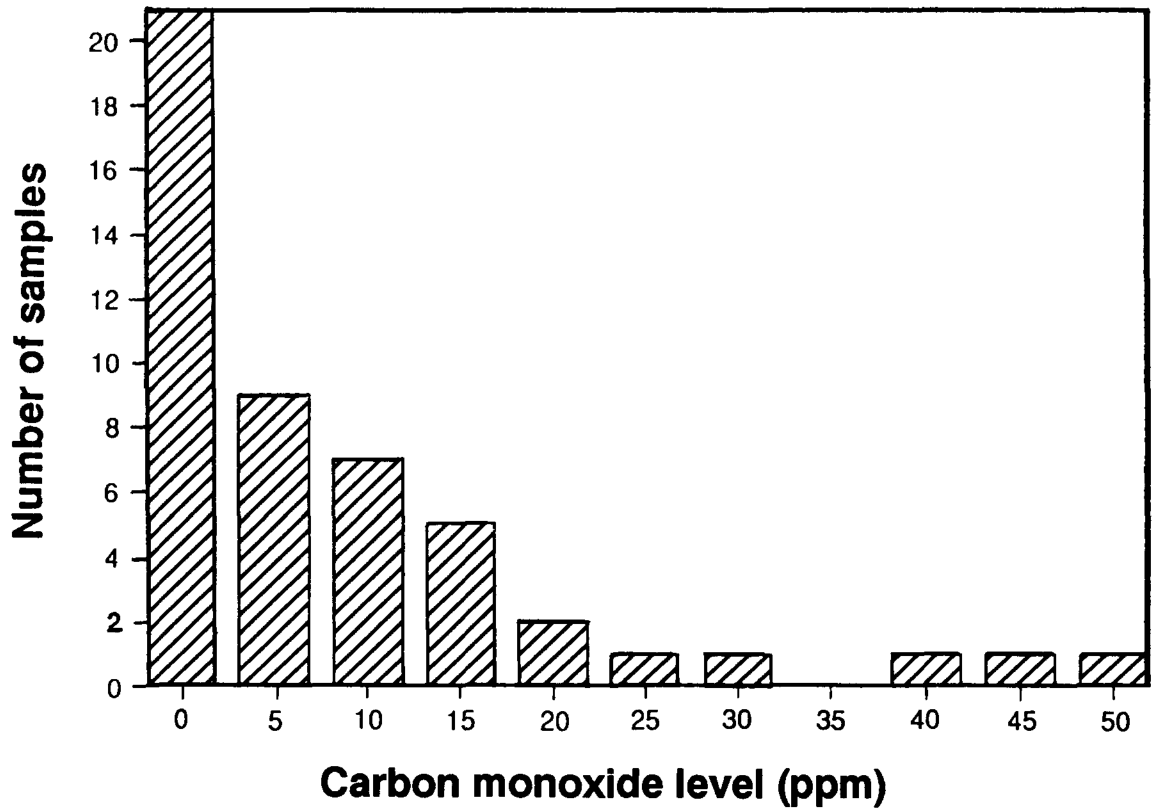

Figure 1—Carbon monoxide concentration summary: four autumn slash burns, 49 samples.

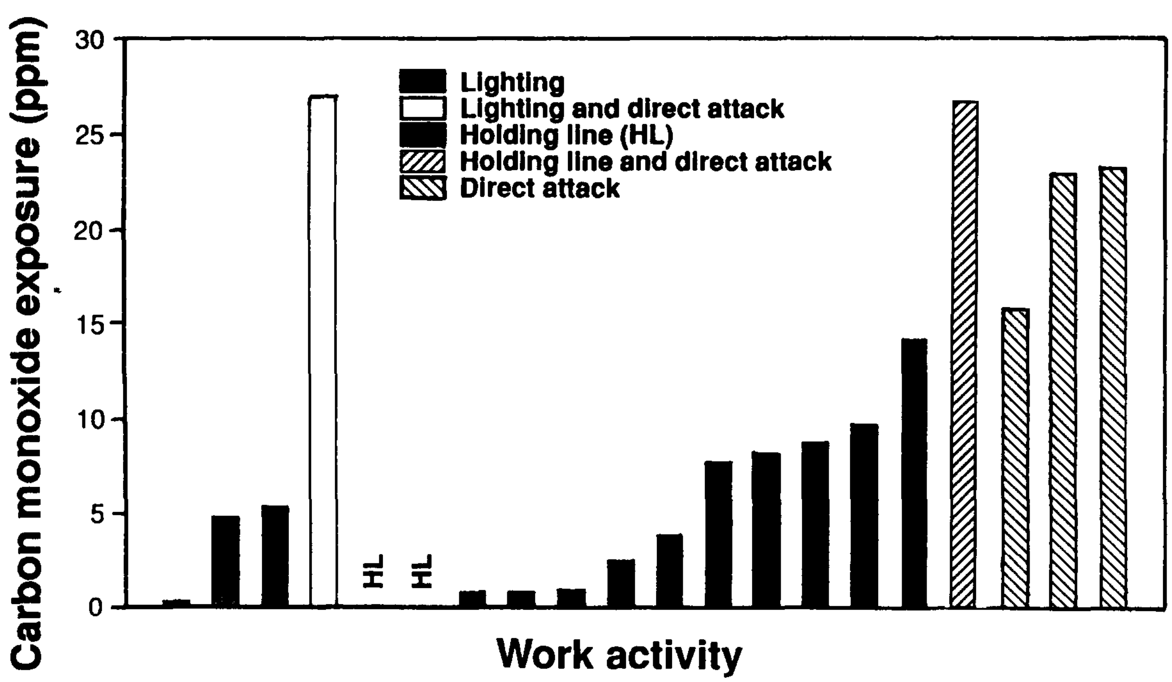

Figure 2—Carbon monoxide exposure by work activity for each firefighter over 1.5 to 3 hours.

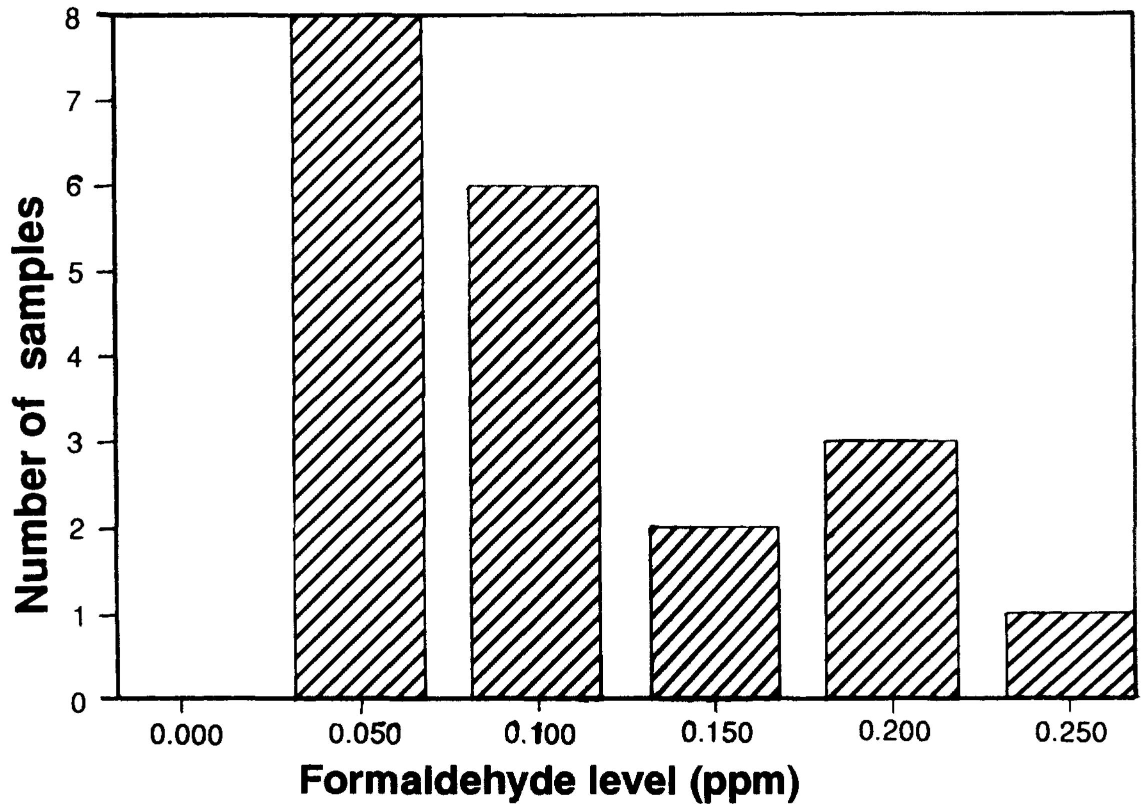

Figure 3—Formaldehyde concentration summary: four autumn slash burns.

The frequency distribution of the formaldehyde sample concentrations is shown in figure 3. There are no zero values because there is a natural low parts per billion (ppb) HCHO background. A skewed trend in the frequency distribution is again evident. The ACGIH limit for formaldehyde is 1 ppm over 8 hours; a short-term limit is further recommended by the National Institute of Occupational Safety and Health (NIOSH), 2 ppm over any 15 minutes. None of the samples exceeded one-quarter of the exposure standards; as with the CO TWA exposures, they are grouped by work activity in figure 4. A similar trend to the CO data is apparent; lighting exposures were higher in intensity relative to the other work activities, line-holding exposures differed, and direct attack of small spot-fires was the highest in HCHO exposure.

Acrolein was detected in 20 samples in the range 0 to 20 ppb. Calibration difficulties at the time precluded our obtaining good quantitative data, but its presence should be mentioned because it is a very potent irritant (ACGIH limit of 100 ppb over 8 hours). Many of the irritation effects complained of among firefighters are similar to those reported for acrolein exposure. Furfural was also detected but not quantified.

The results of the indicator-tube passive dosimeters for CO were compared with the bag sample, infrared spectroscopy method over concurrent periods on the same firefighters. The two methods agreed, but not perfectly, as is shown in figure 5. The dosimeters were relatively insensitive below 6 ppm CO, were reasonable indicators of CO exposure at intermediate levels, and overpredicted CO at the two highest concentrations. A line that would correspond to perfect agreement is included on the graph for reference. We were not able to obtain good results with the dosimeters for HCHO, but the CO dosimeters performed fairly well.

A correlation was found between formaldehyde and carbon monoxide, as shown in figure 6. Twenty each of the active-method CO and HCHO samples taken concurrently on the

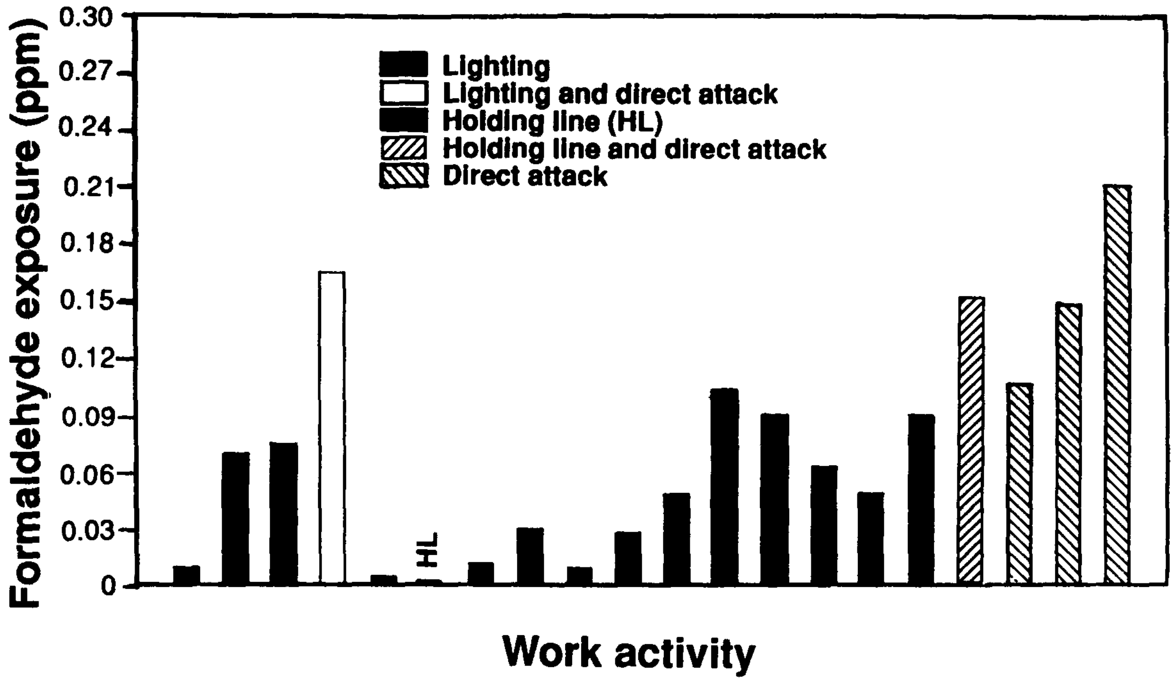

Figure 4—Formaldehyde exposure by work activity for each firefighter over 1.5 to 3 hours.

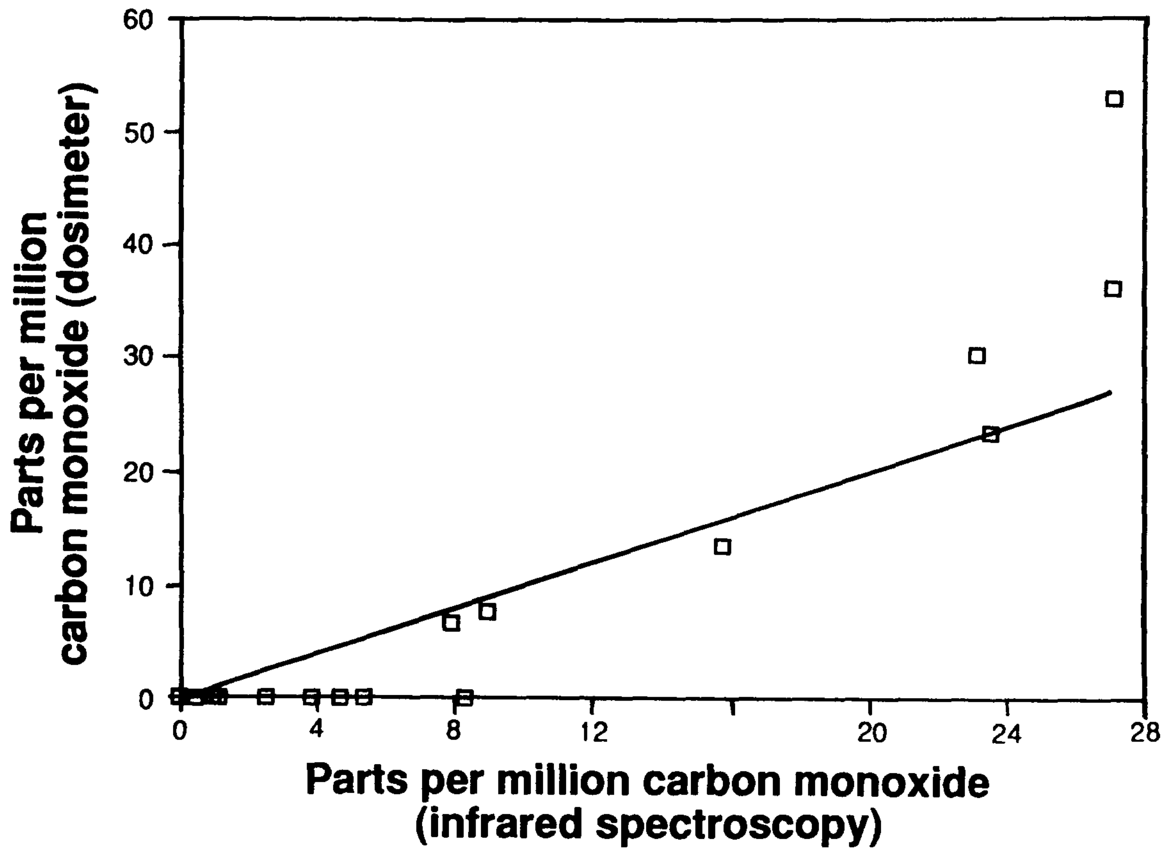

Figure 5—Results of concurrent carbon monoxide sampling by two methods: carbon monoxide dosimeter vs. infrared spectroscopy.

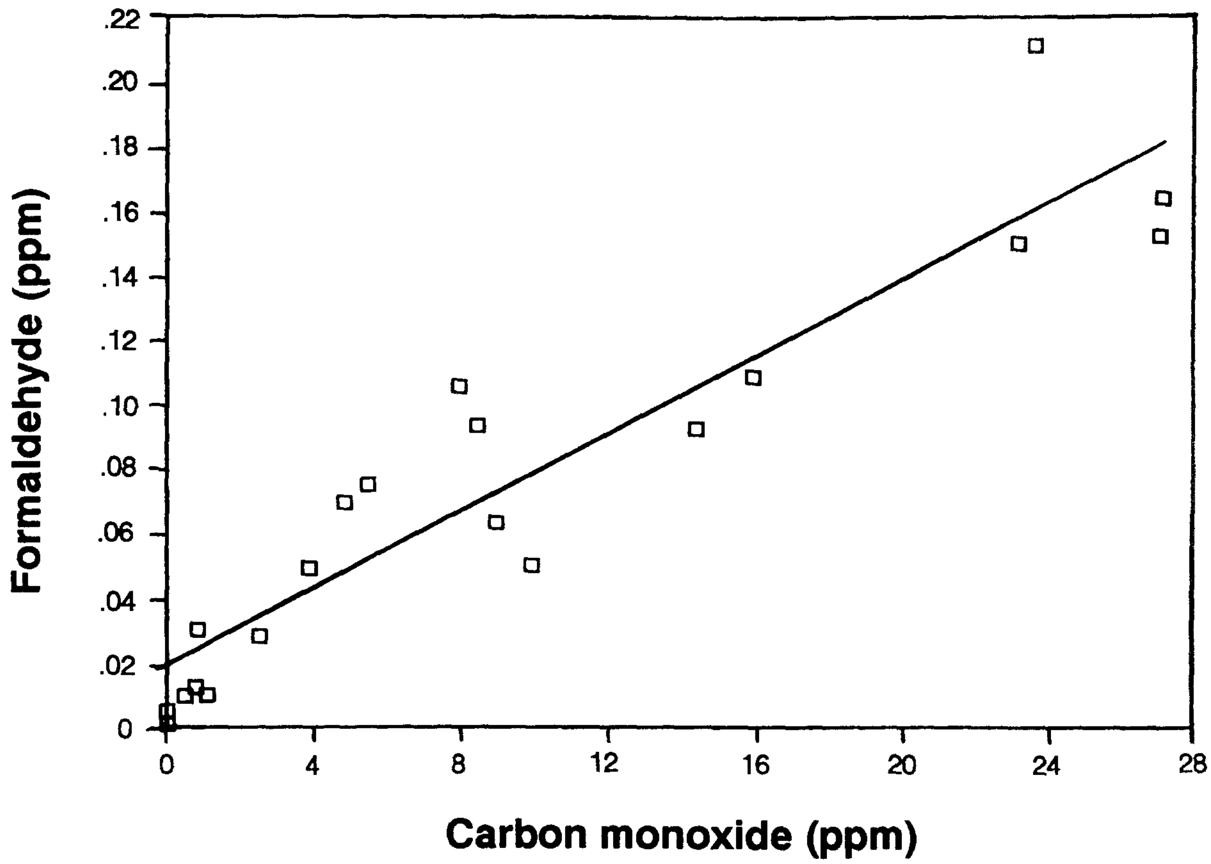

Figure 6—Carbon monoxide vs. formaldehyde: concurrent 1.5- to 3-hour samples.

firefighters were correlated with a simple linear regression; the coefficient of determination (r^2) was 0.865. The equation for the regression was:

$$[HCHO] = [CO] * (6.038 \times 10^{-3}) + 0.019 , \quad (1)$$

where [HCHO] and [CO] are the concentrations of formaldehyde and carbon monoxide in ppm, respectively. The carbon monoxide is a key indicator of combustion efficiency and has been correlated with fine particle mass emissions from broadcast burns of conifer slash (Ward and Hardy 1984).

Discussion

The levels of formaldehyde and carbon monoxide at these burns were significant and had substantial variability. Direct attack and mop up of spot-fires produced the higher exposures, as these situations most often required firefighters to enter areas of dense smoke to extinguish the fires. Lighting crews had more freedom of movement to avoid smoky areas. A breakdown of the convection column at one burn allowed the prevailing winds to carry smoke across firelines and contributed to the line-holder's exposures. The higher smoke exposures were uncomfortable to all involved but were reported to be less than they have experienced at other burns and were not above ACGIH guidelines.

At these burns, the fire managers and firefighters agreed that the smoke exposures seemed to be less than is often encountered. This was due to favorable winds and good burning technique that followed the burn plan. They also agreed that weather and fire behavior combine to frequently produce adverse fire situations, thereby exposing them to denser smoke for longer periods, which can result in health complaints. Mop-up activities may produce higher exposures to some air toxins, because of proximity to the source and the inefficient combustion conditions. We expect that more study will shed further light on which fire situations and activities, if any, result in exposures to air toxins that are a threat to firefighter safety.

Active methods for monitoring firefighters' exposures to carbon monoxide and formaldehyde are feasible. Improvements to our methods will allow acrolein and other aldehydes, respirable particulate and other important air toxins to be concurrently monitored on the same firefighter. An inexpensive passive dosimeter method for CO gives reasonable results. A similar device for formaldehyde was not satisfactory. Laboratory and field validation efforts will continue for active and passive methods.

A linear correlation exists between carbon monoxide and formaldehyde in the smoke exposure samples collected. So far, however, the small data set renders the relation tentative. We will further test this correlation as exposure sampling continues in different fuel types and fire conditions. We hope that a dosimeter that can measure CO feasibly could additionally serve as a useful surrogate for HCHO exposure, thereby allowing widespread monitoring of the two compounds among smoke-impacted populations.

Conclusions

The preliminary data obtained from four autumn prescribed burns of mixed-conifer slash showed that for these broadcast burns, the convection column pulled most of the smoke away from the fireline and minimized firefighter smoke exposures. Exposures to carbon monoxide and formaldehyde were variable and may depend on work activity at the fire. Downwind of the burn, holding fireline and extinguishing spot-fires produced the highest exposure samples among the firefighters.

Substantial progress has been made toward the development of integrative, complementary methods of monitoring different air toxins in the interference-prone fire environment. Passive-type, direct-reading dosimeters for CO have value as an indicator of CO exposure. Similar dosimeters for HCHO did not perform well but may as more experience is gained with them. Further tests of these devices in the fire environment could lead to their common usage by fire managers and crew bosses, who are concerned about firefighters' overexposure to smoke and desire a rapid, simple, and inexpensive exposure indicator.

The emissions of some pollutants may be correlated. We found that carbon monoxide was a good predictor of formaldehyde exposure, based on our limited data. More data are needed to evaluate this correlation.

Research Needs

Future work will involve expansion of our efforts to determine the variability of exposures among firefighters in different fuel types, weather, fire behaviors, and work activities. Other compounds will be monitored as methods are developed. Correlations among individual pollutants will be tested further.

Reports that residual smoke from prescribed burns and wildfires is trapped by topography and impacts down-valley residents is of concern to many. We believe that the smoke exposures of the firefighters may represent the upper bound exposures that rural residents down-valley are likely to face. We hope to test this hypothesis and evaluate correlations among pollutants as they are transported down-valley by monitoring at the source and at intermediate distances toward impacted areas.

Acknowledgments

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