

Health Effects of Exposure

Brian J. Sharkey, Ph.D.

USDA Forest Service Missoula Technology & Development Center and
University of Montana Human Performance Laboratory

For decades, firefighters and fire managers have been concerned about the effects of smoke on wildland firefighters. Interest in the health hazards of smoke intensified after the 1987 and 1988 fire seasons, leading to the development of a comprehensive plan to study emissions, employee exposure, health effects, risk assessment, and risk management (Ward, Rothman, and Strickland, 1989). Studies of the emissions in vegetative smoke indicate the potential for exposure to hazardous emissions. And recent employee exposure studies show that firefighters are exposed to levels exceeding OSHA permissible exposure limits in a small percentage of cases studied. This report summarizes some of the potential health effects of short, intermediate, and long-term exposure to the health hazards of smoke.

Short-Term Exposure

Immediate effects of exposure include symptoms of sore eyes (tearing), cough, and running nose. Data from field first aid stations indicate that 30 to 50% of visits are for upper respiratory problems (cold, cough, sore throat). Some studies indicate that upper respiratory symptoms and problems increase over the course of the fire season. While upper respiratory problems may be due in part to smoke, they may also result from physical exhaustion, psychological stress, and poor nutrition, all factors known to suppress the function of the immune system. The spread of upper respiratory infections may be exacerbated by poor health habits and conditions in fire camps.

The average adult has from one to six colds annually, with approximately 40% caused by rhinoviruses. Athletes and exercise enthusiasts with upper respiratory infections (URI) commonly continue to participate in recreational and competitive sports. Upper respiratory infections caused by rhinoviruses are restricted to the upper respiratory tract. They do not alter pulmonary function measures, or impair submaximal or maximal exercise performance (Weidner et al., 1997). Viruses that produce viremias (virus in the blood) can infect a wide variety of host tissues, including skeletal muscle. When symptoms are “above the neck” (stuffy nose, sneezing, scratchy throat), it is safe to continue work or exercise. If symptoms

include fever, aching muscles, nausea, or diarrhea, hard work or training should be postponed (R. Eichner, M.D., personal communication).

Carbon Monoxide—Carbon monoxide (CO) can cause headaches, dizziness, and nausea, and can impair mental function. Studies of firefighters indicate the potential for overexposure to CO. However, studies of U.S. firefighters (Jackson and Tietz, 1979) and Australian bushfire fighters (Brotherhood, Budd, and Jeffrey, 1990) indicate that cigarette smokers go to a fire with more carbon monoxide in their blood (carboxyhemoglobin-CO_{Hb}) than nonsmoking firefighters have in their blood at the end of a work shift. Documented cases of inversions (Happy Camp, 1987) indicate elevated CO levels in fire camps, levels with the potential to affect the mental function and decisionmaking of incident command personnel.

Blood carbon monoxide levels rise during the period of exposure, taking 8 hours exposure at 35 ppm CO to achieve a blood CO level of 5% CO_{Hb}, the upper limit deemed by OSHA to be consistent with good health (Figure 1). Smokers' CO_{Hb} levels range from 5 to 10% throughout the day. Firefighters are seldom exposed to elevated levels throughout the entire working day, so average exposure is relatively low (4.1 ppm; Reinhardt, Black, and Ottmar, 1995). Since air-purifying respirators do not remove CO from the breathing air, it will be necessary to monitor CO levels to ensure firefighter health and safety and compliance with OSHA standards.

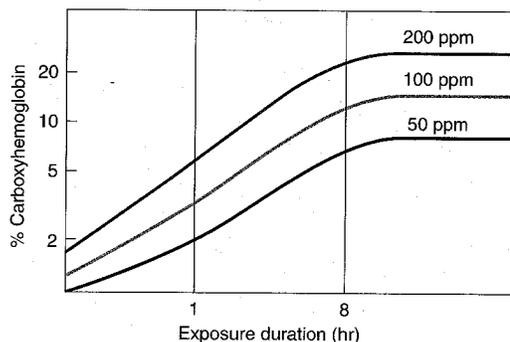


Figure 1—Carbon monoxide (ppm) and %CO_{Hb}.

Pulmonary Function—Studies of firefighters indicate a small but statistically significant decline in lung function from the beginning to the end of the work shift, and from the beginning to the end of the fire season (Bechtley, et al., 1994). Follow-up indicated a return to normal values after a period free from exposure. The respiratory system is over built for its duties, with a maximal breathing capacity (180 liters/minute) that far exceeds ventilatory

requirements at maximal exercise levels (120 liters/minute). Since the ventilatory requirements of firefighting range from 40 to 60 liters/minute, the small (1 to 3%) decline in lung function is not apparent to firefighters.

Intermediate Effects

Days and weeks of smoke exposure can lead to more persistent health effects, including potential suppression of the immune system. Smoke can deaden the ciliary action that sweeps larger particles out of the respiratory tract for expectoration. Without this “ciliary escalator” to clean the lower respiratory tract, particles would slide deeper into the respiratory tract, causing congestion, coughing, and other problems. When such problems are combined with immunosuppression due to smoke, exhaustion, stress, and poor nutrition, the stage is set for bronchitis, and for a prolonged recovery.

Respirable particulate is able to reach the alveolar region of the lung. These small particles are slowly removed by mucus movement up the ciliary escalator, by absorption, or by macrophage destruction. Particulate overload may cause sequestration compartments and formation of chemical reactants. Respirable particulate may transport PAH (polycyclic aromatic hydrocarbon) carcinogens deep into the lungs (Figure 2).

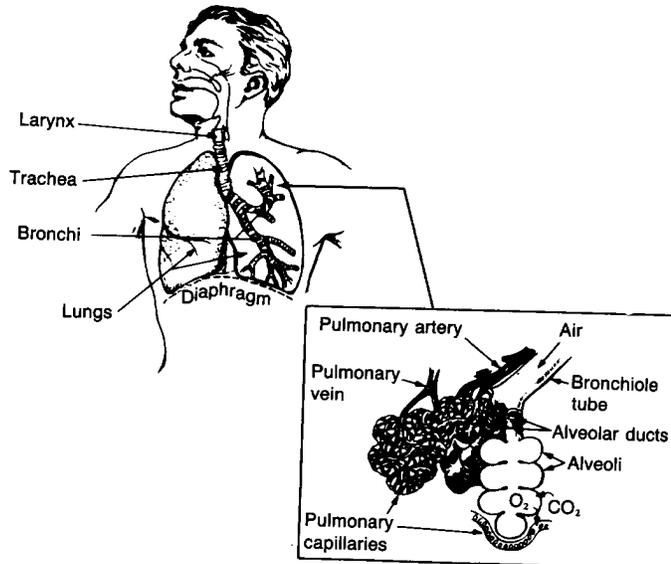


Figure 2—The respiratory system.

In spite of these potential problems, the healthy lung has a remarkable ability to recover from the effects of smoke when it is provided time to recover.

Long-Term Exposure

Little is known about the long-term effects of smoke exposure. Several models, including cigarette smoking, urban air pollution, and structural firefighting have been used to infer possible risks. The literature on cigarette smoking suggests the potential for:

- Coronary artery disease and stroke
- Chronic obstructive pulmonary disease
- Cancer (including the lung and other sites)

However, cigarette smokers reach these end points after decades of daily smoke exposure. Firefighting is seasonal, and exposures are intermittent and episodic. Urban air pollution studies suggest the potential for long-term health effects, especially from fine particulate. But these epidemiological studies encompass the entire range of the population, from the very young to the frail elderly, and do not mirror the population involved in wildland firefighting.

Structural firefighters risk exposure to smoke containing a wide range of toxic substances. Studies do not consistently show an increased risk of heart disease among structural firefighters, but those who smoke have a greater risk of heart and pulmonary disease, and lung cancer. Pulmonary function changes and chronic lung disease have been shown in some studies of structural firefighters, but the effects have not been associated with years of service or exposure, suggesting greater effects in a small subgroup of workers. While several studies fail to find an increased risk for lung cancer among structural firefighters, others have shown increases in brain, bladder, or other cancers.

Retrospective mortality/morbidity studies have not been done to determine the long-term effects of exposure to forest fire smoke. The population of long-term wildland firefighters is limited, exposure data is nonexistent, and potential exposure to other hazards (e.g., smoking, radon, wood burning, or air pollution) confounds the data. Case studies of firefighter retirees indicate the complexity of the problem. A fire manager who died of lung cancer was a long-time smoker; a retired firefighter recovering from open-heart surgery had a strong family history of the disease. Neither of these firefighter retirees spent much time on fires during their last 10 years of employment.

A prospective study of health effects may be required to determine the long-term effects of exposure. The study will require a large initial population, entry level information on

respiratory health and pulmonary function, accurate career-long exposure data, and many years to reach a conclusion. Information concerning the prospective study is included in the Surveillance/Research section of this report.

Pulmonary Function—MTDC has measured the pulmonary function of firefighters before the last four fire seasons. The data indicate that firefighters score above the normative values for pulmonary function. However, the rate of decline in function was somewhat faster for firefighters than for the population at large (Sharkey, et al., 1995). Interestingly, as with structural firefighters, a small subset of workers accounted for a substantial portion of the decline in lung function.

Individual Response

Frequent reference in the literature to individual responses to smoke suggest that a subset of workers may be more susceptible to the health hazards of smoke. Some individuals are hypersensitive because of asthma and allergies. Exposure to smoke or other contaminants (e.g., western red cedar) can lead to sensitization in some individuals. Once sensitized, workers may be affected to a greater degree when exposed to the smoke from forest fires. Methacholine challenge tests conducted on wildland firefighters before and after a fire season showed a significant relationship between methacholine sensitivity and a history of allergies, and a relationship between sensitivity and a history of asthma. All firefighters showed an increase in sensitivity at the end of the season (Harrison et al., 1992).

How can we protect susceptible individuals from the effects of exposure to smoke? Pre-employment medical screening, or pulmonary function or methacholine testing could identify individuals with hypersensitive airways. However, pre-employment screening is outlawed under the Americans With Disabilities Act (ADA). Employed individuals can be tested, but pulmonary function tests are not definitive. Methacholine tests are expensive and require that a physician be present. When sensitive individuals are identified, the ADA requires the employer to make a reasonable accommodation to the disability. Since 15% or more of the general population is classified as asthmatic, and even more suffer with allergies, fire managers could be faced with making a reasonable accommodation for thousands of seasonal employees. And it is not certain that a reasonable accommodation can be found.

An air-purifying respirator is a burden for an asthmatic. A powered air-purifying respirator (PAPR) could be used, but the weight is substantial, the noise presents a safety hazard to the wearer, and the battery would need to be recharged daily. Pending resolution of these

issues, prospective firefighters should be informed about the nature and risks of wildland firefighting before employment, and should be trained to recognize and avoid hazardous conditions on the job.

Summary and Conclusions

Smoke from wildland fires contributes to short-term and intermediate health effects. The effects have been shown to be reversible in most cases. Long-term exposure has the potential to cause or exacerbate health problems such as coronary artery disease, chronic obstructive pulmonary disease, and cancer. However, little data exists to confirm or deny a higher risk for wildland firefighters. Individuals with asthma, allergies, or the capacity to develop reactive airways are more likely to be susceptible to the effects of smoke.

Fire managers should educate firefighters about the health hazards of smoke. They should institute a program to monitor crew exposure, and establish practices that serve to avoid smoke exposure and maintain a healthy immune system in firefighters. Such practices include tactics to avoid exposure to smoke, improved fitness and rest schedules to avoid exhaustion, minimizing stress by communication, concern, and cooperation; and providing adequate nutrition, including antioxidants and foods that help maintain a healthy immune system.

Finally, a surveillance system is needed to track smoke exposures to help determine the effects of long-term exposure on the health of wildland firefighters.

References

Betchley, C., J.Koenig, G. vanBelle, and H. Checkoway, Pulmonary function and respiratory symptoms in forest firefighters. MTDC: Health Hazards of Smoke, Fall 1994.

Brotherhood, J., G. Budd, S. Jeffery, et al., Fire fighters' exposure to carbon monoxide during Australia bushfires, American Industrial Hygiene Journal, 51:234-240, 1990.

Harrison, B., B. Materna, D. Liu, and J. Balmes, Respiratory effects of smoke exposure: methacholine challenge testing and exposure monitoring, California Department of Health Services, 1992.

Jackson, G., and J. Tietz, Firefighters' exposure to carbon monoxide on wildfires and prescribed burns, MTDC, 1979.

Reinhardt, T., J. Black, and R. Ottmar. Smoke exposure at wildfires in the Western United States. USDA Forest Service, PNW Research Station, Seattle, 1995.

Sharkey, B., T. Rothwell, T. deLorenzo Green, and S. Roth. Lung function of wildland firefighters, MTDC: Health Hazards of Smoke, Fall 1995.

Ward, D., N. Rothman, and P. Strickland. The effects of forest fire smoke on firefighters: a comprehensive study plan. National Wildfire Coordinating Group, 1989.

Weidner, T., B. Anderson, L. Kaminsky, et al., Effect of rhinovirus-caused upper respiratory illness on pulmonary function test and exercise responses, *Medicine and Science in Sports and Exercise*, 29: 604-609, 1997.

Assessment of the Health Risks of Chronic Smoke Exposure for Wildland Firefighters

Thomas F. Booze, Ph.D., and Timothy E. Reinhardt

We are presenting the results of a screening health risk assessment for wildland firefighters exposed to smoke from wildfires and prescribed burns. A screening health risk assessment makes use of limited resources to help in identifying areas where significant health risk might be present as well as to identify areas where health risk is not significant. This is done in part by making assumptions about exposure where suitably specific data is absent. These assumptions are designed to be protective of health and to result in estimates of risk that are greater than that which actually occur.

This screening risk assessment focused on a list of chemicals of potential concern (COPC) that had been identified in previous studies (1,2). Respirable particulate matter (RPM), an important COPC in smoke, was omitted from this assessment because acceptable toxicity values were not readily available (It is included in on-going work which will be an extension of the risk assessment reported here. This work will be published when finished). A list of the COPCs evaluated in this assessment is shown below.

- Acrolein
- Anthracene
- Benzene

- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Carbon monoxide
- Chrysene
- Fluoranthene
- Formaldehyde
- Indeno(1,2,3-cd)pyrene
- Phenanthrene
- Pyrene

Average and reasonable maximum exposures (RME) were estimated for Type I and Type II hand crews for both wildfires and prescribed burns. Engine crews were omitted because insufficient data were found to estimate their exposures. The average exposures are based on the mean of available exposure data while the RME exposures are based on the upper 95% confidence limit of the mean of the same exposure data. For example, the risk for the average wildfire exposure of a Type I crewmember was based on an exposure of 8 years, 64 days per year, and 9.4 hours per day. The RME risk was based on an exposure of 25 years, 97 days per year, and 9.4 hours per day. Average estimates for Type II crewmembers were 7 years, 10 days per year, and 9.4 hours per day with the RME exposure being 25 years, 46 days per year, and 9.4 hours per day. The hours per day and the concentration of COPCs were different for prescribed burns and wildfires.

Cancer risks and noncancer hazard indices were estimated for Type I and Type II crewmembers at both wildfires and at prescribed burns and are presented below. It was assumed that a firefighter spent their career at wildfires only or prescribed burns only. The scope of this risk assessment precluded the analysis of time spent at a combination of fire types. It is likely that if such a combination was evaluated that the highest cancer risk would be less and the highest total hazard index would be less.

Cancer Risk Summary

Crew Type	COPC	Wildfires	Prescribed Burns
Type I (RME)	Total	3.0E-04	6.0E-05
	Benzene	1.6E-04	2.1E-05
	Formaldehyde	1.2E-04	3.8E-05
	Benzo(a)pyrene	7.0E-06	9.1E-07
	Benzo(b)fluoranthene	1.5E-06	1.9E-07
	Indeno(1,2,3-cd)pyrene	1.7E-06	2.2E-07
Type I (mean)	Total	2.4E-05	2.6E-06
	Formaldehyde	1.2E-05	1.5E-06
	Benzene	1.1E-05	9.8E-07
Type II (RME)	Total	1.4E-05	7.8E-05
	Benzene	7.6E-05	2.7E-05
	Formaldehyde	5.9E-05	4.9E-05
	Benzo(a)pyrene	3.3E-06	1.2E-06
Type II (mean)	Total	3.2E-06	1.3E-06
	Formaldehyde	1.6E-06	8.1E-07
	Benzene	1.5E-06	5.2E-07

Risks equal to or greater than 1.0E-06 are in bold.

Hazard Index Summary

Crew Type	COPC	Wildfires	Prescribed Burns
Type I (RME)	Total	226	118
	Acrolein	226	118
Type I (mean)	Total	99.4	17.5
	Acrolein	99.3	17.5
Type II (RME)	Total	107	152
	Acrolein	107	152
Type II (mean)	Total	15.5	10.5
	Acrolein	15.5	10.4

Contributor listed only if greater than 1.0. All other COPC (anthracene, carbon monoxide, fluoranthene, formaldehyde, phenanthrene, and pyrene) have an HI less than 1.0.

The carcinogenic risk is an upper bound estimate of the probability of developing cancer over a lifetime of exposure. The true risk probably does not exceed the risk estimate, and may actually be less. Estimated COPC cancer risks were calculated for each firefighter type by multiplying the calculated exposures by the appropriate cancer slope factor. Benzene and formaldehyde were found to be the most significant contributors to cancer risk; polynuclear aromatic hydrocarbons did not contribute significantly to this risk.

The potential for developing non-carcinogenic adverse health effects from chronic exposure was characterized by calculating the hazard index (HI) of the chemical-specific exposures. The HI is the estimated exposure divided by the reference dose. An HI greater than 1.0 indicates the potential for an adverse effect. Acrolein was the only COPC with an HI greater than 1.0. Although the HI is significantly greater than 1.0 this does not mean that an adverse effect is likely. In the case of acrolein the inhalation dose is based on the most sensitive adverse effect, the effect occurring at the lowest dose. The nasal passage response to irritation is the most sensitive effect and is the basis for the RfD. The concentration of acrolein used in this assessment ranged from 0.01 to 0.04 mg/m³, which is well below the NIOSH and ACGIH occupational exposure limits of 0.23 mg/m³.

In summary, this screening-level risk assessment indicates that further risk assessment efforts should be focused to only a few COPCs, and shows that adverse health effects are unlikely for the others, based on the available data and assumptions used. The contribution of respirable particulate matter to the total risk is being evaluated and will be reported elsewhere. The risk levels or HIs identified for the remaining chemicals (acrolein, benzene, and formaldehyde) may be further evaluated, but based on this assessment they are within the ranges considered to be acceptable by regulatory agencies. The first step to improving the risk estimates would be a sensitivity analysis to determine how much of an effect is exerted on the total risk by each component of the risk assessment. Based on this analysis, a hierarchy of data needs can be constructed and resources may be allocated to replace these uncertain assumptions with more representative data.