Fall 1995

Health Hazards of Smoke

USDA Forest Service

Missoula Technology & Development Center

The National Wildfire Coordinating Group coordinates wildland firefighting efforts among Federal and State agencies. The Coordinating Group assigned the Missoula Technology and Development Center (MTDC) to serve as the focal point for ongoing and future studies on the effects of wildland fire smoke on firefighters. This status report, the eleventh in a series, provides an update of project activities.

Project Review

The *Health Hazards of Smoke* project has included studies of smoke emissions, employee exposure, health effects, respiratory protection, and other risk management options. The next step is risk assessment, a process that integrates findings into risk calculations that will guide risk management decisions. Dr. Tom Booze, a toxicologist with the Radian Corporation will conduct the risk assessment, with advice and assistance from the project's technical committee. Dr. Booze met with the panel to outline the assessment process and to begin determining exposure levels, based on available data. A screening assessment will provide direction and determine gaps in the data base. A comprehensive risk assessment will follow. The risk assessment will help estimate the probable incidence of an adverse health effect to workers under various conditions, with a description of the uncertainties involved. Typical and reasonable maximum exposures (RME) will be determined for several categories of firefighters. Once the risks are known, managers will have the information needed to make informed decisions concerning the need for monitoring, tactics, training, medical surveillance, or respiratory protection.

Technical Committee

The *Health Hazards of Smoke* technical committee met from July 11 to 13 in Boise at the National Interagency Fire Center in conjunction with the meeting of the National Wildfire Coordinating Group's Safety and Health Working Team. Technical committee members attending included:

—Roger Ottmar, USDA Forest Service, Pacific Northwest Research Station

—Tim Reinhardt, Radian Corporation

—Matt Silva, California Division of Forestry

—Wei Min Hao, USDA Forest Service, Intermountain Fire Sciences Laboratory

—Brian Olsen, USDI National Park Service

—Brian Sharkey, USDA Forest Service, MTDC.

The agenda included planning, reviews of projects, and discussion of program priorities. Considerable time was spent with Dr. Booze to begin work on the risk assessment procedure. The panel also began work on materials to communicate findings of the project with workers in the field. Following the meeting, program plans and priorities were reviewed with the Safety and Health Working Team.

Subject engages in a work test while wearing a respirator (see page 4).

Lung Function

Studies of firefighter exposure to smoke from prescribed fires and wildfires (Materna et al., HHS Winter/Spring 1992; Betchley et al., HHS Fall 1994) have used lung function tests to evaluate health effects. The results show small, but statistically significant, declines in lung function across work shifts and seasons. Follow-up studies (Betchley et al., 1994) indicate that lung function returns to normal following a period free from exposure. Pulmonary function tests may be used in occupational health surveillance programs, and when selecting workers to ensure their ability to perform while wearing a respirator.

Lung function (also called pulmonary function or spirometry) is evaluated with a calibrated spirometer that measures gas volumes and flow rates in a brief maximum effort test. The subject takes a maximum inspiration then exhales as quickly and forcefully as possible through a tube connected to the spirometer. The subject continues to exhale until all the air is expelled from the lungs. In some cases subjects may also be asked to quickly and forcefully inhale until their lungs are full, which provides information about inspiratory as well as expiratory capacity. The spirometer's computer calculates volumes and flow rates and provides a graphic display (see Figure 1). After the subject takes a brief rest, the test is repeated. Important measures of lung function include:

FVC—forced vital capacity indicates total lung capacity.

FEV1—forced expiratory volume in 1 second–shows the volume expired in 1 second.

FEV1/FVC—FEV1 as % of FVC–shows the proportion exhaled in 1 second.

FEF25-75—forced expiratory flow 25-75–describes the mid-expiratory flow rate, a measure of small airway function.

PEF or PEFR—peak expiratory flow rate (PEFR)–indicates the peak flow rate.

PIF or PIFR—peak inspiratory flow rate (PIFR)–shows the peak inspiratory flow.

These measures help to evaluate pulmonary function and provide a baseline for comparison following occupational or other exposures. Results are compared with population norms for individuals of similar age and height. Test results indicate when a score falls well below predicted levels. However, since pulmonary function may be inherited, low values do not necessarily indicate a problem. And high values, while related to performance, do not predict performance capacity. Tests provide the most information when they are compared with past results, as part of an ongoing occupational health (or wellness) program (see page 3).

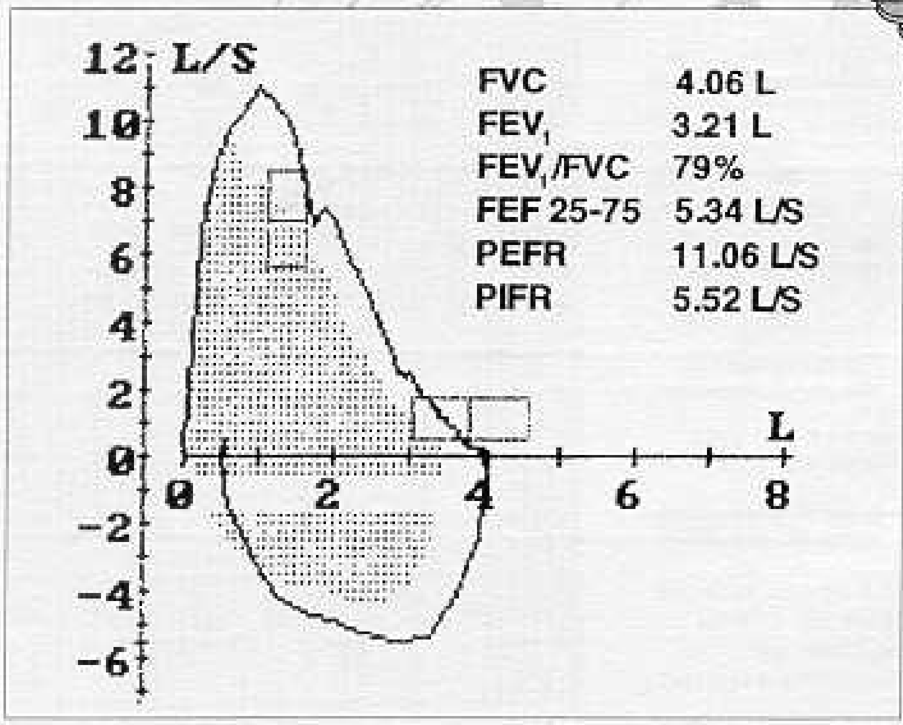


Figure 1—Lung function test report including test results and graphic representation of test volumes (L) and flow rates (L/s).

Fact:

Auto commuters in Mexico City are regularly exposed to CO levels above 50 ppm for the 35- to 60-min duration of the morning and evening commutes.

(Atmospheric Environment, 29:525, 1995)

Research

Smoke Exposure Among Wildland Firefighters: A Review of Current Literature
Reinhardt, T., Radian Corporation, prepared for the USDA Forest Service, Pacific Northwest Research Station, 1995.

This review examines the state-of-the-art knowledge about smoke exposure and the resulting health effects among wildland firefighters. Studies have been done on this problem, but each study has limitations. Overall, the data indicate that smoke exposure at wildfires and prescribed fires is usually no more than an inconvenience, but it approaches or exceeds legal and recommended occupational exposure limits on occasion and thus requires some management. Overexposure to carbon monoxide, respiratory irritants, and crystalline silica is likely among firefighters when direct control of fire is attempted and smoke production is high. Such overexposures are mostly brief events, but sometimes poor atmospheric dispersion or rigorous work schedules cause many hours or even days of unhealthful working conditions. Increases in respiratory health problems have been measured in wildland firefighters. Small but statistically significant declines in lung function have been observed in a number of wildland firefighters, both across workshifts and seasons. These losses could be reversible, but insufficient data have been collected to evaluate this.

The data are limited in geographic scope and representativeness, focusing almost exclusively on large western United States wildfires or prescribed fires in the Pacific Northwest. The field efforts have been hampered by inadequate preparation for the mobility and responsiveness needed to capture smoke exposure during initial attack, and as a result, have many duplicative measures of smoke exposure during the latter stages of fire suppression, when smoke exposure is generally considered low. Some exceptions to this have produced results that converge to identify a limited but significant problem. Smoke exposure is likely to be the highest during initial attack, during direct attack of slow-moving fires, and in large-fire scenarios that suffer from poor atmospheric dispersion.

Recommendations are made to forge ahead with development of smoke exposure management plans. Health surveillance is recommended to accompany exposure management. Additional exposure data are recommended, but only for high-exposure situations and in regions that have insufficient representation in the studies noted in this review.

Lung Function of Wildland Firefighters: 1993-1995
Sharkey, B., Rothwell, T., DeLorenzo-Green, T., and Roth, S. Missoula Technology and Development Center and the University of Montana, 1995.

Studies of wildland firefighters have shown small but statistically significant cross-season declines in pulmonary function, followed by a return to normal function after a period free from exposure. This study was undertaken to determine the long-term effects of firefighting on lung function, and to evaluate aspects of a health surveillance program. Subjects included 134 experienced firefighters measured during preseason training at the Missoula Aerial Fire Depot. Sixty-four subjects were tested in 1993, 59 in 1994, and 90 in 1995. Subjects completed a respiratory health questionnaire before being tested for FVC, FEV1, PEFR, and FEF25-75. Tests were conducted with a Multispiro pulmonary function apparatus that was calibrated before each test session. Subjects performed at least two trials at each test session, and the trial with the best FEV1 was used in the analysis (Figure 2).

Figure 2—Subject participating in a lung function test.

Results were compared to population norms (Knudson) to determine if age-related declines in pulmonary function exceeded the rate of decline in the population. Values for 1993 and 1995 are presented in Table 1.

Table 1—Measured and predicted pulmonary function: 1993 to 1995.

Measure	1993	1995	Diff	%Diff
FVC Meas (L)	5.540	5.438	0.102	1.8%
FVC Pred	5.205	5.175	0.030	0.6
FEV1 Meas (L)	4.490	4.372	0.118*	2.6
FEV1 Pred	4.292	4.248	0.044	1.0
FEV1/FVC Meas (%)	81.0%	80.4%	0.6%	.7
FEV1/FVC Pred	82.5%	82.1%	0.4%	0.5
FEF25-75 Meas (L/sec)	4.543	4.325	.218	.8
FEF25-75 Pred	4.533	4.452	.081	.8
PEFR Meas (L/sec)	11.771	11.271	0.5	.2
n = 31	*p < 0.05			

The firefighters' lung capacity exceeded values predicted for individuals of similar age and height. Only one of the measured declines was statistically significant (FEV1). The rate of decline was somewhat faster in comparison to the predicted values, especially for FEF25-75. Inspection of the data revealed that two subjects accounted for the decline in FEF25-75. In one case a subject had a higher FEF25-75 score on a 1995 trial that wasn't used because of a higher FEV1 score on the other trial. Variations in scores within tests may account for different rates of change. When the two subjects were removed from the analysis, the rate of decline in FEF25-75 was similar to the population (predicted) value.

Thirty-seven individuals were tested in 1994, before the extensive fire season, and again before the 1995 season. Surprisingly, all the measured values increased, but only the FEF25-75 was significant (Diff = +0.342 L/s; $p < 0.01$), an 8.3% increase in FEF25-75 (vs. a predicted decline of 0.022 L/s or 0.49%). Only 18 subjects appeared in all 3 years of testing, so the subjects in the 1993 to 95 analysis were not necessarily the same as those in the 1994 to 95 comparison. Since females comprised only 3% of the total (n = 2, 2 and 4 for the 3 years) the data was not analyzed according to gender. Although the subjects completed a respiratory health questionnaire, variations in the data may reflect the effects of colds, allergies, and confounding factors such as off-season air pollution, residential wood burning, and other occupational or domestic exposures.

These results agree with those reported by Betchley and associates (HHS Fall 1994) who found that lung function values improved during the winter months, returning to preseason levels following a period essentially free from occupational exposure. Early results of this ongoing surveillance indicate that wildland firefighters score above population values for pulmonary function, and that occupational exposure does not consistently accelerate the decline associated with age. Since most of the subjects participated in firefighting activities before the 1993 season, this data does not reflect changes that may have occurred before the surveillance began.

The Effect of an Air-Purifying Respirator on Performance of Upper Body Work

Rothwell, T. and Sharkey, B., Missoula Technology & Development Center and the University of Montana, 1995.

Air-purifying respirators (APR's) have been shown to decrease treadmill performance because of breathing resistance, increased dead space, heat stress, and respirator weight. Studies of upper body work have shown diminished levels of pulmonary ventilation that could exacerbate the effects of an APR. However, a study of upper body work (cranking) found that an air-purifying respirator did not significantly affect performance (Rothwell, DeLorenzo-Green, and Sharkey, HHS Fall/Winter 1993). This study evaluated the effects of an APR on an actual job task, working with a hand tool to build fireline, and sought to predict the ability to perform while wearing an APR. Ten male and 10 female volunteers (ages 20 to 40) performed pulmonary function, strength, VO_2 max, a 4.83-km (3 mi) hike with a 20.5-kg (45-lb; Pack Test) pack, and a 15-min fireline construction test with and without an APR (half-face APR with HEPA + OV/AG cartridges: airflow resistance = 36 mm H_2O @ 42.5 L/min). Energy expenditure during the fireline test ranged from 14.9 to 29.9 ml/kg-min (mean = 22.4 ml/kg-min; Ve = 52.2 L/min).

Results showed that the APR did not significantly reduce performance on the line construction test (36.8 vs. 37.2 m/min with APR). Analysis of the randomly selected order effects found a significant ($p < 0.01$) improvement on the second trial, regardless of the treatment (the APR was the second trial for 12 of 20 subjects). Males and females differed significantly on strength and fireline construction tests.

Predictors ($p < 0.05$) of performance with an APR for combined (male and female) data included: strength (pull-ups, r = 0.77; push-ups, 0.85; upright row, 0.76; lat pull, 0.80), pulmonary function (FVC, 0.57; FEV1, 0.57), and the Pack Test (r = -0.68). Multiple regression analysis of fireline performance with an APR, as predicted by push-ups and the Pack Test, yielded r = 0.87. These results indicate that upper body work is not adversely affected by an APR at the levels of energy expenditure and ventilation found in this study. The ability to work with the APR can be predicted with measures of strength and/or performance on a job-related field test (Pack Test).

Firefighter Exposure to Air Toxics

R. Yokelson, Intermountain Fire Siences Laboratory (Interim Report) 1995.

Intermountain Fire Sciences Laboratory (IFSL) and University of Montana scientists have been using both established and new technology to estimate firefighter exposure levels for comparison with safety guidelines. A full assessment of this issue is complex for a number of reasons: the chemical composition of smoke is complex and the chemical analysis of smoke is difficult; exposure to smoke and the capacity to recover varies for individual firefighters; and there is great uncertainty for both the acute and chronic health effects of the smoke constituents acting individually or in concert.

Several types of studies have been conducted. An extensive study in the Pacific Northwest (Reinhardt et al., HHS Spring 1995) used personal dosimeters and sampled smoke in bags and on absorbent materials to measure firefighter exposure to carbon monoxide (CO) and some other air toxics. This is one of the few studies that have made measurements directly in the firefighters' breathing zone. A study at the University of Montana "froze" smoke from small laboratory-scale fires followed by Gas Chromatography/Mass Spectrometric (GC/MS) analysis. In a joint study by the IFSL and the Universities of Montana and Wollongong (Australia), a fourier transform infrared spectrometer (FTIR) was used to take optical spectra of the smoke from full-scale fires in the IFSL combustion laboratory.

The studies (one field, two lab) measured the average ratio of other air toxics to CO (T/CO) in smoke. The FTIR study looked at the changing chemical composition of smoke in real time, which allows an assessment of possible peak exposure levels. The results of the field study give an average and maximum firefighter exposure to CO that is well below occupational exposure guidelines. Combining the results of the studies allows us to compute long-term exposure to other chemicals from the formula: FET = FECO x T/CO (where FET stands for firefighter exposure to toxin and FECO stands for firefighter exposure to CO). Examples of measurements of T/CO are shown in Table 2, where +/- signs indicate the precision of the measurement in that study. In these examples the FTIR measurement of T/CO is about twice as large as the other measurement. This indicates that the uncertainty in this ratio is about a factor of 2, which is not large compared to the real differences between various types of smoke or the much greater uncertainties in determining a "safe" exposure level.

Using this type of analysis, the average exposure to toxic gases other than CO is also well below occupational guidelines.

Peak Exposures—To complete a risk assessment, we must determine appropriate conditions for measuring Reasonable Maximum Exposure (RME) levels. The peak exposures measured in the field study were well below current occupational guidelines. However, there is a basis for concern because some of the nine fires in the FTIR study showed much higher peak levels than were observed in the field. The highest peak levels are from FTIR measurements made in the smoke 18.3 m (60 ft) above a fire burning with 0.3 to 0.91 meter (1 to 3 ft) flames in green pine needles. The smoke temperature was 153°F with visibility under 1 m. Table 2 shows some of these results and an example of how these measurements can be used to perform preliminary screening of the smoke constituents to determine which are of the most concern for potential health effects. In Table 3 the maximum value of the data points (measured at 1-min intervals) are compared to

Table 2—Intercomparison of measurements of average T/CO.

Toxics/CO ratio	GC/MS (lab)	Field	FTIR (lab)
Formaldehyde/CO	(no data)	0.008 +/- 0.00024	0.021 +/- 0.01
Methanol/CO	0.011 +/- 0.009	(no data)	0.023 +/- 0.01

Table 3—Peak exposures for firefighters compared to safety standards.

Chemical	Maximum	IDLH	Max/IDLH	OSHA peak
CO	587 ppm	1500 ppm	0.4	200 ppm*
Formaldehyde	25	30	0.83	2
Methanol	28	25,000	0.001	-

*Ceiling—not to be exceeded.

the Immediately Dangerous to Life and Health (IDLH) limits set by NIOSH, and the peak exposure limit (10 to 15 min) set by OSHA.

The results of this type of analysis suggest that of the 16 compounds measured in real time in smoke in the FTIR study, formaldehyde may be of the most concern. These are early laboratory results that have not been verified in the field.

Future Research—To complete the risk assessment for firefighters, a number of activities will improve the accuracy of the assessment, including: careful consideration to the appropriate conditions for measuring RME's; deploying at least one more instrumental technique to measure FECO in the field (e.g., using the FTIR near a crew); and reducing uncertainty in T/CO by comparing instruments in the same smoke (e.g., the dosimeter and GC/MS simultaneously with the FTIR in the laboratory, or the dosimeter with the FTIR in the field).

Risk Assessment

Risk Assessment: Wildland Firefighters

Booze, T.

This study involves a health risk assessment for wildland firefighters exposed to smoke from wildland fires or prescribed burns. The objective is to provide the technical information needed to help support risk management decisions to protect wildland firefighters against smoke exposure. The first task is the hazard assessment, identifying the chemicals and physical agents to be addressed in the risk assessment, and identifying the toxicological endpoints of concern. We have currently identified formaldehyde, acrolein, polynuclear aromatic hydrocarbons (PAH's), carbon monoxide, and benzene as chemicals to evaluate. These chemicals were chosen based on previous laboratory and field studies.

The next step is the dose-response assessment, where the appropriate toxicity factors are identified for each chemical. These generally include cancer slope factors, reference doses, and standards with which acute (short-term) exposures are compared. Although many toxicity factors are available, the values may be for adverse effects unrelated to smoke exposure. In these cases toxicity values may need to be developed for effects of interest. The third step is the exposure assessment, where the types of exposures to be evaluated are decided upon. This includes job categories, fuel types, types of fire exposure, exposure frequency, and exposure duration. We have included hand crews and engine crews as two general job categories and have estimated exposure frequency for both typical and reasonable maximum exposures (RME). The concentrations of chemicals in smoke used in this assessment are based on previous field studies.

The final step in the risk assessment is the risk characterization, where exposure estimates are combined with dose-response data to estimate the potential health risk for various job categories and exposures.

—Tom Booze, Ph.D., is a toxicologist associated with the Radian Corporation. He is experienced in wildland firefighting, and worked as a member of the Mendocino Hot Shots.

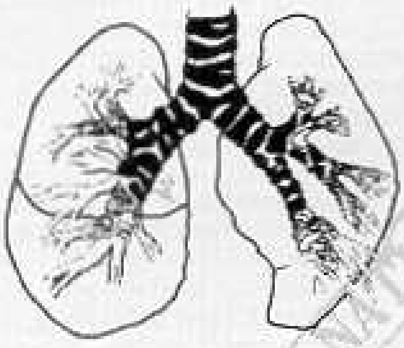
Particulate Standard

The American Conference of Governmental Industrial Hygienists (ACGIH) has proposed a new threshold limit value (TLV) for particulates not otherwise classified (PNOC). In contrast to fibrinogenic dusts, which cause scar tissue in the lungs, so called "nuisance dusts" show little adverse impact on lungs. Nor do they produce significant organic disease or toxic effects when exposures are kept under reasonable control. The PNOC's do not alter air spaces or form collagen to a significant extent, and tissue reactions are potentially reversible. The PNOC TLV is based not on chemical toxicity, but on physical overloading clearance mechanisms of the respiratory tract's.

Recent animal and human studies indicate that exposure to excessive amounts of dust can cause adverse health effects. Particulate overload causes reactions that can stimulate fibrosis. Alveolar macrophages can become sequestration compartments. As dust concentration increases in the lung the retention time increases. Physical overload may lead to chemical toxicity such as pulmonary alveolar proteinosis. For these reasons, the ACGIH proposes lowering the TLV for PNOC to 3 mg/m^3 for respirable particulate containing no asbestos and < 1% crystalline silica.

The ACGIH believes that the lung's clearance mechanisms must continue to be functional. They recommend the 3 mg/m^3 standard to minimize the potential for compromised pulmonary clearance. The current Occupational Safety and Health Administration's permissible exposure limit (PEL) for respirable particulate is 5 mg/m^3. The ACGIH rationale for a lower standard is that the OSHA PEL was developed in 1969 to prevent physical irritation to the worker. The proposed TLV is based on toxicological data involving pulmonary overload of macrophages. The new limit is based on minimizing the potential for loss of pulmonary clearance mechanisms.

Both the ACGIH TLV and the OSHA PEL describe the time-weighted average (TWA) concentration of a normal 8-hr workday, to which nearly all workers may be *repeatedly exposed, day after day, without adverse effect.* Studies of firefighters working on prescribed and wildland fires (Reinhardt et al., 1995) show few cases exceeding the OSHA PEL (5 mg/m³). Workshift particulate exposures averaged 0.63 mg/m³ and 0.69 mg/m³ for prescribed fires and wildland fires. (Note: ACGIH, the National Institute of Safety and Health (NIOSH), and other organizations recommend changes in standards. OSHA reviews proposed changes and solicits public comment prior to making changes in existing standards. Federal agencies are mandated to follow OSHA standards).



Risk Perception

Everything in life carries some risk: the food you eat, the medicines you take, the transportation you use, the job you have, and even the recreation you pursue. Some people are so confused or alarmed by risks that they are unable to enjoy life. Others ignore obvious risks and shorten their lives. Research indicates that perceptions of the magnitude of risk are influenced by factors other than numerical data. Risks are more alarming and less accepted if they are perceived to: be imposed from without, be controlled by others, offer little benefit, be distributed unfairly, be manmade, be catastrophic, come from an untrusted source, be exotic, or affect children. Risks are less alarming and more accepted if they are perceived to: be voluntary, be under an individual's control, offer clear benefits, be distributed fairly, be natural, be statistical, be generated by a trusted source, be familiar, and affect adults. We fear the remote risks associated with the use of certain chemicals while we confidently face the substantial risks of smoking or the daily commute.

Knowledge of risk doesn't always change behavior, especially as the risk becomes more familiar. We may know that a motor vehicle fatality occurs every 13 minutes, and that over 40,000 persons die annually in motor vehicle crashes, but many of us still refuse to buckle a safety belt. We realize that cigarette smoking is the largest preventable cause of disease and death, yet a significant number of us continue to smoke. So knowledge and training do not necessarily ensure risk avoidance or risk-reducing behaviors. Risky recreational pursuits may be viewed as voluntary, under the individual's control, have clear benefits, be natural, and familiar. Given sufficient information, individuals should be able to weigh the risks and benefits associated with the behavior. Workplace risks may be perceived as imposed, controlled by others, offering little benefit, unfairly distributed, exotic, catastrophic, or from an untrusted source.

The risk assessment process currently underway for the Health Hazards of Smoke project will yield risk estimates and suggest risk management procedures for wildland firefighters. In the meantime, remember that 9 out of 10 premature deaths are associated with personal health behaviors, including: smoking, overeating, substance abuse, failure to use seatbelts, and lack of physical activity. Begin today to manage life's major risks, the known risks that are under your control.

Risk Management

Monitoring Crew Exposure

Reinhardt, T.

By using continuous display electronic sensors (dosimeters) to monitor carbon monoxide (CO), fire managers can obtain accurate information about smoke exposure and take effective steps to avoid overexposure. Among the toxic products in vegetative smoke, carbon monoxide is the easiest to measure. Carbon monoxide levels are correlated to respirable particulate and formaldehyde, so CO monitoring can protect workers from other hazards in smoke.

Carbon monoxide is a colorless, odorless, and tasteless gas found in the smoke from wildland fuels, as well as from chainsaws, water pumps, and cigarettes. While firefighters are seldom exposed to high levels, inversions and other conditions can cause exposures leading to reduced work capacity, loss of time awareness, decreased vigilance, and difficulty with decision making, as well as headaches, dizziness, and nausea. With healthy workers these effects are reversed within hours after the exposure ends, but pregnant workers or those with angina or cardiovascular disease, have an increased risk of adverse health effects. Measurements of CO exposure at prescribed fires and wildfires have shown that CO can exceed recommended exposure limits (Reinhardt et al, HHS 1994, 1995).

Dosimeters—There are two basic types of dosimeters:

• Those that measure CO and provide an alarm for high concentrations

• Those that measure, display, and store CO levels, time-weighted averages (TWA), and peak concentrations, and allow transfer of stored data to a computer for additional analysis and record keeping.

These dosimeters are known as datalogging dosimeters. The Draeger Model 190 and MSA MicroMAC are examples of datalogging dosimeters. The TWA can be used to assess exposure and to help managers make effective decisions. A TWA exposure limit of 25 ppm (parts per million) of CO is recommended to protect against CO and the other hazards in smoke. As the TWA approaches 25 ppm, the crew should work in an area of low exposure or be relieved for the day.

While dosimeters are easy to use, they must be calibrated regularly to ensure accurate results. The Forest Service's Pacific Northwest Research Station in Seattle has developed a quality control calibration protocol, involving monthly checks with a tank containing 150 ppm CO, and daily checks with a tank containing 50 ppm. Clean air or nitrogen may be used to set and check the zero reading of the dosimeter. Once it is calibrated, the device is ready for use. The dosimeter should be worn by a crew member subject to average or above-average exposure. The device should be worn within a foot of the worker's breathing zone. The alarm can be set to provide warning of high exposures. At the end of the day the time, TWA and peak exposures are recorded, and the device is checked for accuracy. If desired, the data can be downloaded to a PC computer using a simple adapter. Software allows record keeping, graphics production, and analysis of the data.

It isn't hard to start a smoke monitoring program for your crew. The program provides information that will help you recognize and avoid hazardous situations, and will help you alert workers to CO concentrations before they suffer adverse effects. The equipment is easy to calibrate and operate. Objective smoke exposure information can be used to make decisions on firefighting strategy and crew safety, and to guide future planning and training.

—Tim Reinhardt, Radian Corporation, is principal author of the smoke exposure studies conducted in conjunction with the Pacific Northwest Research Station.

Respirator Studies

Sharkey, B.

Air-purifying respirators (APR's) have been shown to decrease work performance because of:

- Increased breathing resistance
- Increased dead space
- Heat stress
- Respirator weight

They increase the sense of breathlessness (dypsnea) during strenuous effort and may cause claustrophobia. This report summarizes a series of studies conducted by MTDC. The purposes of the studies and a summary of findings follows.

• To compare the effects of APR's with varying breathing resistance on work performance. Studies focused on respiratory protection identified in National Fire Protection Association (NFPA) #1977, which recommended a high efficiency particulate air filter (HEPA) or a HEPA filter with protection from organic vapor and acid gas (OV/AG).

Respirators reduced both maximal and prolonged work performance, and blunted the pulmonary response to vigorous work. When identical masks equipped with different cartridges (HEPA vs. HEPA + OV/AG) were compared, the decline in performance was proportional to the increase in breathing resistance (18 vs. 36 mm H_2O respectively). In general, breathing resistance increased with respiratory protection. The HEPA + OV/AG respirator provides protection from respirable particulate and most gases. Protection from carbon monoxide exposure (CO) could be achieved, but at an additional physiological cost to the wearer. In addition to added breathing resistance, conversion of CO to CO_2 is an exothermic reaction that raises the temperature of the inspired air. In combination with the increased CO_2, the prime respiratory stimulus, the elevated air temperature leads to an increase in breathing rate and a sense of dypsnea and fatigue.

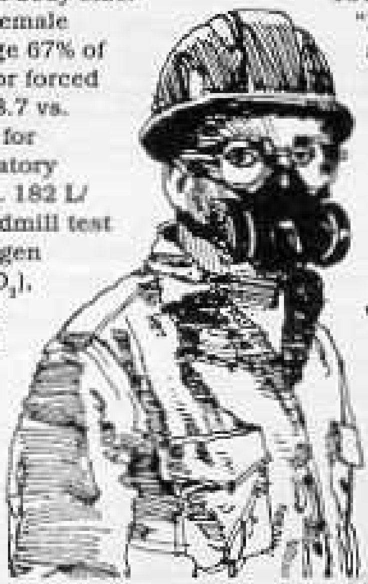
> ***Fact:***
>
> *Smoking in a car can generate CO levels in excess of 150 ppm!*

• To compare the effects of APR's on performance of upper and lower body work. Recent studies of upper body work have shown diminished levels of pulmonary ventilation, which could exacerbate the effects of wearing an APR.

While APR's have consistently reduced submaximal and maximal work performance on the treadmill, arm work (arm cranking, work with a pulaski) was not significantly reduced. Arm work studies did show reductions in arm peak VO_2 (peak oxygen intake) and peak ventilation while subjects wore an APR, but the differences in work performance (4% for males, 8.3% for females) did not achieve statistical significance.

• To evaluate the effects of an APR on women. An extensive review of the literature revealed few studies in which women had been included as subjects. Since women comprise a significant proportion of the firefighting work force, and since their pulmonary function capabilities are, on average, smaller than those of men, it is important to understand the effects of APR's on their ability to perform arduous work.

Pulmonary function measures are associated with body size. The scores of female subjects average 67% of those of men for forced vital capacity (3.7 vs. 5.5 L) and 72% for maximal ventilatory volume (131 vs. 182 L/min). On a treadmill test of maximal oxygen intake (max VO_2), females scored 43.4 ml/kg-min vs. 49.4 for males. A field performance test (3-mi Pack Test) took females 44.9 min to complete, compared to 40.1 min for males. The differences in max VO_2 and the Pack Test were not statistically significant.



On upper body strength tests, females average 50% of male scores. In the arm cranking study, female subjects achieved 53% of the male performance (39.7 vs. 74.7 W). In the line construction test females averaged 67.6% of male values (96.4 vs. 142.6 ft/min). Respirators reduced arm cranking performance by 3.3 W for females and 3 W for males. While neither difference was statistically significant, the percentage change was greater for females (8.3 vs. 4%).

It appears that strength-related upper body performances are lower in women, with or without the APR.

Based on the results of these studies, it appears that females with scores of 45 ml/kg-min on the max VO_2, step test or 1.5-mile run, or a score of 45 min or less on the Pack Test, have sufficient pulmonary capacity and are not adversely affected by the APR.

• To evaluate predictors of the ability to work while wearing a respirator, including pulmonary function, fitness, and field tests. The 11-step respirator program mandated by OSHA (29 CFR 1910.134) stipulates that "Persons should not be assigned to tasks requiring use of respirators unless it has been determined they are physically able to perform the work and use the equipment." At present no test or battery of tests can unequivocally determine the ability to work with an APR.

Initial studies focused on pulmonary function measures as predictors of the ability to work while wearing a respirator. Studies of the maximal ventilatory volume (MVV) confirmed the theoretical value of the measure. The MVV, which measures the maximal capacity of the pulmonary system, is reduced when someone wears a respirator (Raven, 1981, American Industrial Hygiene Association Journal 42: 890-903):

adjusted MVV = 0.49 x MVV + 29 L/min

The adjusted MVV is then multiplied by 0.5 to calculate the long-term ventilatory capacity (workers cannot sustain more than 50% of MVV for an 8-hr shift). If the long-term ventilatory capacity falls below the ventilatory requirements of the job (40 to 60 L/min for wildland firefighting) the candidate may be unsuitable for the job. However, this measure did not adequately reflect the capabilities of females, and the correlation to performance was not statistically significant or sufficiently high to use for job selection. Similarly, the peak inspiratory flow rate (PIFR) promised to provide information concerning the ability to perform prolonged work with respiratory resistance. However, the correlations to performance were no better than those for basic pulmonary function measures (FVC, FEV1).

Maximal oxygen intake (max VO_2) and step test scores are correlated to pulmonary function and the ability to work with a respirator. Aerobic fitness provides information about the functional capacity of the pulmonary system. Muscular fitness measures add to the prediction of performance. Finally, the Pack Test (3-mi field test with a 45-lb pack) was significantly related to performance with the APR. To determine if workers are able to perform with an APR the American Industrial Hygiene Association (AIHA) recommends that a respirator should be worn at least 30 min, and during part of this time, workers should extend themselves to the level that would be required on the job. The Pack Test, which requires the energy expenditure of firefighting tasks, provides information about work capacity and the ability to work while wearing an APR.

Summary: While studies show that smoke exposure exceeds OSHA-permissible exposure limits in fewer than 5% of cases measured on prescribed fires, and fewer still on wildfires, the ongoing risk assessment may identify conditions requiring respiratory protection. Respiratory protection may allow firefighters to continue work, but at some cost in performance, fatigue, and heat stress, and in increased exposure to carbon monoxide. Males and females who meet current work capacity standards have the pulmonary capacity to perform while wearing the APR. Existing fitness tests (step test, 1.5-mi run) and the proposed Pack Test establish that workers are physically able to perform the work and use the respirator.

—Contributors to these studies include Zack Mead, Tara Rothwell, and Theresa DeLorenzo Green. The studies, conducted in the University of Montana Human Performance Laboratory, have been reported at the Occupational Physiology and Medicine research sessions of the American College of Sports Medicine.

Catch 29?

OSHA requires that respirators be NIOSH-approved, where applicable, or be otherwise accepted to provide adequate protection for the hazards encountered ((CFR 29, 1910.134b). Consider the following excerpt from a letter from Christopher Reh, NIOSH Hazards Evaluation and Technical Assistance Branch, sent to Dan Francis, Department of Training and Safety, California Department of Forestry and Fire Protection: "Decision logic in respirator selection must be based on worker exposure data. Wildland fire smoke is composed of many toxic chemicals, most of them present in low to trace concentrations. Exposure assessments of workers fighting forest fires have shown that in many situations, carbon monoxide is the only toxic component of wildland fire smoke that can potentially be generated at levels that pose a serious threat to fire fighter health. Currently, there is not a NIOSH-approved air purifying respirator designed to protect workers from carbon monoxide."

—Christopher Reh is a member of the Health Hazards of Smoke Technical Panel. Dan Francis serves on the NWCG Safety and Health Working Team.

Coming Up

Technical Committee

The *Health Hazards of Smoke* technical committee will meet in conjunction with the NWCG Safety and Health Working Team at its spring meeting in May 1996.

Next Issue

The next issue of *Health Hazards of Smoke* is scheduled for the spring of 1996. If you have questions, wish to contribute to the report, or want to be added to the mailing list, contact:

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