Exposure Monitoring

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This presentation summarizes the objectives and a suggested strategy for a firefighter smoke exposure monitoring program. The program would be an agency-wide effort to define the current baseline and track future progress towards controlling smoke exposure among firefighters. A simplified approach is recommended to acquire the needed information in a cost-effective way.

Why monitor smoke exposure?

- Liability management.
- Determine progress towards goals.
- Achieve regulatory compliance.
- Commitment to employee health.

Monitoring Objectives

- Representative of "firefighters".
- Directed at important pollutants.
- Accurate and Precise.
- Inexpensive--Affordable for wide use.
- Simple--Could be implemented with minimal training.
- Integrated--not a burden.

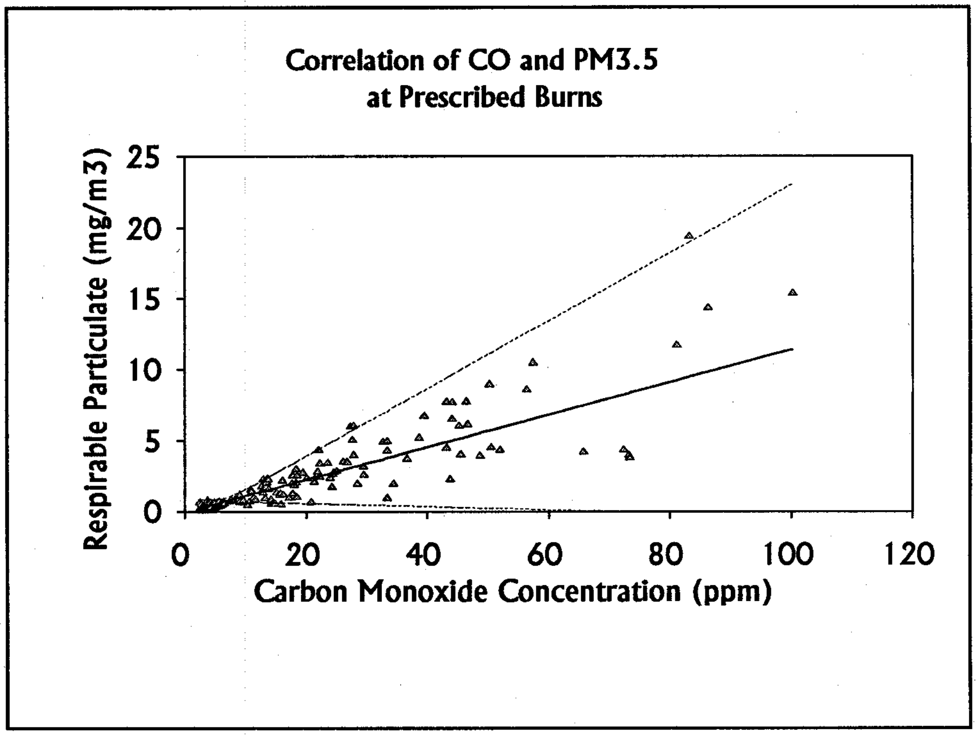
Important Pollutants

- Focus on those we know are problem:
  - Carbon monoxide
  - Respiratory irritants
- Secondarily, assess significance of the "Unknowns"
  - total particulate
  - crystalline silica

Carbon monoxide monitoring provides the key information firefighters and fire managers need to work safely, because CO is an identified hazard and it always accompanies other hazardous components of smoke. Therefore, establishing a routine CO monitoring program should be the initial priority. The CO monitoring program must be planned and well-integrated into the incident management system to ensure that it occurs (even in dynamic situations) without imposing an unnecessary burden on firefighting activities.

Total particulate matter is a potential inhalation hazard that is not entirely correlated to CO levels because entrained soil dust adds to the particulate in smoke. Assessing exposure to total particulate matter can be done once routine CO monitoring programs are in place. For example, a small percentage of firefighters who are monitored for CO can also be monitored for total particulate exposure using a personal sampling pump. Such limited investigations are a manageable adjunct to the CO monitoring program.

As crystalline silica in dust is a concern, archived total and respirable particulate samples could be reanalyzed for crystalline silica content. By analyzing already-sampled filters, the needed information can be obtained without incurring the expense of a field monitoring effort.



The cost of monitoring the important respiratory irritants in smoke is very high. However, data show that exposure to formaldehyde, acrolein and respirable particulate (PM3.5) can be estimated from the CO measurement results. As shown above for PM3.5, the contaminants in smoke that cause respiratory irritation are highly correlated with CO. Similar results have been found for acrolein and formaldehyde. If data from the western U.S. can be bolstered with data from other regions, these correlations can be used to calculate the total respiratory irritant level in smoke from just a CO measurement. Thus the objective of monitoring all the key hazards in smoke can be met by monitoring only CO, at a greatly reduced cost.

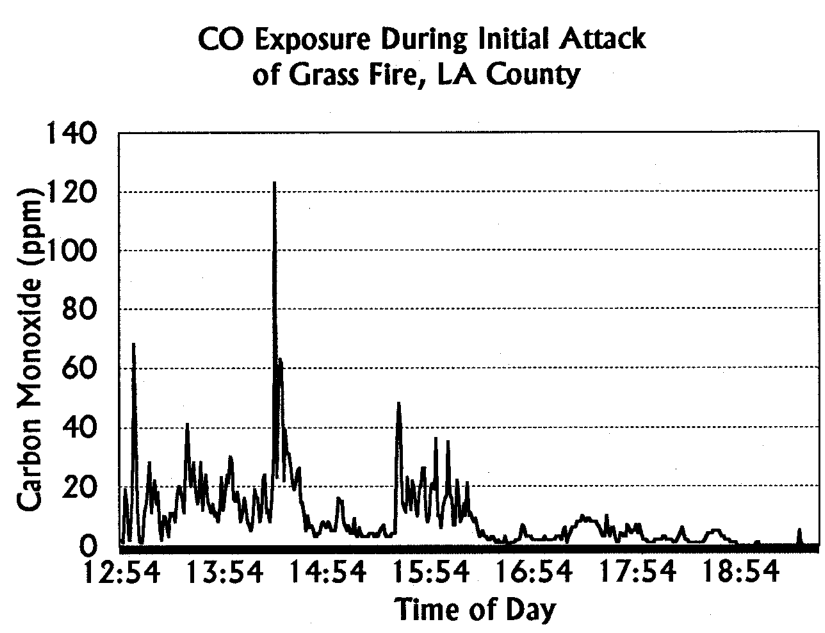
Electronic CO Dosimeter

- Relatively inexpensive: $900-1200 including calibration equipment.
- No subsequent sample analysis cost.
- Minimal support equipment.
- Highly portable.
- Lightweight.
- Simple.

A cost-effective way to meet smoke exposure monitoring objectives uses electronic dosimeter technology to monitor CO exposure among firefighters. Available from many manufacturers, these devices use an electrochemical sensor cell to constantly monitor CO levels in the air. Worn near the face, they are battery-powered devices about the size of a pack of cigarettes. Most have built-in alarm functions to alert crews when CO approaches unhealthful levels. The datalogging versions of these instruments record the CO level vs. time, data retrievable by a computer. These "dataloggers" provide records of monitoring results that are valuable training tools for fire crews.

The datalogger is ideal because it records accurate CO levels minute-by-minute without requiring anything else of the user--the firefighter only has to keep wearing the device during the shift. When concerned about smoke levels, a quick glance at the display of the dosimeter shows the current CO level and the accumulated average exposure for the firefighter.

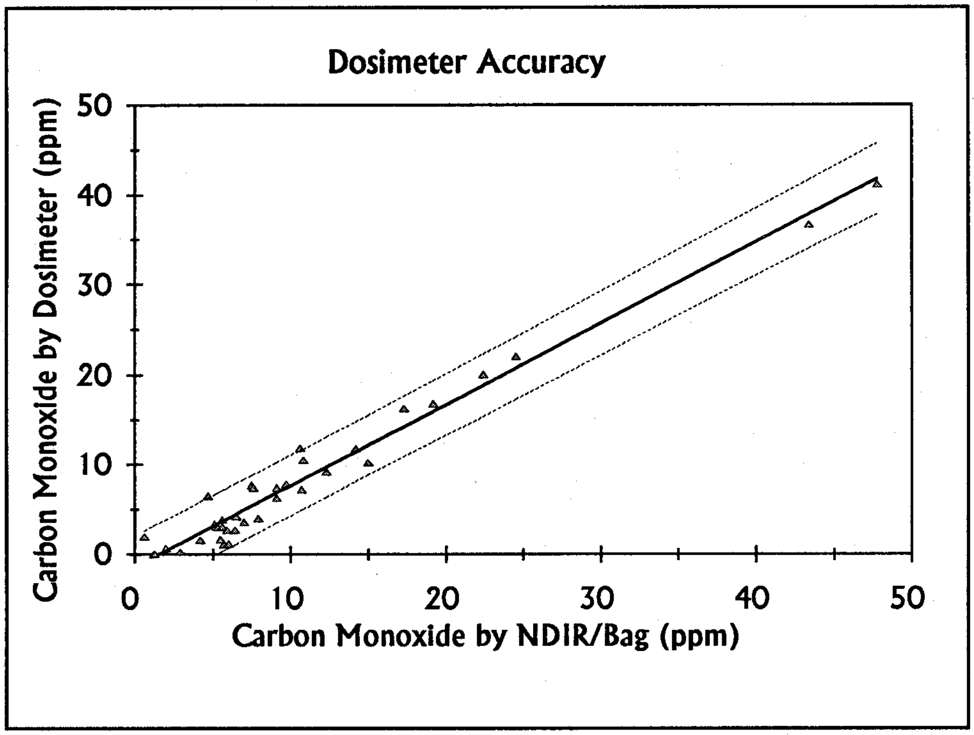
With training, a safety officer or other designated individual could set up and calibrate these devices in minutes, then deploy one per crew for automated data collection during the shift. Data can be retrieved after the shift, or after several shifts for multi-day assignments.



As an example of the detailed exposure data that can be obtained, this graph shows the CO levels that a firefighter encountered during initial attack of a grass fire in southern California. The proposed monitoring program would obtain such a record for every firefighter monitored.

Making sense of this data requires simple notation of key changes in the work activity and fire situation while the monitor is being worn. A crew foreman or firefighter could be assigned this responsibility, which only requires a pen, a pad-sized data form and a watch keeping accurate time. At key moments, just a few descriptive words and a time-of-day entry are all that's necessary.

Matching the datalogger record with the workday notes can be done via computer, and the results can then be shared with the firefighter or crew. The data can also be retained for more sophisticated analysis of exposure during certain fireline situations and to track long-term trends in exposure.



As shown by the data above, the electronic CO dosimeter results agree with other, more complicated methods of CO measurement. The best results can only be obtained through a strict adherence to protocols, however. The graph above plots CO monitoring results on the X-axis that were obtained from a labor-intensive gas bag collection among firefighters followed by infrared spectroscopy analysis in a laboratory. On the Y-axis are electronic dosimeter results obtained at the same time from the same firefighters. The data are in good agreement, although the dosimeter results are biased slightly low, a problem that could be controlled through adherence to a quality assurance plan and standard operating procedures (SOPs) for data collection.

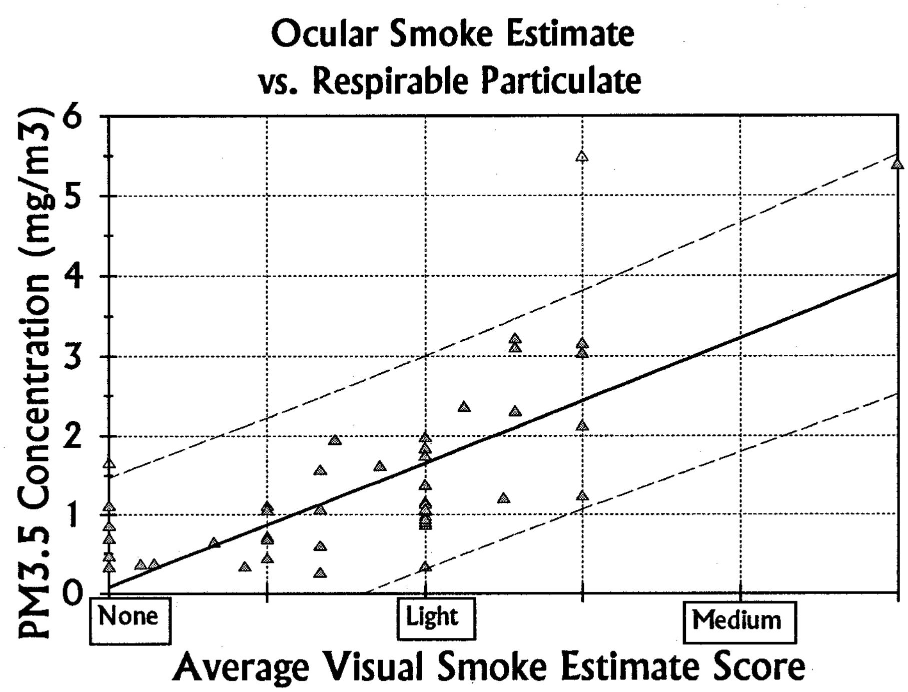
Ensure Data are Accurate and Precise by:

- ◆ Standard methods.
- ◆ Trained monitoring personnel.
- ◆ Quality assurance plan and indicators.
- ◆ Independent review of data quality.

A routine CO monitoring program must use simple equipment and standard methods so that data collection can be successfully accomplished on a broad scale by staff with minimal background in industrial hygiene. The monitoring program must include a quality assurance plan which includes data quality indicators. These quality control indicators are the only way to ensure that the data collected under the program meets the data quality objectives.

Typical indicators include field replicates, field blanks, and independent calibration checks. Field replicates indicate the precision of the exposure measurements. Field blanks and calibration checks provide a measure of the accuracy of the exposure measurements, and help to determine the cause of inaccurate results. Incorporating such quality assurance elements adds roughly 10% to the cost and 25% to the complexity of the program, but without them the data are of unknown reliability and useless for the monitoring objectives.

Annual review of data quality is recommended to identify problems in data collection, analysis or reporting that can go unnoticed by those generating the data. The data quality review is best done by an objective expert so that the monitoring program receives thorough, yet impartial review.



For those with no access to monitoring equipment of any kind, there is some hope that a rough estimate of smoke exposure is possible. The data above are from project wildfires, where an observer noted the apparent smoke exposure within 20-minute intervals. The average smoke estimate is on the x-axis, and the actual exposure to PM3.5 is on the y-axis. Note that there is a correlation, although it is highly variable.

Based on this example, any smoke that was considered "medium" in intensity would average about 3 mg/m3, but could range up to nearly 5 mg/m3. Similar results are found for the other pollutants in smoke, but the correlations are not even this strong. More data and detailed analysis is needed before we can say we don't need objective data such as the CO dosimeter provides.

Suggested Plan

- Select CO dosimeter carefully (test several models vs. standard method).
- Develop SOPs, train, and maintain eqpt.
- Monitor widely, share data.
- Adhere to QA plan.
- Limited irritant and total particulate monitoring to improve correlations.
- Analyze archived samples for crystalline silica to determine significance.

Benefits of Using Dosimeters

- Directly monitors CO--provides instant feedback to crews.
- Surrogate for correlated respiratory irritants.
- Datalogging capability for crew debriefing/incident analysis.
- Simple and inexpensive.

Potential Drawbacks

- Correlations with respiratory irritants need refinement--also must get concurrence from regulators.
- Accountability of monitoring--potential for misuse.
- Potential for useless data if QA plan not implemented.
- Ignores total particulate matter exposure.

Respiratory Protection

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The Missoula Technology and Development Center (MTDC) has previously studied respiratory protection (Thompson and Sharkey, 1966), and firefighter exposure to carbon monoxide (Jackson and Tietz, 1979). In 1989 National Wildfire Coordinating Group assigned MTDC to coordinate the Health Hazards of Smoke project. Part of that responsibility involved work in the area of respiratory protection, including a field survey of respirator use, ongoing literature and product reviews, laboratory and field studies of respirators, participation on National Fire Protection Association and American National Standards Institute committees, and interaction with firefighters, scientists, fire managers, regulators (National Institute of Occupational Safety and Health and the Occupational Safety and Health Administration), manufacturers, and others interested in the effects of smoke on wildland firefighters. This report summarizes some of these activities.

Field Survey

Based on field interviews, a questionnaire was constructed to assess field use of respiratory protective devices by wildland firefighters during wildfire suppression or prescribed burning. Responses from 300 Federal and State agency employees indicated some prior use of respiratory protection. About 82.2% thought the hazards of smoke warranted respiratory protection, especially during direct attack (70.4%), line holding (79.8%), and mop-up (64.8%). Of those who had used a device for respiratory protection, 75% reported that it reduced productivity. Surprisingly, while 69.1% reported problems with communication, only 7.1% reported problems with a beard, with glasses (12.6%), or with a hard hat and goggles (5.5%). Half of the respondents expressed concern that a device that provided protection from some but not all hazards could provide a false sense of security. The results indicate firefighter concern for the health hazards of smoke, that the perceived need for protection increases with prior respirator use, and that fit and other problems are minor and should be manageable with proper training (Driessen, Sharkey, and Buskirk, 1992).

Respirator Studies

Air-purifying respirators (APR's) have been shown to decrease work performance through breathing resistance, increased dead space, heat stress, and respirator weight. They increase the sense of breathlessness (dypsnea) during strenuous effort and have been shown to cause claustrophobia. This section summarizes a series of studies that measured the effects of wearing APR's.

All studies were conducted in the University of Montana Human Performance Laboratory, under the terms of a memorandum of understanding with MTDC. All protocols were reviewed and approved by the University Institutional Review Board to ensure proper use of human subjects. Studies have been reported in the Occupational Medicine and Physiology research section of the American College of Sports Medicine. A review of each study and a discussion of its implications is followed by a summary addressing the purposes of that phase of the project.

This section summarizes the results in terms of the major purposes of the studies.

1. To compare the effects of APR's with varying breathing resistance on work performance. The studies employed the type of protection likely to be needed by wildland firefighters, as identified in the deliberations leading to NFPA 1977 Protective Clothing and Equipment for Wildland Firefighting (specifically comparing a high-efficiency particulate air filter (HEPA) with a high-efficiency particulate air filter that includes protection form organic vapors and acid gases (HEPA + OV/AG).

APR's decrease work performance significantly. They reduce both maximal and prolonged work performance, and blunt the pulmonary response to vigorous work. When identical masks equipped with different cartridges (HEPA vs. HEPA + OV/AG) were compared, the decline in performance with the respirator was proportional to the breathing resistance. It should be noted that, in general, resistance increases with respiratory protection. The HEPA filter protects against inhalation of particulate. The addition of organic vapor/acid gas protection (HEPA + OV/AG) doubles the breathing resistance and doubles the decline in work performance. It is important that the protection be appropriate to the exposure (Sharkey and Mead, 1992; 1993; Thompson and Sharkey, 1966).

Additional protection against carbon monoxide exposure could be achieved, but at a considerable physiological cost. Converting carbon monoxide to carbon dioxide is an exothermic reaction that raises the temperature of the inspired air, increasing breathing rate and the sense of fatigue. The increase in carbon dioxide, the main respiratory stimulus, causes an additional increase in pulmonary ventilation. Finally, the material used to remove carbon monoxide adds to the resistance of the device, causing an even greater decline in performance. Protection from all the health hazards in smoke from wildland fires and prescribed burns would require protection from particulate, organic vapors/acid gases, and carbon monoxide.

Breathing zone exposure studies of firefighters have shown occasional exposures in excess of OSHA permissible exposure limits. Studies of the health effects of smoke have found small but statistically significant changes in pulmonary function over the course of a season. The long-term consequences of these changes and the potential for more serious effects have not been determined.

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

While APR's consistently reduced submaximal and maximal work performance on the treadmill, arm work (cranking) was not reduced significantly ($P < 0.07$). This outcome was surprising since recent studies have shown diminished levels of pulmonary ventilation during work with the arms. We had hypothesized a significant effect of APR use on sustained arm work, but the combined male/female difference was not significant. The results did show a significant reduction in arm peak VO_2 and peak ventilation. The decline in arm performance with the respirator was 4% for males and 8.3% for females. More will be said regarding male/female comparisons in the next section of this summary (Rothwell, deLorenzo-Green, and Sharkey, 1994).

These comparisons were made on an upper body (arm cranking) exercise device, which was used to isolate the arms and allow an accurate measurement of work performance. Work with hand tools usually involves the arms, trunk, and legs, often with trunk flexion (involving restriction of the pulmonary apparatus). So the marginal effects on performance measured in this trial may not reflect the full effect of the APR on work with hand tools. Subsequent tests on simulated fireline construction support the findings of the initial study (Rothwell and Sharkey, 1996). Within the limits of these studies, the APR significantly reduced peak output and ventilation during arm work, but did not cause a statistically significant reduction in sustained performance.

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

Pulmonary function measures are associated with body size. It is understandable that the average valves for forced vital capacity are 67% as high for females as males (3.7 vs. 5.5 L for FVC), and for maximal ventilatory volume are 72% as high for females as males (131 vs. 182 L/min for MVV). In one study, females scored 43.4 ml/kg/min compared to 49.4 for males on treadmill max (VO_2), and 44.9 min vs. 40.1 for males on a field test (Pack Test). These differences were not statistically significant.

On upper body strength tests, females averaged 51% of male values (80 lb vs. 156.7 lb) for the bench press, and 47.7% (45.6 lb vs. 95.6 lb) for the arm curl. These results are consistent with the literature that shows females averaging about 50% of males on upper body strength tests. On leg strength tests, females averaged 64.7% of males on the leg press (313.3 lb vs. 484.4 lb). This value is similar to those in the literature where females typically average 70% of male values. When strength values are calculated per kilogram of lean body weight, females typically average 70% of male arm strength scores and 100% of male leg strength scores.

Females averaged 53.1% of males (39.7 watts vs. 74.7 watts) on the arm ergometry test, reflecting the differences in upper body strength. The decrement in performance with the APR was 3.3 watts for females and 3.0 watts for males. Neither difference was statistically significant. However, the percentage change was greater for females (8.3% vs. 4% for males).

Based on the results of our studies it appears that females who score 45 (ml/kg/min) on the VO_2 max or step test (or 45 min on the pack test) have sufficient pulmonary capacity and are not adversely affected by the APR.

4. To evaluate possible 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.

Early attention focused on the maximal ventilatory volume (MVV) as an indicator of breathing capacity and an individual's ability to work with a respirator. The MVV value is first adjusted for the effects of the respirator:

$$\text{adjusted MVV} = (\text{MVV} \times 0.49) + 29 \text{ L/min}$$

The adjusted MVV is reduced by half to reflect day-long work capacity.
If the final score falls below the ventilatory cost of firefighting (40-60 L/min), the candidate would have difficulty working with the respirator.

For example: MVV = 120; adj MVV = 87.8 L/min x 0.5 = 43.9 L/min

Our results confirmed the theoretical value of the test, but the correlations with performance were not sufficiently high to use the test in job selection. Similarly, the peak inspiratory flow rate (PIFR) promised to provide information concerning the ability to perform prolonged work against the resistance of a respirator. However, the correlations with performance were no better than those based on standard pulmonary function measures (e.g., FEV1, Forced Expiratory Volume in 1 Second). Therefore, it would appear that the basic pulmonary function test provides sufficient data concerning lung function, and that additional analyses (MVV or PIFR) do not add measurably to the prediction of performance.

Maximal oxygen intake (VO_2 max) and step test scores were significantly correlated to performance with the respirator. In addition, these measures of aerobic fitness were highly correlated to pulmonary function measurements. Aerobic fitness, or VO_2 max, is defined as the ability to take in, transport, and use oxygen. This measure of fitness includes information about the function of the pulmonary function apparatus. A Step Test score of 45 provides assurance of an individual's ability to work with a respirator. In the study of upper body work, arm strength scores were also correlated to performance with an APR and to the field (Pack Test). Strength measures improve the prediction of performance, and the field (Pack Test) includes a muscular fitness component.

The Pack Test (3-mile field test carrying a 45-lb pack) was correlated to performance with the APR and to aerobic and muscular fitness tests. The American Industrial Hygiene Association (AIHA) recommends that a respirator should be worn for at least 30 minutes, and during part of this time, workers should exert themselves to the level that would be required on the job. The Pack Test provides information concerning fitness and the ability to work with a respirator. The energy cost of the Pack Test is similar to that demanded on the job (22.5 ml/kg/min). MTDC has conducted laboratory and field studies that confirm the effectiveness of the Pack Test, both as a predictor of work capacity and as an indication of the ability to work with an APR (Sharkey and Rothwell, 1995).

Conclusions

1. Although respirators reduce work capacity, they may be necessary to minimize hazardous exposures. Managers need to know that it will take more time or more firefighters to get the job done when firefighters are wearing an APR. In heavy smoke conditions, such as hot-spotting on a prescribed fire, a respirator may be required to get the job done.

2. Respirators do not seem to impose a disproportional effect on upper body work performance.

3. Female firefighters who meet the current standard for aerobic fitness will be able to perform while wearing a respirator.

4. The ability to work while wearing an APR can be predicted with laboratory or field fitness measures, pulmonary function tests, or a job-related work capacity test such as the Pack Test.

Field Evaluations

MTDC conducted field evaluations of a variety of APRs. Firefighters engaged in wildfire suppression and prescribed burning used disposable or maintenance-free devices, half-face or full-face respirators. Disposables were acceptable for short-term use, but they deteriorated in the heat during several hours of use. Maintenance-free half-face devices were satisfactory, except for the heat stress found with all face masks. Full-face masks were preferred for long-term use on prescribed fire because of the eye protection, but workers often complained of headaches, a sign of excess CO exposure.

Firefighters expressed an interest in a lightweight respirator that is easy to put on and take off, designed specifically for wildland firefighters. A mouthpiece respirator meets the following criteria: lightweight, inexpensive, easy to don and doff, no heat stress, self storing, no problems with beards, glasses, or facial irregularities (e.g., scars). However, current mouthpiece devices are only approved (NIOSH) for escape purposes. And available products are not designed with the large diameter breathing tubes necessary to accommodate the ventilation rates (40-60 L/min) encountered during wildland firefighting.

Any device used by wildland firefighters should be tested for performance in the heat, and for the flammability of exposed filter material. Full face devices protect the eyes, but remove an important early warning of exposure—eye irritation.

Respiratory Protection Program

OSHA requires a written respiratory protection program before respiratory protection can be used. To provide employees adequate protection and comply with the OSHA respiratory protection standard (CFR 29, 1910: 134I), the program must include:

1. Written Operating Guidelines covering the selection and use of respirators for each task or operation where they are employed. The employer must develop a formal written document that addresses each of the following points.
2. Respirator Selection: Respirators must be selected on the basis of the hazard to which the employee is exposed. Guidance concerning respirator selection is contained in ANSI Z88.2-1992.
3. Training: Employees must be instructed and trained in the proper use and limitations of the respirators to which they are assigned. Respirators must be tested for fit and they should not be used if facial hair, eye glasses or other factors interfere with the seal of the face piece.
4. Approved Respirators: Respirators approved by NIOSH or accepted by OSHA must be used when they are available. The respirator must provide adequate protection against the particular hazard for which it has been designed in accordance with standards established by competent authorities (NIOSH, ANSI).
5. Respirator Assignment: Where practical, respirators should be assigned to individual employees for their exclusive use. When it isn't practical, the next step becomes even more important.
6. Cleaning: Respirators must be cleaned and disinfected. Those used exclusively by one employee should be cleaned daily. Devices used by more than one employee must be thoroughly cleaned and disinfected after each use.
7. Storage: Respirators must be stored in a convenient, clean and sanitary location.

8. Inspection and Maintenance: Routinely used devices must be inspected during cleaning. Worn or deteriorating parts must be replaced. Respirators for emergency use must be inspected at least monthly.
9. Monitoring: Appropriate surveillance of work area conditions and the degree of employee exposure must be maintained.
10. Inspection and Evaluation: There must be regular inspections and evaluations to assess the continued effectiveness of the respiratory protection program.
11. Medical Evaluation: Employees should not be assigned to work tasks that require the use of respirators unless they have been determined to be physically able to perform the work and use the equipment. The local physician must determine what health and physical conditions are pertinent. The respirator user's physical condition should be reviewed periodically.

MTDC is developing a model respiratory protection program to meet these requirements. The program includes information of medical evaluation, respirator selection and fitting, monitoring, etc., as mandated in CFR 29 1910:134. The program will be made available on a floppy disk.

NIOSH Respirator Guide

OSHA and NIOSH are updating the standards that regulate the use and certification of respirators in the workplace. Under the new regulations (42 CFR Part 84) NIOSH will certify three classes of filters (N, R and P) with three levels of efficiency (95%, 99%, and 99.97%) in each class. The efficiency indicates the degree to which the filter removes small (0.3 um) particulate.

N series (Not resistant to oil) particulate respirators are for protection from particulates that are free of oil or other severely degrading aerosols. These respirators have no time limitations.

R series (Resistant to oil) respirators may be used for protection from degrading aerosols for no longer than one shift.

P series (Oil proof) filters can be used for protection from any particulate aerosol. They have no time limitations.

All N, R, and P particulate filters must be discarded when they become soiled or damaged, or when breathing becomes difficult.

Assigned protection factors (APF's) are numbers given to classes of respirators, such as half-face or full-face, that indicate the anticipated maximum protection the respirator can provide. A respirator with an APF of 10 could be expected to protect a worker exposed to air concentrations up to 10 times the permissible exposure level (PEL) for a particular toxic chemical, such as formaldehyde. If the contaminant level is up to 50 times the PEL, a full-face respirator is required. If the level of exposure exceeds 50 times the PEL, a self-contained breathing apparatus (SCBA) must be used.

MTDC studies show that breathing resistance increases and work output decreases in proportion to the level of protection. For example, resistance for a HEPA filter with OV/AG protection is greater than for a HEPA filter without OV/AG protection, and resistance for the HEPA filter is greater than for a disposable filter.

HEPA + OV/AG > HEPA > Disposable half-mask

Since exposure studies have not indicated high levels of particulate for most prescribed fire or wildfire conditions, a filter efficiency of 95% should be sufficient. And since oil is not a typical component of vegetative smoke, an N series filter will be appropriate for firefighters.

Note: Removing carbon monoxide from the breathing air currently requires converting of CO to CO_2 in an exothermic reaction. The process adds additional breathing resistance, increases respiratory work with the respiratory stimulus of carbon dioxide, and increases heat stress with the breathing of hot air. No currently available device protects the worker from all the hazards in smoke.

Conclusions

While respiratory protection may sometimes be advised for those engaged in prescribed burning, studies have not confirmed the need for respirators for wildland firefighters. Devices would be required in fewer than 5% of cases studied. Training, tactics, monitoring, and other controls should be instituted and evaluated before a full-scale respirator program is considered. Pilot programs for prescribed burning will assist in developing of the various elements of the respiratory protection program, including training, fit testing, and medical evaluation.

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