Summer 1990

Health Hazards of Smoke

USDA Forest Service — Missoula Technology & Development Center

The National Wildfire Coordinating Group (NWCG) coordinates firefighting efforts among federal and state agencies. As part of their mandate to insure current, shared information, a status report on the Health Hazards of Smoke will be published twice each year by the Missoula Technology and Development Center (MTDC). It will report activities on the project, as well as related study groups. Summaries of research projects will be included; equipment and techniques for managing the hazards of smoke will be described; abstracts of related reports and articles will be reported; and a schedule of upcoming events will be announced.

Background

Each fire season 20,000 to 30,000 firefighters are engaged in suppressing wildfires on federal lands and many more are employed to battle fires on state and private lands. Studies of firefighter exposure to smoke and carbon monoxide indicated only occasional hazardous exposure until the 1987-1988 fire seasons. During the 1988 Yellowstone fires, 12,000 respiratory problems were reported to medical personnel. To address this problem, the National Wildfire Coordinating group, related agencies, employee groups, specialists in occupational medicine, industrial hygiene, and risk management met in January, 1989, to outline a study plan for determining the immediate and long-term effects of exposure to forest fire smoke. In November, 1989, NWCG assigned MTDC to coordinate the national effort and serve as the focal point for on-going and future studies on the effect of forest fire smoke on firefighters. This status report provides an update on project activities to those interested in the problem.

Technical Panel

At the request of NWCG, the Missoula Technology and Development Center (MTDC) convened a technical panel to review existing research, identify research needs, and recommend funding priorities. Based on research and funding priorities developed by the technical panel, a budget request has been submitted to NWCG for FY 1991. The request includes support for the following:

A comprehensive study that integrates measures of fireline emissions, firefighter exposure, and health effects.

Upgraded agency surveillance and record-keeping systems that will eventually allow assessment of long-term effects of exposure to forest fire smoke.

Support for related/ongoing studies of the effects of forest fire smoke on firefighters.

Management/coordination of the NWCG project on the health hazards of smoke.

Panel members include:

- **Nat Rothman**, M.D., Johns Hopkins University, Baltimore,(representing CDFEA)
- **Chris Reh**, Industrial Hygiene, National Institute of Occupational Safety and Health
- **Robert Harrison**, M.D., California Department of Health Services, San Fransisco
- **Dana Headapohl**, M.D. Occupational Medicine and Environmental Engineer
- **Darold Ward**, Ph.D., Forest Service, Intermountain Fire Sciences Laboratory
- **Cathy Davidson**, Industrial Hygiene, USDI Park Service
- **Dick Mangan**, Risk Management, MTDC Missoula

Brian Sharkey, Ph.D.,coordinator of the **Health Hazards of Smoke** MTDC project, chaired the first meeting of the panel in Missoula (April, 1990). The next meeting of the panel is tentatively scheduled for the fall in Cincinnati, the home of the National Institute for Occupational Safety and Health (NIOSH).

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Task Force

An organizational meeting of the National Fire Protective Association (NFPA) Task Force on Respiratory Protection for Wildland Firefighters was held in Hilton Head, S.C., in March, 1990. The task force was created by the NFPA subcommittee on Wildland Clothing and Equipment, to define the problem of health hazards from smoke and determine the need for a standard for respiratory protection for wildland firefighters.

Chaired by Bob Martin, International Association of Fire Fighters, and Brian Sharkey, FS/MTDC, the committee consists of representatives from agencies, employee groups, equipment manufacturers, and technical specialists in occupational medicine, industrial hygiene, work physiology and other areas. The next meeting of the task force is scheduled for July.

Research

Studies on the health hazards of structural firefighting have consistently shown the need for respiratory protection. However, studies on wildland firefighters have not been as conclusive. MTDC examined the situation in 1965 and concluded that the exposure did not warrant using respirators because of the costs and side effects, including increased heat stress, discomfort, reduced work capacity. In 1975 MTDC investigated firefighters' exposure to carbon monoxide and found that the highest readings were often associated with cigarette smoking, poorly located camps, and vehicle operation.

National Institute of Occupational Safety and Health (NIOSH), Cincinnati. *Health hazard evaluation of the Fires in Yellowstone Park;* Christopher Reh, 1989. Industrial hygiene measurements in Yellowstone National Park during the 1988 fire season yielded low levels of carbon monoxide, total particulate and formaldehyde. A medical survey involving blood sampling for carboxyhemoglobin showed that levels did not change significantly between pre- and post-shift measurements. The highest level (4.7%) was a pre-shift measurement on a smoker. The researchers recommended further study to better characterize the toxic components of forest fire smoke and their effects on forest firefighters.

Johns Hopkins University Study, Baltimore. *Changes in pulmonary function and respiratory symptoms in wildland firefighters;* by Nathaniel Rothman, et al., (1990). Changes in pulmonary function were studied in 52 wildland firefighters in Northern California during the summer of 1988. When the study group was divided into three categories based on hours of recent firefighting activity, decreases in both forced expiratory volume in one second (FEV1, the maximal amount of air that can be exhaled in one second) and forced vital capacity (FVC, the maximal capacity of the lungs) were associated with increasing exposure. Firefighters in the high exposure category had a -3.3% change in FEV1, compared to a -0.5% change in non-exposed firefighters; and a -1.9% change in FVC compared with a 0.7% change in non-exposed firefighters. There was an increase in the prevalence of eye and several respiratory symptoms from the beginning to the end of the season, though only eye irritation and wheezing were significantly associated with recent firefighting activity. The authors concluded that further research is needed to define the fire conditions that produce hazardous exposures, the range of exposure patterns present in wildfire environments, and the acute and subacute health effects of wildland firefighting so that effective protective measures can be instituted.

California Department of Health Services, San Fransisco. *Respiratory effects of smoke exposure in wildland firefighters: Methacholine challenge testing and exposure monitoring;* by Robert Harrison, et al., 1990. This study attempted to determine if exposure to wildland fire smoke could result in pulmonary function effects, with special attention to changes in nonspecific airway reactivity, as measured in a methacholine challenge test. 63 hotshot crewmembers (55 males, 8 females) took part in pre and post-season pulmonary function and methacholine challenge testing. Questionnaires were used pre season, post shift and post-season to determine demographic information, medical history, past and current symptoms, smoking habits, job history, past occupational exposure, and any current or past work-related health problems. Industrial hygiene measurements were taken to characterize the exposure of the firefighters. Data were collected on five wildfire work shifts and on prescribed burns.
Breathing zone air samples yielded measurable aldehyde, carbon monoxide and respirable particle levels, but few approached OSHA permissible exposure limits (PEL). For example, one CO measure of 38 ppm exceeded the OSHA PEL of 35 ppm. Mean exposure levels were always well below permissible limits. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV1) decreased over the season (2.2% and 4.4% respectively). Airway reactivity, as measured by the methacholine challenge test, increased significantly. The provocative inhalation dose required to cause a 20% drop in FEV1 decreased from pre- to post-season. Some respiratory and related symptoms (nose, eye irritation, cough, sore throat, chest tightness) were increased following the season, but all symptoms resolved at the end of the season. The authors recommended further studies of exposure, pulmonary function, and airway reactivity, and encouraged

establishing a comprehensive health surveillance system to track possible long-term effects of exposure on firefighters.

Pacific Northwest Research Station, Seattle. *Firefighter smoke exposure at prescribed burns: A study and action recommendation;* by Timothy Reinhardt, 1989. Firefighter smoke exposures during prescribed burning activities have been found to exceed safe worker exposure limits for a number of hazardous chemicals. Allowable worker exposure limits for formaldehyde, carbon monoxide and acrolein have been exceeded in a small proportion of the exposure samples taken. The majority of smoke samples were below levels expected to be harmful over brief periods of exposure, but are high enough that daylong exposure to these smoke levels could easily exceed 8-hour workday exposure limits.

Certain situations seem to produce high smoke exposures. Wind speed, relative humidity, fuel moisture, and duff depth may be positively correlated with smoke exposures among firefighters at prescribed burns. Fuel loading may correlate negatively with smoke exposures. Broadcast burning of western coniferous logging residues produced the highest smoke exposure samples. Smoke concentrations were found to vary by work activity. Holding fireline, direct attack of spot-fires and slopovers, and mop-up are higher in worker exposure than exposure when hand-lighting prescribed burns with drip torches.

Some hazardous components of smoke, such as formaldehyde and respirable particles, are well correlated to carbon monoxide. Others do not appear to be produced in relatively constant ratios. Simple inexpensive dosimeters have accurately measured carbon monoxide exposure at prescribed fires. Fire managers could use dosimeters to help manage firefighters' exposures. The report presents a study plan for a comprehensive characterization of short-term and long-term exposures to the important air toxics in smoke. The author concludes that firefighters at prescribed burns can be exposed to a variety of components in smoke that are above accepted occupational safety limits. The exposures seem to follow patterns that would allow a variety of exposure management techniques to be applied. More attention to the problem is needed to determine the most effective exposure management courses to be taken.

Intermountain Fire Sciences Laboratory, Missoula. *Air toxins and fireline exposure;* Darold Ward. A series of ongoing projects designed to identify the fuel, weather and fire factors that contribute to fire smoke toxicity and exposure. The Fire Chemistry Project is studying the fuel characteristics, both chemical and physical, affecting combustion leading to the production of air toxics and trace materials. The research approach combines burning of modeled fuel arrays in a well instrumented, environmentally controlled combustion laboratory, with field measurements and sampling on wildfire and prescribed burns. The results of these studies will contribute to our knowledge of firefighter exposure.

Southern Forest Experiment Station, Auburn, Alabama. *Evaluation of worker respiratory exposure to herbicide residues in the smoke from prescribed fires in the south;* Charles McMahon (1989 Progress report). Following development of a smoke/herbicide sampling protocol, breathing zone smoke concentrations were monitored on 14 prescribed burns. Burns were conducted 1 to 5 months after the application of herbicide. No detectable herbicide residues were found in the smoke from 48 personal monitors worn by forest workers, 22 monitors worn by research personnel, and 70 stationary area-monitoring samplers. Particulate measures from personal monitors averaged 4083 ug/m3, which is below the OSHA permissible exposure limit for respirable nuisance dusts (5000 ug/m3) for an 8-hour work shift.

Missoula Technology and Development Center. *The effects of breathing resistance on pulmonary function and work capacity;* Brian Sharkey and Zachary Mead, University of Montana Human Performance Laboratory (in progress). Fifteen young men (18 to 30 yrs) underwent tests of pulmonary function and maximum voluntary ventilation (MVV) before progressive treadmill tests. The MVV and treadmill tests were conducted both with and without a half-face respirator equipped with high efficiency air filters (HEPA). Maximal voluntary ventilation was reduced 23.8% (range 4.7 - 42.8%) while wearing the respirator, with greater reductions at higher MVV levels from increased inspiratory resistance at higher flow rates. Maximal work capacity was reduced 6% (+3.5 to -16.7%), and perceived exertion and difficulty of breathing were increased at submaximal and maximal work levels.

These results support the use of the Maximum Voluntary Ventilation test (MVV) as a means of screening candidates for respirator use during prolonged arduous work. MVV can be corrected for respirator effects via the formula:

Adjusted MVV = 0.49 x MVV + 29L/min (Raven et al. AIHA Jrnl, 42:897-903,1981)

The adjusted MVV is then multiplied by 0.5 to calculate the long-term ventilation capability (50% of MVV for 8 hour shift). For longer work shifts, especially when heat stress is a factor, an upward ventilatory drift occurs that increases the ventilatory requirements). If the long-term ventilation capability falls below the 40-60 L/min required for sustained

work with hand tools, the candidate may be poorly suited for respirator use during prolonged arduous work.

Lawrence Livermore National Laboratory (LLNL), Livermore, CA., *Development of "Smart" Air-Purifying Respirators For Use in Wildlands Fires*; James S. Johnson, Ph.D. The need to reduce firefighter exposure to the pyrolysis products from wildlands fires has been recognized by LLNL for many years. To improve the performance of industrial air-purifying respirators currently in use by LLNL wildlands firefighters, the Special Project Division of the Hazards Control Department has developed a prototype respirator that incorporates an electrochemical sensor for carbon monoxide into the air-purifying respirator currently in use. This respirator will provide the wearer with real-time monitoring for carbon monoxide. If the initial Reinhardt study results correlating formaldelyde and other pyrolysis products to carbon monoxide concentrations are confirmed, this unit will also provide the wildlands firefighter with a real-time monitor for multiple gaseous contaminants as well as removing most particulate exposure. Laboratory and field testing of this respirator prototype will be carried out this summer. Additional "smart" respirators will be manufactured in conjunction with Dr. Joseph Stetter of Transducer Research, Inc. this fall and winter so that they are available for routine use by all LLNL firefighters next summer. Additional development work extending the concept of "smart" air-purifying respirators to powered air purifiers (PAPRs) as well as extending the real-time monitoring to oxygen deficiency is also underway.

For more information on these projects contact the principal investigator.

Risk Management

Studies on wildland firefighters suggest some potential for hazardous exposure and the possibility of acute effects of forest fire smoke on pulmonary function. More research is needed to characterize the hazardous chemicals in wood smoke, to determine the degree of exposure, and to document the effects of exposure on the health of firefighters. As that work proceeds MTDC will continue to evaluate a variety of risk management options, including the use of respiratory protective devices, management options that help minimize exposure, and ways to measure the exposure of firefighters to the hazards in wood smoke.

Respirators. Whenever possible, respiratory or other health and safety hazards should be managed or engineered out of the work environment. When it isn't possible to eliminate or reduce the hazard, properly chosen respirators may be an effective way to reduce employee exposure to toxic materials. When health hazards requiring respiratory protection are present in the work environment, and when other management options fail to reduce exposure, the employer has the responsibility of developing an effective respirator program. When considering the use of respiratory protective devices to mitigate the health hazards of smoke, managers are guided by the 11-point program specified by OSHA (CFR 29, 1910.134b):

1. Establish Written Operating Procedures: The employer must develop a formal written document that addresses each of the following points.

2. Respirator Selection: Proper selection of respirators shall be made according to the guidance of ANSI Z88.2-1980. Respirator selection must be based on the hazards to which the worker is exposed.

3. Train Respirator Users: The user must be instructed and trained to operate the respirator properly and recognize its limitations. Respirators cannot be used if anything interferes with the seal of the facepiece to an individual's face. Sideburns, beards, eye glasses, severe scars and wrinkles and even missing dentures can interfere with the seal.

4. Assign Individual Respirators Where Practicable: When it isn't practical to assign respirators individually, the next step becomes even more important.

5. Regularly Clean and Sanitize Respirators: Utilize the 3 step method outlined in the ANSI guide.

6. Respirator Storage: Store respirators in a convenient, sanitary location.

7. Respirator Inspection and Maintenance: Inspect routinely-used respirators during cleaning. Maintain in accordance with manufacturer's recommendations.

8. Monitor the Work Area: Maintain surveillance of work area conditions and degree of employee exposure or stress.

9. Continually Enforce and Evaluate the Respirator Program: Use frequent random inspections by qualified individual to insure that respirators are properly selected, used, cleaned and maintained.

10. Medical Evaluation of Respirator Wearers: Only those persons who are physically able to perform the work and use the equipment should be assigned tasks requiring respirators. Have a qualified physician determine the physical qualifications of the wearer (this could include pulmonary function tests such as the Maximal Voluntary Ventilation test - ANSI, 1984 appendix).

11. Use Approved or Accepted Respirators: Respirators must be

NIOSH/MSHA certified, where applicable, or be otherwise accepted to provide adequate protection for the hazards encountered.

Respirator For Firefighters? If research indicates the need for respiratory protection, and if the exposure can't be managed or avoided, a respiratory protective device may be needed. If so, what sort of respirator will be needed to protect firefighters from the hazards of smoke? Based on the available information concerning the hazards known to be found in wood smoke (carbon monoxide, respirable particulate, formaldehyde, acrolein, etc.), it is doubtful that a disposable device will provide satisfactory protection. In search of an interim answer to the question, we asked an industrial hygiene specialist from NIOSH, with experience on wildfires, to recommend a respirator for firefighters. In his opinion, NIOSH decision logic would call for use of a self-contained breathing apparatus. However, since self-contained breathing apparatuses are heavy, bulky and only effective for short periods, and wildfire work shifts are prolonged and often distant from resupply, they do not offer a practical solution for wildland firefighters.

Some experts have suggested the use of a powered air-purifying respirator. This device uses a battery-operated blower to send contaminated air through a filter or chemical cartridge, and deliver the air to a full-face mask. This type of device has the advantage of supplying clean air under positive pressure. However, to filter and absorb all the constituents of forest fire smoke for extended work shifts would require a large blower and battery pack. The weight would add to the firefighter's workload, and maintenance of battery and blower could be difficult in the field. As noted by Harrison et al. in their report of respiratory effects of smoke exposure, "Suitable respiratory protection is not available to simultaneously control exposure to CO, formaldehyde, respirable dust, and other possible contaminants." Moreover it is possible that protection from one hazard like particulate may encourage greater exposure to another like carbon monoxide. Therefore, until adequate protection is available, the best solution for wildland firefighting may be to limit exposure through better management techniques.

Management of Exposure. It will never be possible to eliminate the smoke from wildland or prescribed burns, so exposure will always be a problem. As an alternative to respirators, or until adequate respiratory protection is available, other management options should be studied:

Determine factors associated with increased exposure (wind, temperature, humidity, depth of duff, etc.) and manage firefighting activities to minimize risks.

Use dosimeters or other air sampling devices to help avoid exposure.

Use disposable or other respirators for symptomatic relief in conjunction with use of dosimeters to avoid excessive exposure.

As needed, move crews to avoid exposure.

Minimize worker exposure on prescribed burns with short periods in smoky sections.

Rotate crews as needed to avoid repeated exposures.

Provide rest and recovery in a smoke-free environment after 7-9 days on the fireline.

Provide a smoke-free environment for decision-makers.

Sleep crews in a smoke-free environment.

Well-trained safety officers, working with cooperative fire overhead and crew bosses, will be able to reduce firefighter exposure to the health hazards in fire smoke.

Heat Stress. A recent article in Fire Engineering (Goldman, May, 1990) discusses the heat stress in firefighting. Based on lab tests of evaporative cooling, the fully-clothed structural firefighter (wearing self-contained breathing apparatus) has about 10% of the evaporative cooling allowed by the environment. This severely limits work output in a hot environment. While the wildland clothing ensemble is somewhat more permeable, it still limits evaporative cooling. Since approximately 20% of heat loss occurs via the head, addition of a half or full-face respirator will further reduce evaporative cooling and work capacity, and could increase respiratory distress anxiety (some workers terminate hard physical work while wearing a respirator because they experience a sensation of suffocation, claustrophobia or an inability to breathe - Morgan and Raven, AIHA Jrnl., 46:363, 1985). Managers should try to avoid the combined stresses of high heat, hard work and reduced evaporative cooling.

Carbon Monoxide Dosimeters. In a Pacific Northwest Station study of firefighter smoke exposure at prescribed burns (already cited), Reinhardt reported on the accuracy of carbon monoxide dosimeters (National Draeger, Inc.), which compared favorably with expensive laboratory analyzers. The carbon monoxide measurements were also correlated to respirable particulate and formaldehyde measures. Because of these findings, the Station plans to study the use of carbon monoxide dosimeters in the field. And they are preparing a video to instruct users in operating dosimeters. NIOSH will also be evaluating the accuracy of dosimeters, and dosimeters will be used in other studies of firefighter exposure and health effects.

Due to the correlation with other constituents of smoke, the carbon monoxide dosimeter may be an

inexpensive tool to monitor and help limit exposure to the health hazards of smoke. Unlike simple sensing indicators and badges, dosimeters allow quantification of exposure and calculation of time weighted averages. For further information contact MTDC, PNW or National Draeger, Inc. (412-787-8383).

Field Notes

Full-face Respirators. Lawrence Livermore National Laboratory (LLNL), Livermore, CA; *Routine Use of Air-Purifying Full-face Respirators for Wildlands Firefighting;* James S. Johnson, Ph.D. For the past five seasons LLNL has routinely used full-face air-purifying respirators for protecting wildland firefighters. When this equipment was introduced, it took some time for the firefighters to accept the limitations created by the respirator. However, after several wildlands responses, the firefighters reported that their typical post-response symptoms of eye irritation, respiratory irritation, tightness in the chest, and coughing up of dark sputum had decreased significantly or were completely eliminated, and that the limitations resulting from the use of this equipment were overcome by adjusting their firefighting activities accordingly. Air-purifying respirators are now a regular part of the LLNL wildlands firefighting equipment.

Air-purifying Respirators. Battalion Chief Jeff Money of the Brevard County Fire and Rescue Department, Merritt Island, Florida reports that his department has used air-purifying respirators for the past six months. The introduction of this new respiratory equipment resulted from experience gained from several firefighters who had earlier spent their own money to buy the equipment. Chief Money reports that the post brushfire headaches are gone as well as respiratory and eye irritation. The need to provide training and enforce the strict use of this equipment for only wildlands firefighting applications was also noted. To date, the department is very pleased with the new equipment, and they feel it has significantly improved the protection provided to their firefighters when they fight wildlands fires.

Firefighter Respirators. Missoula Technology and Development Cent. John Driessen, Ph.D., and Brian Sharkey, Ph.D., are conducting field interviews to determine the extent of respirator use by wildland firefighters. Interview results will be used to construct a questionnaire that will allow Servicewide sampling of firefighter experience with respiratory protective devices. The interviews indicate that a number of units have experimented with the use respirators in wildfire and prescribed burning conditions. While few units endorse the use of respiratory protective devices on wildfires, several are enthusiastic concerning their use on prescribed burns. Half and full-face air purifying respirators are currently being used during periods of actual exposure. Firefighters know that the respirators do not provide protection from carbon monoxide and limit exposure accordingly. They note relief from respiratory and even visual symptoms (when full-face devices are used). A Servicewide sampling of respirator use will soon be available to indicate the extent of use in the Forest Service and other agencies.

Coming Up

PNW Smoke Exposure Study. As part of the Fire and Air Resource Management Project, the PNW Research Station plans a comprehensive smoke exposure assessment of fireline workers during prescribed burns. Associated with this study will be assessment of the health effects of exposure, in cooperation with researchers at the University of Washington.

MTDC Project. MTDC will continue to evaluate the effects of respirators on pulmonary function and work capacity. The next phase of this project will include pulmonary function and treadmill tests on female subjects. Goals of this project are to determine the effects of respirator wear, and to predict those best able to work while wearing respirators.

Respirator Use. MTDC had planned to distribute several types of respirators for field trials. However, since no respirator other than self-contained breathing apparatus provides full protection against the hazards in smoke, we have decided to avoid distribution (and assumed endorsement) of respirators. Instead we will develop and disseminate a questionnaire to determine current use and experience with respirators, respiratory problems, smoking, and other factors associated with exposure to smoke or with successful use of respiratory protective devices.

Next Update. The next issue will be available this winter. For further information on this project contact Brian Sharkey, Ph.D., USDA/FS/MTDC, Bldg. #1, Ft. Missoula, Missoula, MT 59801 [(406) 329-3989].