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NIOSH HEALTH HAZARD EVALUATION REPORT

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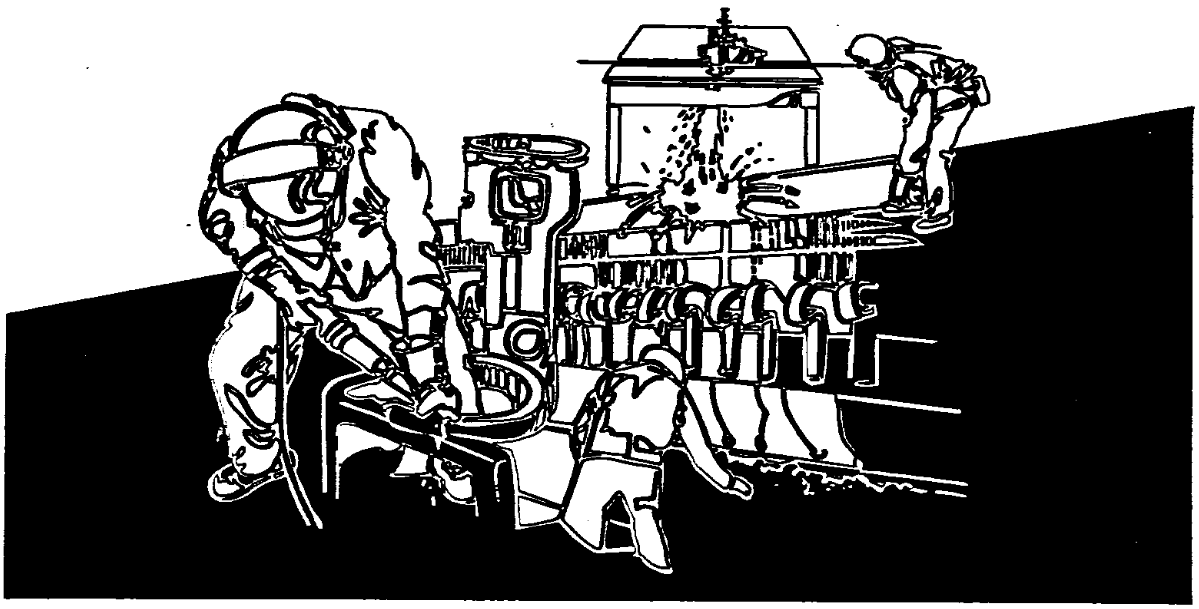
U.S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
YOSEMITE NATIONAL PARK, CALIFORNIA



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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I. SUMMARY

On August 13, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request from the U.S. Department of the Interior, National Park Service (NPS) to characterize exposures and evaluate possible respiratory effects among forest fire fighters at the Arch Rock Fire in Yosemite National Park, California. On August 15-16, 1990, NIOSH conducted industrial hygiene (IH) and medical surveys on fire fighters belonging to three fire fighting crews (two Type I and one Type II). The IH survey measured forest fire fighters' exposures to carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), respirable particulate matter (RPM), polynuclear aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), aldehydes, and acid gases. Also, samples of new and old bandannas (frequently used as respiratory protection by the forest fire fighter) were submitted for scanning electron microscopic analysis to measure the pore size of the fabric. The medical survey evaluated cross-shift changes in lung function, CO levels in exhaled breath (to estimate carboxyhemoglobin [COHb] level), and irritant, respiratory or central nervous system (CNS) symptoms during one workshift.

The average CO and SO_2 exposure concentrations measured in the breathing zone of the Pike Hot Shots were 18.3 parts per million (ppm) and 1.4 ppm, respectively. All of the CO exposure concentrations were below the NIOSH recommended exposure limit (REL), the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV); however, one of six air samples for SO_2 was above the NIOSH REL of 2.0 ppm. The CO breathing zone exposure concentrations in the Plumas Hot Shots averaged 3.9 ppm, and the average breathing zone exposure level for SO_2 was 1.4 ppm, with one of five air samples above the NIOSH REL of 2.0 ppm. Nitrogen dioxide was not detected in the ten time-weighted average (TWA) air samples collected in the breathing zones of the fire fighters.

The 35 ppm standard may not be appropriate for forest fire fighters. In developing the REL for CO, NIOSH used the Coburn, Foster, Kane (CFK) equation (Appendix I) to determine the CO exposure level that would result in a COHb level less than 5% in most workers. Some of the variables (length of workshift, level of work activity, and altitude) used by NIOSH in the CFK equation were adjusted by the NIOSH investigators in this report to better describe the forest fire fighter's work environment. Using these new variables, the CFK equation predicts that a 5% COHb level would be reached at an exposure concentration of 21 ppm. Ten (30%) of the Pike Hot Shots, and none of the Plumas Hot Shots, had exposures in excess of 21 ppm.

Low airborne concentrations of particulate-bound acenaphthene, anthracene, and naphthalene; and gaseous acenaphthene, anthracene, fluoranthene, and benzo(b)fluoranthene, were measured in the breathing zones of the fire fighters. In addition, low airborne concentrations of the following aldehydes and other VOCs were measured in the fire fighters' breathing zones: acetaldehyde, formaldehyde, acrolein, furfural, benzene, toluene, xylene, and total hydrocarbon compounds. The concentrations of hydrochloric acid, sulfuric acid, and hydrofluoric acid measured in the air samples for acid gases were also considered to be low. The exposure levels for RPM were below the OSHA PEL for respirable particulates not otherwise regulated (RPNOR) of 5 milligrams per cubic meter (mg/m^3). The OSHA PEL for RPNOR may not be applicable when evaluating exposures to this particulate matter, since the dust contains particulate-bound PAHs. Scanning electron microscope (SEM) pictures of the new and old bandanna samples demonstrate that the rectangular pore size of the fabric exceeds of 100 microns (μm) in both length and width. The bandannas pore size will allow both respirable and inhalable particles to freely pass through the fabric, and to enter the workers respiratory tract.

Overall, the mean cross-shift changes in lung function for the 21 participants were -0.7% in forced vital capacity (FVC), -1.2% in forced expiratory volume in 1 second (FEV_1), -0.4% in the mean forced expiratory flow during the middle half of the FVC (FEF_{25-75}), and -1.4% in the ratio of FEV_1 to FVC (FEV_1/FVC). The Type I crew had larger declines than the Type II crew in all spirometric values, and those for FVC, FEV_1, and FEV_1/FVC were significant at the level of $p = 0.05$ although each changed by 3% or less. The Type II crew had small cross-shift declines in FEV_1, FEV_1/FVC, and FEF_{25-75}, none of which were statistically significant at the level of $p = 0.05$. The magnitude of the cross-shift declines in lung function did not appear to increase with self-reported increases in exposure. Overall the mean cross-shift increase in estimated COHb% was 1.4% (95%

confidence interval: 1.1%, 1.7%). Cross-shift increase in COHb% was not observed with increasing self-reported exposure to smoke.

Cross-shift symptom data were available on 10 participants from the Type II crew. The most frequent respiratory symptom developing during the shift was nose irritation; headache was the most frequent CNS symptom. The occurrence of respiratory or CNS symptoms was not associated with self-reported degree of exposure, but the validity of these findings is limited by the small number of fire fighters evaluated and self-estimates of exposure.

The NIOSH investigators conclude that a potential health hazard existed from exposure to carbon monoxide and sulfur dioxide at the Arch Rock Forest Fires in Yosemite National Park. This is based on the three CO exposure concentrations above the adjusted guideline of 21 ppm and the two of eleven exposure concentrations for SO_2 above the NIOSH REL of 2.0 ppm. There is limited evidence of acute changes in lung function associated with activities of Type I crew members. Recommendations are made for respiratory protection, and a respiratory surveillance program to further examine the effects of forest fire fighting on lung function.

Keywords: SIC 0851 (Forestry Services), forest fire fighting, carbon monoxide, sulfur dioxide, extended workshifts, lung function tests, breath analysis, carboxyhemoglobin, respiratory symptoms, central nervous system symptoms.

II. INTRODUCTION

On August 13, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request from the U.S. Department of the Interior, National Park Service (NPS) to characterize exposures and evaluate possible health effects among workers fighting the Arch Rock Fire in Yosemite National Park, California. On August 15-16, 1990, the NIOSH investigators conducted concurrent industrial hygiene (IH) and medical surveys of forest fire fighters belonging to three fire fighting crews (two Type I [the Pike Hot Shots, the Plumas Hot Shots] and a Type II [Magdalena 14] crews). The IH survey assessed fire fighters' exposure to carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), respirable particulate matter (RPM), polynuclear aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), aldehydes, and acid gases. In addition, samples of new and washed bandannas were collected for measuring the pore size using an electron microscope. The medical survey was conducted to determine if forest fire fighters incurred cross-shift changes in lung function, carbon monoxide (CO) levels in exhaled breath, and respiratory and central nervous system (CNS) symptoms during one work-shift. Individual medical results of the NIOSH survey were mailed to participants in August of 1991.

III. BACKGROUND

Each year, an estimated 80,000 forest fire fighters fight approximately 70,000 forest fires that burn, on the average, 2 million acres of forested land.[1] Forest fire smoke contains a wide variety of toxic components, including CO and several pulmonary irritants such as particulates, formaldehyde, acetaldehyde, acrolein, furfural, SO_2, and acids.[1,2] Forest fire fighters may be exposed to smoke for long, uninterrupted periods.[1] They typically work 12- to 24-hour shifts for 6 straight days, with the 7th day off. At a fire, forest fire fighters may be on duty for two or more weeks. In addition, base camps may be located in areas of continuous smoke exposure.

The techniques used to fight forest fires are basically the same from fire to fire. Fire fighters use hand tools, chain saws, and/or earth-moving equipment to remove all biomass from a given area. Thus, the fire fighters dig a fireline down to the "mineral soil," which is the inorganic earth beneath the surface levels. When the surface levels (which contain combustible organic matter) are cleared away, an incombustible line of mineral soil is formed. The fire fighters attempt to contain the fire within these lines. In the early stages of a fire, or when a fire jumps the containment lines, direct attack is used in an attempt to suppress the fire. Usually, this consists of the use of hand tools on the leading edges of the fire to slow or alter the progress of the fire. Air attack (the dropping of water or fire retardant from fixed or rotary winged aircraft) is also used to slow the progress of the fire and to extinguish spot fires that may develop downwind of the main fire. Unburned land inside of the fireline may be ignited to remove fuels from areas around the advancing fire. If this burning is done to consume fuel lying in the path of the fire, it is referred to as "backfiring." If done on a smaller scale to remove fuel between the fire and the control line, it is referred to as "burning-out." During burn-outs, fire fighters are required to hold the fireline to insure that the fire does not advance into other forest areas and/or develop into an uncontrollable fire. Once the fire is controlled, fire fighters begin "mop-up" activities. Mop-up consists of the use use of hand tools, chain saws, soil, and water to completely extinguish the fire. Mop-up activities include digging up smoldering stumps, roots, and mineral soil and felling burning snags (a standing dead tree or branch).

Workers involved in forest fire fighting or related activities wear Nomex™ pants and shirts, Vibram™-soled boots with 6- to 8-inch leather uppers, hard hats, goggles, and gloves. Many tie a bandanna across the nose and mouth in an attempt at respiratory protection.

Fire fighting crews involved in building firelines by hand consist of approximately 20 crew members (3 sawyers who operate chain saws, 3 swampers who assist the sawyers, and the remainder of the crew who are equipped with hand tools). These crews are classified as either Type I or Type II crews. Type I crews, also referred to as "hot shots," are highly trained crews used primarily for hand fireline construction in direct attack. Type II crews are also used for hand fireline construction, but are primarily relied on for mop-up activities.

In 1987, smoke inhalation accounted for 38% of all reports of injuries and illnesses among all fire fighters in California.[1] A California Department of Health Services (CDHS) study of 94 forest fire fighters at the Klamath National Forest fires of 1987, found that 76% reported respiratory symptoms (cough, wheezing or shortness of breath) and 70% reported at least one neurologic symptom (dizziness, lightheadedness, headache, loss of consciousness, diminished concentration, confusion, or visual disturbances).[3] During the 1988 Yellowstone fires, 40% of the approximately 30,000 medical visits made by forest fire fighters were for respiratory problems.[1] These data suggest that smoke inhalation may be a problem among workers engaged in forest fire fighting.

IV. METHODS

The primary objectives of this study were to assess the fire fighters' exposures to combustion products, and to determine if fire fighters experienced cross-shift changes in lung function, elevated CO levels in exhaled breath, or respiratory or CNS symptoms, and if so, whether these were associated with a subjective assessment of smoke exposure.

A. Industrial Hygiene Survey

The IH survey consisted of personal breathing zone (PBZ) air sampling for CO, SO_2, NO_2, respirable particulate matter (RPM), PAHs, VOCs, aldehydes, and acid gases. On each Type I crew, three volunteers were solicited per analyte to wear air sampling equipment for PAHs, RPM, VOCs, acid gases, and aldehydes. In addition, selected crew members were chosen to wear long term diffusion tubes for CO, SO_2, and NO_2. All air sampling equipment was calibrated pre- and postshift, with periodic calibration checks performed in the field. Below are the methods used to collect these samples.

1. Carbon Monoxide, Sulfur Dioxide, Nitrogen Dioxide

Personal breathing zone air samples for CO, SO_2, and NO_2 were collected using Dräger long-term diffusion tubes. These tubes are colorimetric indicators which produce a time-weighted average (TWA) concentration for the specific analytes.

2. Respirable Particulate Matter

Air samples were collected for RPM according to NIOSH Method 0600.[4] Sample air is drawn through a Dorr-Oliver cyclone which removes particles with an aerodynamic diameter larger than 10 microns (µm) from sample air. The remaining respirable dust particles are collected on a tared polyvinyl chloride filter (37 millimeter diameter, 5 µm pore size) using a portable, battery-powered sampling pump. A determination of the weight of particulate matter deposited on each sample was made by weighing the samples on an electrobalance and subtracting the previously determined tare weights. The instrumental precision for this method was 0.01 milligrams (mg) per sample.

3. Volatile Organic Compounds

Volatile organic compounds were measured using NIOSH Methods 1003, 1500, and 1503.[4] Sample air was drawn through a charcoal tube using a portable, battery-powered sampling pump. After sampling, the charcoal was desorbed with carbon disulfide and one sample was qualitatively screened by gas chromatography (GC) with a flame ionization detector (FID), using a fused silica capillary column in the splitless mode. Based on these results, standards were prepared and the other samples were quantitated for the identified compounds.

4. Aldehydes

Aldehydes were measured using NIOSH Method 2539 to collect the PBZ air samples.[4] Sample air was drawn through an Orbo-23 sorbent tube (manufactured by Supelco, Inc.), which contains washed XAD-2 resin coated with 10% hydroxymethyl piperazine, using a portable, battery-powered sampling pump. After sampling, the sorbent was desorbed with toluene in an ultrasonic bath. A GC-FID with a fused silica capillary column in the splitless mode was used to screen one of the samples for aldehydes. Based on these results, standards were prepared and the other samples were quantitated for the identified compounds.

5. Polynuclear Aromatic Hydrocarbons

The particulate and gaseous forms of PAHs were collected using NIOSH Method 5515.[4] Sample air was drawn through a polytetrafluoroethylene filter and sorbent tube (washed XAD-2 resin in Orbo-43 sorbent tube, manufactured by Supelco, Inc.) in series. The filter removes the particulate matter, whereas, the sorbent tube removes the gaseous PAHs. The filter and sorbent tube samples were extracted with benzene, and aliquots were injected into a GC-FID and analyzed for the following PAHs: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene.

6. Inorganic Acids

Air samples for hydrochloric, hydrofluoric, sulfuric, hydrobromic, nitric, and phosphoric acids were collected using NIOSH Method 7903.[4] Sample air was drawn through a silica gel sorbent tube (Orbo 53 manufactured by Supelco, Inc.) using a portable, battery-powered sampling pump. After sampling, each sample was desorbed with a bicarbonate/carbonate buffer solution and heated in a boiling water bath for 10 minutes. An aliquot of each sample was analyzed by ion chromatography. Liquid standards for the above acids were analyzed with the samples.

7. Electron Microscopy

Samples of both new and old (washed and hot air dried several times) bandannas were submitted to determine the pore size of the fabric. The samples were coated with gold and viewed with a JEOL JSM-T330 Scanning Electron Microscope (SEM) with a tungsten filament. The working distance was 20 centimeters, with an accelerating voltage of 20 kilovolts. Pictures of the magnified bandanna samples were taken with a Polaroid camera.

B. *Medical Survey*

The NIOSH investigators identified a Type I crew (Pike Hot Shots) and a Type II crew (Magdalena 14 Crew) to participate in the medical portion of this study. The Type I crew worked a 12 hour daytime shift, while the Type II crew worked the night shift that immediately followed. A total of 24 forest fire fighters were asked to participate in the medical evaluation. Three refused to participate, leaving a total of 21 study participants (11 Type I crew members and 10 Type II members, 88% of those eligible). Informed consent was obtained from all 21 study participants.

1. Data Collection

During August 15-16, 1990, spirometry and breath analysis for CO were performed, and a questionnaire was administered to the 21 study participants before and after their work-shift. The preshift questionnaire used was a revision of one developed by the California Department of Health Services, Occupational Health Department for studies of forest fire fighters. The data collected using the questionnaire consisted of information regarding demographics, smoking history, medical and occupational history, recent work exposures, and irritant, respiratory, and CNS symptoms. The postshift questionnaire elicited the same irritant, respiratory, and CNS symptoms, and an estimate of the greatest amount of smoke exposure during the shift. Both questionnaires were self-administered but were checked by, and reviewed with, one of the investigators after completion.

2. Lung Function Tests

Spirometry was performed by trained technicians using two Sensormedics Model 827 volume spirometers interfaced with a computer built in-house; American Thoracic Society (ATS) guidelines were followed.[5] The spirometers were calibrated with a 3-liter syringe before each testing session. Each participant performed a minimum of five forced expiratory maneuvers. Pre- and postshift spirometry for each participant was performed by the same technician using the same spirometer. Spirometric values were considered reproducible when the two best values for 1-second forced expiratory volume (FEV_1) and forced vital capacity (FVC) did not vary by more than 5% or 100 milliliters (ml), whichever was greater. All spirometric measurements were corrected to body temperature and pressure, saturated with water vapor (BTPS) using a dynamic BTPS correction factor model developed by Hankinson et al.[6] This model was used to correct for cross-shift spirometer temperature differences that can result in an error in spirometric values. Each participant's height was measured in stocking feet. To compare preshift spirometric results among the study participants and to population norms, FEV_1, FVC, the mean forced expiratory flow during the middle half of the FVC (FEF_{25-75}) and the ratio of FEV_1 to FVC (FEV_1/FVC) were expressed as percentages of corresponding values predicted (on the basis of age, sex, and height) using the equations of Knudson.[7] To assess cross-shift changes in pulmonary function, the percent change across the shift was calculated for FEV_1, FVC, FEF_{25-75}, and FEV_1/FVC for each participant as follows:

For FEV_1, FVC, and FEF_{25-75}:
% change = 100 X (postshift - preshift)/preshift

For FEV_1/FVC:
% change = postshift - preshift

Cross-shift differences were also calculated as the difference of preshift and postshift values. The significance of the cross-shift differences in FEV_1, FVC, FEF_{25-75}, and FEV_1/FVC was tested using the paired T-test.

3. Breath Analysis

NIOSH investigators instructed study participants in the collection of breath samples for CO using the method described by Ringold et al.[8] Instructions in the collection of breath samples for CO were as follows:

1) After a full breath, exhale completely.
2) Inhale rapidly until lungs are filled.
3) Hold breath for 20 seconds.
4) Exhale a small portion of breath into the ambient air.
5) Exhale the remainder of the breath into a plastic bag.

The CO concentration in the exhaled breath was measured in parts per million (ppm) with an Ecolyzer® Series 2,000 CO analyzer (Energetics Science, Elmsford, New York). The Ecolyzer® was calibrated before and after each series of measurements using a compressed air-CO gas mixture. The percentage of carboxyhemoglobin (COHb%) in the blood was then estimated using the equation developed by Ringold et al.:[8]

$$COHb\% = 0.5 + ([CO\ in\ ppm] \div 5)$$

To assess cross-shift changes in CO the difference in COHb% was calculated for each participant as follows:

Cross-shift difference COHb% = Postshift COHb% - Preshift COHb%

4. Exposure Estimation

Each study participant was asked to rate the intensity of the smoke during his/her work-shift using a scale from 1 to 4, with 1 representing no smoke, 2 representing light smoke, 3 representing medium smoke, and 4 representing heavy smoke. Participants rating their smoke exposure as light were placed in the low-exposed category, while those rating it as medium or heavy were placed in the medium-exposed or high-exposed category, respectively.

Personal breathing zone samples for CO were collected on 7 of the 11 Type I crew members who participated in the medical survey. Three or fewer PBZ samples for sulfur dioxide (SO_2), nitrogen dioxide (NO_2), respirable particulate matter (RPM), polynuclear aromatic hydrocarbons (PAHs), and acid gases were also collected. No IH monitoring was done on the Type II crew because IH personnel were already committed to work involving the Type I crew.

V. EVALUATION CRITERIA

A. General Guidelines

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure which most workers may be exposed up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy).

Evaluation criteria for chemical substances are usually based on the average PBZ exposure to the airborne substance over an entire 8- to 10-hour workday, expressed as a TWA. To supplement the 8-hour TWA where there are recognized adverse effects from short-term exposures, some substances have a short-term exposure limit (STEL) for 15-minute peak periods; or a ceiling limit, which is not to be exceeded at any time. Additionally, some chemicals have a "skin" notation to indicate that the substance may be absorbed through direct contact of the material with the skin and mucous membranes.

The primary sources of evaluation criteria for the workplace are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[9] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[10] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[11] The OSHA PELs reflect the economic feasibility of controlling exposures in various industries, public notice and comment, and judicial review; whereas, the NIOSH RELs are based primarily on concerns related to the prevention of occupational disease. An additional complication is due to the fact that a Court of Appeals decision vacated the OSHA 1989 Air Contaminants Standard in *AFL-CIO v OSHA,* 965F.2d 962 (11th cir., 1992); and OSHA is now enforcing the previous 1971 standards, (listed as Transitional Limits in 29 CFR 1910.1000, Table Z-1-A).[12] However, some states which have OSHA-approved State Plans will continue to enforce the more protective 1989 limits. NIOSH encourages employers to use the 1989 limits or the RELs, whichever are lower.

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects, even if the occupational exposures are controlled at the level set by the evaluation criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus, potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

B. Carbon Monoxide and Carboxyhemoglobin

Carbon monoxide is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials, e.g., vegetation. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma or death may occur if high exposures continue.[13,14,15,16,17,18]

Carbon monoxide combines with hemoglobin in red blood cells to form carboxyhemoglobin (COHb), reducing the bloods ability to carry oxygen to the organs and other vital body parts, and exerting stress on the body.[9,10,11,12,13] In fact, hemoglobin has a 210 to 240 times greater affinity for CO than for oxygen.[12,13] This reduction in the ability of blood to transport oxygen to the body can result in a state of oxygen deficiency known as tissue hypoxia. The body compensates for this stress by increasing cardiac output and the blood flow to specific areas, such as the heart and brain.[9,10,11,12,13] Carboxyhemoglobin is completely dissociable following cessation of exposure, and has a biologic half-life of 5 hours.[13] After dissociation, CO is eliminated from the body via the lungs, i.e., during exhalation.[9,13]

The blood of smokers typically contains 2 to 10% COHb. Non-exposed, non-smokers usually have a COHb level of 1% or less, but non-smokers in large cities may have a COHb level of 1-2%, with the probable source of CO being air pollution from the combustion of fossil fuels.[9,13,14] As the level of COHb in the blood increases, the victim experiences health effects which are progressively more injurious. Initially, the victim is pale; later the skin and mucous membranes may be cherry red in color. Loss of consciousness occurs at about a 50% COHb level, and death occurs at levels of 70%.[9,12,13] The physiologic reaction to a given level of COHb in blood is extremely variable from person-to-person. The symptoms associated with various percent blood saturation levels of COHb are shown below:[9,11]

% COHb in Blood	Symptoms
0-10	No symptoms
10-20	Tightness across forehead, slight headache, dilation of cutaneous blood vessels.
20-40	Moderate to severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, collapse.
40-50	Increased probability of collapse, loss of consciousness, rapid pulse and respiration.
50-60	Loss of consciousness, rapid pulse and respiration, coma, convulsions.
60-70	Coma with intermittent convulsions, depressed heart rate and respiration, possible death.
Greater than 70	Weak pulse, slow respiration, respiratory failure, death.

A number of cardiovascular effects are associated with CO exposure. As previously discussed, this is because COHb reduces the amount of oxygen transported by the blood. Persons with chronic heart and/or lung disease are at serious risk, since they already have impaired ability to obtain oxygen from inhaled air, or supply oxygen-rich blood to the heart muscle. Even at low levels, CO exposure increases the risk for angina (heart pain), heart attacks, and cardiac arrest in some people.[9,10,11,13]

The NIOSH REL and the OSHA PEL for CO are an 8-hour per day, 40 hours per week TWA exposure of 35 and 50 ppm, respectively. Both NIOSH and OSHA have set a ceiling limit (level not to be exceeded during a work shift) for CO of 200 ppm.[19,20] The ACGIH recommends an 8-hour TWA TLV of 25 ppm.[21] In addition to these standards, the National Research Council has developed a CO exposure standard of 15 ppm, based on a 24-hour day, 90-day TWA exposure.[22]

The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[9] NIOSH used the Coburn, Foster, Kane (CFK) equation to calculate the maximum 8-hour exposure level that would result in this 5% COHb level. The CFK equation is an exponential equation that describes the relationship between CO exposure and COHb levels, considering such variables as duration of exposure, lung ventilation rate, rate of endogenous CO production, diffusion rates in the lung, blood volume, barometric pressure, and the partial pressure of CO and oxygen in the lung. In using the CFK equation to determine the REL of 35 ppm, NIOSH considered an exposure duration of 8-hours per day, and a sedentary worker activity level (as defined by a lung diffusion rate [D_L] of 30 milliliters per minute per millimeters of mercury [ml/min/mm Hg] and lung ventilation rate [V_A] of 6000 milliliters per minute [ml/min]). The CFK equation does not take into account the effects of altitude on CO exposure and COHb levels. When CO exposures occur at altitudes above 5000 feet, NIOSH recommends a lowering of the REL to compensate for the decreased availability of blood oxygen to the tissues.[9]

C. *Sulfur Dioxide*

Sulfur dioxide (SO_2) is a primary irritant of the eyes, mucous membranes, upper respiratory tract and skin. Its irritating effects are due to the speed in which SO_2 forms sulfuric acid when contacting a moist surface, e.g., the mucous membranes and eyes. Other symptoms of SO_2 exposure include frequent cough, choking, rhinorrhea ("runny nose"), and reflex bronchoconstriction with increased pulmonary resistance.[12,14] An epidemiologic investigation of workers exposed to SO_2 in a copper smelter documented a decline in pulmonary function over a 1-year period, and an increase in cough and sputum production. The exposure levels in this facility ranged from 1.0-2.5 ppm of SO_2.[23]

The OSHA PEL for SO_2 is 5.0 ppm when based on an 8-hour TWA exposure. The ACGIH TLV for SO_2 is an 8-hour TWA exposure of 2 ppm, and a STEL of 5 ppm as a 15-minute TWA exposure that should not be exceeded at any time during the workshift.[15,17] In 1988, NIOSH raised the REL for SO_2 from 0.5 ppm to 2.0 ppm, for up to a 10-hour TWA exposure.[24]

D. *Other Contaminants*

The evaluation criteria for the other chemical contaminants studied in this investigation (VOCs, PAHs, aldehydes, NO_2, and RPM) are presented at the bottom of the data tables for these specific analytes. Some of the chemicals that potentially could have been present are considered by NIOSH to be potential human carcinogens (e.g., formaldehyde, certain VOCs and PAHs, etc.). Since there is no recognized safe exposure to carcinogens, NIOSH recommends that exposure to these compounds be reduced to the lowest feasible level (LFL).[20]

E. *Sampling and Analytical Limits of Detection*

When using air sampling to determine exposures, the possibility arises that the substance being sampled will not be detected by the analytical method.

When this occurs, the concentration will be reported as none detected (ND) in the data tables. In order to interpret ND values, a minimum detectable concentration (MDC) is calculated using the analytical limits of detection and an average sample volume. The MDCs can be found in the bottom portion of Tables 3 through 7, and the units are the same as the concentration units for that specific chemical and/or substance. Whenever a ND is encountered in the data tables, this indicates that the actual exposure or concentration is less than the MDC listed for that chemical in the table. A MDC cannot be determined when using long-term diffusion tubes to determine exposure.

F. *Lung Function Tests*[25,26,27]

Lung function tests that measure how well the lungs and air passages move air in and out include, among others:

1. Forced vital capacity (FVC), the total amount of air one can force out of the lungs after breathing in as deeply as possible.

2. One-second forced expiratory volume (FEV_1), the amount of air one can breathe out in the first second of a forced exhalation.

3. The mean forced expiratory flow during the middle half of the (FEF_{25-75}), the average rate of air flow in the middle of a forcefully exhaled breath.

4. The calculated ratio of FEV_1 to FVC (FEV_1/FVC).

Lung function values are evaluated by comparing them to predicted values that take into account age, height, sex, and race. For screening purposes, lung function is commonly considered normal if the FVC and FEV_1 are 80% or more of their predicted values and the actual FEV_1/FVC (not percent predicted) is 70% or more. Interpretation of the FEF_{25-75} is more difficult as there is wide variation among apparently healthy individuals. As a rough guide, a FEF_{25-75} as low as 65% of predicted may be within the acceptable range.[28]

A low FEV_1/FVC, or a low FEV_1 with a normal FVC, indicates an obstructive impairment to exhaling air rapidly. A low FVC, with a normal FEV_1/FVC, indicates a restrictive impairment of lung capacity. Other combinations are more difficult to interpret without additional information. A low FEF_{25-75} indicates small airways obstruction.

VI. RESULTS

A. *Industrial Hygiene Study*

On August 15, 1990, the Pike and Plumas Hot Shots deployed to a valley area to conduct a burn-out. The Pike Hot Shots were charged with lighting the burn-out with drip torches and holding the fire line; the Plumas Hot Shots were positioned on a flank-portion of the fireline and performed mostly mop-up of burned areas. The valley was located at an altitude of approximately 6,100 feet above sea level, and the temperature was between 66 and 70°F with approximately 32% relative humidity. During the morning hours, the temperatures were low and humidity was relatively high; conditions not conducive for a successful burn-out. As the day progressed, the temperature rose and the humidity dropped; thus, the majority of the burning-out was performed after the noon hour. Two teams of NIOSH IHs were deployed with the two hot shot crews. Based on a visual assessment of the work environment, the NIOSH IHs estimated that the Plumas Hot Shots worked under light smoke exposure conditions, whereas, the Pike Hot Shots worked under moderate smoke exposure conditions. The valley designated for the burn-out was approximately a 2-hour hike from the transportation drop-off point. Thus, air samples were only collected during the 9- to 10-hour period the fire fighters were at the work location. Since, the fire fighters hiked through unburned areas to get to the valley, the NIOSH investigators assumed the contribution of exposures incurred during the hike were negligible when compared to the exposures on the fireline.

Exposure data from the breathing zone air sampling for CO, SO_2, and NO_2 are presented in Table 1 (Pike Hot Shots) and Table 2 (Plumas Hot Shots). The average CO and SO_2 exposure concentrations in the Pike Hot Shots were 18.3 ppm (n=10) and 1.4 ppm (n=6), respectively. All the CO exposure concentrations were below the NIOSH REL, OSHA PEL, and ACGIH TLV; one of the six fire fighters monitored for SO_2 had an exposure concentration above the NIOSH REL of 2.0 ppm. Conversely, the CO exposure concentrations in the Plumas Hot Shots averaged 3.9 ppm (n=9), and the average exposure to SO_2 was 1.4 ppm (n=5), with one of the five samples being above the NIOSH REL of 2.0 ppm. NO_2 was not detected in the 10 TWA samples collected in the breathing zones of the fire fighters in these crews.

Tables 3 through 7 contain the exposure data for particulate and gaseous forms of PAHs, aldehydes, acid gases, and RPM. From Tables 3 and 4, particulate-bound acenaphthene, anthracene, and naphthalene; and gaseous concentrations of acenaphthene, anthracene, fluoranthene, and benzo(b)fluoranthene, were the only PAHs measured in the breathing zones of the fire fighters. Also, PBZ air sampling (Table 5 and Table 6) measured detectable levels of acetaldehyde, formaldehyde, acrolein, furfural, hydrochloric acid, sulfuric acid, and hydrofluoric acid. These low to trace concentrations were well below the respective evaluation criteria for these chemicals, and individually would not be expected to cause acute health effects at these levels.

Personal breathing zone air sampling for VOCs was conducted on a Pike sawyer, a Pike swamper, a Plumas crewman, and the Plumas crew foreman. This sampling was performed over the entire workshift, and the following VOCs were identified on the samples: benzene, toluene, xylene, and total hydrocarbon compounds. The concentrations of these VOCs were either below the MDC, or between the LOD and LOQ for the analytical method. The highest measured exposure concentrations of these compounds were as follows: 0.03 ppm of benzene, 0.02 ppm of toluene, 0.02 ppm of xylene, and 0.1 ppm of total hydrocarbons. The NIOSH investigators consider these VOC concentrations to be trace levels, and are well below the concentrations recognized to produce adverse health effects in most exposed workers.

The breathing zone exposure concentrations for RPM ranged from 0.6 to 1.7 milligrams per cubic meter (mg/m^3), and were below the OSHA PEL for respirable particulates not otherwise regulated (RPNOR) of 5 mg/m^3. The OSHA PEL for RPNOR is not applicable when evaluating exposure to this particulate matter, since the NIOSH investigators found particulate-bound PAHs. Since a large portion of the RPM exposure is a product of combustion of the surrounding vegetation, it may contain significant amounts of various other substances that may also be an inhalation hazard. Further research is needed to identify other potential combustion products which may be present in the RPM.

It is interesting to compare some of the measured exposure levels from the Pike Hot Shots versus the Plumas Hot Shots. As previously mentioned, the Pike Hot Shots were exposed to what was visually considered to be moderate levels of smoke, and the Plumas Hot Shots were exposed to light levels of smoke. This fact is reflected in the CO exposure data; i.e., the Pike Hot Shots had an average CO exposure of 18.3 ppm, while the Plumas Hot Shots had an average CO exposure of 3.9 ppm. This relationship also exists when comparing the exposure levels for RPM and particulate-borne PAHs.

Figures 1 and 2 contain the SEM pictures of the new and old bandanna samples, respectively. The pictures clearly demonstrate that the rectangular pore size of the fabric is in excess of 100 μm in both length and width; thus, the bandanna is ineffective in removing RPM from inhaled air.

B. *Medical*

1. *Demographic, Medical History, and Occupational Characteristics*

Characteristics of the 21 participants are presented in Table 8. Seventy-one percent of the participants were male and fourty-eight percent Caucasian. The mean age of the participants was 28 years (standard deviation [sd]=8), and they had worked an average of 5 seasons (sd=5) fire fighting. Ninety-five percent were seasonal employees. Seventy-five percent had never smoked. Histories of allergies and asthma were each reported by 10% of the participants.

Characteristics of the 21 participants differed by crew type (Table 9). The Type I crew was younger and had fewer males than the Type II crew. Ninety-one percent of the Type I crew were Caucasian, whereas, eighty percent of the Type II crew were Native American. The Type II crew worked, on the average, more fire seasons than the Type I crew. None of the Type I crew members were current smokers, whereas 30% of the Type II crew were current smokers. The only crew members with a reported history of asthma or allergies were in the Type I crew.

2. *Preshift Lung Function*

Mean preshift spirometry results for the 21 participants were greater than or close to predicted values for FEV_1, FVC, and FEF_{25-75}, and are shown in Table 9.

3. *Preshift Breath Analysis*

Overall, the mean preshift CO in exhaled breath was 4.0 ppm (sd=1.0), corresponding to a COHb saturation of 1.3% (sd=0.2). The Type I crew had a minimally mean higher preshift COHb saturation level than the Type II crew (Table 9).

4. Cross-Shift Changes

a. Lung Function

Overall, the mean cross-shift changes in lung function for the 21 participants were -0.7% ($p=0.10$) in FVC, -1.2% ($p=0.03$) in FEV_1, -0.4% ($p=0.26$) in FEF_{25-75}, and -1.4% ($p=0.19$) in FEV_1/FVC. The Type I crew had larger declines in all spirometric values, and those for FVC, FEV_1, and FEV_1/FVC were significant below the level of $p=0.05$ although each changed by 3% or less (Table 10). The Type II crew had small cross-shift declines in FEV_1 and FEV_1/FVC, and small increases in FVC and FEF_{25-75}, none of which were statistically significant at the level of $p=0.05$ (Table 10). The difference in response between the two crews cannot be explained by cigarette smoking, as none of the Type I crew members was a current smoker and only one person had ever smoked, compared to the Type II crew where three were current smokers and one other was a former smoker. The mean cross-shift changes in lung function by exposure category are shown in Table 11. A cross-shift decline in lung function was not observed with self-reported increasing exposure. Linear regression models were used to study whether cross-shift changes in pulmonary flow or volume could be explained age, gender, race, crew, or reported smoke exposure; none of these models significantly accounted for the measured changes in pulmonary function.

b. Breath Analysis

The results of the analysis of CO in exhaled breath appear in Table 12. Overall, the mean postshift CO in exhaled breath was 10.8 ppm (sd=3.1) corresponding to a estimated carboxyhemoglobin saturation of 2.66% (sd=0.6). Among nonsmokers the mean postshift CO in exhaled breath was 11.1 ppm (sd=3.1) corresponding to a estimated COHb saturation of 2.71% (sd=0.6). Among smokers the mean postshift CO in exhaled breath was 9.2 ppm (sd=2.5) corresponding to a estimated COHb saturation of 2.33% (sd=0.5).

The mean postshift CO level in exhaled breath was higher among the Type I crew than among the Type II crew; the postshift CO level in the type I crew was 12.0 ppm (sd=2.3) (estimated COHb%=2.9%

[sd=0.5]) and in the Type II crew was 9.4 ppm with a standard deviation of 3.3 (estimated COHb%=2.4% [sd=0.7]).

The exposure levels of CO for the seven individuals from the Type I crew who were monitored, and their corresponding postshift estimated COHb% levels, are shown in Table 13. There was no apparent correlation between the PBZ CO levels and the postshift COHb%. All seven individuals reported that their highest smoke exposure was of "medium" intensity (defined as "thick enough to make it difficult to see beyond about 100 yards).

c. *Symptoms*

Preshift symptom information was not obtained from the Type I crew. The frequencies of pre- and postshift symptoms among the Type II crew are shown in Table 14, as are the number of participants in the Type II crew who developed symptoms across the shift (i.e., those who did not report the symptom preshift but did at postshift). The numbers in "Change" column do not correspond because the "Preshift" and "Postshift" columns represent actual numbers of crew members reporting symptoms at pre- and postshift, whereas, the "Change" column represents the numbers of crew members who did not report symptoms at preshift but did at postshift. For example, the two crew members who reported eye irritation at postshift did not report eye irritation at preshift (and the two crew members who reported eye irritation at preshift did not report it at postshift), therefore, resulting in a cross-shift change of two. For nose irritation only four of the six crew members reporting nose irritation at postshift did not report nose irritation at preshift. The symptom which participants most frequently developed across the shift was nose irritation; headache was the most frequent CNS symptom.

VII. DISCUSSION

In developing the REL for CO, NIOSH used the CFK equation to determine the CO exposure level that would result in a COHb level less than 5% in most workers.[9] Several factors should be considered when using this equation for forest fire fighters:

1. The duration of exposure for forest fire fighters is longer than the duration used in the CFK equation to determine the NIOSH REL. Forest fire fighters typically work 12-hour shifts six days a week (total of 72 working hours per week). Conversely, the NIOSH REL is for an exposure duration of 8 hours per day, 40 hours per week.[9]

2. In many regions of the U.S., forest fires are fought at altitudes above 5,000 feet. In fact, the Pike and Plumas Hot Shots were positioned on a ridge 6,100 feet above sea level.

3. The NIOSH investigators believe that the level of work activity (sedentary) used by NIOSH in the CFK equation is not appropriate for forest fire fighting.[9] The NIOSH investigators believe that the D_L and V_A values for heavy work activity levels are more descriptive of this type of work, and should be used in the equation. D_L and V_A values for sedentary, light, and heavy work activity levels are presented in the NIOSH recommended standard for CO.[9]

Considering the above information, the NIOSH investigators made adjustments to these variables, and used these adjustments to calculate a proposed exposure guideline for CO. These adjustments, along with a description of the CFK equation and the variables used in the equation, are presented in Appendix I. Using the time spent on the fireline of 9-hours (540 minutes), D_L and V_A values for a heavy level of work activity, and an altitude of approximately 6,100 feet above sea level, the NIOSH investigators calculated that 5% COHb levels would be reached with CO exposures above 21 ppm. In evaluating the CO exposure concentrations measured during the NIOSH survey, ten (30%) of the Pike Hot Shots had exposures in excess of this proposed exposure guideline of 21 ppm. These data indicate that members of this fire fighting team may be overexposed to CO. Conversely, the CO exposure concentrations in the members of the Plumas Hot Shots were all below the proposed 21 ppm exposure guideline.

A cross-shift increase in COHb saturation was found in this study, although none of the participants' postshift COHb% exceeded 5%. In a California Department of Health Services (CDHS) study postshift COHb% levels exceeded 5% in 17 (18%) of 94 forest fire fighters studied.[3] The biologic half-life of carboxyhemoglobin is 4.5 hours. Because the length of the shift is longer than the half-life of carboxyhemoglobin, the effects of any excessive exposures to CO early in the shift may not have been apparent by the end of the shift. In addition, there was a delay of approximately 2 hours from the time the forest fire fighters left the fireline at the end of the shift, to the time the CO testing of exhaled breath was conducted at base camp. For these reasons the cross-shift change does not reflect a simple accumulation of additional CO during the shift. Higher postshift COHb% levels might have been detected if testing for CO in exhaled breath had been done on the fireline.

As previously discussed, the OSHA PELs were developed to account for doses that are imparted to a worker during a normal 8-hour day, 40-hour week. Therefore, the NIOSH investigators used a model developed by OSHA to calculate proposed exposure guidelines to assess exposures that occur during the unusual work schedules worked by forest fire fighters.[29] The ACGIH has also recommends that this model be used to adjust the TLVs whenever the TLVs are being used to determine exposures during unusual work schedules.[17] The NIOSH investigators used the model to adjust either the OSHA PEL or ACGIH TLV (adjustment was performed on the more protective criterion of the two) for a 9-hour day, 6-day week work schedule. A description of the OSHA Model, and the calculated adjustments (referred to as proposed exposure guidelines in the tables), are presented in Appendix II. It is important to note that the OSHA Model recommends no adjustment for some substances (e.g., SO_2, hydrochloric acid, acrolein, etc.). The concentrations of NO_2, PAHs, aldehydes, and VOCs measured during this evaluation were still below the proposed exposure guidelines. No adjustment was made in evaluation criteria for RPM, since the actual composition of the particulate material has yet to be determined. Also, no adjustment was made for formaldehyde or acetaldehyde, since NIOSH considers these substances to be potential human carcinogens and recommends exposures be reduced to the lowest feasible level. The PAHs measured during the NIOSH survey, except for naphthalene, do not have criteria for evaluating exposure.

The aerodynamic diameter of a solid or liquid particle is the parameter which determines where in the respiratory tract the particle will deposit. Thus, small particles can travel through the turbinate bone structure of the nose and sinus, and the bifurcations of the bronchial tree, depositing in the sensitive alveolar (non-ciliated) region of the lungs. Generally, particles less than 10 μm in diameter are considered to be capable of reaching the alveolar region, and have a greater hazard potential than larger particles. Particles with an aerodynamic diameter less than 100 μm are considered inhalable, and are capable of being deposited anywhere in the respiratory tract. The SEM photographs demonstrate the pore size of the bandannas is sufficiently large to allow both inhalable and respirable particles to freely pass through the fabric and enter the respiratory tract. Shrinkage from the frequent washing and hot-air drying of the fabric does not significantly reduce the pore size. In addition, the bandanna offers no protection from the gaseous components (e.g., CO, SO_2, PAHs, aldehydes, etc.) of the smoke. Thus, bandannas are an inadequate form of respiratory protection against the particulate and gaseous compounds generated by a forest fire.

In this study, cross-shift declines were observed in FVC, FEV_1, FEF_{25-75}, and FEV_1/FVC; when considering both crews together, only the cross-shift decline in FEV_1 was statistically significant, but significant declines were observed in FVC, FEV_1, and FEV_1/FVC in one of the two groups. Although the two groups were studied on different shifts, it is unclear whether diurnal variation can account for some of the difference between groups in the cross-shift changes. Some investigators have reported a statistically significant effect of workshift schedule on changes in pulmonary function, but in a study of workers not exposed to respiratory hazards, the time of the schedule was not a significant determinant of FEV_1.[30]

Despite the statistical significance of some cross-shift changes in pulmonary function test results, the medical significance of these changes is uncertain. None of the mean changes within a crew exceeded 3%, and the change in FEV_1 was only 2.3% in the Type I crew. Based upon their study of the variability of cross-shift change in FEV_1 among 944 workers not exposed to respiratory hazards, some investigators have recommended that medical monitoring programs regard cross-shift changes in FEV_1 of about 8% or higher as significant.[30]

Cross-shift decline in lung function was not related to increasing self-reported exposure. It is possible, however, that the self-reported exposure assessments in the two crews are not comparable because the exposure question relied on the respondents' visual assessments of how far they could see through the smoke. The Type II crew working at night may have had more difficulty making such as assessment than the Type I crew, who worked during the daytime.

Three studies of forest fire fighters have reported cross-seasonal declines in lung function. Investigators from The Johns Hopkins University found a significant cross-seasonal decline in FEV_1 of -1.2%.[31] Cross-seasonal declines in FEV_1 and FVC were significantly associated with increasing hours of fire fighting in the final week of their study. A study by the CDHS Occupational Health Program revealed significant cross-seasonal declines in FVC, FEV_1, FEF_{25-75}, and FEV_1/FVC in forest fire fighters.[32] In a NIOSH study, a significant cross-season decline in FEF_{25-75} and FEV_1/FVC was found among 78 hot shot crew members.[33] Dose-related decreases in FEF_{25-75} and FEV_1/FVC were associated with higher exposure (test for linearity: p = 0.08 and 0.16, respectively). The small number of participants and the subjective nature of self-reported exposures in this investigation may account for the failure to demonstrate an association between smoke exposure and cross-shift declines in pulmonary functions.

Except for nose irritation, there was little to no change in symptom prevalence across the shift. However, due to the small number of fire fighters evaluated, it is not clear whether these data are representative of most forest fire fighters. In The Johns Hopkins University study, forest fire fighters had a cross-seasonal increase in the prevalence of eye and nose irritation, cough, phlegm production, and wheezing.[31]

The exposure variable (self-reported smoke intensity) used in this study may be only crudely associated with participants' actual exposures to CO and irritants, and some misclassification of participants by exposure category may have occurred. All seven individuals who received PBZ monitoring for CO reported the same maximum smoke exposure, so it was not possible to study whether self-reported exposures were correlated with measurements of exposure.

Further exposure assessments are needed to better define the exposures involved with forest fire fighting. Exposures during other fire suppression activities (e.g., direct attack, line holding) should be investigated. In addition, more exposure assessment data is needed to characterize worker exposures during intense smoke conditions. Not only should TWA exposures be measures, but peak exposures and the variability in exposure should also be determined in order to develop different exposure metrics. The comparison of different exposure metrics to medical and/or epidemiologic data may aid in determining which aspect of exposure contributes to the occurrence of a given health effect.

This study of lung function in forest fire fighters found evidence of acute changes in lung function and COHb% over a work-shift. Further studies with sufficiently large sample sizes may be useful in determining more reliably the acute effect of smoke exposure on the lung functioning of forest fire fighters. In order to better assess the relationship between exposures and cross-shift changes in pulmonary function, such studies should ideally include fullshift monitoring of personal exposures of as many participants as possible.

Future studies assessing CO in exhaled breath should include the collection of postshift samples on the fireline rather than at base camp, which may be located hours from the fireline. Exhaled breath samples for CO could also be taken at intervals during the work-shift, and/or when either exposure monitoring or workers' symptoms indicate a potentially high CO exposure.

VIII. RECOMMENDATIONS

1. The use of bandannas as respirators should be prohibited. Any training and/or certification instruction on the use of bandannas as protective devices should be prohibited; this may provide the forest fire fighter with a false and dangerous belief that the bandanna will provide him/her with a level of protection from hazardous exposures to gases and dusts. The NIOSH investigators recommend that at a minimum, fire fighters be provided with disposable, dust/mist respirators designed to remove particulates. These will provide a more consistent and effective level of protection than the presently used bandannas, provided they are worn properly. In addition to providing the fire fighters with these respirators, the NPS should develop and implement a written respiratory protection program. NIOSH recommends this program be consistent with the guidelines set forth in the NIOSH publication "Guide to Industrial Respiratory Protection" (DHHS [NIOSH] Publication No. 87-116), and the minimum requirements in the OSHA General Industry Occupational Safety and Health Standards (29 CFR 1910.134). The respirator training could be provided at the fire fighters annual "red card" training and re-certification. It is important that the fire fighters be instructed that this respirator will not protect them from the fire gases, such as CO. Also, the presence of facial hair will compromise the face-to-facepiece seal; thus, all fire fighters should be clean-shaven in area of the face seal.

2. Presently, NIOSH recommends that whenever there is overexposure to CO, that workers be provided with supplied air respiratory protection. Supplied air respirators are not feasible to use during forest fires due to the remote location of the fires, the length of the workshift (12 to 24 hours per day), and the potentially adverse conditions on the fire line. In lieu of the design and development of a respirator specific for the parameters of forest fire fighting, administrative controls will have to be used to reduce CO exposure. Since the NIOSH data from this investigation indicates that CO may be a potential health hazard to forest fire fighters, the NPS and other fire fighting agencies should consider the implementation of administrative

controls to reduce exposure to CO, and to give the fire fighter a sufficient period of time in a no exposure area to allow the COHb to dissociate and to allow the fire fighter's body to recover from the effects of exposure. The NIOSH investigators suggest the consideration of reducing the length of the workshift, reducing the number of consecutive days on the fire line, and moving the base camps to locations further away from the fire to reduce the amount of smoke in these camps. The forest fire fighting agencies should conduct routine CO and SO_2 exposure monitoring of workers performing fire-related jobs and tasks.

3. The establishment of a respiratory surveillance program could provide data to assess the long-term respiratory effects of forest fire fighting. Components of a respiratory surveillance program should include (but need not be limited to) a respiratory and occupational history and periodic spirometric testing according to American Thoracic Society (ATS) standards.

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1. Loss Control Manager, National Park Service
2. Pike Hot Shots
3. Plumas Hot Shots
4. Magdalena 14 Crew
5. Superintendent, Yosemite National Park
6. Chairman, National Wildfire Coordinating Group Technical Panel
7. Chief, Branch of Fire Management, National Park Service
8. RLM Staff Officer, Toiyabe National Forest
9. NIOSH Denver Region
10. OSHA Region IX

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 days.

Table 1
Results of Personal Breathing Zone Air Sampling for CO, SO_2, and NO_2-Pike Hot Shots
Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Carbon Monoxide[1]	Sulfur Dioxide[1]	Nitrogen Dioxide[1]
Pike Swamper	0903-1815	19.2	1.1	---
Pike Swamper	0902-1812	---	1.4	---
Pike Swamper	0902-1812	---	---	ND
Pike Sawyer	0907-1815	---	1.1	---
Pike Sawyer	0901-1815	---	---	ND
Pike Sawyer	0901-1815	15.4	---	---
Pike Crew Foreman	0905-1815	18.9	---	---
Pike Crewman	0901-1738	21.1	---	---
Pike Crewman	0930-1752	22.2	---	ND
Pike Crewman	0930-1740	18.3	2.4	---
Pike Crewman	0903-1755	---	1.2	---
Pike Crewman	0903-1755	19.0	---	---
Pike Crewman	0903-1735	6.1	---	---
Pike Crewman	0903-1740	24.2	---	---
Pike Crewman	0903-1740	18.3	---	---
Pike Crewman	0903-1755	---	---	ND
Pike Crewman	0903-1755	---	1.4	ND
Proposed Exposure Guidelines		21	---	2.2
OSHA PEL		50	5.0	5.0-C
NIOSH REL		35	2.0	1.0
ACGIH TLV		25	2.0	3.0

[1] Concentrations expressed in parts per million (ppm) of the given analytes.
ND = Analyte not detected on sample; C = Ceiling Limit.

Table 2
Results of Personal Breathing Zone Air Sampling for CO, SO_2, and NO_2-Plumas Hot Shots
Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Carbon Monoxide[1]	Sulfur Dioxide[1]	Nitrogen Dioxide[1]
Plumas Swamper	0933-1659	---	1.4	---
Plumas Swamper	0840-1740	5.6	---	---
Plumas Swamper	0912-1712	---	---	ND
Plumas Sawyer	0907-1715	---	---	ND
Plumas Sawyer	0932-1640	---	0.7	---
Plumas Sawyer	0851-1730	5.9	---	---
Plumas Crew Foreman	0905-1725	9.4	---	---
Plumas Crewman	0841-1747	5.5	---	---
Plumas Crewman	0857-1733	1.2	---	---
Plumas Crewman	0857-1735	1.2	---	---
Plumas Crewman	0910-1738	---	---	ND
Plumas Crewman	0946-1652	---	2.9	---
Plumas Crewman	0934-1709	1.3	---	---
Plumas Crewman	0925-1703	---	---	ND
Plumas Crewman	0842-1719	2.4	---	---
Plumas Crewman	0947-1825	---	0.2	---
Plumas Crewman	0947-1647	---	1.9	---
Plumas Crewman	0924-1657	---	---	ND
Plumas Crewman	0842-1642	2.5	---	---
Proposed Exposure Guidelines		21	---	2.2
OSHA PEL		50	5.0	5.0-C
NIOSH REL		35	2.0	1.0
ACGIH TLV		25	2.0	3.0

[1] Concentrations expressed in parts per million (ppm) of the given analytes.
ND = Analyte not detected on sample; C = Ceiling Limit.

Table 3

Results of Personal Breathing Zone Air Sampling for Gaseous PAHs

Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Sample Volume[1]	Acenaphthene[2]	Anthracene[2]	Naphthalene[2]
Pike Sawyer	0901-1439	668	0.9	1.5	35.9
Pike Sawyer	0902-1351	574	ND	ND	20.9
Pike Crewman	0903-1735	1024	1.0	26.5	26.5
Plumas Sawyer	0932-1640	850	0.7	0.7	11.6
Plumas Swamper	0851-1730	626	0.9	ND	23.9
MDC			0.67	0.67	0.67
Proposed Exposure Guidelines			---		37000
OSHA PEL			---	---	50000
NIOSH REL			---	---	---
ACGIH TLV			---	---	52000

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in micrograms per cubic meter of air ($\mu g/m^3$) of the given analytes.
ND = Analyte not detected on sample.
MDC = minimum detectable concentration.

Table 4

Results of Personal Breathing Zone Air Sampling for Particulate-Bound PAHs

Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Sample Volume[1]	Acenaphthene[2]	Anthracene[2]	Benzo(b)fluoranthene[2]	Fluoroanthene
Pike Sawyer	0901-1439	668	0.7	ND	1.0	3.1
Pike Sawyer	0902-1351	574	1.7	1.2	1.7	8.2
Pike Crewman	0903-1735	1024	1.5	0.7	0.6	9.3
Plumas Sawyer	0932-1640	850	ND	ND	ND	ND
Plumas Swamper	0851-1730	626	ND	ND	ND	ND
MDC			0.67	0.67	0.67	0.67
OSHA PEL			---	---	---	---
NIOSH REL			---	---	---	---
ACGIH TLV			---	---	---	---

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in micrograms per cubic meter of air ($\mu g/m^3$) of the given analytes.
ND = Analyte not detected on sample.
MDC = minimum detectable concentration

Table 5
Results of Personal Breathing Zone Air Sampling for Aldehydes

Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Sample Volume[1]	Acetaldehyde[2]	Formaldehyde[2]	Acrolein[2]	Furfural[2]
Pike Swamper	0903-1815	26.7	0.04	0.06	0.01	0.008
Pike Crewman	0902-1812	27.5	0.03	0.07	0.01	0.005
Plumas Swamper	0912-1712	24.7	0.01	0.04	ND	0.002
Plumas Crewman	0906-1725	25.8	0.01	0.02	ND	0.004
Plumas Crew Foreman	0841-1747	27.6	0.02	0.05	0.01	0.004
MDC			0.008	0.015	0.015	0.008
OSHA PEL			200	1.0	0.1	5.0
NIOSH REL			LFL	LFL	0.1	
ACGIH TLV			100	0.3-C	0.1	2.0

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in parts per million (ppm) of air of the given analytes.
ND = Analyted not detected on sample.
LFL = Substance considered by NIOSH to be a potential human carcinogen; NIOSH recommends that exposures be reduced to the lowest feasible level.
MDC = minimum detectable concentration
C = Ceiling Limit

Table 6
Results of Personal Breathing Zone Air Sampling for Acid Gases

Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Sample Volume[1]	Hydrochloric Acid[2]	Surlfuric Acid[2]	Hydrofluoric Acid[2]
Pike Crewman	0901-1738	258	0.04	0.05	0.15
Pike Crewman	0903-1755	266	0.01	0.09	0.13
Plumas Crewman	0946-1652	213	0.01	0.02	0.14
Plumas Crewman	0934-1709	227	0.01	ND	0.03
MDC			0.012	0.012	0.012
Proposed Exposure Guidelines			---	---	1.9
OSHA PEL			7.0-C	1.0	2.5
NIOSH REL			7.0-C	1.0	2.5
ACGIH TLV			7.5-C	1.0	2.6

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in milligrams per cubic meter of air (mg/m^3) of the given analytes.
ND = Analyte not detected on sample
C = Value is a ceiling limit that should not be exceeded during the workshift
MDC = minimum detectable concentration

Table 7
Results of Personal Breathing Zone Air Sampling for Respirable Particulate Matter

Yosemite National Park
HETA 90-0365
August 15, 1990

Sample Location	Sample Time	Sample Volume[1]	Concentration of RPM[2]
Pike Crewman	0903-1755	904	1.3
Pike Crewman	0903-1740	879	1.7
Pike Crewman	0902-1743	878	1.7
Pluman Crewman	0857-1733	877	0.6
Plumas Crewman	0857-1735	879	0.9
Plumas Crewman	0910-1738	865	1.1
MDC			0.00001

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in milligrams per cubic meter of air (mg/m^3) of RPM.
MDC = minimum detectable concentration

Table 8
Characteristics of Study Participants

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Characteristics	Forest Fire Fighters
Number of Participants	21
Age [mean, (sd[1])]	28 (8)
Gender (% male)	71 %
Race:	
Caucasian	48 %
Native American	38 %
Hispanic	14 %
Employment Status:	
seasonal	95 %
# fire seasons [mean, (sd)]	5 (5)
Smoking Status:	
never smokers	76 %
former smokers	10 %
current smokers	14 %
Medical History:	
asthma	10 %
allergy	10 %
Preshift Lung Function [mean, (sd)]:	
FVC % predicted	115 (12)
FEV_1 % predicted	111 (10)
FEF_{25-75} % predicted	99 (16)
FEV_1/FVC % predicted	96 (4)
Preshift COHb % [mean, (sd)]:	1.3 % (0.2)

[1] sd = standard deviation

Table 9
Characteristics of Study Participants by Crew Type

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Characteristics	Crew Type	
	Type I	Type II
Number of Participants	11	10
Age [mean, (sd[1])]	25 (5)	31 (10)
Gender (% male)	64 %	80 %
Race:		
Caucasian	91 %	0 %
Native American	0 %	80 %
Hispanic	9 %	20 %
Employment Status:		
seasonal	91 %	100 %
# fire seasons [mean,(sd)]	4 (4)	7 (6)
Smoking Status:		
never smokers	91 %	60 %
former smokers	9 %	10 %
current smokers	0 %	30 %
Medical History:		
asthma	18 %	0 %
allergy	18 %	0 %
Preshift lung function [mean, (sd)]:		
FVC % predicted	118 (13)	111 (10)
FEV_1 % predicted	114 (12)	107 (7)
FEF_{25-75} % predicted	97 (5)	96 (3)
FEV_1/FVC (actual value)	83 (4)	81 (3)
Preshift COHb % [mean,(sd)]	1.4 (0.2)	1.2 (0.1)
Number of days at fire	2	4
Smoke Exposure Category:		
Low	0 %	30 %
Medium	100 %	20 %
High	0 %	50 %

[1] sd = standard deviation

Table 10
Cross-Shift Changes in Lung Function by Crew

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Lung Function	Type I Crew	Type II crew
# Participants	11	10
FVC	-1.5 % (p=0.03)	0.1 % (p=0.77)
FEV_1	-2.3 % (p=0.01)	-0.1 % (p=0.84)
FEF_{25-75}	-3.0 % (p=0.12)	0.5 % (p=0.92)
FEV_1/FVC	-0.6 % (p=0.03)	-0.1 % (p=0.83)

Table 11
Cross-shift Changes in Lung Function by Self-reported Exposure Category

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Lung Function	Exposure Category		
	Low	Medium	High
# Participants	3	13	5
FVC	0.2 %	- 1.3 %	0.2 %
FEV_1	- 1.5 %	- 2.0 %	1.1 %
FEF_{25-75}	- 9.1 %	- 3.3 %	8.4 %
FEV_1/FVC	- 1.4 %	- 0.6 %	0.8 %

Table 12
Mean Pre- and Postshift Carboxyhemoglobin Levels

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Category	Number	Preshift	Postshift
Overall	21	1.29%	2.66%
Smokers	3	1.33%	2.33%
Nonsmokers	18	1.28%	2.71%
Type I crew	11	1.40%	2.91%
Type II crew	10	1.17%	2.38%

Table 13
Personal Breathing Zone (PBZ) Results for Carbon Monoxide (CO) and Postshift COHb% by Forest Fire Fighter

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Participant	CO[1]	Postshift COHb%	COHb% Change
Type I Crewman	24.2	2.7 %	1.4 %
Type I Crewman	22.2	3.2 %	1.7 %
Type I Crewman	21.1	2.3 %	0.7 %
Type I Crewman	18.9	3.0 %	1.5 %
Type I Crewman	18.3	3.1 %	1.4 %
Type I Crewman	18.3	2.5 %	1.3 %
Type I Crewman	6.1	2.3 %	1.2 %

[1] Concentration expressed in parts per million (ppm).

Table 14
Frequency of Symptoms Among Type II Crew, and Cross-shift Change
[Number, (%)]

Yosemite National Park
HETA 90-0365
August 15-16, 1990

Symptoms	Preshift	Postshift	Change
Number of Participants	10	10	
Eye irritation	2 (20%)	2 (20%)	2 (20%)
Nose irritation	3 (30%)	6 (60%)	4 (40%)
Throat irritation	4 (40%)	6 (60%)	2 (20%)
Cough	2 (20%)	2 (20%)	0 (0%)
Phlegm	4 (40%)	4 (40%)	0 (0%)
Wheezing	0 (0%)	2 (20%)	2 (20%)
Shortness of breath	1 (10%)	2 (20%)	2 (20%)
Chest tightness	0 (0%)	1 (10%)	1 (10%)
Headache	1 (10%)	2 (20%)	2 (20%)
Nausea/vomiting	0 (0%)	1 (10%)	1 (10%)
Weakness	1 (10%)	0 (0%)	0 (0%)
Dizziness	0 (0%)	0 (0%)	0 (0%)
Confusion	1 (10%)	2 (20%)	1 (10%)
Loss of coordination	0 (0%)	0 (0%)	0 (0%)

Figure 1.
SEM Photographs of New, Unwashed Bandanna Samples at X50 and X200 Magnification.
National Park Service
Yosemite National Park, California
HETA 90-0365

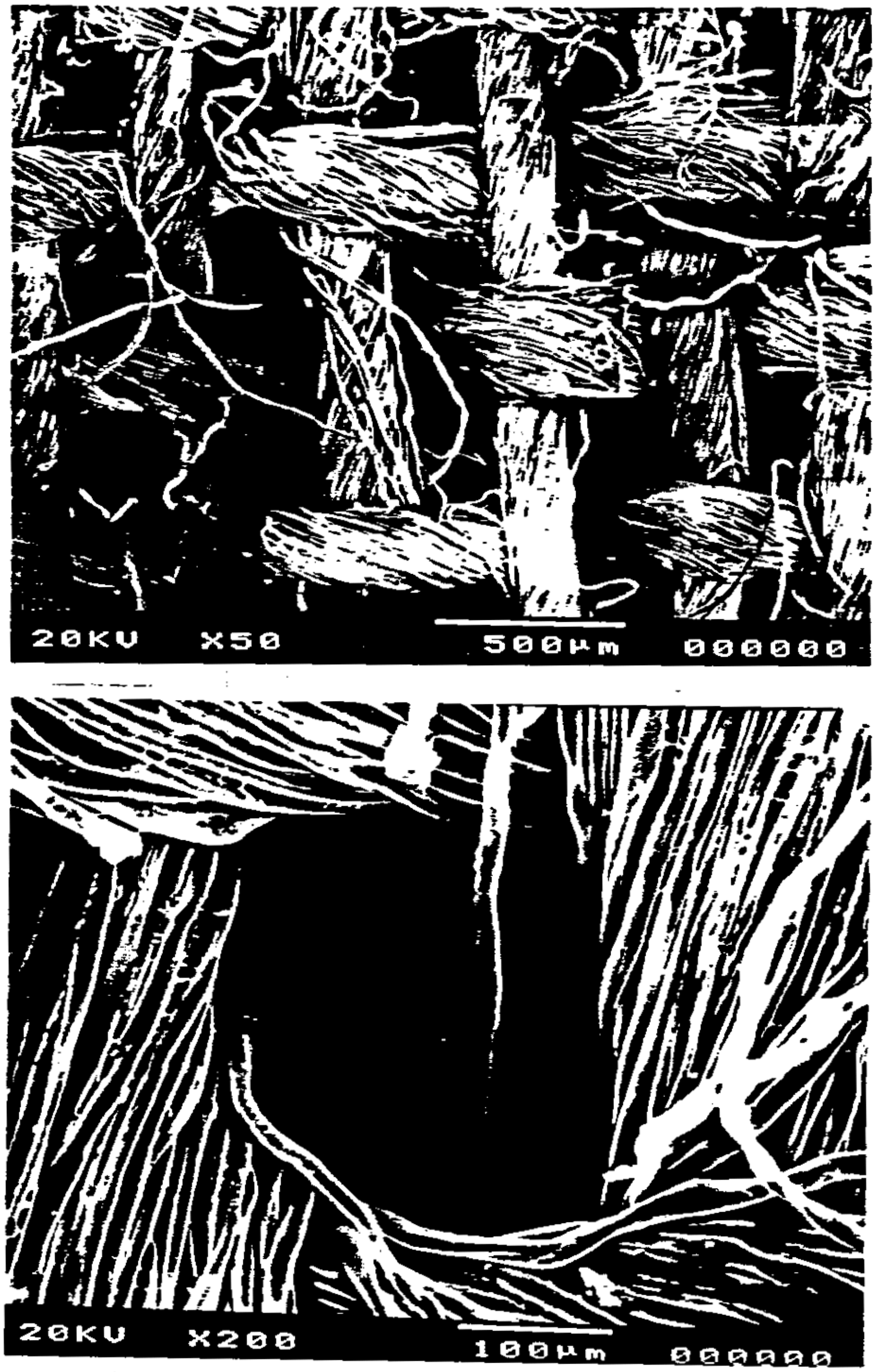

Figure 2.
SEM Photographs of Old, Washed Bandanna Samples at X35 and X200 Magnification.

National Park Service
Yosemite National Park, California
HETA 90-0365

Appendix I

Using the CFK Equation to Adjust the NIOSH REL for CO and to Predict the CO Exposure Concentration that Results in a 5% COHb Level in Forest Fire Fighters

Appendix I

Using the CFK Equation to Adjust the NIOSH REL for CO and to Predict the CO Exposure Concentration that Results in a 5% COHb Level in Forest Fire Fighters

In the NIOSH document "Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide,"[1] NIOSH used the Coburn, Foster, Kane (CFK) equation to develop the NIOSH REL for CO of 35 ppm, as an 8-hour TWA. This is the exposure level that would result in a 5% COHb level in workers exposed at sea level, involved with a sedentary level of work activity, and exposed for 8 hours per day. The CFK equation is:

$$[CO] \text{ that results in 5\% COHb} = \frac{1316\{AC - V_{CO}B + a(V_{CO}B - AD)\}}{1 - a}$$

where:

$A = P_{C\text{-}O2} \div M(O_2Hb)$

$B = (1 \div D_L) + (P_L \div V_A)$

$a = e^{-AT/V_bB}$

The variables in the above equations were given in the NIOSH criteria document for CO and are presented below[1]:

C = COHb concentration at time T; 0.01 ml COHb/ml blood (5% COHb).

D = background COHb level at time=0; 0.0015 ml COHb/ml blood (0.75%).

V_{CO} = rate of endogenous CO production; 0.007 ml/min.

V_b = blood volume; 5500 ml.

O_2Hb = oxyhemoglobin concentration; 0.2 ml/ml blood.

M = ratio of affinity of CO vs. O_2 to hemoglobin; 218.

T = length of workshift in minutes; 480 minutes.

D_L = CO diffusion rate in lungs for sedentary level of activity; 30 ml/min/mm Hg.

V_A = lung ventilation rate for sedentary level of activity; 6000 ml/min.

P_L = dry barometric pressure in the lungs in mm Hg. In the NIOSH criteria document, NIOSH used the standard atmospheric pressure at sea level minus the pressure of water vapor at body temperature (760 mm Hg - 47 mm Hg = 713 mm Hg).

$P_{C\text{-}O2}$ = partial pressure of oxygen in the capillaries; 100 mm Hg.

Many of these variables are constants based on physiological processes. Some of the variables can be changed from those used in the NIOSH criteria document to better describe the work environment of the forest fire fighter. Changes in these variables by the NIOSH investigators can be classified into three categories: length of workshift, level of work activity, and altitude.

Length of Workshift (T)

NIOSH used an 8-hour workshift (480 minutes) in calculating the REL of 35 ppm. During the days of the NIOSH survey, the fire crews were on the fire line for approximately 9-hours (540 minutes). Thus, a time of 540 minutes was used in the CFK equation.

Level of Work Activity (D_L and V_A)

The NIOSH criteria document lists the variables D_L and V_A which were used in the CFK equation to define level of work activity.[1] The values for these variables represent three levels of work activity: sedentary, light, and heavy. These variables and values are shown below.

Work Activity Level	D_L	V_A
Sedentary	30 ml/min/mm Hg	6,000 ml/min
Light	40 ml/min/mm Hg	18,000 ml/min
Heavy	60 ml/min/mm Hg	30,000 ml/min

In calculating the NIOSH REL of 35 ppm, NIOSH used the D_L and V_A values for a sedentary level of work activity.[1] The NIOSH investigators contend that using the values for heavy work activity would be more descriptive forest firefighting. Thus, the above values for a heavy work activity level were used by the NIOSH investigators in their calculations.

Altitude (P_L and $P_{C\text{-}O2}$)

The two variables within the CFK equation that are directly affected by altitude are the dry barometric pressure in the lungs (P_L) and the partial pressure of oxygen in the capillaries ($P_{C\text{-}O2}$). The adjustment of these variables to reflect the effect of altitude, as related to the CFK equation, was previously discussed in a U.S. Department of Health and Human Services, Public Health Service intra-agency memorandum.[2] The following will present the changes in these variables caused by exposure to CO at an altitude of approximately 6100 feet.

P_L is the most obvious variable in the CFK equation that would be effected by altitude. In the NIOSH criteria document, NIOSH used the standard atmospheric pressure at sea level minus the pressure of water vapor at body temperature (760 mm Hg - 47 mm Hg = 713 mm Hg).[1] To account for altitudes other than sea level, the NIOSH investigator obtained the standard pressure of 596 mm Hg for an altitude of 6500 feet from the CRC Handbook of Chemistry and Physics, 66th Edition.[3] In discussing altitude, Best & Taylor[4] state that the partial pressure of water remains the same, and is only dependent on body temperature. Thus, 47 mm Hg was subtracted from these values to obtain the P_L.

The partial pressure of oxygen in the capillaries ($P_{C\text{-}02}$) is directly related to the atmospheric pressure. From the above intra-agency memorandum[2], $P_{C\text{-}02}$ can be calculated using the following formula

$$P_{C\text{-}02} = P_L \times 0.21 - 45$$

Using the above given values for C, D, V_{CO}, V_b, 0_2Hb, and M; the calculated values for A, B, and a; and the new values for T, V_A, D_L, P_L, and $P_{C\text{-}02}$, the NIOSH investigators calculated the maximum CO exposure concentration which would result in a 5% COHb level in most workers. For forest fire fighters working a 9-hour shift with a heavy level of work activity, and at an altitude of 6500 feet, the CFK equation predicts that a 5% COHb level will be reached at a CO exposure concentration of approximately 21 ppm.

REFERENCES - APPENDIX I

1. NIOSH [1972]. Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide. DHEW (NIOSH) Publication No. 73-11000, Second Printing. Cincinnati, Ohio: U.S. Dept. of Health Education and Welfare, Public Health Service, Centers for Disease Control, NIOSH.

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Appendix II

OSHA Model for Adjusting Exposure Limits for Unusual Work Schedules

The OSHA PELs were developed for a doses imparted by exposures to toxic chemicals during a normal 8-hour workday and normal 40-hour workweek. In developing the PELs, OSHA recognized that these exposure limits were based on different types of toxic effects, and placed each of the chemicals into one of the following six work schedule categories: (1A) ceiling limit, (1B) prevention of irritation, (1C) technological feasibility limitations, (2) acute toxicity, (3) cumulative toxicity, and (4) acute and cumulative toxicity.[5] The parameters used by OSHA to develop these categories were primary type of health effect, biologic half-life, feasibility of reducing exposure to this compound to a level lower than the current OSHA PEL, and the rationale for the limit. Using these categories, OSHA developed a model for evaluating exposures (to these substances) during unusual work schedules. From the OSHA Model[6], which is described in the OSHA Compliance Officer's Field Manual, substances in Categories 1A, 1B, and 1C do not require adjustments in their respective PELs when exposure occurs during long or unusual workshifts. This recommendation is based on the rationale for developing the PEL, the primary toxic effect associated with exposure to the substances, and/or the feasibility of reducing exposure to levels lower than the OSHA PEL.

The OSHA Model provides formulae for assessing exposure to substances in Categories 2, 3, and 4 during unusual work schedules.[2] For chemical substances considered to have acute toxicity (Category 2, biologic half-life less than 12-hours), the OSHA Model recommends modifying the PEL for extended workshifts using the following formula:

$$\text{Equivalent PEL} = \text{PEL} \times (\text{8-hours} \div \text{No. of Hours of Workshift per Day})$$

The "Equivalent PEL" represents a dose level for the unusual workshift which would be no greater than the dose obtained during a 8-hours of exposure at the PEL.

For chemical substances in Category 3 and considered to have a cumulative toxicity, a different formula is recommended in the OSHA Model to prevent the cumulative effects of repeated exposure over an extended workshift. Toxic chemicals in this category have a biologic half-life in excess of 12-hours, and may not be totally eliminated from the body before the worker returns to work for her/his next scheduled shift. Thus, the OSHA Model recommends adjusting the PEL according to the following formula:

$$\text{Equivalent PEL} = \text{PEL} \times (\text{40-hours} \div \text{No. of Hours of Exposure per Week})$$

to ensure that workers exposed to the toxic substance more than 40-hours/week will not develop a body burden of that substance in excess of workers working normal 8-hour/day, 40-hour/week schedules.

As previously mentioned, substances in Category 4 may be considered as both an acute and cumulative health hazard. Because of this, the OSHA Model recommends that when exposure to these substances exceeds a normal 8-hour/day, 40-hour/week schedule, the PEL should be adjusted using either of the above formulae; i.e., whichever provides the greatest level of protection.

In discussing unusual work schedules, the ACGIH stated that when a work schedule differs from the normal 8-hour/day, 40-hour/week, that the ACGIH TLVs should be reduced to account for increased exposure time. The ACGIH recommends the use of the OSHA Model to develop these adjusted TLVs, and also recommends medical supervision during the initial use of these adjusted TLVs.[7]

In interpreting the exposure assessment data presented in this report, "Equivalent PELs" were calculated for the chemicals identified in the exposure monitoring. These are presented in the data tables as "proposed exposure guidelines for forest fire fighters", along with the respective OSHA PELs, ACGIH TLVs, and NIOSH RELs.

These proposed exposure guidelines were calculated by using the OSHA Model to adjust the ACGIH TLV or the OSHA PEL (whichever exposure limit is the more protective of the two) for the specified substance for a 9-hour/day, 54-hour/week work schedule. Below is a table which presents the specific toxic substances adjusted for this work schedule, the assigned OSHA category for this toxic substance, which evaluation criteria was used for the adjustment (OSHA PEL or ACGIH TLV), and the adjusted evaluation criteria as proposed exposure guidelines.

Toxic Substance	OSHA Category[1]	Evaluation Criteria[2]	Proposed Evaluation Guideline[3]
Sulfur Dioxide	1B	TLV=2.0 ppm	NA
Nitrogen Dioxide	3	TLV=3.0 ppm	2.2 ppm
Acrolein	1B	PEL=0.1 ppm	NA
Hydrochloric Acid	1A	PEL=7.0 ppm	NA
Sulfuric Acid	1B	PEL=1.0 ppm	NA
Hydrofluoric Acid	4	PEL=2.5 mg/m³	1.0 mg/m³
Acetaldehyde	1B	TLV=100.0 ppm	NA
Formaldehyde[4]	4	NIOSH-LFL	NA
Furfural	1B	TLV=2.0 ppm	NA
Naphthalene	4	PEL=50.0 mg/m³	37. mg/m³

[1] OSHA Work Schedule Category from the OSHA Compliance Officers: Field Operations Manual.
[2] Adjustments made to either the ACGIH TLV (TLV) or the OSHA PEL (PEL).
[3] NA-no adjustment recommended for substances in OSHA Categories 1A, 1B, 1C.
[4] No adjustment made for formaldehyde; NIOSH considers this to be a potential workplace carcinogen and recommends that exposures be reduced to the lowest feasible level (LFL).

ppm-parts per million.
mg/m^3-milligrams per cubic meter.

The OSHA PELs were developed for a doses imparted by exposures to toxic chemicals during a normal 8-hour workday and normal 40-hour workweek. In developing the PELs, OSHA recognized that these exposure limits were based on different types of toxic effects, and placed each of the chemicals into one of the following six work schedule categories: (1A) ceiling limit, (1B) prevention of irritation, (1C) technological feasibility limitations, (2) acute toxicity, (3) cumulative toxicity, and (4) acute and cumulative toxicity.[1] The parameters used by OSHA to develop these categories were primary type of health effect, biologic half-life, feasibility of reducing exposure to this compound to a level lower than the current OSHA PEL, and the rationale for the limit. Using these categories, OSHA developed a model for evaluating exposures (to these substances) during unusual work schedules. From the OSHA Model[2], which is described in the OSHA Compliance Officer's Field Manual, substances in Categories 1A, 1B, and 1C do not require adjustments in their respective PELs when exposure occurs during long or unusual workshifts. This recommendation is based on the rationale for developing the PEL, the primary toxic effect associated with exposure to the substances, and/or the feasibility of reducing exposure to levels lower than the OSHA PEL.

The OSHA Model provides formulae for assessing exposure to substances in Categories 2, 3, and 4 during unusual work schedules.[2] For chemical substances considered to have acute toxicity (Category 2, biologic half-life less than 12-hours), the OSHA Model recommends modifying the PEL for extended workshifts using the following formula:

$$\text{Equivalent PEL} = \text{PEL} \times (\text{8-hours} \div \text{No. of Hours of Workshift per Day})$$

The "Equivalent PEL" represents a dose level for the unusual workshift which would be no greater than the dose obtained during a 8-hours of exposure at the PEL.

For chemical substances in Category 3 and considered to have a cumulative toxicity, a different formula is recommended in the OSHA Model to prevent the cumulative effects of repeated exposure over an extended workshift. Toxic chemicals in this category have a biologic half-life in excess of 12-hours, and may not be totally eliminated from the body before the worker returns to work for her/his next scheduled shift. Thus, the OSHA Model recommends adjusting the PEL according to the following formula:

$$\text{Equivalent PEL} = \text{PEL} \times (\text{40-hours} \div \text{No. of Hours of Exposure per Week})$$

to ensure that workers exposed to the toxic substance more than 40-hours/week will not develop a body burden of that substance in excess of workers working normal 8-hour/day, 40-hour/week schedules.

As previously mentioned, substances in Category 4 may be considered as both an acute and cumulative health hazard. Because of this, the OSHA Model recommends that when exposure to these substances exceeds a normal 8-hour/day, 40-hour/week schedule, the PEL should be adjusted using either of the above formulae; i.e., whichever provides the greatest level of protection.

In discussing unusual work schedules, the ACGIH stated that when a work schedule differs from the normal 8-hour/day, 40-hour/week, that the ACGIH TLVs should be reduced to account for increased exposure time. The ACGIH recommends the use of the OSHA Model to develop these adjusted TLVs, and also recommends medical supervision during the initial use of these adjusted TLVs.[3]

In interpreting the exposure assessment data presented in this report, "Equivalent PELs" were calculated for the chemicals identified in the exposure monitoring. These are presented in the data tables as "proposed exposure guidelines for forest fire fighters", along with the respective OSHA PELs, ACGIH TLVs, and NIOSH RELs.

These proposed exposure guidelines were calculated by using the OSHA Model to adjust the ACGIH TLV or the OSHA PEL (whichever exposure limit is the more protective of the two) for the specified substance for a 9-hour/day, 54-hour/week work schedule. Below is a table which presents the specific toxic substances adjusted for this work schedule, the assigned OSHA category for this toxic substance, which evaluation criteria was used for the adjustment (OSHA PEL or ACGIH TLV), and the adjusted evaluation criteria as proposed exposure guidelines.

Toxic Substance	OSHA Category[1]	Evaluation Criteria[2]	Proposed Evaluation Guideline[3]
Sulfur Dioxide	1B	TLV=2.0 ppm	NA
Nitrogen Dioxide	3	TLV=3.0 ppm	2.2 ppm
Acrolein	1B	PEL=0.1 ppm	NA
Hydrochloric Acid	1A	PEL=7.0 ppm	NA
Sulfuric Acid	1B	PEL=1.0 ppm	NA
Hydrofluoric Acid	4	PEL=2.5 mg/m^3	1.0 mg/m^3
Acetaldehyde	1B	TLV=100.0 ppm	NA
Formaldehyde[4]	4	NIOSH-LFL	NA
Furfural	1B	TLV=2.0 ppm	NA
Naphthalene	4	PEL=50.0 mg/m^3	37. mg/m^3

[1] OSHA Work Schedule Category from the OSHA Compliance Officers: Field Operations Manual.
[2] Adjustments made to either the ACGIH TLV (TLV) or the OSHA PEL (PEL).
[3] NA-no adjustment recommended for substances in OSHA Categories 1A, 1B, 1C.
[4] No adjustment made for formaldehyde; NIOSH considers this to be a potential workplace carcinogen and recommends that exposures be reduced to the lowest feasible level (LFL).

ppm-parts per million.
mg/m^3-milligrams per cubic meter.

REFERENCES - APPENDIX II

1. OSHA [1991]. Air Contaminants-Permissible Exposure Limits. Title 29 Code of Federal Regulations Part 1910.1000. Washington, D.C.: U.S. Dept. of Labor, OSHA.

2. OSHA [1979]. Compliance Officer's Field Operations Manual. Washington, D.C.: U.S. Department of Labor, OSHA.

3. ACGIH [1992]. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, Ohio: ACGIH.

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