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I. SUMMARY

On July 14, 1988, 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 forest fires in Yellowstone National Park, Wyoming (YNP). In August of 1988, investigators from NIOSH conducted concurrent industrial hygiene and medical studies at the Shoshone Fire (August 1-2), the Clover Mist Fire (August 18), and the North Fork Fire (August 20). The fire fighting activities investigated were mop-up and fire break construction.

The industrial hygiene survey consisted of personal breathing zone air monitoring for carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). Area air sampling was performed for the above analytes, aldehydes, volatile organic compounds (VOCs), total particulate matter (TPM), and polynuclear aromatic hydrocarbons (PAHs). The medical survey consisted of pre- and postshift blood sampling for carboxyhemoglobin (COHb) and the administration of a questionnaire. The crews surveyed were selected through cooperation with the local Incident Commanders, Safety Officers, and the NPS liaison.

The CO exposure levels ranged from 1.9 to 7.8 parts per million (ppm); this is below NIOSH recommended exposure limit (REL) and the Occupational Safety and Health Administration (OSHA) permissible exposure level (PEL) of 35 ppm (8-hour time weighted average exposure). In addition, the exposure levels for CO_2 and NO_2 were well below the NIOSH and OSHA exposure limits. Most of the area air samples for CO, CO_2, NO_2, aldehydes, VOCs, and PAHs were well below the NIOSH, OSHA, and American Conference of Governmental Industrial Hygienists (ACGIH) evaluation criteria. CO concentrations measured in the base camps were as high as those exposure levels measured on the fire fighters studied in this evaluation. This indicates that the base camps cannot be considered no-exposure areas. Area air sampling results for TPM in the base camps ranged from 0.1 to 0.6 milligrams per cubic meter of air (mg/m^3), and at the fires ranged from 0.2 to 47.6 mg/m^3. Two of the nine area air samples for TPM were above the OSHA PEL for particulates not otherwise regulated (PNOR) and the ACGIH Threshold Limit Values (TLV) for particulates not otherwise classified (PNOC). Because the TPM may contain some toxic substances, the OSHA PEL for PNOR and ACGIH TLV for PNOC may not be appropriate evaluation criteria.

The medical surveillance found frequent reports of symptoms related to eye, nose, and throat irritation; 91% of the participating fire fighters reported these complaints at the end of their shift. COHb levels did not significantly change over the workshifts and were generally below levels associated with health effects.

In evaluating the rationale behind the NIOSH REL for CO, the NIOSH investigators believe that the 35 ppm standard may not be protective for forest fire fighters. In developing the REL, NIOSH used the Coburn, Foster, Kane (CFK) equation to determine the CO exposure level that would result in a COHb level less than 5% in most workers.[1] 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 approximately 17 ppm. Two area air samples at the Shoshone Fires measured CO concentrations of 22.2 and 23.3 ppm, suggesting that a potential health hazard may have existed from exposure of the forest fire fighters to CO. The procedure for adjusting the NIOSH REL for CO using the CFK equation is described in Appendix II. Adjustments were made to either the OSHA PEL or ACGIH TLV (whichever was the most protective standard) using an OSHA model for adjusting evaluation criteria based on length of workshift or workweek.[23] Forest fire fighters typically work 12 hours per day, 6 days per week. The procedure for performing these adjustments using the OSHA Model is discussed in Appendix III. Adjusted exposure criteria are presented in the data tables as proposed exposure guidelines. Exposures measured during the NIOSH surveys were still considered low when comparing the measured levels to these guidelines.

The industrial hygiene data suggests that a potential health hazard may exist at forest fires from exposure to CO. In addition, the medical questionnaires found a high prevalence of eye and upper respiratory tract irritation in the fire fighters. Recommendations are made in this report to eliminate the use of bandannas as respirators, to conduct further exposure assessment and medical research in forest fire fighting activities, and to consider the implementation of administrative controls to reduce exposures.

KEYWORDS: SIC 0851 (Forestry Services); forest fire fighting; mop-up; fire break construction; carbon monoxide; sulfur dioxide; particulate matter; carboxyhemoglobin; Coburn, Foster, Kane equation; altitude; extended workshifts.

II. INTRODUCTION

On July 14, 1988, NIOSH received a request from the U.S. Department of Interior, National Park Service (NPS) to evaluate worker exposure to forest fire smoke at Yellowstone National Park, Wyoming. The NPS requested NIOSH's assistance in identifying and quantifying the potential exposures to chemicals in smoke, and in evaluating the impact of inhalation of this smoke on the forest fire fighter.

On August 1-2, 1988, NIOSH investigators performed concurrent industrial hygiene and medical surveys at the following forest fires: the Shoshone Fire (August 1-2, 1988), the Clover Mist Fire
(August 18, 1988), and the North Fork Fire (August 20, 1988). An interim report containing the data from these studies was issued to the NPS on January 20, 1989. On August 19, 1988, the NIOSH investigators conducted an investigation of a geothermal area in the northeast portion of the Park. Fire fighters who worked in this area were experiencing health effects that were believed to be related to exposures unique to fighting fire in a geothermal area. The report from this investigation, issued August 9, 1989 to YNP, is included as Appendix I. The objective of these surveys was to characterize exposures and health effects to forest fire fighters involved with mop-up and fire break building activities.

III. BACKGROUND

Nationwide, an estimated 80,000 fire fighters are involved with fire suppression activities on approximately 70,000 fires that burn 2,000,000 acres per year. In 1988, over 5,000,000 acres of wildland burned at a total cost in excess of 600 million dollars.[2]

The techniques used to fight forest fires are basically the same from fire to fire. Fire fighters use hand tools and/or earth moving equipment to remove all biomass from a given area. Thus, the fire fighters attempt to dig a fire line down to the soil and 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 extinguish 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, i.e. the dropping of water or fire retardant from various types of aircraft, is used to slow the progress of the fire and to extinguish spot fires that may develop downwind of the main fire. Unburned areas of land may also be ignited in a controlled burn to remove fuels from areas ahead of the advancing fire line. During these burnouts, fire fighters are required to hold the fire line to insure that the fire does not advance into other wildland areas and/or develop into an uncontrollable fire. Some research and development has been performed on personal protective equipment for forest fire fighters. Workers typically wear Nomex pants and shirt, Vibram-soled boots with 6-8" leathers, hard hats, goggles, gloves, and use a bandanna for respiratory protection. Forest fire fighters typically work 12 hours per day, 6-7 days per week.

Yellowstone National Park is a 2.2 million acre reservation that was designated in 1872 as the first U.S. national park.[3,4] Starting in 1886, the U.S. Cavalry was charged with the task of protecting the Park, which included the suppression of all fires.[3,5] In 1916, the National Park Service was formed, and personnel assigned to the Park continued the fire suppression efforts.[5] For the first 100 years of the Park's history, most forest fires were actively fought to minimize the scorching of land. Then in 1972, YNP management initiated its Fire Management Plan (FMP), which reserved certain areas of the Park for natural fire burns. Under the FMP, all naturally-caused fires were allowed to burn; immediate suppression only occurred when the fire was caused by humans, or when the fire threatened life, property, historic and cultural sites, endangered species, and specific natural features.[5-7] In the first 16 years of the FMP (1972-1988), YNP experienced 235 fires which were permitted to burn for a total burned area of 34,157 acres. The largest fire during this period consumed 7,400 acres; only 15 of the fires burned over 100 acres of the Park.[5,8]

During 1982-1987, most of the West experienced drought conditions, and precipitation in YNP was below average. In the five years prior to the summer of 1988, the winters in the Park were extremely dry, whereas the summers were unusually wet (precipitation averaged 200% of normal during July of 1982-1987). The weather during the first five months of 1988 led YNP management to believe they were in a weather pattern similar to that of the previous years, and that all naturally-caused fires should be allowed to burn per the FMP.[6,7] Average snowpack for the winter of 1988 was 60% of normal, and the spring rainfall in the Park was well above average (155 and 181% of normal for April and May, respectively).[3,7,9] Then in June, rainfall dropped to only one-fifth of normal, and virtually no rain fell during July and August.[6,7,9] During late May and June, 20 fires started, with 11 of these naturally burning out. By July 15th, the fires covered almost 9,000 acres in YNP. On July 21, the fires had burned 16,600 acres, and the NPS made the decision to actively suppress all existing and new fires in the Park.[3,5,9] During July, August, and September, six cold fronts with dry winds of 40 to 60 miles per hour passed through the YNP area. These gusty winds fanned the fires, causing them to run up to 10 miles a day, and igniting spot fires over 1 mile ahead of the advancing fire front. These winds, along with the record low levels of precipitation during the summer months, produced spotting behavior that rendered useless barriers such as roads, rivers, and hand- and bulldozer-constructed fire lines. These were routinely jumped, starting new fires on the other side of the barrier.[5,7-9] For example, on August 20 (also known as "Black Sunday"), the wind-driven fires raged through 160,000 previously unburned acres, of which 62,000 acres were within YNP.[3,4,8] By September 26, 50 fires had been ignited by lightning, 8 of which were still active.[9] Using aerial photography and Landsat satellite imagery, detailed mapping and analysis of burned areas found that 793,880 of YNP's 2.2 million acres were affected by these wildfires.[10] During the peak of fire activity and suppression efforts, over 9,500 forest fire fighters were involved in fighting the YNP forest fires, with a total involvement of 25,000 civilian and military personnel. Aircraft logged more than 18,000 hours of flight time, dropping approximately 1.4 million gallons of fire retardant and 10 million gallons of water on the fires.[6,8]

The NIOSH investigations were conducted at the Shoshone Fire, the Clover Mist Fire, and the North Fork Fire. The Shoshone Fire was started by natural causes on June 23 and was allowed to burn per the Park's fire management plan. It grew to approximately 24,000 acres before being included as part of the Snake River Complex[7,9] (which burned a total of 142,182 acres[10]). The Clover Mist Fire was started by lightning on July 9 and was originally allowed to burn before being actively fought. The fire grew to 142,780 acres within YNP[10], and moved outside the park boundaries to threaten the towns of Silver Gate and Cooke City.[7,9] Finally, the North Fork Fire was the largest and most well-known of the YNP fires. The fire was human-caused on July 22 in the Targhee National Forest (west of the Park), and quickly moved into the Park and threatened Old Faithful, Old Faithful Lodge, Madison Junction, Mammoth Hot Springs, Canyon Village, and the Towns of Gardiner and West Yellowstone.[3,7,9] The North Fork Fire burned approximately 406,359 acres within YNP[10]

The impact of fighting wildland fires on the health of the fire fighter has yet to be determined. Statistics from previous fire seasons suggest that fire fighters may be experiencing both long- and short-term health effects as a result of their work.[2] During the 1987 fire season in California, 38% of all reports of injuries and illnesses among forest fire fighters were from smoke inhalation. During the Yellowstone National Park fires of 1988, over 30,000 medical visits were made by fire fighters, of which 12,000 were for respiratory problems. In addition, approximately 600 fire fighters required subsequent medical care for these various respiratory problems.

IV. EVALUATION DESIGN

Each morning, with the assistance of the base camp Safety Officer, Incident Commander, and the NPS liaison, a crew was identified for participation in the NIOSH industrial hygiene and medical studies. Information on the participating crews, the location of their base camps, the type of fire fighting activity being performed on the study dates, and the number of fire fighters studied can be found in Table 1.

A. Industrial Hygiene

The industrial hygiene surveys at the three fires consisted of personal breathing zone air sampling for CO, CO_2, SO_2, and NO_2, and area air sampling for CO, CO_2, SO_2, NO_2, TPM, VOCs, aldehydes, and PAHs. The area air samples were collected at the respective base camp for each crew, and from two sampling locations near each crew as they performed their respective tasks. All air sampling equipment was calibrated pre- and postshift, with periodic checks of the flowrates performed during the workshift. The following methods were used to collect and analyze the personal breathing zone and area air samples:

1. Carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) - both personal breathing zone and area air samples were collected using Dräger long-term diffusion tubes. These tubes are colorimetric indicators which produce a time-weighted average (TWA) concentration for specific analytes. During the Shoshone Fire, air samples for CO only were collected using this method. During the time period between site visits at the Park, telephone conversations with scientists from the U.S. Forest Service, Missoula Technology and Development Center, indicated that CO_2, SO_2, and NO_2 may also be evolved during these fires. Because of this, the protocol was expanded to include these analytes for the Clover Mist and North Fork Fires.

2. Total particulate matter - were measured by collecting area air samples using NIOSH Method 0500.[11] Sample air was drawn through a tared polyvinyl chloride filter (37 millimeter diameter, 5 micron 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 - both aliphatic and aromatic VOCs were measured by area air sampling using NIOSH Methods 1003, 1500, and 1503.[11] Sample air was drawn through a standard charcoal tube using a portable, battery-powered sampling pump. After sampling, the charcoal was desorbed with carbon disulfide and the samples were 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 samples were quantitated for the identified compounds.

4. Aldehydes - were measured using NIOSH Method 2539 to collect area air samples.[11] Sample air was drawn through an Orbo-23 sorbent tube (manufactured by Supelco, Inc.), which contained 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 the samples for ALDs. Based on these results, standards were prepared and the samples were quantitated for the identified compounds.

5. Polynuclear aromatic hydrocarbons - area air samples for both particulate and gaseous forms of PAHs were collected according to NIOSH Method 5515 by drawing sample air through a polytetrafluoroethylene filter and sorbent tube (washed XAD-2 resin in Orbo-43 sorbent tube, manufactured by Supelco, Inc.) in

series.[11] The filter collects the PAH-containing particulate matter, whereas the sorbent tube collects 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. Portable, battery-powered sampling pumps were used to collect these samples.

B. Medical

A protocol was designed to study the health effects of carbon monoxide and irritants on forest fire fighters. Study participants consisted of volunteers from the fire fighting crews studied in the industrial hygiene surveys. Signed informed consent was obtained from the members of the individual crews.

Participants completed a questionnaire which contained questions pertaining to demographic information and symptoms experienced prior to leaving base camp. Each volunteer's heart rate and percent blood oxygen saturation were recorded using a portable transcutaneous blood oximeter, and respiratory rate was visually assessed by a NIOSH medical officer. Approximately 5 milliliters (ml) of venous blood was collected by peripheral venipuncture from each volunteer. When each volunteer returned to base camp that evening, he or she completed a postshift symptoms questionnaire. Heart rate, oxygen saturation, and respiratory rate were assessed, and a postshift blood sample was collected. Blood samples were mailed to a commercial laboratory for measurement of carboxyhemoglobin.

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 to 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).

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.

The primary sources of environmental evaluation criteria for the workplace are the following: 1) NIOSH criteria documents and recommendations, including recommended exposure limits (RELs),
2) the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), and 3) the U.S. Department of Labor, OSHA permissible exposure limits (PELs). The OSHA standards may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH-recommended standards, by contrast, are based primarily on concerns relating to the prevention of occupational disease. In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required by the Occupational Safety and Health Act of 1970 to meet those levels specified by an OSHA standard.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA, where there are recognized toxic effects from high short-term exposures.

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.[1,12-16]

CO combines with hemoglobin in red blood cells to form carboxyhemoglobin (COHb), reducing the ability of the blood to carry oxygen to the organs and other vital body parts, and exerting stress on the body.[1,12-15] In fact, hemoglobin has a 210 to 240 times greater affinity for CO than for oxygen.[14,15] 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.[1,12-15] Carboxyhemoglobin is completely dissociable following cessation of exposure, and has a biologic half-life of 5 hours.[15] After dissociation, CO is eliminated from the body via the lungs during exhalation.[1,15]

The blood of smokers typically contains 2 to 10% COHb. Non-exposed, non-smokers usually have a COHb level of 1% or less. In addition, non-smokers in large cities will have a COHb level of 1-2%, with the most probable source of CO being ambient air pollution from the combustion of fossil fuels.[1,14,15] As the level of COHb in the blood increases, the victim experiences health effects which become progressively more serious. 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 can occur at levels of 70%.[1,13,14] It should be noted that 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:[1,13]

% 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, and Cheyne-Stokes (periodic decreased) respiration.
60-70	Coma with intermittent convulsions, depressed heart rate and respiration, possible death.
Greater than 70	Weak pulse, slow respiration, respiratory failure, death.

Because COHb reduces the amount of oxygen transported by the blood, a number of cardiovascular effects are associated with CO exposure. Persons with chronic heart and/or lung disease are at increased risk. Even at low levels, CO exposure increases the risk for cardiac arrest in some people, particularly those with pre-existing cardiac ischemia (inadequate blood flow to the heart).[1,12,13,15]

Both the NIOSH REL and the OSHA PEL for CO are an 8 hours per day, 40 hours per week TWA exposure of 35 ppm, and a ceiling limit of 200 ppm.[17,18] The ACGIH recommends an 8-hour TWA TLV of 50 ppm, with a ceiling level of 400 ppm. Currently, the ACGIH is reconsidering its TLV for CO, and will issue a change in the TLV, if necessary, within a year.[19] In addition to these standards, the National Research Council has developed a CO exposure standard of 15 ppm, based on a 24 hours per day, 90-day TWA exposure.[20]

The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[1] 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. Thus, NIOSH recommends that when CO exposures occur at altitudes above 5000 feet the REL should be appropriately lowered to compensate for the loss in the oxygen-carrying capacity of the blood.[1]

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.[14,16] An epidemiologic investigation of workers in a copper smelter documented a decline in pulmonary function over a one year period, and an increase in cough and sputum. The exposure levels in this facility ranged from
1.0-2.5 ppm of SO_2.[21]

The OSHA PEL and ACGIH TLV for SO_2 are 8-hour TWA exposure levels of 2 ppm, and STELs of 5 ppm as 15-minute TWA exposures that should not be exceeded at any time during the workshift.[17,19] 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.[22]

D. Other Contaminants

The evaluation criteria for the other chemical contaminants studied in this investigation (VOCs, PAHs, aldehydes, CO_2, NO_2, and TPM) 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).

VI. RESULTS AND DISCUSSION

A. Industrial Hygiene Results

Industrial hygiene sampling results for CO, CO_2, SO_2, NO_2, TPM, VOCs, aldehydes, and PAHs are presented in Tables 2 through 7. As shown in Table 2, the CO exposure concentrations ranged from 1.9 to 7.8 ppm and were below the NIOSH REL and OSHA PEL of 35 ppm. Typically, the outdoor, ambient concentration of CO_2 is approximately 350 ppm. Considering this, the CO_2 exposures were approximately 3 times higher than the normal background concentration, but were still well below the applicable occupational exposure limits. No detectable levels of NO_2 were found in the 10 breathing zone samples (limit of detection [LOD] of approximately 0.2 ppm). Finally, all 10 of the personal breathing zone air samples for SO_2 determination were below the NIOSH, OSHA, and ACGIH exposure criteria of 2.0 ppm. SO_2 exposure levels ranged from non-detectable to 1.2 ppm, with a mean exposure level of 1.0 ppm. It should be noted that personal sampling was performed at the Clover Mist fire on the Lassen Hot Shot crew, which worked a 24-hour shift in an area that was not accessible to the NIOSH investigators. Because of this, the duration time for the samplers was exceeded, and these samples were considered invalid.

The data from the area air sampling for CO, CO_2, SO_2 and NO_2, are shown in Table 3. CO levels in the base camps ranged from 1.6 to 6.2 ppm; whereas area CO levels at the three fires ranged from 3.9 to 23.3 ppm, with the 2 area samples obtained at the Shoshone fire being above 20 ppm. Area SO_2 concentrations at the Clover Mist Fire were 1.8 and 1.9 ppm, and were 1.0 ppm at the Madison Base Camp. Again, the CO, SO_2, NO_2 and CO_2 area concentrations were low when compared to the respective exposure limits.

The area air sampling data for TPM are presented in Table 4. Two of the 9 samples detected concentrations of particulate matter of 47.6 and 15.9 mg/m^3, which were above the ACGIH TLV for particles not otherwise classified (PNOC) and the OSHA PEL for particles not otherwise regulated (PNOR). The remaining samples detected low TPM concentrations (less than 1.3 mg/m^3). The two samples which were above the OSHA and ACGIH limits were obtained at the Clover Mist and North Fork Fires. However, it may not be appropriate to make this comparison of the concentrations measured during the NIOSH survey to the ACGIH TLV for PNOC or the OSHA PEL for PNOR. The ACGIH criteria for inhalation of PNOC is a lung-tissue reaction that has the following characteristics: (1) the architecture of the air spaces remains intact; (2) scar tissue (collagen) is not formed to a significant extent; (3) the tissue reaction is potentially reversible.[19] The OSHA PEL for PNOR is applicable when particulate matter does not contain substances that are regulated by an existing OSHA standard. Since a large portion of the TPM exposure is a product of combustion of the surrounding vegetation, and may contain carcinogenic and/or otherwise toxic substances, neither the ACGIH TLV nor OSHA PEL are applicable to this exposure.

The scan for aldehydes detected only formaldehyde in the area air samples. Table 5 contains the measured concentrations of formaldehyde in the air samples, all of which ranged between the limit of detection (LOD) and limit of quantitation (LOQ) and are considered to be trace levels. It should be noted that NIOSH considers formaldehyde to be a potential human carcinogen, and recommends that exposures be reduced to the LFL.[18]

As shown in Table 6, results from the qualitative and quantitative analyses of charcoal tube air samples found low concentrations of either some or all of the following VOCs on each sample: methyl acetate, 2-methyl furan, benzene, toluene, furfural, and terpenes ($C_{10}H_{16}$ isomers, including pinene). NIOSH considers benzene to be a potential human carcinogen, and recommends that exposures be reduced to 0.1 ppm.[18] Evaluation criteria do not exist for 2-methyl furan and terpenes.

The data from the area air sampling for PAHs are shown in Table 7. Of the 17 PAHs analyzed using this method, only acenaphthene was found in all of the samples, and fluorene and naphthalene were found in some of the samples. In addition, only gaseous levels of these three PAHs were measured; no PAHs in particulate form were detected on these samples. The NIOSH investigators consider these to be low to trace levels of PAHs.

B. Medical Results

Three fire fighting crews were studied as part of the medical investigation. The Willamette and Basin crews were studied according to the previously discussed protocol. The Lassen crew did not return to Pebble Creek Base Camp because of the previously discussed circumstances. For this group of forest fire fighters, postshift data and blood samples were collected at the Cache Creek site the next morning.

As shown in Table 8, the 22 participants ranged in age from 20 to 45 with a mean age of 26. Nineteen participants were male, and 3 were female. Two participants were cigarette smokers, 2 were former smokers, and 17 were lifetime nonsmokers (one participant did not report smoking status).

Table 9 shows the results of the pre- and postshift symptoms questionnaire. The greatest increase in number of firefighters reporting symptoms after the shift, compared to preshift reports, was noted for complaints related to mucosal irritation (eye, nose and throat), but the increase in reported prevalence of these symptoms was not statistically significant. Five firefighters reported a decrease in alertness at the end of the shift, compared to 2 reports before the shift (p=0.043). The number of firefighters complaining of headaches decreased by one. However, the change in the prevalence of all symptoms other than alertness was not statistically significant.

Physiologic variables recorded were within normal ranges. Blood oxygen saturation did not change significantly between pre- and postshift measurements. Carboxyhemoglobin (COHb) measurements are shown in Table 10. The highest COHb measured (4.7%) was a preshift level in a smoker. For the entire group, the increase in COHb between pre- and postshift measurements was not significant by Student's T-test. COHb levels for the Lassen crew increased by a statistically significant amount (p=.001, Student's T-test) and decreased by a significant degree for the Basin crew (p=.005, Student's T-test). The decrease noted in the Willamette crew was not statistically significant.

C. Discussion and Conclusions

On the days of the NIOSH surveys, the breathing zone exposure levels for CO, CO_2, SO_2, and NO_2 were all below the respective OSHA, NIOSH, and ACGIH exposure limits, and were at levels that would not be expected to pose a hazard to the health of the workers. In addition, most of the area air samples for CO, CO_2, SO_2, NO_2, aldehydes, VOCs, and PAHs were below the NIOSH, OSHA, and ACGIH evaluation criteria for personal exposures. It is interesting to note the CO levels measured in the base camps were similar to those exposure levels measured on the fire fighters constructing fire line and mopping-up at the three fires. This indicates that the base camps cannot be considered no exposure areas for carbon monoxide. The measured area air concentrations of aldehydes, VOCs, and PAHs were low, and individually would not be expected to cause acute health effects in most workers. Finally, 70% (7 of 10) of the personal breathing zone air samples, and, all three of the area air samples for SO_2, measured levels within at least 50% of the NIOSH REL, OSHA PEL, and ACGIH TLV. The presence of the SO_2 concentrations is probably due to the high sulfur content of soil and rock, and the number of geothermal vents in the Yellowstone area.

Two of the area air samples for TPM had concentrations above the ACGIH TLV for PNOC and OSHA PEL for PNOR. As previously mentioned, using the OSHA PEL and ACGIH TLV to evaluate exposure to the TPM is not appropriate since this TPM exposure does not fit the definitions for PNOC and/or PNOR. The NIOSH investigators used these standards for comparative purposes only; it is possible that further chemical analysis of the TPM may provide justification for use of a more protective exposure standard. It is interesting to note that the area air sampling for particulate-borne PAHs did not measure detectable concentrations of these compounds. The sampling equipment used to collect the TPM and PAH air samples were collected side-by-side (within 1 foot of each other). These data suggest that PAHs measured may not be present in the TPM.

In evaluating the rationale behind the NIOSH REL for CO, the NIOSH investigators believe that the 35 ppm standard may not be protective for forest fire fighters. In developing the REL, NIOSH used the CFK equation to determine the CO exposure level that would result in a COHb level less than 5% in most workers.[1] There are several factors to be considered when utilizing the CFK equation to predict the CO exposure concentration that would result in a 5% COHb level in forest fire fighters:

1. The duration of exposure for forest fire fighters is longer than that used in the CFK equation to determine the NIOSH REL. Forest fire fighters typically work 12-hour shifts per day, and at least 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.[1]

2. In many regions of the U.S., forest fires are fought at altitudes above 5000 feet. In fact, the majority of Yellowstone National Park is at an altitude over 8000 feet.

3. The level of work activity (sedentary) used by NIOSH in the CFK equation is not descriptive of the type of work performed while fighting forest fires.[1] The NIOSH investigators believe that the D_L and V_A values for heavy work activity levels are more descriptive of the type of work performed at forest fires, and should be used in the equation. D_L and V_A values for sedentary, light, and heavy work activity levels are presented in Appendix II of the NIOSH recommended standard for CO.[1]

Considering the above information, the NIOSH investigators made adjustments to these variables, and used the new values 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 II. Using a workshift length of 12 hours (720 minutes), D_L and V_A values for a heavy level of work activity, and altitudes of both 5000 and 10000 feet above sea level, the NIOSH investigators calculated that 5% COHb levels would be reached with CO exposures of 23 ppm (for an altitude of 5000 feet) and 17 ppm (for an altitude of 10000 feet). Given that most of YNP is at an altitude of at least 8000 feet above sea level, the NIOSH investigators believe that forest fire fighters may have been overexposed to CO when exposure concentrations exceeded 17 ppm. Though none of the personal breathing zone air samples exceeded this proposed guideline, the two area air samples at the Shoshone Fires measured CO concentrations of 22.2 and 23.3 ppm. This suggests that a potential health hazard may have existed from exposure of the forest fire fighters at YNP to CO.

In addition, the NIOSH investigators used an OSHA model to calculate proposed exposure guidelines for the other substances identified and measured in this evaluation.[23] The OSHA PELs were developed to account for doses that are imparted to a worker during a normal 8-hour day, 40 hours/week. OSHA recommends the use of this model to assess exposures that occur during unusual work schedules, such as those worked by forest fire fighters.[23] The ACGIH has also recommended that this model be used to adjust the TLVs whenever the TLVs are being used to determine exposures during unusual work schedules.[19] Considering this, the NIOSH investigators used this model to adjust either the OSHA PEL or ACGIH TLV (adjustment was performed on the more protective criterion of the two) for a 12-hour day, 6 days/week work schedule. A description of the OSHA Model and the calculated adjustments (referred to as proposed exposure guidelines) are presented in Appendix III. The OSHA Model recommended no adjustment to the evaluation criteria for SO_2 and CO_2. The concentrations of NO_2, PAHs, aldehydes, and VOCs measured by the NIOSH exposure monitoring at the YNP forest fires were still below these exposure guidelines. No adjustment was made in evaluation criteria that may be used to assess exposure to the TPM, since the actual composition of the TPM has yet to be determined. Also, no adjustment was made for formaldehyde since NIOSH considers it to be a potential human carcinogen, and recommends that exposures be reduced to the lowest feasible level.

The NIOSH investigators believe that it is possible that exposures to forest fire fighters would be higher under different circumstances. Smoke conditions were light for the crews participating in the NIOSH study, which may account for the relatively low levels of CO, and the low area concentrations of PAHs, VOCs, SO_2, aldehydes, and NO_2. More research is needed to better define exposures in other jobs and in smokier conditions. Exposures may be greater among fire fighters involved with direct attack, line holding, and those performing burnout. When viewed as a whole, these data demonstrate that forest fire smoke is biphasic in nature, consisting of both gaseous and particulate contaminants. The specific concentrations and types of chemicals/substances generated during this combustion process are dependent on the type of woodland and/or forest being burned, the short- and long-term meteorological conditions, and the geographical location of the fire. The combined effects of these factors on worker exposures during fires is unknown.

In this investigation, the NIOSH investigators measured a limited number of medical parameters. Of the symptoms assessed, only those associated with exposure to airborne irritants were frequently reported. Although the increase noted in the frequency of irritant symptoms was not statistically significant, this may be due to the small number of fire fighters studied. In addition, the prevalence of these symptoms before the shift started were already 40% to 60%, suggesting that the participating fire fighters either had not adequately recovered from exposures in previous workshifts or had incurred irritant exposures during the interval since the last shift. Also, the warm, dry weather associated with forest fires is irritating to the mucous membranes, and may exacerbate the effect of other irritant exposures. Symptoms possibly associated with carbon monoxide intoxication were infrequently reported, and only the prevalence of reported decrease in alertness increased at a statistically significant level. This symptom could be an effect of fatigue. This is consistent with the results of the CO exposure monitoring and COHb measurements; none of the samples reached levels associated with serious health consequences.

In viewing the CO exposure data and COHb data in this report, the NIOSH investigators realize this data neither supports nor refutes the previously described adjustments to the NIOSH REL for CO using the CFK equation. There are several factors to consider when comparing the data collected during the YNP surveys.

1. The CO exposure levels were below the CFK-adjustment to the NIOSH REL for CO, and at levels that would not result in across-workshift increases in serum COHb. To generalize these observed exposures to all forest fire fighting, *in toto*, would be inappropriate. The NIOSH surveys assessed exposures to a small number of fire fighters engaged in either mop-up or fire break building work activities. In addition, the two area air samples of 22.2 and 23.3 ppm indicate the potential for overexposure of forest fire fighters to CO.

2. Since COHb is metabolized at a fairly rapid rate, i.e. has a half-life of about 4 hours, the timing for the collection of the postshift blood samples is critical if COHb levels are to be used as an indicator of exposure. During the NIOSH survey, the Willamette and Basin crews had 1 to 2 hour hikes through unburned areas of the Park before reaching their respective base camps. Since the postshift blood samples for COHb were collected in the base camps, the reported COHb levels in the tested members of these crews may have been higher considering when the samples were collected. The postshift blood samples for the Lassen crew were collected on the fireline, minimizing the time between cessation of exposure and collection of the blood sample. Because of the nature of the work activities and length of workshift of this crew, the NIOSH investigators were unable to determine the CO exposure levels for the members of this crew. Thus, the NIOSH investigators are unable to properly evaluate the reasons for the observed COHb levels in the Lassen crew.

3. These surveys were not experimentally designed to evaluate the field application of the CFK equation in determining safe exposure levels for CO. The discussions presented in Section V, Part B and Appendix II of this report, are to inform the parties associated with this investigation that the traditional exposure limits for CO may not be protective for the work environment encountered by forest fire fighters. This information is important to properly protect fire fighters from the deleterious health effects associated with CO intoxication.

The use of bandannas for respiratory protection is inappropriate. First, the bandanna provides the forest fire fighter with no degree of protection from the gaseous contaminants present in smoke (e.g., CO, SO_2, PAHs, aldehydes, etc.). Second, the ability of a respirator to provide the wearer with an acceptable degree of protection from a hazardous exposure is dependent on the seal between the respirator and the wearer's face. A bandanna is unable to achieve and maintain this airtight seal, and airborne contaminates will leak through the interface between the bandanna and the skin/face.

Thus, the bandanna will provide the wearer with minimal protection from airborne particulate matter.

VII. RECOMMENDATIONS

The following recommendations are made per the data collected and observations made during the NIOSH surveys at the YNP forest fires:

1. 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 implementing 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.

2. The use of bandannas as respirators should be prohibited. Until more definitive exposure assessments are available, the NIOSH investigators recommend that fire fighters be provided with NIOSH/MSHA-approved, disposable, single-use filter respirators designed to remove dusts and mists. These masks are considered to have a lower filter efficiency, and are 99% efficient in removing a silica dust particle with a geometric mean diameter of 0.4 to 0.6 microns and a standard geometric mean deviation no greater than 2.[24] The NIOSH investigators recommend that these masks be obtained with exhalation valves, increasing the level of comfort to the user. These respirators will provide the fire fighter with a more consistent and effective level of protection than the presently used bandannas, provided they are worn properly and the wearer has been fit-tested. In addition to providing the fire fighters with these respirators, NPS and the other forest fire fighting agencies should develop and implement a written respirator program. NIOSH recommends that this program be consistent with the guidelines set forth in the NIOSH publication "Guide to Industrial Respiratory Protection" (DHHS Publication No. 87-116)[24] 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 recertification. It is important that the fire fighters are 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 the area of the face seal.

3. Further exposure assessments and medical research are needed to better define the exposures and health effects in fire fighters. Exposures during other fire suppression activities (e.g. direct attack, line holding, burnout) should be investigated. In addition, more exposure assessment data is needed to characterize worker exposures during intense smoke conditions. Due to the complex nature of the smoke, many different air sampling methods were employed during the YNP surveys. Many of these methods measured low to trace levels of the analytes. As more industrial hygiene data is obtained, it may be possible to rule out some contaminants in the smoke as posing a health hazard to the forest fire fighter. One confounding factor to this is that the airborne concentrations measured during the NIOSH surveys were in areas where the smoke conditions were considered to be light. Future medical studies should investigate the effect of this complex exposure on the respiratory system, and further define the impact of CO exposure on the fire fighter's health.

4. In this evaluation, the NIOSH investigators proposed a downward adjustment in the NIOSH REL for CO. This adjustment was made using variables for work activity, altitude, and length of workshift that were more descriptive for forest fire fighters, and inserting these variable in the CFK equation to calculate the predicted CO exposure level (17 ppm) that would result in a 5% COHb level in these workers. Future industrial hygiene and medical investigations are needed to document if fire fighters are experiencing elevated COHb levels at CO exposure concentrations below the NIOSH REL of 35 ppm (for an 8-hour TWA exposure). This will require the targeting of fire fighting crews (in future investigations) that will be working under heavier smoke exposure conditions, and at altitudes above 5000 feet, if possible. Though the YNP fires provided NIOSH with the opportunity to investigate if elevated COHb levels were occurring at exposure concentrations below the NIOSH REL (35 ppm), the crews selected for participation worked in light smoke conditions, which probably resulted in the low CO exposure levels (below 8 ppm). The two area air samples with CO concentrations of 22.2 and 23.3 ppm provide some indication that higher CO levels may occur in smokier conditions. If concurrent industrial hygiene and medical studies indicate that forest fire fighters are experiencing elevated COHb levels from exposure to CO concentrations below the NIOSH REL, then the CFK equation may be used by the forest fire fighting agencies as a predictor to develop a CO exposure standard specific for workers involved with forest fire fighting activities.

5. Future industrial hygiene studies should include a chemical analysis of the total particulate matter (TPM) to which forest fire fighters are exposed. After the composition of the TPM has been determined, the NIOSH investigators may be able to determine if the level of exposure experienced during forest fire fighting activities poses a health hazard. This information may also assist in the interpretation of medical data related to respiratory system effects.

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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 calendar days.

Table 1

Information on Crews Studied

Yellowstone National Park
HETA 88-320
August 1988

Crew Name	Work Activity	Name of Fire	Base Camp	# of Workers
Willamette	Mop-Up	Shoshone	Grant/West Thumb	5
Lassen	Fire-Break	Clover Mist	Pebble Creek	7
Basin	Fire-Break	North Fork	Madison	10

Table 2

Results of Personal Breathing Zone Air Sampling for CO, CO_2, SO_2, and NO_2

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Concentrations[1] CO	CO_2	SO_2	NO_2
Shoshone Fire, Willamette	0745-1445	3.6	-	-	-
Shoshone Fire, Willamette	0745-1443	7.2	-	-	-
Shoshone Fire, Willamette	0745-1440	7.2	-	-	-
Shoshone Fire, Willamette	0745-1410	7.8	-	-	-
Shoshone Fire, Willamette	0745-1415	3.8	-	-	-
North Fork Fire, Basin Crew	0729-1022	3.9	1000	1.2	ND
North Fork Fire, Basin Crew	0730-2022	3.9	1000	1.2	ND
North Fork Fire, Basin Crew	0735-2022	2.0	1000	0.8	ND
North Fork Fire, Basin Crew	0722-2030	3.8	1000	1.1	ND
North Fork Fire, Basin Crew	0724-2022	3.8	1000	1.2	ND
North Fork Fire, Basin Crew	0724-2020	3.9	1000	1.2	ND
North Fore Fire, Basin Crew	0725-2027	3.8	1000	ND	ND
North Fork Fire, Basin Crew	0728-2020	1.9	1000	1.2	ND
North Fork Fire, Basin Crew	0728-2022	3.9	1000	0.6	ND
North Fork Fire, Basin Crew	0735-2018	3.9	1000	1.2	ND
Adjusted Exposure Guidelines[2]		17.0	NA	NA	0.6
OSHA PEL		35.0	10000	2.0	1.0
NIOSH REL		35.0	5000	2.0	1.0
ACGIH TLV		50.0	5000	2.0	3.0

[1] Concentrations are expressed in parts per million (ppm) of the given analyte and are time weighted averages (TWA).
ND-analyte not detected on sample.
NA-Per the OSHA Model[23], no adjustment for unusual work schedule.

[2] See Appendices II and III for discussion on these exposure guidelines.

Table 3

Results of Area Air Sampling for CO, CO_2, SO_2, and NO_2

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Concentrations[1] CO	CO_2	SO_2	NO_2
Grant Base Camp	0700-1503	6.2	-	-	-
Shoshone Fire, Grant South	1135-1605	22.2	-	-	-
Shoshone Fire, Grant South	1148-1604	23.3	-	-	-
Pebble Creek Base Camp	0715-1730	1.6	1000	-	-
Clover Mist Fire, Division A	1020-1545	4.6	700	1.9	ND
Clover Mist Fire, Division B	1120-1700	3.9	750	1.8	ND
Madison Base Camp	0658-1650	5.1	815	1.0	ND
North Fork Fire	0920-1535	7.9	-	-	-
North Fork Fire	1100-1520	11.5	-	-	-
Adjusted Exposure Guidelines[2]		17.0	NA	NA	0.6
OSHA PEL		35.0	10000	2.0	1.0
NIOSH REL		35.0	5000	2.0	1.0
ACGIH TLV		50.0	5000	2.0	3.0

[1] Concentrations are expressed in parts per million (ppm) of the given analyte.
ND-none detected
NA-per the OSHA Model[23], no adjustment for unusual work schedule.
[2] See Appendices II and III for discussion on these exposure guidelines.

Table 4

Results of Area Air Sampling for Total Particulate Matter (TPM)

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Sample Volume[1]	Concentration of TPM[2]
Grant Base Camp	0809-1503	828	0.2
Shoshone Fire, Grant South	1124-1605	562	0.9
Shoshone Fire, Grant South	1148-1604	512	1.0
Pebble Creek Base Camp	0715-1730	1230	0.1
Clover Mist Fire, Division A	1030-1545	630	15.9
Clover Mist Fire, Division B	1115-1625	620	0.2
Madison Base Camp	0715-1835	1360	0.6
North Fork Fire	0920-1525	730	1.2
North Fork Fire	1100-1520	520	47.6

[1] Sample volume expressed in liters of air.
[2] Concentration expressed in milligrams of dust per cubic meter of air.

Table 5

Results of Area Air Sampling for Aldehydes

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Sample Volume[1]	Concentration of Formaldehyde[2,3]
Clover Mist Fire	1030-1545	16.2	(0.03)
Clover Mist Fire	1115-1615	15.0	(0.03)
Madison Base Camp	0715-1825	33.5	(0.02)
North Fork Fire	1100-1552	14.6	(0.03)
OSHA PEL			1.0
ACGIH TLV			1.0
Proposed ACGIH TLV			0.3
NIOSH REL			LFL

[1] Sample volumes expressed in liters of sample air.
[2] Concentration expressed in parts per million of formaldehyde.
LFL-lowest feasible level.
[3] Concentrations in parenthesis fall between the limit of detection and the limit of quantitation for formaldehyde and should be considered semi-quantitative.

Table 6

Results of Area Air Sampling for Hydrocarbons

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Sample Volume[1]	Methyl Acetate[2]	2-Methyl Furan[2]	Benzene[2]	Toluene[2]	Furfural[2]	Terpenes[2]
Grant Base Camp	0700-1503	242	ND	0.01	0.01	0.01	ND	0.02
Shoshone Fire, Grant South	1129-1605	138	0.02	0.04	0.02	0.01	0.04	0.09
Shoshone Fire, Grant South	1148-1609	131	0.02	0.04	0.03	0.01	0.05	0.09
Pebble Creek Base Camp	0730-1730	300	ND	ND	ND	ND	ND	ND
Clover Mist Fire, Division A	1030-1545	158	ND	ND	0.02	ND	ND	ND
Clover Mist Fire, Division B	1115-1615	150	ND	ND	ND	ND	ND	ND
Madison Base Camp	0715-1836	341	ND	ND	0.01	0.01	ND	0.01
North Fork Fire	0920-1525	183	ND	ND	ND	ND	ND	ND
North Fork Fire	1100-1520	130	ND	ND	ND	ND	ND	ND
Proposed Exposure Guidelines[3]			111	-	NA	66	NA	-
OSHA PEL			200	-	1.0	100	2	-
NIOSH REL			-	-	0.1	100	-	-
ACGIH TLV			200	-	10	100	2	-

[1] Sample volumes expressed in liters of sample air.
[2] Concentrations expressed in parts per million (ppm) of the given analytes.
ND-analyte not detected on sample.
LFL-lowest feasible level.
NA-Per the OSHA Model[23], no adjustment for unusual work schedule.
[3] See Appendix III for discussion on these exposure guidelines.

Table 7

Results of Area Air Sampling for Polynuclear Aromatic Hydrocarbons

Yellowstone National Park
HETA 88-320
August 1988

Sample Location	Sample Time	Sample Volume[1]	Acenaphthene[2]	Fluorene[2]	Naphthalene[2]
Grant Base Camp	0700-1503	483	0.83	1.04	ND
Shoshone Fire, Grant South	1129-1605	276	1.45	ND	ND
Shoshone Fire, Grant South	1148-1609	261	1.53	ND	ND
Pebble Creek Base Camp	0715-1730	1230	0.89	0.65	0.98
Clover Mist Fire, Division A	1030-1545	870	0.57	ND	ND
Clover Mist Fire, Division B	1115-1615	840	0.95	ND	2.74
Madison Base Camp	0715-1835	1360	0.88	0.29	3.53
North Fork Fire	0920-1525	970	0.93	0.41	2.99
North Fork Fire	1100-1520	520	1.35	0.58	3.27
Proposed Exposure Guidelines[3]			-	-	28000
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.
3 See Appendx III for discussion on this exposure guideline.

Table 8

Demographics of Participants

Yellowstone National Park
HETA 88-320
August 1988

Variable	Mean	Std Dev	Minimum	Maximum
Age in Years	25.8	5.8	20	45
Years as a Fire Fighter	3.1	2.6	<1	9

Table 9

Number and Percent of Participants Reporting Symptoms

Yellowstone National Park
HETA 88-320
August 1988

Symptoms	Preshift # (%)	Postshift # (%)	Significance of difference[1]
Headache	7 (32)	6 (27)	p=0.054
Lightheaded	1 (5)	4 (18)	p=1.000
Tinnitus	0 (0)	0 (0)	p=1.000
Dim vision	0 (0)	0 (0)	p=1.000
Nausea	1 (5)	0 (0)	p=1.000
Weakness	2 (10)	6 (29)[2]	p=0.071
Decreased alertness	2 (9)	5 (23)	p=0.043
Impaired coordination	1 (5)	3 (14)	p=0.136
Loss of consciousness	0 (0)	0 (0)	p=1.000
Nose/throat irritation	14 (64)	20 (91)	p=1.000
Eye irritation	10 (46)	20 (91)	p=0.481
Cough	12 (55)	15 (68)	p=0.172

[1]Two-tailed Fisher exact test used for small sample size.
[2]One respondent did not complete this question.

Table 10

Carboxyhemoglobin Levels (%)

Yellowstone National Park
HETA 88-320
August 1988

Variable	Mean (%)	Std Dev	Minimum (%)	Maximum (%)
All participants				
COHB1	1.86	1.01	.5	4.7
COHB2	1.96	1.03	.5	3.8
Basin Crew				
COHB1	2.39	.92	1.5	4.7
COHB2	1.09	.68	.5	2.5
Lassen Crew				
COHB1	.76	.33	.5	1.2
COHB2	2.89	.64	1.8	3.8
Willamette Crew				
COHB1	2.46	.18	2.3	2.7
COHB2	2.06	.78	1.3	3.2

APPENDIX I

Report to Safety and Health Officer for Yellowstone National Park
Exposure Incident from Burning of Geothermal Area by Clover Mist Fire

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
National Institute for
Occupational Safety & Health
Robert A. Taft Laboratories
4676 Columbia Parkway
Cincinnati OH 45226

August 9, 1989
HETA 88-320

Health and Safety Officer
P.O. Box 527
Yellowstone National Park, Wyoming 82190

On August 18, 1988, the National Institute for Occupational Safety and Health (NIOSH) conducted an investigation of a geothermal area in the northeast region of Yellowstone National Park. This area was burned by the Clover Mist Fire and was fought by a firefighting crew of 33 males and females. The geothermal area consisted of white mineral deposits which were believed to contain large amounts of sulfur. When this area burned, the firefighters observed brilliant orange, blue, and green flames. The flames were doused by water from a helicopter "dip and dump" unit. As soon as the water hit the fire, a large white cloud was produced that the fire crew described as being very irritating to the eyes, nose, and mucous membranes. After this incident, 26 members of the fire crew (21 male and 5 female, 19 were Native Americans) reported to Mammoth Clinic with the following prevalence of symptoms: nausea/vomiting (69%), headache (38%), eye irritation (27%), cough (23%), shortness of breath (19%), and chest pain (19%). No respiratory protection was used by these crews. The affected firefighters departed from the Park prior to the arrival of the NIOSH team and were not available for interview or examination by the NIOSH investigators. The attending physician at Mammoth Clinic reported his observations and impressions, based on the examinations he performed on these workers. The patients he examined had more complaints of gastrointestinal symptoms than symptoms of mucosal irritation. However, on physical examination, some patients did show signs of conjunctival injection or reddened oral or nasal mucosa. Two patients had active coughing which promptly cleared upon treatment with metaproterenol, an aerosolized bronchodilator. These symptoms suggest a possible exposure to an airborne irritant, but the nature of that exposure can not be determined in retrospect.

The next day, NIOSH industrial hygienists hiked to the geothermal area for a site visit and evaluation. We observed a large plain-like area with white and yellow mineral deposits that had been burned in several areas. Bulk samples of the soil and rock were obtained to determine its composition and the by-products of combustion.

Initial observations pertaining to the regolith's mineralogy were made by simple microscopic examination. Each sample was then ground, mixed, and sieved prior to analysis by polarized light microscopy. Analysis of the samples found them to contain sulfur, calcite, gypsum, quartz, orthoclase, and limonite. To confirm these observations, a portion of the sample was submitted for qualitative X-ray powder diffraction (XRD) analysis. The qualitative XRD results confirmed the presence of the previous minerals, and also identified small quantities of lime and hedenbergite in the regolith. Portions of the bulk samples were also submitted for trace metals analysis by inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The portions were pulverized and digested with aqua regia and hydrofluoric acid, and the residues were dissolved in a dilute solution of nitric and perchloric acids. Aliquots were injected into the ICP-AES. The limit of detection of trace metals for this method is 0.01% by weight. The following metals were found in the samples: aluminum (1.5%), barium (0.11%), calcium (0.25%), iron (3.4%), magnesium (0.19%), sodium (.62%), phosphorus (0.08%), strontium (0.03%), titanium (0.43%), and zinc (0.31%).

To determine combustion products, the pulverized rock was heated in a tube furnace at 500°C and the effluent was sampled with a Tedlar® gas bag, a charcoal tube, an ORBO 23 sorbent tube, and H_2S and chlorine detector tubes. Sample air from the sampling bag was qualitatively analyzed for chemical contaminants with a fourier transform infrared spectrophotometer and gas chromatography with mass spectroscopic detection. The charcoal tube sample was desorbed with carbon disulfide and screened for hydrocarbons by GC with a flame ionization detector (FID). The ORBO 23 sorbent tubes were desorbed with toluene and analyzed for aldehydes by GC-FID. These analyses were qualitative (i.e. to determined which compounds were present in the effluent). Sulfur (molecular S_8) was the major component found in the effluent, with high levels of sulfur dioxide, hydrogen sulfide, and water also being present. Low levels of C_6-C_7 alkanes, toluene, xylene, and terpenes were identified, with trace levels of thiophenes, formaldehyde, acetaldehyde, benzene, and some furans detected in these samples. No detectable levels of chlorine were found in the effluent.

An experiment was performed on the regolith sample to determine the chemicals evolved during the burning of the rock and the quenching of the flames. A large sample of the rock and dirt were ignited and burned with a propane torch. Orange and green flames were observed during the burning of this sample. Detector tubes indicated that large amounts of SO_2 evolved during combustion, while trace levels of H_2S were also detected. Upon quenching the flames with water, a white smoke was produced which was sampled by drawing air through silica gel tube. The sample was analyzed by ion chromatography according to NIOSH Method 7903. The sampling and analysis found the white smoke to contain 13.1 milligrams of sulfuric acid per cubic meter of air (mg/m^3). The OSHA permissible exposure limit (PEL) and the NIOSH recommended exposure limit for sulfuric acid is 1 mg/m^3.

From the above data, we conclude that SO_2 and H_2S were generated when the mineral deposits in the geothermal area burned, and that high concentrations of sulfuric acid were produced when these flames were doused with water. Due to the proximity of the firefighting crew, it is very likely that the crew members were exposed to these contaminants. Because the NIOSH investigators were not present during the fire fighting episode in the geothermal area, it is not possible to determine the actual airborne concentration to which the firefighters were exposed. However, based on our laboratory data and the irritative symptoms reported by the attending physician at Mammoth Clinic, we believe that this fire crew was exposed to the chemical by-products generated when sulfur-rich soil and rock burns, such as that found in the geothermal areas at Yellowstone National Park. These sulfur-based compounds are known irritants of the eyes, mucous membranes, and upper respiratory tract.

If we can be of further assistance please contact either Mr. Reh at (513) 841-4374, or Dr. Deitchman at (513) 841-4386.

Sincerely yours,

Christopher M. Reh
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Appendix II

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:

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

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

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

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 (O.75%).

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

V_b = blood volume; 5500 ml.

0_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 through 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).

$P_{C\text{-}02}$ = 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. Since forest fire fighters typically work 12-hour shifts per day, the NIOSH investigators used 720 minutes in their calculations.

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	6000 ml/min
Light	40 ml/min/mm Hg	18000 ml/min
Heavy	60 ml/min/mm Hg	30000 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 at the Yellowstone forest fires contend that using the values for heavy work activity would be more descriptive of the work. 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 ($P_{C\text{-}02}$). 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.[25] The following will present the changes in these variables caused by exposure to CO at altitudes of 5000 and 10000 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 following standard pressures per altitude from the CRC Handbook of Chemistry and Physics, 66th Edition[26]:

Altitude in meters (feet)	Standard Pressure in mm Hg
1500 (5000)	634
3000 (10000)	526

In discussing altitude, Best & Taylor[27] 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-02}) is directly related to the atmospheric pressure. From the above intra-agency memorandum[25], P_{C-02} can be calculated using the following formula

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

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-O2}, the NIOSH investigators calculated the maximum CO exposure concentrations at 5000 and 10,000 feet which would result in a 5% COHb level in most workers. For forest fire fighters working a 12-hour shift with a heavy level of work activity, and at an altitude of 5000 feet, the CFK equation predicts that a 5% COHb level will be reached at a CO exposure concentration of 23 ppm. For the same level of work activity, length of workshift, and at an altitude of 10000 feet, the CFK equation predicts that a 5% COHb level will be reached at a CO exposure concentration of 17 ppm.

Appendix III

OSHA Model for Adjusting Exposure Limits for Unusual Work Schedules

The OSHA PELs were developed for 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.[17] 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[23], 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.[23] 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 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.[19]

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 "adjusted exposure guidelines for forest fire fighters," along with the respective OSHA PELs, ACGIH TLVs, and NIOSH RELs. These adjusted 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 12-hour/day, 72-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 exposure guidelines.

Toxic Substance	OSHA Category[1]	Evaluation Criteria[2]	Adjusted Exposure Guideline[3]
Carbon Dioxide	1C	TLV=5000 ppm	NA
Sulfur Dioxide	1B	PEL=2 ppm	NA
Nitrogen Dioxide	3	PEL=1 ppm	0.6 ppm
Methyl Acetate	4	PEL=200 ppm	111 ppm
Benzene	1C	PEL=1 ppm	NA
Toluene	2	PEL=100 ppm	66 ppm
Furfural	1B	PEL=2 ppm	NA
Naphthalene	4	PEL=50 mg/m^3	28 mg/m^3

[1] - OSHA Work Schedule Category from the OSHA Compliance Officers: Field Operations Manual.[23]
[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.
ppm-parts per million.
mg/m^3-milligrams per cubic meter.

The OSHA PEL and ACGIH TLV for carbon monoxide were not adjusted for length of workshift/workweek using the above OSHA Model. The reason for this is that an adjusted exposure guideline for carbon monoxide was calculated from the pharmacokinetic model (CFK equation) that had been used in developing the NIOSH REL. Also, an adjustment was not made in the OSHA/ACGIH evaluation criteria for formaldehyde since NIOSH considers it to be a potential human carcinogen and recommends that exposures be reduced to the lowest feasible level.