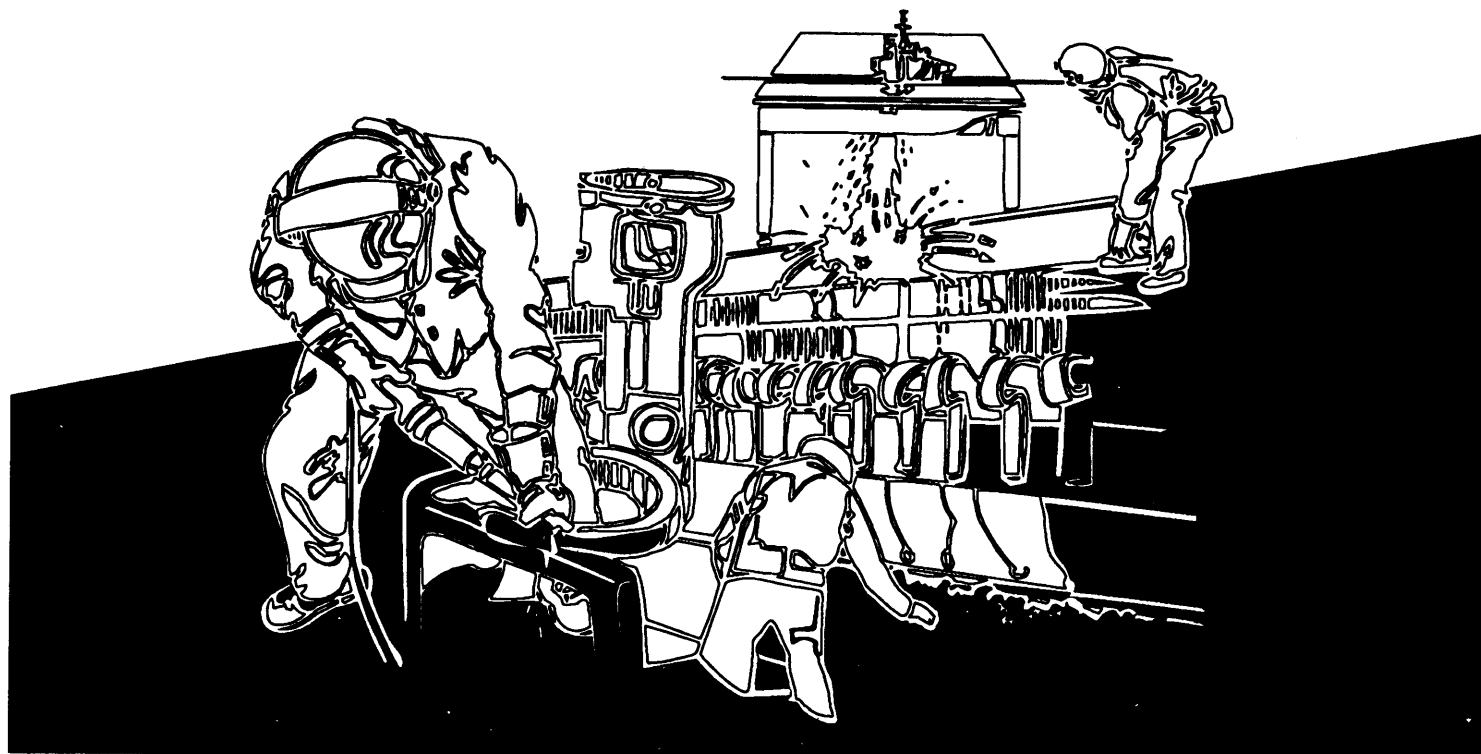




# NIOSH HEALTH HAZARD EVALUATION REPORT

**HETA 92-045-2260**  
**U.S DEPARTMENT OF THE INTERIOR**  
**NATIONAL PARK SERVICE**  
**NEW RIVER GORGE NATIONAL RIVER**  
**WEST VIRGINIA**



**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.

Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

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U.S. DEPARTMENT OF THE INTERIOR  
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## SUMMARY

On November 1, 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the U.S. Department of Interior, National Park Service (NPS). The purpose of the HHE was to characterize fire fighters' exposures to chemical contaminants during fire suppression operations. Industrial hygiene data was collected on November 3 and 4, 1991, during the Gauley Mountain Fire at the New River Gorge National River in West Virginia.

During the HHE, personal breathing zone (PBZ) and area air samples were collected to measure airborne concentrations of carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), aldehydes, volatile organic compounds (VOCs), respirable particulate matter (RPM), crystalline silica, benzene solubles, and polyaromatic hydrocarbons (PAHs).

Eight-hour time-weighted average (TWA) exposures ranged up to nine parts per million (ppm) for both CO and SO<sub>2</sub>, with average exposures of four and two ppm, respectively. CO exposures were well below the NIOSH recommended exposure limit (REL) of 35 ppm. Twenty-three of the 40 PBZ measurements of SO<sub>2</sub> exposures were at or above the NIOSH REL of two ppm. Formaldehyde concentrations ranged up to 0.10 ppm. NIOSH considers formaldehyde to be a potential occupational carcinogen, and recommends that exposures be reduced to the lowest feasible level. Air concentrations of other aldehydes detected; acetaldehyde, acrolein, and furfural, were below the minimum quantifiable concentrations (MQC). VOCs were not detected. Air concentrations of RPM ranged up to 1.5 milligrams per cubic meter (mg/m<sup>3</sup>). Silica was not detected. Air concentrations of benzene solubles ranged up to 0.67 mg/m<sup>3</sup>; however, PAHs were not detected on these samples. Air concentrations of naphthalene measured from the tube portion of the PAH samples ranged up to 6.1 micrograms per cubic meter (μg/m<sup>3</sup>). This is well below the NIOSH REL of 50 mg/m<sup>3</sup>. Concentrations of other PAHs were below the MQC.

Results indicate that fire fighters were overexposed to SO<sub>2</sub> during wildfire suppression activities. Recommendations for reducing SO<sub>2</sub> exposures, and for future collection of exposure data are provided.

KEYWORDS: SIC 0851 (Forestry Services); forest fire fighting; carbon monoxide; sulfur dioxide; aldehydes; volatile organic compounds; particulate matter; crystalline silica; benzene solubles; polyaromatic hydrocarbons.

## INTRODUCTION

On November 1, 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the U.S. Department of Interior, National Park Service (NPS). The purpose of the HHE was to characterize fire fighters' exposures to chemical contaminants during fire suppression operations. Industrial hygiene data was collected on November 3 and 4, 1991, during the Gauley Mountain Fire at the New River Gorge National River in West Virginia.

NIOSH assistance in evaluating chemical exposures of wildland fire fighters was first requested in 1988. The NPS requested assistance from NIOSH in identifying and quantifying the potential exposures to chemicals in smoke, and in evaluating the impact of inhalation of this smoke on the health of fire fighters. In 1988, data was collected during the Yellowstone National Park fires which swept through nearly half of the park's 2.2 million acres (HETA 88-320-2176).<sup>1</sup> In 1990, data was collected at Yosemite National Park during the Arch Rock Fire (HETA 90-365); a report summarizing the findings of this study is currently being prepared. In 1991, data was collected during the Thompson Creek fire at Gallatin National Forest<sup>2</sup> and during the Gauley Mountain Fire at the New River Gorge National River.

## BACKGROUND

There are two distinct classifications of wildland fires, prescribed and wildfire. A prescribed fire is designated as such when it is in the "prescription" of the burn. The prescription includes a specific geographic area and predetermined burning properties, such as flame height and fuel consumption. Conversely, a wildfire is a wildland fire that is outside of prescription.

Wildfire suppression activities may have up to five stages for a given fire: dispatch, initial attack, buildup, mop-up, and demobilization. After the fire is spotted and the location is identified, fire fighters are dispatched to the fire for initial attack. If initial attack activities do not control the fire, build-up of suppression activities to a project or campaign fire takes place. Once the fire is controlled, demobilization of resources occurs. At this point mop-up efforts, the actual extinguishment of all fire, are the focus of suppression activities.

Although the strategies used to fight forest fires can vary dramatically, the techniques used from one fire to another are basically the same. Fire suppression relies on removing one or more of the three requirements of a fire: oxygen (O<sub>2</sub>), fuel, and heat. For an uncontrolled fire, suppression efforts focus on removing the vegetation which is the fuel for the fire. Procedures that remove heat and O<sub>2</sub> are relied on during the mop-up stage.

Fire fighters use hand tools to remove vegetation down to the mineral soil, thus forming containment lines around the fire. The containment lines are referred to as fireline. When firelines are constructed adjacent to the fire,

it is referred to as direct attack line construction. When they are constructed at a distance from the fire, it is referred to as indirect attack. Direct attack generally requires less time to control the fire, and results in less acreage burned. However, direct attack usually requires building more fireline, with personnel working nearer to the heat and smoke. Direct attack therefore, is generally considered to result in greater exposures of fire fighters to smoke than is indirect attack. Air attacks, 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. To remove fuels from areas ahead of the advancing fire, or to affect the direction or spread of the wildfire, unburned areas of land may be ignited intentionally within prescription. During this operation, referred to as burning out or backfiring, fire fighters are required to "hold the fireline to insure that the fire does not escape its prescription.

Forest fire fighters typically work 12 hours per day, six to seven days per week. They are allowed to work up to 13 days straight, at which time they must take one day off (after 21 days, they are required to take two days off). The crew is usually transported by ground or air to and from staging areas. The duration of time that a fire fighter spends in travel during one shift can range from minutes to hours. This depends on the distance between the staging area and base camp, and the number of staging areas that the fire fighter travels to during that shift. After arriving at the staging area, crews may spend up to several hours hiking before initiating line construction.

During suppression activities, fire fighters typically wear Nomex™ pants and shirt, Vibram™-soled boots, hard hats, goggles and leather gloves. Nomex™ is a chemically treated material which is flame resistant. It will burn only if an ignition source is present. This differs from plain cotton which will continue to burn when the ignition source is removed.

Because fire suppression strategies can vary depending on fire behavior, the smoke exposure which fire fighters experience can also vary dramatically. For this reason, NIOSH investigators targeted their efforts at fires which appeared to have the potential for prolonged direct attack activity, which were believed to result in the greatest exposure, i.e., monitoring the worse case. To collect exposure data on direct attack, it is critical that data collection occur during the early stages of fire suppression, because once a fire is contained, prolonged direct attack is less likely.

On November 1, the NIOSH team was dispatched to the fire out of Region 9 of the United States Forest Service (USFS). On November 2, the team members were at base camp preparing to collect data the following day. (Data collection began within 36 hours of being dispatched.)

The crew monitored, the Alpine Hot Shots, was selected through the cooperation of the local Incident Commander. A "Hot Shot" crew, also called a Type 1 crew, was chosen because they are more likely to perform direct attack than a Type 2 crew, which generally performs indirect attack and mop-up. Though designated as a "Hot Shot" crew, the Alpine crew at the Gauley Mountain Fire

consisted of Type 1 crew members from the Alpine Hot Shots, and members from various Type 2 crews.

A crew typically consists of one superintendent who is in charge of up to four squads. Each squad is led by a squad boss who is in charge of approximately five fire fighters. Some of the fire fighters, referred to as sawyers, use chainsaws during line construction to remove trees and other large fuels. The majority of the fire fighters use manual tools designed specifically for removing fuels.

On November 3, the crew backfired up a hill from a dirt road. The road was utilized as a natural fire break; therefore, firelines were not constructed on that day. The crew monitored the road to assure that the fire did not cross onto the downhill slope. Crew members described the smoke exposure during that shift as very low. On November 4, the crew constructed fireline (indirect attack), and backfired from another dirt road. Crew members described the smoke exposure as low during most of that shift and moderate during one intense backfiring operation that lasted approximately 45 minutes. Crews worked 12 hours each day including travel time. The amount of travel time each day was approximately three hours; this included time spent in road transport and hiking.

## METHODS

Data collected at the Gauley Mountain Fire consisted of personal breathing zone samples (PBZ) full-shift air measurements for the following analytes: carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), respirable particulate matter (RPM), crystalline silica, aldehydes, benzene solubles, and polycyclic aromatic hydrocarbons (PAHs). These compounds were chosen based on data previously collected by NIOSH and other investigators that suggests these compounds may be present during wildfires or prescribed burns.<sup>14</sup> A total of 20 fire fighters were monitored for two days (November 3 & 4). One area air measurement for each of the above analytes was made at the Canyon Rim Visitor's Center on November 4. These measurements were made using the same methods as for PBZ samples.

### CO and SO<sub>2</sub>

Thirty-nine PBZ measurements for CO and 40 PBZ measurements for SO<sub>2</sub> were made using Dräger long-term diffusion tubes. The average duration of these samples was 8.2 hours. The Dräger tubes are colorimetric indicators which produce a length of stain proportional to the time-weighted average (TWA) concentration. The range of measurement for an eight hour sample is 6 to 75 parts per million (ppm) for CO and 0.7 to 19 for SO<sub>2</sub>.<sup>5</sup> The relative standard deviation of the method is reported to be 25% for CO at an air concentration of 30 ppm, and 20% for SO<sub>2</sub> at an air concentration of 2 ppm.

### Aldehydes

Ten PBZ measurements were made for aldehydes using NIOSH Method 2539.<sup>6</sup> Sample air was drawn through an SKC sorbent tube (catalog number 226-30-15-2) at a flowrate of 0.05 liters per minute (lpm) using a portable battery-powered sampling pump. The average sample volume was 28 liters. The samples were analyzed by gas chromatography for the following aldehydes: acetaldehyde, formaldehyde, acrolein and furfural.

### Volatile Organic Compounds (VOCs)

Ten PBZ measurements for VOCs were made using NIOSH Methods 1003, 1500, and 1503. Sample air was drawn through a standard charcoal tube using a portable, battery-powered sampling pump at a flow rate of 0.05 lpm. The average sample volume was 29 liters. After sampling, the charcoal was desorbed with carbon disulfide and the samples were qualitatively screened by gas chromatography (GC) and mass spectroscopy. Based on these results, standards were prepared and the samples were quantitated for benzene, toluene, xylene and trimethylbenzene by GC.

### RPM and Silica

Nine PBZ measurements of RPM were made using NIOSH Method 0600.<sup>6</sup> Sample air was drawn through a Dorr-Oliver cyclone and then through a tared polyvinyl chloride filter (37 millimeter diameter, 5 micron pore size) at a flow rate of 1.7 lpm using a portable, battery-powered sampling pump. The average sample volume was 890 liters. The cyclone removes the non-respirable particulate from the airstream, that which has an aerodynamic diameter of greater than 10 micrometers ( $\mu\text{m}$ ). A determination of the weight of the RPM deposited on each sample was made by weighing the filters on an electrobalance after sample collection and subtracting the previously determined tare weights. These samples were then analyzed for respirable crystalline silica content by x-ray diffraction (NIOSH Method 7500).<sup>6</sup>

### Benzene Solubles and PAHs

Nine measurements of benzene solubles, and both particulate and gaseous forms of PAHs, were made using NIOSH Methods 5023 & 5515. 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, at a flow rate of 1.0 lpm using a portable, battery-powered sampling pump. The average sample volume was 530 liters. 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. Aliquots of the extract from the filters were evaporated to determine the benzene-soluble fraction of the extract (NIOSH Method 5023). Separate aliquots of the filter and tube extracts 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(b)fluoranthene,

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.

## EVALUATION CRITERIA

### 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).

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, Occupational Safety and Health Administration (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. Industry is legally required by the Occupational Safety and Health Act of 1970 to meet those levels specified by an OSHA standard. The requirements of the act were extended to federal employees in 1980 under executive order 12196, Occupational Safety and Health Programs for Federal Employees.

A full-shift 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.

Listed below is a brief summary of the known health effects from overexposure to the chemicals which were monitored during this survey.



### Carbon Monoxide

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. Advanced symptoms include vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma or death may occur if high exposures continue.<sup>7,12</sup> The NIOSH REL and OSHA PEL for an 8-hour TWA are 35 ppm. The ACGIH TLV is 25 ppm (this was reduced from 50 ppm this year).<sup>13</sup> The REL was developed by NIOSH using the Coburn, Foster, Kane (CFK) equation.<sup>7</sup> It is designed to reflect the 8-10 hour TWA exposure to CO that would result in a 5% carboxyhemoglobin (COHb) level for individuals working at a low level of activity at an elevation close to sea level. NIOSH recommends adjusting the REL when environmental conditions or work loads differ from those which the guideline was designed.<sup>7</sup> After adjusting for these factors, the NIOSH investigators calculated RELs of 17 and 21 ppm for fire fighters at the Yellowstone and Thompson Creek fires respectively.<sup>1,2</sup> Based on the work conditions observed for fire fighters during the Gauley Mountain Fire, an adjusted REL of 30 ppm CO was calculated. The calculation of this value and the parameters used in its calculation are provided in Appendix I.

### Sulfur Dioxide

SO<sub>2</sub> is a colorless gas that results from the combustion of sulfur-containing materials. It is a severe irritant of the eyes, mucous membranes, skin, and the upper respiratory tract. The irritation of the upper respiratory tract can result in changes in pulmonary mechanics due to irritant induced bronchoconstriction.<sup>14-17</sup> Individuals who suffer from asthma are particularly sensitive to SO<sub>2</sub> exposure, experiencing pulmonary effects at levels of 0.5 to 1 ppm.<sup>18</sup> The NIOSH REL, OSHA PEL and ACGIH TLV for an 8-hour TWA are 2.0 ppm.

### Aldehydes

Collectively, aldehydes constitute a broad class of organic compounds which are highly reactive biochemically. Acute health effects from exposures to aldehydes can include irritation to the eyes, nose, throat and mucous membranes; chemical sensitization; and pulmonary edema at higher concentrations.<sup>19,20</sup> The OSHA PEL and ACGIH TLV for acetaldehyde, formaldehyde, acrolein, and furfural are 100 ppm, 1 ppm, 0.1 ppm, and 2 ppm respectively. NIOSH considers acetaldehyde and formaldehyde to be potential occupational carcinogens and recommends that exposures be reduced to the lowest feasible level. The NIOSH REL for acrolein is 0.25 mg/m<sup>3</sup>. NIOSH does not currently have an exposure guideline for furfural.

### Respirable Particulate Matter (RPM)

RPM refers to particulate material that has a mean aerometric diameter of 10 micrometers or less. Because of their small size, these particles are capable of reaching the alveolar region of the lung; hence, they are referred to as respirable particulate. NIOSH does not have an REL for RPM. OSHA has

established a PEL of 5 mg/m<sup>3</sup> for respirable particulate not otherwise regulated (RPNOR). NIOSH investigators feel that the OSHA PEL for RPNOR is not an appropriate evaluation criteria for wildland fires, because previous research has demonstrated that smoke from forest fuels can contain a variety of toxic compounds including PAHs.<sup>21</sup>

### Crystalline Silica

Crystalline silica consists of clear crystals composed of silicone and oxygen, that can be present in soils and become airborne when soil is disturbed. Exposure to crystalline forms of silica: quartz, cristobolite, tridymite, and tripoli are known to cause silicosis,<sup>22</sup> a disabling form of pulmonary fibrosis.<sup>a</sup> NIOSH considers all forms of crystalline silica to be potential human carcinogens. The OSHA PEL and ACGIH TLV are 0.1 mg/m<sup>3</sup> for quartz and 0.05 mg/m<sup>3</sup> for cristobalite.

### Polyaromatic Hydrocarbons (PAHs)

PAHs constitute a large class of organic compounds that consist of two or more fused aromatic rings. They are often associated with the combustion or pyrolysis of organic matter, especially coal, wood, and petroleum products. The analytical method for PAHs measures 17 individual compounds. Evaluation criteria for the majority of these compounds do not currently exist. The NIOSH REL and OSHA PEL for naphthalene is 50 mg/m<sup>3</sup>. For Chrysene, NIOSH recommends that exposures be reduced to the lowest feasible level because of the carcinogenic potential of chrysene. The OSHA PEL for coal tar pitch volatiles pertains to emissions containing PAHs that result from the burning of wood as well as coal. This standard of 0.2 mg/m<sup>3</sup>, is for benzene-solubles from which at least one of the following PAHs has been identified: anthracene, benzo(a)pyrene, phenanthrene, acridine, chrysene, or pyrene.

## **RESULTS AND DISCUSSION**

Eight-hour TWA exposures for CO and SO<sub>2</sub> are presented in Table 1. Exposures ranged up to 9 ppm for both CO and SO<sub>2</sub>. Average exposures for CO and SO<sub>2</sub> were 4 and 2 ppm, respectively. One SO<sub>2</sub> measurement of 9 ppm was much greater than the other 39 samples which ranged from 1 to 3 ppm. An explanation for this was not identified. Twenty-three of the 40 PBZ exposures measured for SO<sub>2</sub> were at or above the NIOSH REL of 2 ppm.

Reducing SO<sub>2</sub> exposures requires the removal of SO<sub>2</sub> emissions from the air that is inhaled, or a reduction in the time that fire fighters are in areas with elevated concentrations of SO<sub>2</sub>. The reduction of SO<sub>2</sub> exposures during suppression activities through engineering controls such as local exhaust ventilation is not feasible for wildland fires. Respirators approved by NIOSH for controlling SO<sub>2</sub> exposures include chemical cartridge respirators (CCRs),

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<sup>a</sup> Pulmonary fibrosis refers to the formation of fibrous tissue in the lung which generally impairs pulmonary function.

and air supplied respirators (ASRs). Fire suppression agencies may choose to use CCRs; however, employee discomfort, the additional pulmonary load, and the reliance on employee cooperation, are factors which must be considered beforehand. If CCRs are used, a complete respiratory program consistent with the OSHA respiratory standard (29 CFR 1910.134)<sup>23</sup> should be implemented. An ASR, either an airline type or self-contained breathing apparatus (SCBA), does not offer a feasible method of controlling contaminant exposures at wildland fires. Airline respirators are not practical because of the remote locations, topography of the environment, and distances traveled during wildland fire suppression. SCBAs have too short of a service life (generally 30 minutes or less), and are too heavy and bulky for the fire fighters to carry while performing fire suppression.

Administrative controls aimed at reducing the time that fire fighters are exposed to elevated SO<sub>2</sub> concentrations could effectively reduce SO<sub>2</sub> exposures. Options include shortening the duration of the workshift and/or restricting the fire fighter from areas where SO<sub>2</sub> concentrations are above the REL. Fire suppression agencies may choose to rely on administrative control methods that depend on smoke intensity; however, that requires an objective assessment of intensity. Currently, smoke intensity is a subjective judgement made by fire suppression personnel based primarily on visual observation. (It is worth noting that overexposures to SO<sub>2</sub> occurred at the Gauley Mountain Fire even though the smoke intensity was judged to be low to moderate by fire fighters.) Furthermore, there is no evidence that smoke intensity, even if based on objective data, reflects the air concentrations of individual contaminants. Routine monitoring of workers under various wildland fire conditions is the only reliable method of determining fire fighters' exposures to individual compounds.

Formaldehyde exposures ranged up to 0.10 ppm. The average exposure was 0.07 ppm. NIOSH considers formaldehyde to be a potential occupational carcinogen, and recommends that exposures be reduced to the lowest feasible level. Exposures to furfural ranged up to 0.03 ppm. This concentration is well below the OSHA PEL of 2 ppm. Exposures to acetaldehyde and acrolein were below the minimum quantifiable concentration (MQC). The MQCs for acetaldehyde and acrolein are 0.06 and 0.02 ppm, respectively. These MQC values are based on a sample volume of 28 liters. VOCs were not detected. The minimum detectable concentration (MDC) for a 29 liter sample is 0.03 mg/m<sup>3</sup> for benzene; and 0.3 mg/m<sup>3</sup> for toluene, xylene, and trimethylbenzene. RPM exposures ranged up to 1.5 mg/m<sup>3</sup>. The average exposure to RPM was 0.49 mg/m<sup>3</sup>. Crystalline silica was not detected. The MDC for a 890 liter sample is 0.02 mg/m<sup>3</sup> of silica. Air concentrations of benzene solubles ranged up to 0.67 mg/m<sup>3</sup>; however, PAHs were not detected on these samples. The MDC for a 530 liter sample is 0.9 µg/m<sup>3</sup>. Concentrations of naphthalene from the PAH tube samples ranged up to 6.1 µg/m<sup>3</sup>. This is well below the NIOSH REL of 50 mg/m<sup>3</sup>. Exposures of other PAHs detected on the tube samples; acenaphthylene, acenaphthene, and fluorene, were below the MQC. The MQC for a 530 liter sample is 3 µg/m<sup>3</sup>.

The air concentrations of contaminants measured at the visitors center were low. The air concentration of CO was one ppm and SO<sub>2</sub> was not detected. The limit of detection (LOD) of the method used to measure SO<sub>2</sub> is reported to be 0.7 ppm for an 8-hour sample.<sup>5</sup> The formaldehyde concentration was below the MQC of 0.03 ppm for a sample volume of 30 liters. Neither acetaldehyde, acrolein, nor furfural were detected. The MDCs for a 28 liter sample are 0.02, 0.006, and 0.003 ppm for acetaldehyde, acrolein, and furfural, respectively. VOCs were also not detected. The air concentration of RPM was 0.07 mg/m<sup>3</sup>. Crystalline silica was not detected. The benzene-solubles concentration was 0.11 mg/m<sup>3</sup>; however, PAHs were not detected on this samples. PAHs were not detected on the tube portion of the sample either. The MDC for a 530 liter sample is 0.9 µg/m<sup>3</sup>. These measurements indicate that contaminant concentrations at the visitors center were low and did not pose a health concern for visitors, or park personnel working at the center.

The dirt roads from which backfiring occurred, served as natural fire breaks. This precluded the need for direct attack fireline construction. Exposures during direct attack, what some fire suppression personnel believe may depict the worse case exposure conditions, were therefore not measured. Discussions with crew members from several Type 1 crews has suggested that prolonged direct attack does not frequently occur. It may be unrealistic to expect investigations performed at a few fires to provide data on what may be a relatively rare event. Routine exposure monitoring of crews would improve the probability of collecting exposure data during direct attack line construction. The monitoring of individual fire fighters for an entire fire season would provide both daily (short-term) and seasonal (long-term) exposures. This might best be accomplished by assigning an industrial hygienist to a fire crew for the duration of a fire season.

Many factors affect a wildland fire, but probably none more so than the weather. Despite improved weather forecasting, local weather events are often unpredictable. This unpredictability, as it relates to fire behavior, is intensified because the fire itself influences wind patterns. Unpredictable changes in weather, and the subsequent changes in fire behavior, are factors that influence the effectiveness of suppression activities at extinguishing the fire. Similarly, the effectiveness of data collection efforts are influenced by unpredictable weather and fire behavior. NIOSH teams have arrived at several fires since 1988, only to be notified that the fire was nearly controlled.

An alternative to collecting exposure data at wildfires is to collect data at prescribed burns ignited by fire suppression personnel. These are planned events that coincide with predicted weather patterns. Because the weather and fire behavior is likely to be more predictable, exposure studies of prescribed burns such as the study performed by the United States Forest Service,<sup>3</sup> may prove to be more productive. One argument against using data from prescribed burns, is that the data would not represent exposures at wildfires. Objective evidence that supports this argument however, does not exist. It is unlikely though, that monitoring at a prescribed burn would provide exposure data for direct attack, unless the fire escaped its prescription.

## RECOMMENDATIONS

1. Administrative controls to reduce the fire fighter's exposure to SO<sub>2</sub> should be determined by the NPS and other agencies responsible for fire suppression. If controls are used which depend on smoke intensity; objective criteria for assessing the intensity should be established.
2. Routine exposure monitoring of the crews during fire suppression activities should be conducted. This can best be done by the NPS and other agencies responsible for fire suppression. Although setting up such a program is a large task and would require additional resources, it is an important measure for assuring the health and safety of the fire fighters.
3. The monitoring of individual fire fighters for the entire fire season should be conducted to provide both daily and seasonal exposures.
4. The focus of future research efforts should include data collection at prescribed burns.

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#### **AUTHORSHIP AND ACKNOWLEDGEMENTS**

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Table 1  
Results of Air Measurements for Carbon Monoxide and Sulfur Dioxide  
 Gauley Mountain Fire  
 New River Gorge National River, West Virginia  
 HETA 92-045  
 November 3-4, 1991

Sample Number	Job Title or Location	Start (HH:MM)	Stop (HH:MM)	CO (PPM)	SO2 (PPM)
11/3/91					
1	NIOSH IH *	9:05	17:20	9	1
2	FF **	8:50	18:50	4	1
3	FF	8:50	17:20	5	1
4	SQUAD BOSS	8:50	17:20	4	1
5	FF	8:50	17:20	5	1
6	FF	8:50	17:20	5	2
7	FF	8:50	17:20	5	3
8	CREW BOSS TRAINEE	8:50	16:50	3	2
9	FF	8:50	17:20	6	3
10	FF	8:50	17:20	3	1
11	CREW BOSS	9:10	17:20	3	1
12	FF	8:50	17:20	6	2
13	FF	8:50	17:20	4	3
14	SAWYER	8:50	17:20	2	2
15	FF	8:50	17:20	6	2
16	NIOSH IH	9:05	17:20	8	1
17	FF	8:50	17:20	6	2
18	FF	8:50	18:50	2	1
19	FF	8:50	18:50	5	1
20	FF	8:50	18:50	4	2
21	SQUAD BOSS	8:50	17:20	3	1
11/4/91					
22	FF	8:10	16:00	3	2
23	FF	8:10	16:00	5	2
24	FF	8:10	15:10	1	3
25	FF	8:15	16:00	3	2
26	CREW BOSS	8:35	16:00	***	3
27	SQUAD BOSS	8:10	16:00	2	1
28	FF	8:10	16:00	3	2
29	FF	8:35	16:00	2	2
30	SAWYER	8:10	16:00	4	9
31	FF	8:10	15:10	5	2
32	FF	8:10	16:00	1	1
33	SQUAD BOSS	8:10	15:10	3	2
34	FF	8:30	16:00	9	1
35	CREW BOSS TRAINEE	8:10	16:00	2	1
36	FF	8:10	15:10	3	2
37	FF	8:10	16:00	1	1
38	FF	8:15	16:00	1	2
39	SWAMPER	8:35	16:00	2	2
40	FF	8:10	16:00	2	1
41	VISITORS CENTER	11:45	21:00	1	< 0.7
	NIOSH REL			35	2
	OSHA PEL			35	2
	ACGIH TLV			25	2

\* Refers to NIOSH industrial hygienist.

\*\* Refers to firefighter using manual tools for line construction.

\*\*\* The CO dosimeter was lost during fire suppression activities.

## Appendix I

### Using the CFK equation to adjust the NIOSH REL for CO

In the NIOSH document: "Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide,"<sup>7</sup> 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:

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

where:

$$A = P_{\text{C-O}_2} + M(\text{O}_2\text{Hb})$$

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

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

The variables in the above equations were given in the NIOSH criteria document for CO and are presented below:<sup>7</sup>

- 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%).
- $V_{\text{CO}}$  = rate of endogenous CO production; 0.007 ml/min.
- $V_b$  = blood volume; 5500 ml.
- $\text{O}_2\text{Hb}$  = oxyhemoglobin concentration; 0.2 ml/ml blood.
- M = ratio of affinity of CO vs.  $\text{O}_2$  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).

## Appendix I (cont'd)

$P_{c.o_2}$  = 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. Although forest fire fighters typically work 12-hour shifts per day, the NIOSH investigators retained the use of 8 hours in their calculations because this reflects the time period that was monitored.

### 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.<sup>7</sup> The values for these variables represent three levels of work activity: sedentary, light, and heavy. These variables and values are shown below.

<u>Work Activity Level</u>	<u><math>D_L</math></u>	<u><math>V_A</math></u>
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.<sup>7</sup> The NIOSH investigators at the Thompson Creek forest fire 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 $P_{c.o_2}$ )

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 ( $P_{c.o_2}$ ). The adjustment of these variables to reflect the effect of altitude, as related to the CFK equation, was previously discussed in an U.S. Department of Health and Human Services, Public Health Service intra-agency memorandum.<sup>22</sup> The following will present the changes in these variables caused by exposure to CO at an altitude of 7000 ft.  $P_L$  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).<sup>7</sup> To calculate  $P_L$ , the NIOSH investigator used

### Appendix I (cont'd)

737 mm Hg. This is the average value of three measurements of barometric pressure made on 11/4/91 using a Thommen altimeter-barometer. This pressure corresponds to the elevation of approximately 1000 feet.<sup>23</sup>

In discussing altitude, Best & Taylor<sup>24</sup> 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 ( $P_{c.O_2}$ ) is directly related to the atmospheric pressure. From the above intra-agency memorandum<sup>22</sup>,  $P_{c.O_2}$  can be calculated using the following formula

$$P_{c.O_2} = P_L \times 0.21 - 45$$

Using the above given values for C, D,  $V_{CO}$ ,  $V_b$ ,  $O_2Hb$ , T and M; the calculated values for A, B, and a; and the new values for  $V_A$ ,  $D_L$ ,  $P_L$ , and  $P_{c.O_2}$ , 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 at a heavy activity level at an altitude of 1000 feet for eight hours, the CFK equation predicts that a 5% COHb level will be reached at a CO exposure concentration of 30 ppm. Although the typical work shift of the fire fighter is 12 hours, it was observed that on the days during monitoring, the majority of this extra four hours was spent in travel to and from the worksite. The contributed exposure to the fire fighters during travel for this particular fire was estimated to be low.