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GALLATIN NATIONAL FOREST, MONTANA

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SUMMARY

On July 18, 1991, 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 request was to collect information on the potential health effects from fire fighter's exposure to smoke during fire suppression activities at wildland fires. Industrial hygiene data was collected from July 20 to July 22, 1991, during the Thompson Creek Fire in Gallatin National Forest.

During the HHE, personal breathing zone (PBZ) air samples were collected for carbon monoxide (CO), sulfur dioxide (SO_2), aldehydes, respirable particulate matter (RPM) and respirable crystalline silica.

The CO exposure levels ranged from non-detected to 17 parts per million (ppm); these levels are below the evaluation criteria used by NIOSH, the Occupational Safety and Health Administration (OSHA), and the American Conference of Governmental Industrial Hygienists (ACGIH). Sulfur dioxide concentrations ranged from 0.6 to 3.0 ppm. Three of the 26 PBZ samples were above the evaluation criteria of 2.0 ppm used by NIOSH, OSHA and ACGIH for an 8-hour time-weighted average (TWA). Aldehyde concentrations were an order of magnitude or more below the evaluation criteria used by OSHA and ACGIH. NIOSH considers acetaldehyde and formaldehyde to be potential occupational carcinogens and therefore recommends that exposures be reduced to the lowest feasible level. Of the 14 samples analyzed for respirable silica, one sample was above the OSHA and ACGIH evaluation criteria for quartz. NIOSH considers silica to be a potential occupational carcinogen and therefore recommends that exposures be reduced to the lowest feasible level.

> The industrial hygiene data collected during this survey suggests that a potential health hazard from SO_2 exposure existed during fire suppression activities. This conclusion is based on the results from personal air monitoring. Three of the 26 PBZ samples collected for SO_2 were above the NIOSH REL and OSHA PEL of 2.0 ppm.

KEYWORDS: SIC 0851 (Forestry Services); forest fire fighting; carbon monoxide; sulfur dioxide; particulate matter.

INTRODUCTION

On July 18, 1991, NIOSH received a request from the U.S. Department of Interior, National Park Service (NPS) to evaluate worker exposure to forest fire smoke at Gallatin National Forest, Montana.

NIOSH assistance in evaluating smoke exposure to 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 forest 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).[1] NIOSH investigators also collected data in 1990 at Yosemite National Park during the Arch Rock Fire (HETA 90-365); a report summarizing the findings of this study is currently being prepared.

BACKGROUND

There are two distinct classifications of wildland fires, prescribed and wildfire. A prescribed fire is designated as such if 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. A wildfire is a wildland fire which is outside of the prescription, either because 1) a prescription was never determined or 2) because it has "escaped" its prescription.

Fire suppression activities may have up to 5 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, buildup 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_2), fuel and heat. During fire suppression of an uncontrolled fire, techniques focus on removal of fuel. Steps to remove heat and O_2 are relied on during the mop-up stage.

To remove the fuel, fire fighters use hand tools and/or earth moving equipment to remove all fuel from strips of land around the fire. Thus, the fire fighters attempt to form containment lines around the fire by digging down to the mineral soil; these lines are referred to as fireline. If these lines are dug adjacent to the fire, it is referred to as direct attack, if they are dug at a distance from the fire it is indirect attack. Direct attack usually allows for sooner control with less acreage burned. However, direct attack usually requires building more fireline with personnel working directly in the heat and smoke, resulting in greater exposures. 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 be ignited intentionally within prescription, to remove fuels from areas ahead of the advancing fire, or to affect the direction of the wildfire. 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, 6-7 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 given 2 days off. The crew is usually transported by ground or air to and from the worksite. The duration of this travel can be minutes or hours, depending on the distance from base camp and the number of work locations during the shift. In addition to transport by vehicles, crews may have to hike several hours before they begin fire suppression activities.

During suppression activities, fire fighters typically wear Nomex pants and shirt, Vibram-soled boots with 8" uppers, 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, unlike plain cotton which will continue to burn even when the ignition source is removed.

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

On July 18, the NIOSH team was dispatched to the fire out of Region 9 of the U.S. Forest Service. On July 19, the team members were at base camp preparing to collect data the following day; data collection began within 36 hours of being dispatched. On July 19, the fire activity was high with spot fires occurring across the fireline and no expected containment date. At that point it appeared that the fire would provide the opportunity to collect data under heavy smoke conditions during direct attack activity. The following night however, 0.45 inch of rain fell which greatly reduced the activity of the fire. By July 22, mop-up activities had begun and by July 24, the fire was nearly completely lined, and by July 26 it was contained.

The crews surveyed were selected through the cooperation of the local Incident Commander, Safety Officer, and the NPS liaison. Hot shot crews, also called Type 1 crews, were chosen because they are generally more likely to perform direct attack than are Type 2 crews. A hot shot crew typically consists of one crew 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 July 20 and 21, the Boise Hot Shot Crew was monitored; on July 22, the Redmond Hot Shot Training Crew was monitored.

The Boise Hotshot Crew spent July 20 protecting private homes. The homes being protected were well removed from the fire; crew members described the smoke exposure during this day as very low. The crew dug fireline on a hillside most of July 21. Direct attack was performed on small spot fires for about two hours in the morning, then on occasion during the rest of the day; crew members described the smoke exposure as low during most of the day and moderate during direct attack activity. On July 22, the Redmond Hotshot Crew dug fireline much of the day along a ridge which had burned on one side. On this day, scattered spot fires were suppressed using direct attack; crew members described the smoke exposure on this day as low. Crews worked approximately 12 hours each day including travel time. The amount of time the crew spent in travel to and from the worksite for July 20, 21, and 22 was approximately 4, 3, and 6 hours respectively; this included time spent in road transport and hiking before and after fire suppression activities.

METHODS

Data collected at the Thompson Creek Fire consisted of personal full-shift air samples for the following analytes: carbon monoxide (CO), sulfur dioxide (SO_2), respirable particulate matter (RPM), silica, and aldehydes. These compounds were chosen based on data previously collected by NIOSH and other investigators that suggests these compounds may be present during fires at concentrations which may cause adverse health effects.[1-3] A total of 20 fire fighters were monitored each day. Two area samples, one for RPM and silica, and one for aldehydes, were also collected at the base camp on July 20. These area samples were collected to evaluate the fire fighters' exposures to these compounds while sleeping at the base camp located in a valley. Although the base camp was removed from the actual fire, smoke could be seen in the base camp on the night of July 19. This was due to a temperature inversion which caused the smoke to settle in the valley.

Carbon monoxide and SO_2 personal breathing zone samples were collected using Dräger long-term diffusion tubes. These tubes are colorimetric indicators which produce a length of stain proportional to the time-weighted average (TWA) concentration for the specific analytes. The range of measurement for an eight hour sample as reported by the manufacturer is 6 to 75 ppm for CO and 0.7 to 19 for SO_2. 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_2 at an air concentration of 2 ppm.

Aldehydes were measured using NIOSH Method 2539 to collect personal and area air samples.[4] Sample air was drawn through an SKC sorbent tube (catalog number 226-30-15-2) at a flowrate of 0.05 lpm using a portable battery-powered sampling pump. The average volume of air sampled was approximately 28 liters per sample. The samples were analyzed by gas chromatography for the following aldehydes: acetaldehyde, formaldehyde, acrolein and furfural.

Respirable particulate matter was measured by collecting personal and area air samples using NIOSH Method 0600.[4] 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 liters per minute (lpm) using a portable, battery-powered sampling pump. The cyclone removes the non-respirable particulate from the airstream, that which has an aerodynamic diameter of greater than 10 micrometers (um). 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. One half of these samples were then analyzed for respirable crystalline silica content using NIOSH Method 7500.[4]

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, 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. The NIOSH and ACGIH criteria are recommendations which do not bear legal authority.

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.

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.[5-10] The NIOSH REL and OSHA PEL for an 8-hour TWA is 35 ppm. The current ACGIH TLV is 50 ppm; however, a proposed TLV of 25 ppm is listed in the notice of intended changes for 1991-1992. The REL was developed by NIOSH using the Coburn, Foster, Kane (CFK) equation.[5] It is designed to reflect the air concentration of CO that would result in a 5% carboxyhemoglobin (COHb) level for workers exposed to CO for 8 hours per day, working at sea level, and whose level of work activity is close to sedentary. NIOSH recommends adjusting the REL when environmental conditions or work loads differ from those which the guideline was designed.[5] Adjusting for these factors, the NIOSH investigators calculated a REL of 17 ppm for fire fighters at the Yellowstone fires[1]. Based on the work conditions observed for fire fighters during the Thompson Creek Fire, an adjusted REL of 21 ppm CO was calculated. The calculation of this value and the parameters used in its calculation are provided in Appendix I.

Sulfur Dioxide

Sulfur dioxide (SO_2) 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.[11-14] Individuals who suffer from asthma are particularly sensitive to SO_2 exposure, experiencing pulmonary effects at levels of 0.5 to 1 ppm.[15] The NIOSH REL, OSHA PEL and ACGIH TLV for an 8-hour TWA are 2.0 ppm.

Aldehydes

Acute effects from aldehydes can include irritation to the eyes, nose, throat and mucous membranes; chemical sensitization; and pulmonary edema at higher concentrations.[16-17] The OSHA PEL and ACGIH TLV for acetaldehyde, formaldehyde, acrolein, and furfural are 180, 1.2, 0.25, and 8.0 mg/m^3 respectively. NIOSH considers acetaldehyde and formaldehyde to be potential occupational carcinogens and for this reason, recommends that exposures to these two compounds be reduced to the lowest feasible level. The NIOSH REL for acrolein is 0.25 mg/m^3. NIOSH does not currently have an exposure guideline for furfural.

Respirable Particulate Matter

NIOSH does not have an REL for respirable particulate matter. OSHA has set a standard of 5 mg/m^3 for respirable particulate not otherwise regulated (RPNOR). NIOSH investigators feel that the OSHA PEL for RPNOR is not an appropriate evaluation criteria in this case, because research has demonstrated that smoke from forest fuels can contain a variety of compounds including several polyaromatic hydrocarbons (PAHs) which are suspected to be human carcinogens.[18]

Crystalline Silica

Exposure to crystalline forms of silica: quartz, cristobolite, tridymite, and tripoli are known to cause silicosis, a disabling form of pulmonary fibrosis.[19] NIOSH considers all forms of crystalline silica to be potential human carcinogens. The OSHA PEL and ACGIH TLV are 0.1 mg/m^3 for quartz and 0.05 mg/m^3 for cristobalite.

RESULTS and DISCUSSION

The results of the air samples collected for CO and SO_2 are presented in Table 1. The mean concentrations of CO for July 20, 21, and 22 were 1.6, 6.9, and 6.2 ppm respectively. The concentrations ranged from not detectable to 17 ppm over the three days. All of the TWA measurements for CO were well below the OSHA PEL and ACGIH TLV of 35 ppm. One sample measured 17 ppm CO and another measured 16 ppm CO; these values approach the adjusted NIOSH REL of 21 ppm. The calculation of the adjusted REL and the parameters used in its calculation are provided in Appendix I.

The mean concentrations of SO_2 for July 20, 21, and 22 were 1.0, 1.7, and 1.5 ppm respectively. The concentrations ranged from 0.6 to 3.0 ppm over the three days. Three of the TWA measurements for SO_2 were above the NIOSH REL and OSHA PEL of 2.0 ppm. Reducing the exposure of fire fighters to SO_2 requires either the removal of the SO_2 emissions from the air being inhaled, or the removal of the worker from the area where the SO_2 is being emitted into the environment. Removal of the SO_2 from the air using engineering controls is not a viable option at a forest fire. Administrative controls which reduce the fire fighter's exposure are likely to be the most effective methods available for reducing exposure to SO_2. Options for this method of control include shortening the duration of the workshift and/or restricting the fire fighter from areas with heavy smoke. Respirators approved by NIOSH for removing SO_2 from the air being inhaled might be used during times of unusually "high" exposure or as an interim measure, but they are not recommended as a primary method of controlling exposure. Relying on control methods which vary depending on smoke intensity, requires an accurate assessment of the smoke intensity. At this point in time, determining those situations which have heavy smoke exposure is a subjective judgement made by fire suppression personnel based primarily on visual observation. It is important to note that there was overexposure to SO_2 even though the smoke exposures were reported by fire fighters to range from low to moderate.

The air concentrations of aldehydes ranged from trace amounts to 0.10 mg/m^3 for acetaldehyde and formaldehyde, from below the LOD to trace amounts for acrolein, and from below the LOD to 0.04 mg/m^3 for furfural. In this context, trace amounts refer to concentrations of the compound between the LOD and the limit of quantitation (LOQ) for the analytical method used. For a 25 liter sample, the LOD and LOQ for the above aldehydes was 0.008 mg/m^3 and 0.028 mg/m^3 respectively.

The concentrations of aldehydes in all samples were well below the OSHA and ACGIH criteria of 180, 1.2, 0.25, and 8.0 mg/m^3 for acetaldehyde, formaldehyde, acrolein, and furfural respectively. NIOSH considers acetaldehyde and formaldehyde to be potential occupational carcinogens and for this reason, recommends that exposures to these two compounds be reduced to the lowest feasible level. The concentration of acrolein for all samples was below the NIOSH REL of 0.25 mg/m^3. NIOSH does not currently have an exposure guideline for furfural.

The results of the samples collected for RPM and crystalline silica are presented in Table 2. The highest concentration of RPM measured was 4.3 mg/m^3. This is approximately one order of magnitude greater than the mean concentration of 0.37 mg/m^3 from the remaining 24 samples. It is unclear why this individual's exposure would be so much greater, because the tasks performed and work practices used by this individual did not appear to be different than that of the other fire fighters.

One half of the samples collected for RPM were further analyzed for crystaline silica content. Only two of the samples contained measurable amounts of crystalline silica. The quartz concentration of one of these samples, 0.35 mg/m^3 is well above both the OSHA PEL and ACGIH TLV of 0.1 mg/m^3; the other sample measured 0.04 mg/m^3. The sample measuring 0.35 mg/m^3 was the same sample that measured 4.3 mg/m^3 for RPM. Again, the reason for this elevated concentration is unclear.

On July 20, 1991, five of the fire fighters being monitored for RPM and silica, and eight of the fire fighters being monitored for aldehydes, turned their pumps off and were not certain when they had done so. The crew members had reportedly turned their pumps off because they felt the exposure was very low and was not worth monitoring; the NIOSH team members were at another site during this time. For this reason, the sample volumes needed to calculate air concentrations could not be determined. Therefore, these samples were not used in calculating the results.

The concentration of RPM measured during the morning of July 20 at base camp was low (0.1 mg/m^3). The concentration of respirable silica in this sample was below the limit of detection. Trace amounts of formaldehyde, acrolein, and furfural were detected on the area sample collected for aldehydes.

CONCLUSIONS AND RECOMMENDATIONS

Personal air monitoring data collected during the Thompson Creek Fire did not result in overexposure to carbon monoxide. Several fire fighters were overexposed to sulfur dioxide. Fire fighters should be made aware that there is a potential for being overexposed to SO_2 during fire suppression activities. Furthermore, they should understand the possible health effects resulting from overexposure. Administrative controls to reduce the fire fighter's exposure to SO_2 should be evaluated by those agencies responsible for fire suppression.

Aldehyde concentrations were well below the evaluation criteria used by OSHA and ACGIH. With the exception of one sample, the concentrations of respirable crystalline silica were below the OSHA, NIOSH, and ACGIH evaluation criteria. The one sample which measured 0.35 mg/m^3 quartz silica, suggests that overexposure to silica occurred for this individual, however twelve of the remaining 13 samples contained either trace or non-detectable levels of silica.

Although direct attack was monitored during this survey, it was not of the prolonged nature along a raging fire that fire suppression personnel believe may depict the worse case exposure condition. Discussions with crew members suggest that this worse case scenario may be an infrequent event. It may be unrealistic to expect investigations performed at a few fires to provide data on what may be a relatively rare event. Routine or periodic monitoring of the crews may be the only way to collect this data.

NIOSH investigators recommend that routine exposure monitoring of the crews be conducted during the fire season. This can best be done by the agencies which are responsible for fire suppression. Although setting up such a program is a large task and would require additional resources, it is important that employers take steps to assure the health and safety of their workers. A critical step in this goal is to provide a health and safety program which includes routine monitoring of the worksite, whether the worksite be an office building, a factory, or a forest.

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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
Results of Air Sampling for
Carbon Monoxide and Sulfur Dioxide
Thompson Creek Fire
Gallatin National Forest, Montana
HETA 91-312
July 20-22, 1991

worker #	sample time (hours)	CO concentration (ppm)	SO_2 concentration (ppm)
July 20, 1991			
1	10.2	1.3	
2	10.6	3.0	
3	10.6	3.6	0.6
4	10.6	0.0	
5	10.6	0.0	1.0
6	10.2	0.0	
7	10.6	3.0	
8	10.6	0.6	
9	10.6	6.1	
10	10.2	0.0	1.3
11	10.6	0.0	
12	10.6	0.0	
13	10.6	3.0	
14	10.2	3.2	
15	10.2	1.3	
16	11.0	1.2	0.6
17	10.2	2.5	1.3
18	10.2	1.3	0.8
19	10.2	1.3	1.3
20	10.2	0.6	
mean for 7/20/91		1.6	1.0
July 21, 1991			
1	9.1	4.3	
2	9.1	7.1	1.0

Table 1 (cont'd)
Results of Air Sampling for
Carbon Monoxide and Sulfur Dioxide
Thompson Creek Fire
Gallatin National Forest, Montana
HETA 91-312
July 20-22, 1991

worker #	sample time (hours)	CO concentration (ppm)	SO_2 concentration (ppm)
3	10.6	7.3	
4	9.1	5.7	1.4
5	9.1	7.1	1.1
6	9.1	4.3	3.0
7	9.1	7.1	
8	9.1	4.3	
9	10.6	8.7	2.2
10	9.1	4.3	
11	10.6	1.8	
12	9.1	4.3	
13	9.1	17	1.7
14	9.1	7.1	1.4
15	9.1	0.0	
16	9.1	16	
17	9.1	10	1.7
18	9.1	5.7	
19	9.1	5.7	1.4
20	9.1	7.1	1.7
mean for 7/21/91		6.9	1.7
July 22, 1991			
21	8.5/5.0 *	7.6	1.6
22	8.5	7.6	
23	8.5	4.6	
24	8.5/5.0 *	7.6	1.3
25	8.5/5.0 *	4.6	1.3

Table 1 (cont'd)
Results of Air Sampling for
Carbon Monoxide and Sulfur Dioxide
Thompson Creek Fire
Gallatin National Forest, Montana
HETA 91-312
July 20-22, 1991

worker #	sample time (hours)	CO concentration (ppm)	SO_2 concentration (ppm)
26	8.5/5.0 *	7.6	1.3
27	8.5/5.0 *	6.1	1.3
28	8.5	3.8	
29	8.5	7.6	
30	8.5/5.0 *	4.6	1.6
31	8.5	6.1	
32	8.5	3.1	
33	8.5	7.6	
34	8.5	7.6	1.3
35	8.5	3.0	
36	8.5	7.6	
37	8.5	7.6	2.6
38	5.0	**	1.3
39		5.3	
40		7.6	
mean for 7/22/91		6.2	1.5
Evaluation Criteria			
NIOSH REL		35.0	2.0
OSHA PEL		35.0	2.0
ACGIH CURRENT TLV		50.0	2.0
ACGIH PROPOSED TLV		25.0	N/A

* CO diffusion tube worn for 8.5 hours, SO_2 tube worn for 5.0 hours.
** dosimeter lost

Table 2
Results from Air Sampling for
Respirable Particulate Matter (RPM) and Silica
Thompson Creek Fire
Gallatin National Forest, Montana
HETA 91-312
July 20-22, 1991

Worker #	Sample volume (liters)	RPM mg/m^3	quartz mg/m^3	cristobolite mg/m^3
July 20, 1991				
area +	780	.10	ND	ND
11	1140	.05	ND	ND
12	1140	.04	tr	ND
13	*	*		
14	1090	.25	tr	ND
15	*	*		
16	*	*		
17	*	*		
18	1080	.50		
19	970	.19		
20	*	*		
July 21, 1991				
2	1260	4.30	.35	tr
7	1260	.29		
8	1260	.52	ND	ND
11	1290	.38		
12	1290	.21		
13	1260	.56	ND	ND
14	1260	.07	tr	ND
15	1260	.48		
17	1260	.48		

Table 2
Results from Air Sampling for
Respirable Particulate Matter (RPM) and Silica
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20	1260	.23		Worker #Sample volume (liters)RPM mg/m^{3}quartz mg/m^{3}cristobolite mg/m^3
July 22, 1991				
21	1,030	.48	ND	ND
22	1,030	.11	ND	ND
23	1,030	.42	.04	ND
24	1,030	.46	ND	ND
25	1,030	.43		
26	1,030	.60		
27	1,030	.43		
28	1,030	.55		
29	1,030	.69	ND	ND
30	1,030	.44	ND	ND
Evaluation Criteria				
NIOSH REL		N/A	0.05	0.05
OSHA PEL		N/A	0.1	0.05
ACGIH TLV		N/A	0.1	0.05

\+ area sample collected at base camp
* sample volume could not be determined, see results section of this report
ND analyte not detected on sample. The limit of detection (LOD) for RPM in a 1000 liter sample is 0.01 mg/m3, and the LOD for quartz and cristobolite is 0.015 mg/m^3. The limit of quantitation (LOQ) for quartz and cristobolite is 0.03 mg/m^3.
tr trace levels detected, between the LOD and LOQ

Appendix I

Using the CFK equation to adjust the OSHA REL for CO

In the NIOSH document: "Criteria for a Recommended Standard...Occupational Exposure to Carbon Monoxide"[5], 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:

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

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[5]:

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-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. 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.[5] 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.[5] 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-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-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.[20] 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).[5] To calculate P_L, the NIOSH investigator used a standard pressure of 585 mm Hg which corresponds to the altitude of 7000 feet.[21]

Appendix I (Cont'd)

Using the CFK equation to adjust the OSHA REL for CO

In discussing altitude, Best & Taylor[22] state that the partial pressure of water remains the same, and is only dependent on body temperature. Thus, 47 mm Hg was subtracted from these values to obtain the P_L.

The partial pressure of oxygen in the capillaries ($P_{C\text{-}02}$) is directly related to the atmospheric pressure. From the above intra-agency memorandum[20], $P_{C\text{-}02}$ can be calculated using the following formula

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

Using the above given values for C, D, V_{CO}, V_b, 0_2Hb, T and M; the calculated values for A, B, and a; and the new values for V_A, D_L, P_L, and $P_{C\text{-}O2}$, the NIOSH investigators calculated the maximum CO exposure concentrations at 7000 feet 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 7000 feet for eight hours, the CFK equation predicts that a 5% COHb level will be reached at a CO exposure concentration of 21 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.