Characterization of Firefighter Exposures During Fire Overhaul

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Previous studies have characterized firefighter exposures during fire suppression. However, minimal information is available regarding firefighter exposures during overhaul, when firefighters look for hidden fire inside attics, ceilings, and walls, often without respiratory protection. A comprehensive air monitoring study was conducted to characterize City of Phoenix firefighter exposures during the overhaul phase of 25 structure fires. Personal samples were collected for aldehydes; benzene; toluene; ethyl benzene; xylene; hydrochloric acid; polynuclear aromatic hydrocarbons (PNA); respirable dust; and hydrogen cyanide (HCN). Gas analyzers were employed to continuously monitor carbon monoxide (CO), HCN, nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Area samples were collected for asbestos, metals (Cd, Cr, Pb), and total dust. During overhaul the following exceeded published ceiling values: acrolein (American Conference of Governmental Industrial Hygienists [ACGIH®] 0.1 ppm) at 1 fire; CO (National Institute for Occupational Safety and Health [NIOSH] 200 ppm) at 5 fires; formaldehyde (NIOSH 0.1 ppm) at 22 fires; and glutaraldehyde (ACGIH 0.05 ppm) at 5 fires. In addition, the following exceeded published short-term exposure limit values: benzene (NIOSH 1 ppm) at two fires, NO_2 (NIOSH 1 ppm) at two fires, and SO_2 (ACGIH 5 ppm) at five fires. On an additive effects basis, PNA concentrations exceeded the NIOSH recommended exposure limits (0.1 mg/M^3) for coal tar pitch volatiles at two fires. Maximum concentrations of other sampled substances were below their respective permissible exposure limits. Initial 10-min average CO concentrations did not predict concentrations of other products of combustion. The results indicate that firefighters should use respiratory protection during overhaul. In addition, these findings suggest that CO should not be used as an indicator gas for other contaminants found in this atmosphere.

Keywords: characterization of hazards during fire overhaul, fire overhaul, fire overhaul contaminants, recommended respiratory protection

A number of studies have identified toxic chemicals in fire smoke,[1–3] but there are few that classify the fire overhaul environment.[4] Fire overhaul is the firefighting stage in which fire suppression is complete and firefighters are searching the structure for hidden fire or hot embers, which may be found above ceilings, in between walls, or in other obscure areas. The overhaul phase of a fire lasts an average of 30 min.[5] It is during this phase of a fire, when there is little or no smoke in the environment, that a firefighter is most likely to remove his or her respirator facepiece and work in this environment without respiratory protection.[6]

Removal of respiratory protection during fire overhaul could expose firefighters to a variety of toxic gases. A typical structure fire may involve destruction of plastics, foams, fabrics, carpets, asbestos-containing materials, and wood products. Gases, vapors, and airborne particulates are liberated when these materials are compromised by fire, and may remain in the overhaul environment for extended periods of time. In addition, organic vapors as well as halogenated compounds may use airborne respirable size particulates as a vehicle for entry into the firefighters' lungs. The purpose of this study was to characterize exposures that firefighters may encounter during the overhaul phase of fire incidents.

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METHODS

Twelve firefighters with hazardous materials experience were trained on the sampling strategy, set-up, and pre- and postcalibration of all sampling equipment. Training was conducted over several days and included several hours of hands-on experience with the sampling equipment, followed by a competency test to allow an opportunity for these individuals to demonstrate their knowledge as well as expose any areas that needed additional attention. These 12 individuals worked rotating 12-hour shifts and were assigned to a single fire station. For this study these firefighters will be referred to as industrial hygiene assistants. Additional firefighters, identified as participating firefighters, wore the sampling media during fire overhaul.

The participating firefighters were positioned at a single fire station, and all sampling equipment was staged on a hazardous materials (HM) response truck. The study team was dispatched to all working structural fires within a reasonable logistical area, requiring two additional fire engines and one ladder as a back-up team to relieve the first firefighting team if necessary. The participating firefighters did not directly perform overhaul activities, but instead shadowed working firefighters or positioned themselves in rooms with active overhaul activities. This configuration allowed monitoring of four firefighters at each fire incident without compromising the integrity of firefighting operations already in place. In addition, this method allowed for the personnel and monitoring equipment to be delivered to a fire scene in a simple, efficient manner.

The sampling strategy involved the collection of both personal and area samples. Personal sampling trains consisted of three personal sampling pumps and one 4-gas meter (Metrosonics, West Henrietta, N.Y.) for each of the four individuals monitored. The sampling pumps were held in a custom-made sleeve that fit over the air tank of the firefighter's self-contained breathing apparatus (SCBA) unit. The configuration of the sampling train included one pump dedicated to the collection of respirable dust, one pump dedicated to the collection of polynuclear aromatic hydrocarbons (PNAs), and one pump equipped with a low-flow adapter with adjustable flow rates for aldehydes and BTEX (benzene, toluene, ethyl benzene, and xylene), and a t-adapter to a hydrochloric acid sampling tube.

The area sampling train consisted of two area sampling pumps for the area of origin and another area adjacent to the fire origin where overhaul activities occurred within the structure. The configuration of the area sampling train included one pump dedicated to the collection of airborne asbestos fibers and the other pump dedicated to the collection of total dust and metals (Cd, Cr, Pb). A t-adapter was used to connect the different types of media utilized for the collection of total dust and airborne metals samples. Preweighed 5.0 μm polyvinyl chloride and 0.8 μm mixed cellulose ester filters were used to collect total dust and metal samples, respectively. Flow rates were set for total dust near 4.0 L/min and ranged between 1.0 and 2.0 L/min for the metals samples.

To ensure the validity and integrity of sample collection for this study, the industrial hygiene assistants were directed to calibrate all of the pumps daily and record the results. The industrial hygiene assistants were provided with a reference document regarding their responsibilities and target flow rates for collection of each sample on the sampling train. The four gas meters were calibrated weekly.

Prior to arrival at a scene, sampling media were preloaded. At the scene, firefighters removed filter plugs, broke sampling tubes, and the industrial hygiene assistant initiated sampling. Set-up time averaged 7 min. After collection, all sample media were placed in their respective prelabeled bags and stored in a refrigerator located on the HM truck. Other documentation requirements of the industrial hygiene assistant included a record of unusual events, a schematic diagram indicating area of fire origin and other area, the location of stationary ventilation fans, and a brief description of the fire and the stage of the fire at the time of their arrival.

During the study, it was noted that the hydrogen cyanide (HCN) direct-read instruments were reporting HCN concentrations at least 10 times higher than anticipated based on information from previous studies.[4, 7,8] To resolve the apparent disparity, a sorbent tube was added to at least one of the personal sampling trains to sample for HCN utilizing NIOSH Method 6010.[9] This change in the sampling train occurred prior to Fire 11 and continued through the remainder of the study.

A minimum sampling time of 20 min was required to accommodate the various limits of detection for the analytical methods. All samples were submitted to an American Industrial Hygiene Association-accredited laboratory for analysis. Table I provides a description of the analytical methods and limits of detection for each analyte.[9–12]

In addition to evaluating average concentrations for the four gas readings per fire incident, these data also were evaluated based on the first 10 min of data logging (the first 10 min began 4 min after the data logger was turned on to allow for firefighter travel time to get into the structure from the set-up point). The purpose of this additional data evaluation was to test the data for correlations to see if the direct read instrumentation could predict concentrations of other contaminants in the fire overhaul environment.

A logistic regression (SPSS version 7.5) was performed to test the hypothesis that CO was an indicator or a predictor of other contaminants present in the overhaul environment. Specifically, initial 10 min average concentrations of CO, SO_2, and NO_2 were compared with averages over the entire overhaul period for acetaldehyde, benzene, formaldehyde, and hydrochloric acid.

RESULTS

Twenty-six fires were evaluated from June 13–September 25, 1998. However, all results from 1 fire were eliminated because there were essentially no overhaul activities at this fire scene, leaving 25 fires for complete analysis. Monitoring activities occurred at 14 houses, 6 apartments, and 5 commercial buildings. Not all analytes were collected at all fires due to equipment and sampling difficulties. Sampling results are provided in Tables III–VI.

During overhaul, the following analytes exceeded published ceiling values: acrolein (American Conference of Governmental Industrial Hygienists [ACGIH®] 0.1 ppm) at 1 fire; CO (National Institute for Occupational Safety and Health [NIOSH] 200 ppm) at 5 fires; formaldehyde (NIOSH 0.1 ppm) at 22 fires; and glutaraldehyde (ACGIH 0.05 ppm) at 5 fires. In addition, the following analytes exceeded published short-term exposure limit (STEL) values: benzene (NIOSH 1 ppm) at two fires; NO_2 (NIOSH 1 ppm) at two fires; and SO_2 (ACGIH 5 ppm) at five fires. Table II summarizes published exposure standards and guidelines used for the interpretation of firefighter exposure data. The following analytes were not measured in concentrations above the limit of detection (LOD): ethyl benzene, toluene, and xylene. A limited number of PNA samples resulted in concentrations above the LODs. Laboratory analysis of the PNA samples identified 17 separate chemicals (Table V). Reviewing the data on a chemical-by-chemical basis revealed low concentrations of PNAs. However, reviewing the data on an additive effects basis revealed concentrations that exceeded the NIOSH recommended exposure

TABLE I. Analytical Limits of Detection

Analyte	NIOSH Method	Analytical Detection Limit	Sample Media[B]	Flow Rate	Calculated Sensitivity per Sample[A]
Area Samples					
Asbestos	7400	7 fibers/field	0.8 μm, 25 mm MCE filter	11 L/min	0.03 f/cc
Cadmium (Cd)	7300	0.005 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.000125 mg/M³
Chromium (Cr)	7300	0.05 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.00125 mg/M³
Lead (Pb)	7300	0.025 μg	0.8 μm, 37 mm MCE filter	2.0 L/min	0.00625 mg/M³
Total dust	0500	0.05 mg	5 μm, 37 mm PVC filter	4.0 L/min	0.00625 mg/M³
Personal Samples					
Acetaldehyde	2532	2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.2 mg/M³
Acrolein	2532	0.4 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.04 mg/M³
Benzaldehyde	2532	2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.2 mg/M³
Benzene	1501	2 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	0.5 mg/M³
Ethyl benzene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³
Formaldehyde	2532	0.4 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.04 mg/M³
Glutaraldehyde	2532	0.2 μg	DNPH tube (SKC 226-118)	0.5 L/min	0.02 mg/M³
Hydrochloric acid	7903	2 μg/tube	ORBO 53 tube	0.5 L/min	0.2 mg/M³
Hydrogen cyanide	6010	2 μg/tube	soda lime tube (SKC 226-28)	0.18 L/min	1 mg/M³
PNAs	5515	2 μg/tube	PTFE filter/ ORBO 43 tube	2.0 L/min	0.05 mg/M³
Respirable dust	0600	0.05 mg	preweighed PVC filter	1.8 L/min	3.0 mg/M³
Toluene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³
Xylene	1501	20 μg/tube	small charcoal tube (SKC 226-01)	0.2 L/min	5.0 mg/M³

[A]Based on a 20-min sample.
[B]SKC West, Fullerton, Calif.

limit (REL; 0.1 mg/M³) for coal tar pitch volatiles at two fires and exceeded the OSHA permissible exposure limit (PEL) and ACGIH threshold limit value (TLV®; 0.2 mg/M³) at one fire.

Of the 16 fires in which NIOSH method 6010 was used to sample HCN, only 4 samples resulted in concentrations above the LOD. None of these four samples had concentrations of HCN above 10 μg, hence, the concentrations could not be quantified, but were all well below 1 mg/M³.

Initial 10-min average CO and NO_2 concentrations did not correlate by logistic regression with other products of combustion (POCs). However, by regression analysis 54.9% of the acetaldehyde variation and 48.4% of the formaldehyde variation was explained ($p = 0.000$) by initial SO_2 average concentration readings obtained within the first 10 min of fire overhaul activities. Evaluation of the data on a fire-by-fire basis revealed that even low concentrations of CO (4–5 ppm) did not predict ($p>0.05$) the presence of other contaminants, as concentrations of formaldehyde that exceeded the NIOSH ceiling of 0.1 ppm were determined at the same scene. Further, this analysis revealed that as the formaldehyde concentration approached 1.0 ppm, glutaraldehyde was present in concentrations above the ACGIH ceiling value of 0.05 ppm.

DISCUSSION

This study demonstrated that maximum concentrations of selected contaminants in the overhaul atmosphere exceeded occupational exposure limits and could therefore result in adverse health effects in firefighters without respiratory protection. In a variable number of fires, concentrations of acrolein, CO, formaldehyde, and glutaraldehyde exceeded their respective ceiling values; concentrations of sulfur dioxide exceeded the STEL value; and concentrations of coal tar pitch volatiles (PNAs) exceeded the OSHA PEL, ACGIH TLV, and NIOSH REL. The other POCs sampled occurred at concentrations below published occupational exposure limits. Among fires there was tremendous variation in concentrations of the sampled contaminants. This variation may be explained by the diverse nature of each fire, including contents, number of rooms, commercial building versus residential, etc. However, certain contaminants, such as formaldehyde, were found at elevated concentrations at a majority of fires.

PNAs consist of POCs that are present in smoke. Most of the 17 identified and quantifiable compounds within the PNA family

TABLE II. Exposure Standards and Guidelines for the Interpretation of Firefighter Exposure Data

Chemical	OSHA PEL	ACGIH TLV	NIOSH REL	STEL[A]	IDLH[A]
Acetaldehyde	200 ppm	—	LF[A]	25 ppm (C)[B]	2000 ppm
Acrolein	0.1 ppm	—	0.1 ppm	0.1 ppm (C)[B] 0.3 ppm[C]	2 ppm
Asbestos	0.1 f/cc	0.1 f/cc	LF	—	—
Benzene	1 ppm	0.5 ppm	0.1 ppm	2.5 ppm[B] 1 ppm[C]	3000 ppm
Benzaldehyde	—	—	—	—	—
Carbon monoxide	50 ppm	25 ppm	35 ppm	200 ppm (C)[C]	1200 ppm
Formaldehyde	0.75 ppm	—	0.016 ppm	2 ppm[D] 0.3 ppm (C)[B] 0.1 ppm (C)[C]	20 ppm
Glutaraldehyde	—	—	—	0.05 ppm (C)[B] 0.2 ppm (C)[C]	—
Hydrogen chloride	—	—	—	5 ppm (C)[B–D]	50 ppm
Hydrogen cyanide	10 ppm	—	—	4.7 ppm[C] 4.7 ppm (C)[B]	50 ppm
Isovaleraldehyde	—	—	—	—	—
Nitrogen dioxide	—	3 ppm	—	5 ppm (C)[B,D] 1 ppm[C]	20 ppm
Particulates, respirable	5 mg/M^3	3 mg/M^3	—	—	—
Particulates, total	15 mg/M^3	10 mg/M^3	—	—	—
Sulfur dioxide	5 ppm	2 ppm	2 ppm	5 ppm[B,C]	100 ppm

[A]IDLH = immediately dangerous to life or health; LF = lowest feasible concentration; C = ceiling (not to be exceeded).
[B]American Conference of Governmental Industrial Hygienists (ACGIH).
[C]National Institute for Occupational Safety and Health (NIOSH).
[D]Occupational Safety and Health Administration.

are considered to be carcinogens. Because during overhaul activities there is little or no smoke, the presence of PNAs was not expected. Although the OSHA PEL (0.2 mg/M^3) was exceeded for coal tar pitch volatiles at one fire, this may be the result of fire suppression activities that were continuing on the roof when the monitoring commenced inside the structure.

Due to suspected interference from extreme temperature and humid environments, invalid results were experienced on the direct-read instrument for HCN. Samples collected using NIOSH Method 6010 were either below the LOD or too low to quantify. As a result of these findings and in consideration of other published studies[4,7,8] that have quantified HCN at extremely low concentrations, the readings obtained from the four-gas meters were eliminated from further analysis.

The chemicals found to exceed occupational exposure limits in this study have the potential to cause adverse health effects in firefighters. Acrolein produces intense irritation to the eye and mucous membranes of the respiratory tract. Acute exposures may result in bronchial inflammation, resulting in bronchitis or pulmonary edema. Carbon monoxide is present in all fire environments as a product of incomplete combustion and decreases the oxygen transport of the blood, which results in an inadequate supply of oxygen to the tissues. Adverse health effects due to formaldehyde may occur after exposure by inhalation, ingestion, or skin contact. Eye irritation can occur at concentrations of 0.01–2.0 ppm, irritation of the nose and throat at 1.0–3.0 ppm, and severe respiratory symptoms at 10–20 ppm.[13] Formaldehyde is classified as a probable carcinogen.[10,12,14] Glutaraldehyde is a potent sensory irritant with the capability to cross-link, or fix proteins. SO_2 is irritating to mucous membranes of the upper respiratory tract. Chronic exposures may result in fatigue, altered sense of smell, and symptoms

TABLE III. Summary of Data on CO, NO_2, and SO_2 Obtained from Direct-Read Four-Gas Meter

Gas	Number of Samples	Average Sample Time (min)	Average Sample Conc.	STD DEV	MAX	Average Calculated 8-hour TWA[A]	MAX TWA
CO	65	42.2	52.6 ppm	66	260[B] ppm	3.95 ppm	26.9 ppm
CO[C]	65	10	89.5 ppm	134	671[B] ppm	—	—
NO_2	65	42.2	0.24 ppm	0.64	3.6 ppm	0.017 ppm	0.31 ppm
NO_2[C]	65	10	0.13 ppm	0.21	0.89 ppm	—	—
SO_2	65	42.2	1.60 ppm	2.06	8.69[D] ppm	0.114 ppm	0.71 ppm
SO_2[C]	65	10	2.95 ppm	4.91	21.7[D] ppm	—	—

[A]TWA = time-weighted average.
[B]Exceeded NIOSH ceiling—200 ppm.
[C]Average of first 10 min of readings.
[D]Exceeded ACGIH/NIOSH STEL—5 ppm.

TABLE IV. Summary Data for Nonparticulate Samples

Analyte	Number of Samples Collected	Number of Samples Above LOD	Average Sample Conc.	STD DEV	MIN	MAX
Acetaldehyde	96	71	0.34[A] ppm	0.41	0.041 ppm	1.75[A] ppm
Acrolein	96	7	0.123[B] ppm	0.133	0.013 ppm	0.3[B] ppm
Benzaldehyde	96	18	0.057 ppm	0.031	0.016 ppm	0.13 ppm
Formaldehyde	96	86	0.25[C] ppm	0.252	0.016 ppm	1.18[C] ppm
Glutaraldehyde	96	24	0.046 ppm	0.04	0.005 ppm	0.15[D] ppm
Isovaleraldehyde	96	18	0.07 ppm	0.038	0.02 ppm	0.16 ppm
Benzene	95	53	0.383 ppm	0.425	0.07 ppm	1.99[E] ppm
Hydrochloric acid	95	34	0.99 mg/M^3	1.10	0.1 mg/M^3	3.96 mg/M^3
Hydrogen cyanide	25	4[F]	—	—	—	—

[A]Exceeded NIOSH lowest feasible concentration.
[B]Exceeded ACGIH ceiling 0.1 ppm.
[C]Exceeded NIOSH ceiling 0.1 ppm; exceeded ACGIH ceiling 0.3 ppm.
[D]Exceeded ACGIH ceiling 0.05 ppm.
[E]Exceeded NIOSH STEL 1 ppm.
[F]Above analytical limit of detection but below quantification limit all samples were less than 1.0 mg/M^3.

representing chronic bronchitis (i.e., dyspnea on exertion and cough).

In addition to the contaminants evaluated in this study, fire scenes include a diverse mix of chemicals that are not easily characterized. Published health effects often are not available for many of these chemical contaminants, and in addition there are inadequate health effects data available on the combined effects of multiple low-level exposures. Adverse health effects may occur from exposure to a mixture of products of combustion, even if individual components do not exceed occupational exposure limits.

One of the challenges of this study involved getting to the fire scene in time to conduct environmental air monitoring during overhaul activities. Training the hazardous materials firefighters to function as industrial hygiene assistants played a key role in meeting this challenge. In addition, the ability to station all supplies, equipment, and personnel at one fire station minimized response time to a particular incident. Finally, the ability to simplify a complicated sampling train through color coding all of the instruments and sample media collection bags minimized human errors.

TABLE V. Summary Data for PNA Samples*

Analyte	Number Samples Above LOD	Avg. Sample Conc. (μg/M^3)	STD DEV	MIN (μg/M^3)	MAX (μg/M^3)
Acenaphthene	2	77.7	15.8	66.5	88.8
Acenaphthylene	34	415.0	536	88	2,440
Anthracene	1	22.2	—	—	—
Benz(a) anthracene	3	24.9	4.90	19.3	27.9
Benzo(a)pyrene	5	33.2	13.6	18.7	50
Benzo(b)fluoranthene	4	22.3	10.6	9.5	34
Benzo(ghi)perylene	2	29.0	23.3	12.5	45.4
Benzo(k)fluoranthene	2	23.8	1.67	22.6	25
Chrysene	1	12.9	—	—	—
Dibenz(a,h)anthracene	2	45.5	31.6	23.2	67.9
Fluoranthene	4	120	39.9	79.1	169
Fluorene	0	—	—	—	—
Indeno(1,2,3-cd)pyrene	3	19.5	8.35	14.3	29.1
Naphthalene	28	223.0	101	73	540
Phenanthrene	13	24.3	9.19	10.8	40.5
Pyrene	4	93.1	83.8	13.8	211

*Total = 88 PNA samples collected.

Limitations of this study included inconsistencies in recording observational information regarding details of the fire scene and definitions of when overhaul phase begins and fire suppression ends. Due to logistical challenges, it was not possible to begin monitoring within a uniform number of minutes after fire suppression at each incident. Finally, it was discovered late in the study that the gas-powered ventilation fans may have confounded the CO readings obtained during overhaul monitoring. During the study, firefighters discovered that the ventilation fans used to purge the environment of smoke generate CO in concentrations up to 39 ppm.

Although many studies have discussed the protective value of SCBA during fire suppression activities, few suggest the need for respiratory protection during fire overhaul activities.[4] Based on the findings of this study, it is apparent that firefighters should use respiratory protection during fire overhaul. SCBA units provide optimum respiratory protection with a given protection factor of approximately 10,000, but they are heavy, and for this reason may not be used by firefighters during fire overhaul. Full-face air purifying respirators (APRs) equipped with appropriate cartridges would provide a protection factor of approximately 50, and their use during fire overhaul would reduce the physical burden of carrying the extra weight associated with the SCBA unit. Overhaul activities could therefore occur more quickly and more efficiently. Currently, the City of Phoenix is utilizing Scott Air Products. Scott Air has a t-bar assembly that can be easily interchanged with the regulator of the Scott SCBA unit. Replacement of the regulator with a t-bar assembly modifies the respirator from a full-face, pressure demand SCBA to a negative pressure, full-face APR in seconds.

Currently, NIOSH approved cartridges for APRs do not provide protection for CO. In consideration of the NIOSH ceiling value for CO as well as OSHA PEL (50 ppm), NIOSH REL (35 ppm), and ACGIH TLV (25 ppm), the study findings support the use of SCBA during overhaul activities for CO concentrations in excess of 150 ppm, and the use of APRs equipped with combination cartridges appropriate for particulates, aldehydes, acid gases, and organic vapors for CO concentrations less than 150 ppm. The 150 ppm concentration is based on a 60-min exposure during 8 working hours, which results in an average

TABLE VI. Summary Data for Particulate and Metals (Cd, Cr, Pb) Samples

Analyte	Number of Samples	Number of Samples above LOD	Ave. Sample Conc.	STD DEV	MIN	MAX
Personal Samples						
Respirable dust	93	29	8.01 mg/M³	8.02	0.71 mg/M³	25.7 mg/M³
Total chlorides	93	16	0.232 mg/M³	0.18	0.038 mg/M³	0.68 mg/M³
Total sulfates	93	8	0.232 mg/M³	0.20	0.062 mg/M³	0.53 mg/M³
Area Samples						
Asbestos	46	15	0.073 f/cc	0.063	0	0.2 f/cc
Total dust	46	22	1.82 mg/M³	8.73	0.364 mg/M³	30.79 mg/M³
Cadmium	46	0	—	—		
Chromium	46	0	—	—		
Lead	46	2	0.03 mg/M³	—	0.03 mg/M³	0.033 mg/M³

CO exposure of 18.75 ppm (150 ppm × 60 min/480 min), which is 25% below the most stringent published concentration (ACGIH TLV 25 ppm). However, additional health-based studies on the use of APRs during overhaul should be used to confirm their effectiveness.

CONCLUSION

Concentrations of air contaminants during fire overhaul exceed occupational exposure limits. Without the use of respiratory protection, firefighters are overexposed to irritants, chemical asphyxiants and carcinogens. Therefore, respiratory protection is recommended during fire overhaul. SCBA should be used in atmospheres with CO concentrations above 150 ppm, and APRs may be used when CO concentrations are below 150 ppm. Finally, CO concentrations should not be used to predict the presence of other contaminants found in the overhaul environment.

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