Evaluation of Chemical Exposures during Fire Fighter Training Exercises Involving Smoke Simulant

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CDC Workplace Safety and Health

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a fire department in Texas. The employer was concerned about respiratory health effects from exposures to smoke simulants used during training exercises.

What We Did

- We sampled the air for components of two types of smoke simulant during training exercises in January 2012 and July 2012.

- We observed training exercises and interviewed five trainers to obtain an understanding of their work practices and work-related safety and health concerns.

- We reviewed the fire department's fire fighter training logs of work-related injuries and illnesses for the years 2005–2012.

- We reviewed medical records concerning a trainer's exposure to an oil-based smoke simulant resulting in acute respiratory injury and hospitalization.

What We Found

- Levels of mineral oil mist in air were above exposure limits. These measurements were taken during training exercises involving only oil-based smoke simulant.

> We evaluated fire fighter trainers' chemical exposures and health effects during training exercises involving smoke simulant. Trainers could be overexposed to mineral oil mist, diethylene glycol, and thermal decomposition products. Wearing appropriate and fit-tested respiratory protection during training exercises should prevent eye and respiratory irritation and more serious acute respiratory effects.

- Levels of diethylene glycol in air were above the exposure limit. Levels of formaldehyde in air were about half the exposure limit. These measurements were taken during a training exercise that involved only glycol-based smoke simulant.

- Levels of mineral oil mist, diethylene glycol, formaldehyde, and acrolein in air were above exposure limits. These measurements were made during training exercises that involved smoke simulants, heat, and fire.

- Levels of these compounds in air could exceed exposure limits outside the training room when a trainer opens the door to look inside.

- The mineral oil mist and diethylene glycol aerosols were small enough to penetrate deeply into the lungs.

- Brief exposures to the compounds we measured could irritate the eyes and lungs or cause more serious lung damage.

- Levels of mineral oil on trainers' turnout gear and surfaces in the training room after training exercises were mostly non-detectable.

What We Found (continued)

- From our interviews, the most commonly reported symptom was cough.

- Our medical record review confirmed a respiratory illness due to prolonged exposure to mineral oil mist.

What the Employer Can Do

- Rotate training officer duties throughout a full day of training exercises.

- Ensure that trainers do not re-enter the training tower without wearing appropriate respirators until the tower is visibly clear of smoke simulant.

- Require trainers to wear self-contained breathing apparatus inside the training tower even if they are outside the training room during training exercises that involve heat or fire.

- Require trainers to wear self-contained breathing apparatus or full-facepiece air purifying respirators with cartridges or canisters that are effective against oil-based aerosol and formaldehyde during training exercises that involve only smoke simulants. Trainers should wear these respirators inside the training tower even if they are outside the training room. Respirators should also be worn during maintenance and adjustment activities if smoke simulant release is expected.

- Maintain all respirators and make sure they fit and function properly.

- Create a schedule for changing out respirator cartridges and canisters.

- Fit test the trainers for each of the respirators that they are to wear.

- Encourage trainers to report any health concerns or symptoms associated with work tasks to a supervisor.

What Employees Can Do

- Report health concerns or symptoms that could be work-related to a supervisor.

- Follow all procedures including work rotations, personal protective clothing, and respirator use.

- Make sure you are fit-tested for each respirator you wear.

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Abbreviations

°F	Degrees Fahrenheit
μm	Micrometer
ACGIH®	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
CFR	Code of Federal Regulations
DNPH	2,4-Dinitrophenylhydrazine
EPA	Environmental Protection Agency
GC/MS	Gas chromatography/mass spectrometry
Lpm	Liters per minute
mL	Milliliter
mm	Millimeter
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic aromatic hydrocarbon
PTFE	Polytetrafluoroethylene
SCBA	Self-contained breathing apparatus
STEL	Short-term exposure limit
TLV®	Threshold limit value
VOC	Volatile organic compounds

Introduction

The Health Hazard Evaluation Program received a request from fire department managers. The request concerned exposures and potential health effects to fire fighter trainers from a mineral oil-based smoke simulant used during training exercises.

The fire department consisted of approximately 255 full-time fire fighters and 5 full-time fire fighter trainers. The number of fire fighter trainers on-site varied from two to five a day. Fire fighters at this fire department worked 24 hours on and 48 hours off. The fire fighter trainers worked about 40 hours a week and conducted almost 100 training exercises every year in a cinder-block three-story training tower built in 2007.

In October 2011, three fire fighter trainers reported respiratory symptoms after being exposed to a dense cloud of oil-based smoke simulant for at least 30 minutes during preparations for a training exercise. None of the trainers involved were wearing respiratory protection. Symptoms subsided for two of the trainers, but symptoms persisted and worsened for the other trainer. The medical records for this trainer indicated that symptoms started after exposure to the oil-based smoke simulant. His condition was severe enough to warrant a weeklong hospital admission. He was diagnosed and treated for work-related pneumonitis/lipoid pneumonia; his symptoms improved over the next few months.

Figure 1. Cinder-block tower during a training exercise.

Exercises involving smoke simulant are conducted to train fire fighters on proper fire-attack and victim-rescue techniques in low visibility conditions inside the training tower (Figure 1). Figure 2 provides a schematic of the first floor of the training tower. The other two floors were similar to this floor. The training rooms on each floor had different obstacles, all made of steel. The first floor training room had a stove, the second floor training room had a bed, and the third floor training room had a desk.

A built-in MDG Fog Generator System generated the oil-based smoke simulant. This system was controlled remotely from a nearby classroom. MDG Neutral Fluid was heated (maximum of 140 degrees fahrenheit [°F]) in an external reservoir and pressurized (50 pounds per square inch). It was then transported along with pressurized nitrogen sheath
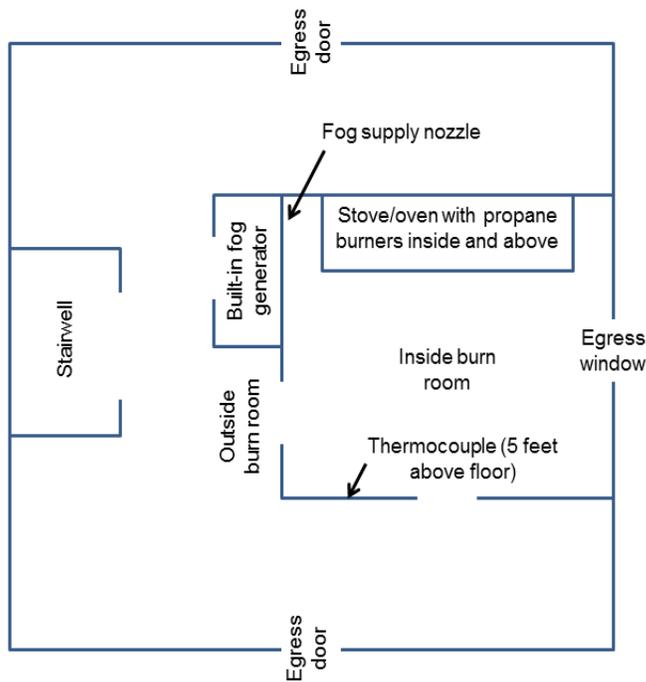
Figure 2. Overhead schematic of the first floor of the training tower.

Figure 3. Mineral oil-based smoke simulant exiting the supply nozzle in the corner of the first floor training room.

gas (50 pounds per square inch) to the training rooms on each floor. The gas and fluid terminated at the nozzle in each room to produce airborne oil-based aerosol with a reported particle size of 0.5 to 0.7 micrometers (μm) (Figure 3) [MDG 2003].

In addition to the oil-based smoke simulant, the fire department occasionally used a glycol-based smoke simulant. Portable fog machines (High End FQ-100) generated the glycol-based smoke simulant. Glycol-based fluid was poured into the machine, heated, and aerosolized into the training room. The portable fog machines are less expensive to operate than the built-in oil-based fogging system; however, the portable units require longer periods to reach a smoke saturation point necessary for training exercises.

After generating oil-based smoke simulant, glycol-based smoke simulant, or both, the fire department also occasionally (35%–40% of the time) used propane burners and heaters to generate rollover fire conditions inside the training room (Figure 4). This process was controlled remotely from the nearby classroom. Exercises involving heat and fire were intended to mimic conditions that a fire fighter may encounter in the field, including temperatures above 400°F.

Figure 4. Training exercise containing oil-based smoke simulant and propane-generated heat and fire.

The trainers' activities before initiating smoke simulant or propane-generated heat and fire included refilling the fog machine reservoirs (usually without wearing gloves), orienting the crew, assigning a trainer to the control room, inspecting the building, checking hose lines, opening valves, checking oil and glycol fluid levels, and turning on the built-in fogging system and/or portable fog machines. For the exercises involving propane-generated heat and fire, the trainers also preheated the building to 400ºF–425ºF. The oil-based smoke simulant and propane burners and heaters operated for 10 minutes (timer-controlled). After the exercises, the trainers inside the tower opened doors, windows, and turned off equipment while an exhaust system in the tower was activated remotely to clear the building of smoke simulant and heat.

National Fire Protection Association-compliant structural fire-fighting ensembles, including self-contained breathing apparatus (SCBA), were mandatory for the training exercises involving propane-generated heat and fire. At the time of our visit, the trainers were also required to wear structural fire-fighting ensembles during the exercises involving only smoke simulant. Prior to the incident in October 2011, it was not uncommon for trainers to wear station uniforms and National Institute for Occupational Safety and Health (NIOSH)-approved N95 respirators during these exercises. We were informed that trainers would also occasionally open training rooms without wearing SCBA or other appropriate respiratory protection to check progress during exercises involving heat and fire. It was less common for the trainers not to wear respirators (as was the case during the October 2011 incident) when they were checking the generation of the oil-based smoke simulant. All the trainers received a medical clearance examination every 3 years and a respirator fit test for SCBA every year.

Methods

Prior to our initial visit, we held telephone conferences with the fire department's battalionchief and a trainer. We requested a roster of the current trainers and copies of the fire department's fire fighter training logs of work-related injuries and illnesses. The fire department provided statements from the trainers involved in the October 2011 incident and

an MDG Neutral Fluid sample analysis report, which showed that this fluid was composed of > 98% petroleum-based mineral oil (i.e., highly refined mineral oil).

We first visited the facility in January 2012. During this visit, we held confidential, voluntary medical interviews with four trainers on-site and one former trainer via telephone. All trainers were asked about their work responsibilities; work practices before, during, and after a training exercise; use of personal protective equipment; and work-related health concerns. There were no selection criteria as all trainers were interviewed. We also discussed the October 2011 incident. In addition, we assessed exposure during two exercises involving only oil-based smoke simulant (Exercises 1A and 1B). One trainer was assigned to a room on each of the three floors during these exercises. Each exercise lasted approximately 15 minutes and included 10 minutes of smoke simulant generation.

We visited the facility again in July 2012, to further assess exposure during training exercises. Only the first floor training room was used for these exercises. One trainer was assigned to this room for each exercise. Each exercise lasted approximately 15 minutes with 10 minutes of smoke simulant and heat generation (if applicable). Table 1 describes the sampling plans, Table 2 summarizes the air sampling methods, and Table 3 summarizes the surface and bulk sampling methods. Figure 5 shows an example of how we set up the area air samples. We used turnout gear jackets and Nomex® hoods to shield the sampling equipment from the radiant heat load produced by the propane burners.

Table 1. Sampling plans for training exercises

Exercise	Description	Area air sampling		Personal air sampling‡	Other sampling
		Inside room*	Outside room†		
1A and 1B	Oil-based smoke simulant, training rooms on all 3 floors, 1 trainer on each floor	Mineral oil mist§ Size distribution of oil mist aerosol (1st floor only)§	Mineral oil mist	Mineral oil mist	Mineral oil mist deposition on surfaces** and clothing††, bulk sampling of oil fluid (from reservoir), collection of oil condensate (Exercise 1A, 1st floor only)
2	Glycol-based smoke simulant, training room on first floor, 1 trainer	Diethylene glycol Aldehydes PAHs VOCs Size distribution of glycol aerosol	Diethylene glycol	Diethylene glycol	Bulk sampling of glycol fluid (from reservoir)
3	Oil-based smoke simulant, propane-generated heat and fire, training room on first floor, 1 trainer	Mineral oil mist Aldehydes PAHs VOCs	Mineral oil mist Aldehydes PAHs VOCs Carbonaceous particles	Mineral oil mist Aldehydes PAHs	None
4	Glycol-based smoke simulant, propane-generated heat and fire, training room on first floor, 1 trainer	Diethylene glycol Aldehydes PAHs VOCs	Diethylene glycol Aldehydes PAHs VOCs Carbonaceous particles	Diethylene glycol Aldehydes PAHs	None
5	Oil-based and glycol-based smoke simulant, propane-generated heat and fire, training room on first floor, 1 trainer	Mineral oil mist¶ Diethylene glycol¶ Aldehydes¶ PAHs¶ VOCs¶ Carbonaceous particles	Mineral oil mist Diethylene glycol Aldehydes PAHs VOCs Carbonaceous particles	Mineral oil mist Diethylene glycol Aldehydes PAHs	None

PAH = polycyclic aromatic hydrocarbon

VOCs = volatile organic compounds

*Collected 1–3 feet above the floor in the middle of the training room(s) unless otherwise noted.

†Collected 5 feet above the floor just outside one of the doors. We documented whether the doors were opened or closed. All other doors were closed.

‡Collected outside and just below each trainer's SCBA mask.

§Additional sample collected near the supply nozzle to examine spatial variability.

¶Additional sample collected 5 feet above the floor to examine spatial variability.

**Filters to measure deposition of oil mist were placed 3 feet above the floor in the middle of each room.

††Patch samples were placed on the sleeve, front, back, and pant leg of two trainers per exercise.

Table 2. Summary of air sampling methods

Analyte	Sampling media/ equipment	Flow rate (Lpm)	Method	No. of area air samples	No. of personal air samples	No. of background samples
Mineral oil mist	37-mm, 2-µm pore size PTFE filter, open-face cassette	1	NIOSH 5026*	25	9	NA
Size distribution of oil mist aerosol	8-stage high flow cascade impactor with 75-mm PTFE filters‡	100	NIOSH 5026*	4	NA	NA
Diethylene glycol	XAD-7 OSHA versatile sampler	1	NIOSH 5523*	7	3	NA
Size distribution of glycol aerosol	8-stage high flow cascade impactor with 75-mm PTFE filters‡	100	NIOSH 5523*	1	NA	NA
Aldehydes	DNPH-impregnated silica gel tube	1	EPA TO-11A†	7	3	2
PAHs	XAD-7 OSHA versatile sampler	1	NIOSH 5528*	7	3	2
VOCs	1- or 6-liter evacuated canisters	0.07 or 0.4	EPA TO-15†	7	NA	1
Characteristics of carbonaceous particles	37-mm, 0.8-µm pore size polycarbonate filter, open-face cassette	1	Scanning electron microscopy	4	NA	1

DNPH = 2,4-dinitrophenylhydrazine

EPA = Environmental Protection Agency

Lpm = liters per minute

mm = millimeters

NA = not applicable

PTFE = polytetrafluoroethylene

*NIOSH Manual of Analytical Methods [NIOSH 2010].

†EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air [EPA 1999a,b].

‡MSP® Corp. Model 130. The last stage held a 90-mm, 2-µm pore PTFE filter.

Table 3. Summary of surface and bulk sampling methods

Analyte	Sampling media/equipment	Volume collected (mL)	Method	No. of samples
Mineral oil mist deposition	90-mm glass fiber filter patches in paperboard holder with 75-mm opening	NA	NIOSH 5026*	16
	90-mm PTFE filters in petri-dishes placed face-up on surfaces	NA	NIOSH 5026*	6
Purity of mineral oil fluid	20-mL glass vial	5 (from oil reservoir)	GC/MS	1
	20-mL glass vial	Condensate (from supply nozzle)†	GC/MS	1
Glycol identification	20-mL glass vial	5 (from glycol reservoir)	NIOSH 5523*	1

GC/MS = gas chromatography/mass spectrometry

mL = milliliter

*NIOSH Manual of Analytical Methods [NIOSH 2010]

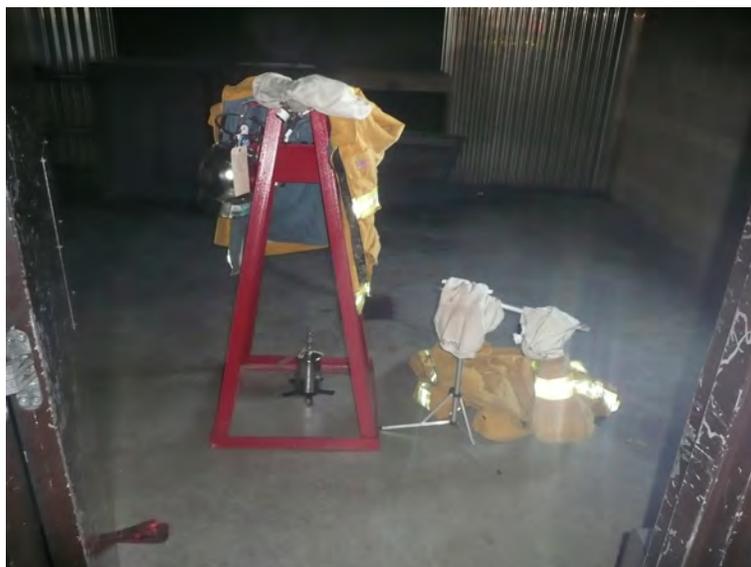†Condensate was collected by opening the vial and placing near the supply nozzle for 1 minute.

Figure 5. Area air sampling set-up for Exercise 5.

For the exercises that involved propane-generated heat and fire, we focused on characterizing possible thermal decomposition products of mineral oil and glycol, such as aldehydes, PAHs, and VOCs [Teschke et al. 2005]. The method we used to analyze for aldehydes on air samples included 10 aldehyde analytes [EPA 1999a]; samples were also analyzed for acrolein. The method we used to analyze for PAHs on air samples included 16 PAH analytes [NIOSH 2010]. The method we used to analyze for VOCs on air samples included 65 VOC analytes [EPA 1999b]; samples were also analyzed for 20 tentatively identified compounds, including acrolein. Air samples were also collected during these exercises for scanning electron microscopy to determine if carbonaceous particles were being produced and, if so, their physical characteristics (i.e., particle size, shape, and agglomeration). We had not considered thermal decomposition products when we assessed exposures during Exercises

1A and 1B, which is why aldehydes, PAHs, and VOCs were not measured. These exercises also did not involve propane-generated heat and fire. Without heat and fire, we expected low concentrations of aldehydes, PAHs, and VOCs. This is why we did not collect personal air samples for aldehydes and PAHs during Exercise 2. Personal air sampling for VOCs could not be done because of the large size of the sampling media.

Area air samples were collected outside the training rooms because we were informed that trainers occasionally opened the doors to look inside the room without wearing respiratory protection. We documented whether these doors were opened or closed during the exercises. Filters were placed on the trainer's turnout gear and face-up inside the training rooms to measure the deposition of oil mist because the fire department expressed concern about surface contamination. A bulk sample of the oil fluid and a sample of the oil condensate (from the supply nozzle during Exercise 1A) were collected to determine the fluid's initial purity and whether its purity changed at the point of aerosol generation. A bulk sample of the glycol fluid was collected to determine the predominant type of glycol composing the fluid.

For most of the analytes, background samples were collected inside and outside the training room in the morning before exercises began. For VOCs one background sample was collected inside the training room and for carbonaceous particles one background sample was collected outside the training room. We were not aware of any outside environmental sources of mineral oil mist or diethylene glycol near the fire department. Therefore, we did not collect background samples for these compounds. Furthermore, we did not sample the air for these compounds unless they were being aerosolized for the training exercises.

In addition to the area air samples collected 1–3 feet above the floor in the middle of the room(s), we collected area air samples 1–3 feet above the floor near the supply nozzles in each room for measuring mineral oil mist and aerosol size distribution (Exercises 1A and 1B). We also collected area air samples 5 feet above the floor in the middle of the room for measuring mineral oil mist, diethylene glycol, aldehydes, PAHs, and VOCs (Exercise 5). These samples were collected to examine spatial variability. More information on the sampling and analytical methods is provided in Appendix A.

Data Analysis

The smoke simulation portion of the training exercises lasted 10 minutes, and the trainers typically remained in the structure for another 5 minutes to open windows and doors and turn off equipment. Therefore, all air concentrations were calculated using 15 minutes of sampling time unless the pumps malfunctioned. Four of the five pumps that malfunctioned ran for 5–9 minutes during the exercises, which we assumed was a sufficient duration to obtain an accurate sample of the air. Therefore, only one air sample was excluded from the results because the sampling pump malfunctioned immediately after the exercise began. Two other air samples were excluded from the results because the tubing between the filter and the pump became disconnected.

The sampling pumps we used have isothermal flow control systems that are supposed to maintain the set flow rate at varying temperatures and pressure with an accuracy of ±5%. The operating temperature range of the sampling pumps is 32°F–113°F. According to the fire department, when propane burners and heaters were used, air temperatures inside the training room were about 400°F at 5-foot height and about 250°F near the floor, and air temperatures outside the training room were about 150°F at 5-foot height. Because the performance of the sampling pumps at these elevated temperatures is unknown (i.e., flow rates could increase, decrease, or stay the same), the air concentrations were not adjusted for the higher temperatures. Air collected by evacuated canisters, on the other hand, occupies less volume as it cools. Therefore, we adjusted the air concentrations measured using an evacuated canister (expressed in mass per volume) according to the ideal gas law by the ratio of the absolute air temperature in the lab during analysis to the absolute air temperature during collection.

The air concentrations we measured are most appropriately compared to short-term occupational exposure limits (OELs). The short-term OELs for the most prevalent compounds in air are provided in Table 4. A short-term exposure limit (STEL) is a 15-minute time-weighted average exposure that should not be exceeded at any time during a workday. A ceiling limit is an exposure that should not be exceeded at any time. Both the American Conference of Governmental Industrial Hygienists (ACGIH®) and the American Industrial Hygiene Association (AIHA) have excursion limits for compounds that do not have STELs or ceiling limits, but otherwise have work-shift (8-hour) time-weighted average OELs. These excursion limits are determined by multiplying the organizations' work-shift time-weighted average OELs by five [AIHA 2011; ACGIH 2013]. These excursion limits are similar to ceiling limits and should not be exceeded at any time. In the absence of instantaneous exposure data, comparing 15-minute time-weighted average air concentrations to ceiling and excursion limits is appropriate.

Table 4 also gives the minimum detectable and quantifiable concentrations for each analyte. These are the lowest concentrations of an analyte that can be detected or quantified in air with the sampling method. The minimum detectable and quantifiable concentrations were calculated by dividing the detection and quantitation limits by the average volume of air sampled for each analyte. Air concentrations below their minimum detectable concentrations were assigned values by dividing the minimum detectable concentration by the square root of two. Total PAHs were calculated by summing the air concentrations of individual PAHs after assigning levels below the minimum detectable concentrations. All minimum detectable concentrations were well below the most protective short-term OELs; therefore, non-detectable air concentrations should be considered well below the applicable short-term OELs.

Table 4. Short-term OELs for the most prevalent compounds measured in air

	Agency/ organization*	Type of short-term OEL	OEL (µg/m³)	Minimum detectable concentration (µg/m³)	Minimum quantifiable concentration (µg/m³)
Aldehydes:					
Crotonaldehyde	ACGIH	Ceiling limit	860	2	160
Formaldehyde	NIOSH	Ceiling limit	120	1	4.6
	ACGIH	STEL	370		
	OSHA	STEL	2,500		
Acrolein	ACGIH	Ceiling limit	230	1†–1.4‡	4.0†–4.8‡
	NIOSH	STEL	800		
Total PAHs	ACGIH	Excursion	1,000§	30¶	NA**
Mineral oil mist	ACGIH	Excursion	25,000††	400	1,300
Diethylene glycol	AIHA	Excursion	50,000	2,000	6,700
VOCs:					
1,3-Butadiene	OSHA	STEL	11,000	1	4.7
	ACGIH	Excursion	22,000		
Benzene	NIOSH	STEL	3,200	2	6.6
	ACGIH	STEL	8,000		
	OSHA	STEL	16,000		

OSHA = Occupational Safety and Health Administration

*ACGIH Threshold Limit Values (TLVs®) [ACGIH 2013], NIOSH recommended exposure limits and OSHA permissible exposure limits [NIOSH 2010], AIHA workplace environmental exposure levels [AIHA 2011]

†For EPA TO-11A method

‡For EPA TO-15 method for air collected at 150°F

§For coal tar pitch volatiles

¶Calculated using the sum of the LODs for all 16 PAH analytes.

**Could not be calculated because the lab was unable to determine using NIOSH criteria the LOQs for benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

††Inhalable particulate matter

Results

Work-Related Injuries and Illnesses

We reviewed the fire department's fire fighter training logs of work-related injuries and illnesses (such as strain/sprain, fracture, wound, exhaustion, respiratory illness, and chest pain) for the years 2005–2012. The fire department appropriately reported the respiratory illness that occurred in the October 2011 incident.

Employee Interviews and Symptoms

The interviewees included four males and one female. Their average age was 43 years (age range: 36–47 years) and their average years working as a trainer was 6 years (range: 1–13 years). Fire fighter trainers worked 40 hours a week (five 8-hour shifts). The trainers were typically stationed at the training tower where they conducted training exercises.

Work-related health symptoms reported by trainers are listed in Figure 6. The most commonly reported symptom was cough. Chest pain and dry, itching, or tearing eyes were each reported by one trainer. Some trainers reported that they experienced similar symptoms when hauling hay in a dusty environment. We asked trainers about a wide variety of respiratory conditions. The most commonly reported health problem was pneumonia; the presence of asthma in one of these individuals may have been a predisposing factor. Two trainers reported having a history of physician-diagnosed asthma. Regarding other physician-diagnosed medical conditions, three trainers reported hay fever and one trainer reported chronic bronchitis.
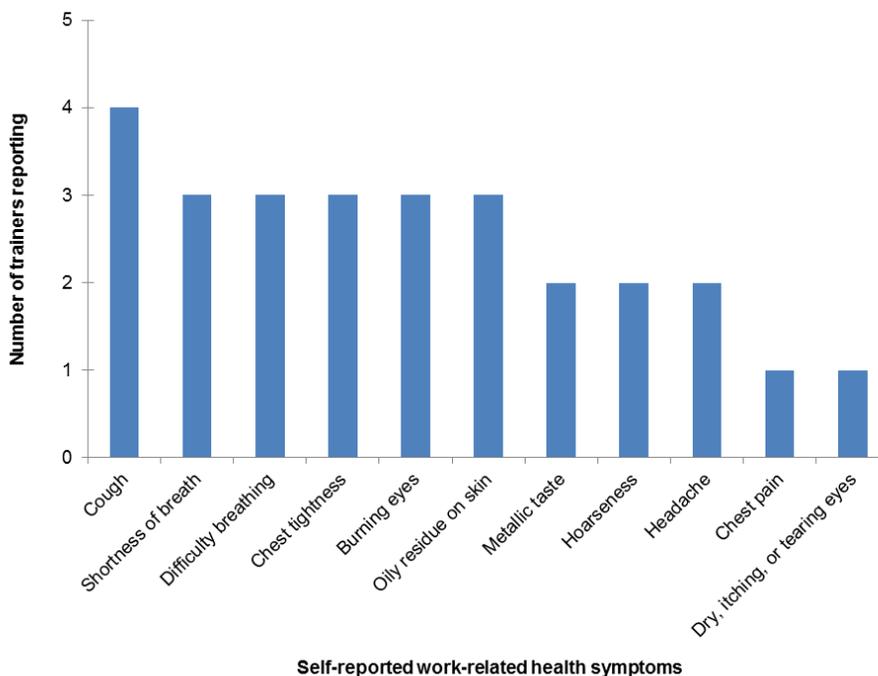

Figure 6. Self-reported work-related health symptoms (n = 5).

The adequacy of personal protective equipment during training exercises (specifically respiratory protection) was a general concern among the trainers. Long-term effects from exposure to the oil-based and glycol-based smoke simulant were additional concerns. The employer also mentioned dermal exposure as a concern. The trainers wore shorts and t-shirts during the incident in October 2011; they reported feeling an oily residue on their skin, but did not report developing rashes or acne.

Medical Record Review

We reviewed the medical records for the hospitalized trainer and agreed with the stated physician diagnosis of work-related acute pneumonitis/lipoid pneumonia, likely developed after inhaling a heavy mineral oil mist over a 30-minute period.

Chemical Exposures during Training Exercises

Our analysis of the bulk samples confirmed that the oil-based fluid was composed of high molecular weight hydrocarbons characteristic of mineral oil. The glycol-based fluid was composed of a 34% aqueous solution of diethylene glycol. The mineral oil mist condensate collected from the supply nozzle during Exercise 1A had the same composition and purity as the oil-based fluid. Therefore, alteration of the composition or thermal decomposition of the mineral oil fluid did not appear to occur within the fogging system.

Of the VOCs and aldehydes measured in air, we only report the results of benzene, 1,3-butadiene, crotonaldehyde, formaldehyde, and acrolein. The air concentrations of these compounds were above or within one tenth of their applicable short-term OELs. All other VOC and aldehyde air concentrations were less than one twentieth of their applicable short-term OELs. The area air concentrations of acrolein measured using EPA TO-15 and EPA TO-11A methods [EPA 1999a,b] are reported together. The scanning electron microscopy analysis of the air samples for carbonaceous particles was problematic. Only four samples were analyzed because volatiles on the samples contaminated the sample chamber. Most of these samples were collected outside the training room. One of these samples was collected inside the training room during Exercise 5. Material collected on these samples did not vary from the field blanks. Therefore, the lab determined that these samples did not collect nonvolatile carbonaceous particulate (i.e., soot) originating from the training atmosphere.

Exercise 1: Oil-Based Smoke Simulant

Figure 7 presents the average air concentrations of mineral oil mist measured during Exercises 1A and 1B. The ACGIH excursion limit for mineral oil mist of 25,000 µg/m³ is also provided in this figure as a horizontal line [ACGIH 2013]. It is only appropriate to compare area air concentrations to OELs if they are representative of exposures in an employee's personal breathing zone. The trainer who suffered acute respiratory injury in October 2011, spent several minutes near the supply nozzle while the oil-based smoke simulant was being generated. Therefore, comparing area air concentrations measured near the supply nozzle during Exercises 1A and 1B is meaningful. All other area air concentrations for Exercises 1A, 1B, and the other exercises were measured in locations and at heights that were intended to be representative of a trainer's breathing zone during normal operations. For

example, most area air samples inside the training room were collected in the middle of the room at 1–3-foot height, which is representative of a trainer's breathing zone while kneeling or crouching; area air samples outside the training room were collected just outside the door at 5-foot height, which is representative of a trainer's breathing zone while standing.
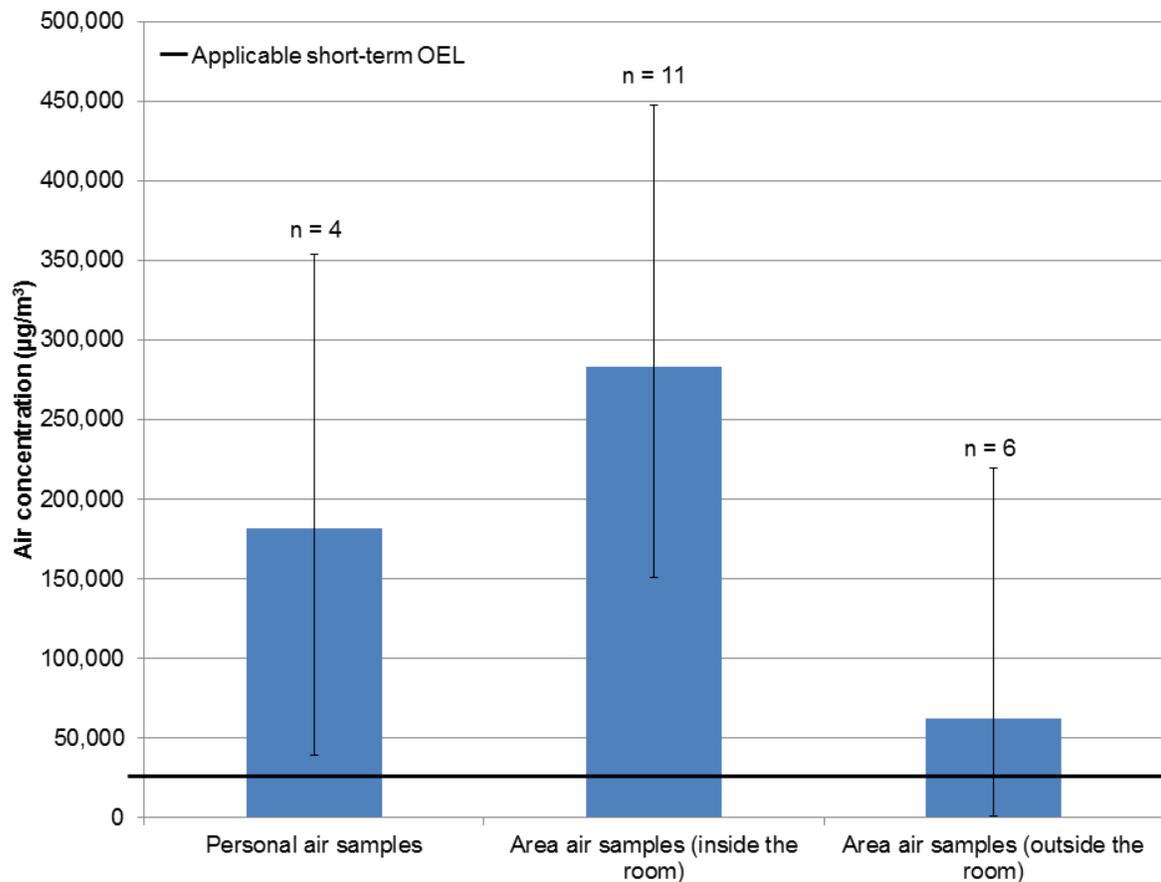

Figure 7. Average air concentrations of mineral oil mist measured during Exercises 1A and 1B (error bars represent the minimum and maximum measurements).

All the personal and area air concentrations of mineral oil mist inside the room exceeded the ACGIH excursion limit for mineral oil mist. The area air concentrations of mineral oil mist outside the room, on average, also exceeded this excursion limit. One personal air sample from Exercise 1A and one personal air sample from Exercise 1B were excluded from the results because the tubing was disconnected from the sampling pump. One area air sample collected inside the room during Exercise 1B was excluded from the results because the sampling pump malfunctioned early in the exercise.

Table 5 shows the area air concentrations of mineral oil mist inside and outside the training room stratified by location in the room and how much the door to the room was opened. Both factors appear to explain some of the variability in the area air concentrations. For example, the highest levels inside each room were measured near the supply nozzle, and highest levels outside the room were measured when the door was mostly opened. Air concentrations of mineral oil mist outside the training room were well below the ACGIH excursion limit [ACGIH 2013] when the door was mostly closed.

Table 5. Area air concentrations measured inside and outside the training room stratified by location and door opening

	No. of samples	Air concentration (µg/m³)		
		Mean	Minimum	Maximum
Area air samples (inside the room)				
Near supply nozzle	5*	320,000	230,000	450,000
Middle of room	6	250,000	150,000	300,000
Area air samples (outside the room)				
Door mostly opened	2	150,000	84,000	220,000
Door partially opened	2	33,000	9,100	57,000
Door mostly closed	2	1,100	920	1,200

*One sample was excluded due to sampling pump malfunction.

Figures 8 and 9 present the air concentrations of the mineral oil mist aerosol by aerodynamic diameter measured inside the training room during Exercises 1A and 1B. The impactor filters collecting aerosol between 0.77 µm and 0.25 µm were oversaturated for each sample location and exercise. Therefore, the actual concentrations of these particles were greater than what we report. For Exercise 1B, we neglected to include the post filter for particles < 0.25 µm. Nevertheless, on a mass basis, most airborne particles were < 0.77 µm in aerodynamic diameter, and higher levels were generally measured near the supply nozzle than in the middle of the room.
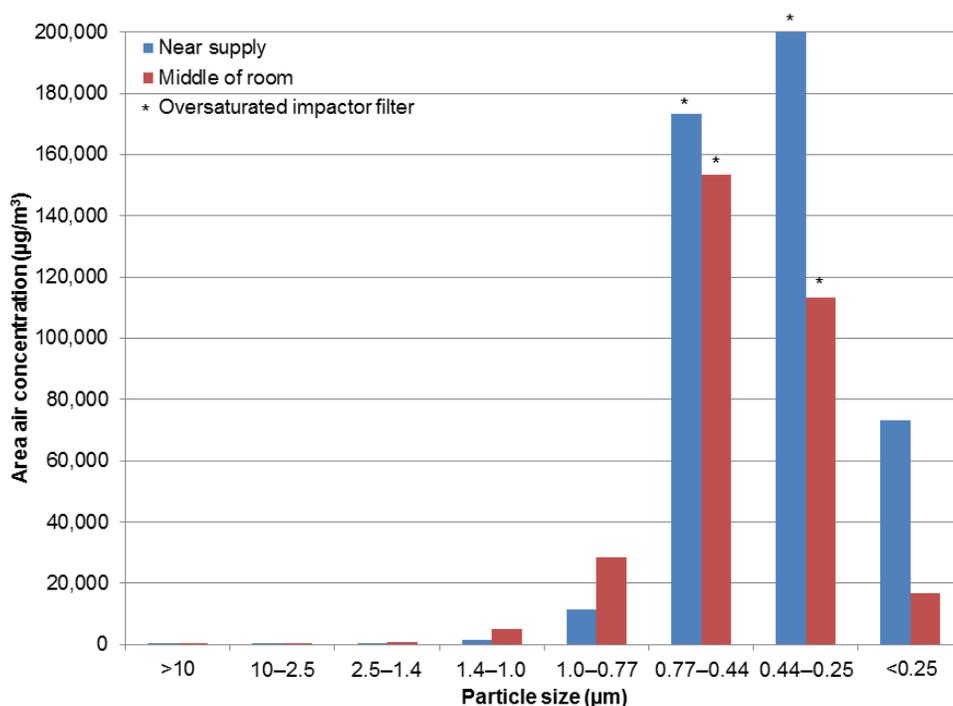

Figure 8. Area air concentrations of mineral oil mist aerosol by aerodynamic diameter during Exercise 1A.
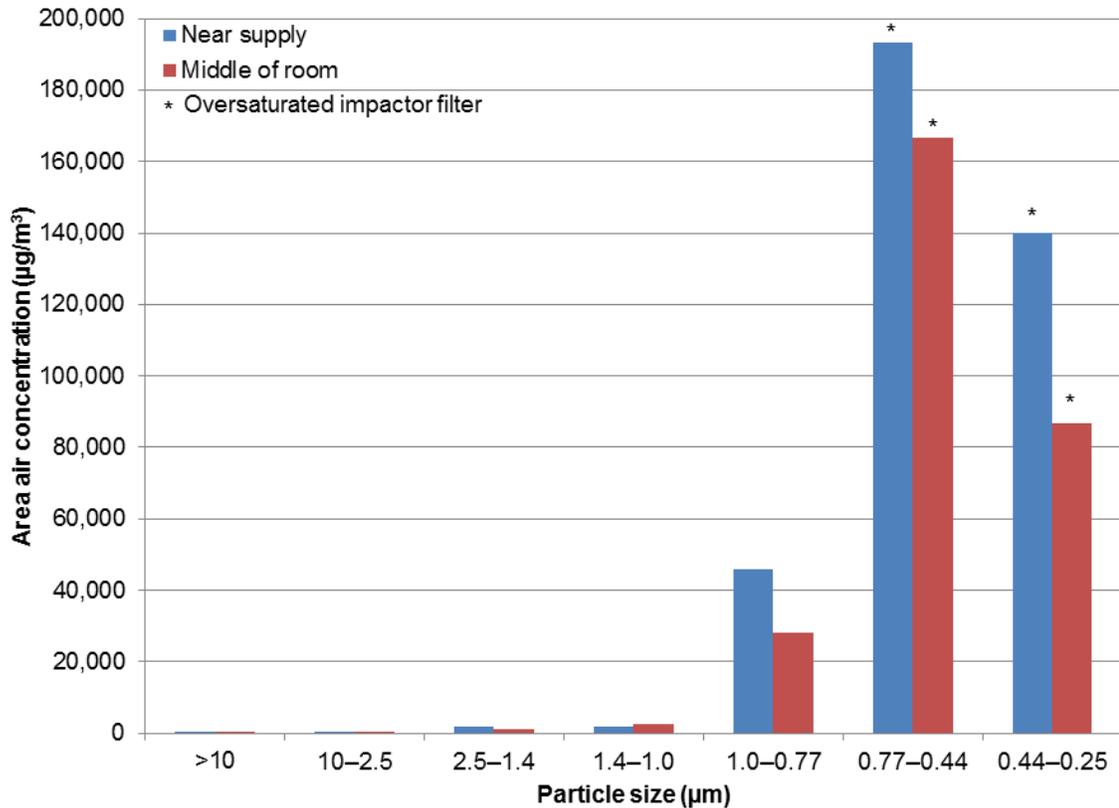
Figure 9. Area air concentrations of mineral oil mist aerosol by aerodynamic diameter during Exercise 1B.

All the filters used to collect the deposition of mineral oil mist onto surfaces (n = 6) were below the detection limit of 0.8 $\mu g/m^2$. All but two of the patches used to collect the deposition of mineral oil mist onto the trainers' clothing (n = 16) were below the detection limit of 0.5 $\mu g/m^2$, and all were below the quantitation limit of 1.6 $\mu g/m^3$.

Exercise 2: Glycol-Based Smoke Simulant

Figure 10 presents the air sampling results for diethylene glycol and its thermal decomposition products during Exercise 2. The background sampling results and the most protective short-term OELs for these compounds (as horizontal lines) are also provided in this figure. All personal and area air concentrations of diethylene glycol were well above background levels and exceeded the AIHA excursion limit [AIHA 2011]. The door to the training room was fully opened during this exercise, which could explain why the air concentrations of diethylene glycol outside the room were similar to those inside the room. The area air concentration of formaldehyde inside the room was nearly 10 times background levels and > 40% of the NIOSH ceiling limit [NIOSH 2010]. All other air sampling results were near the background levels and well below their short-term OELs.
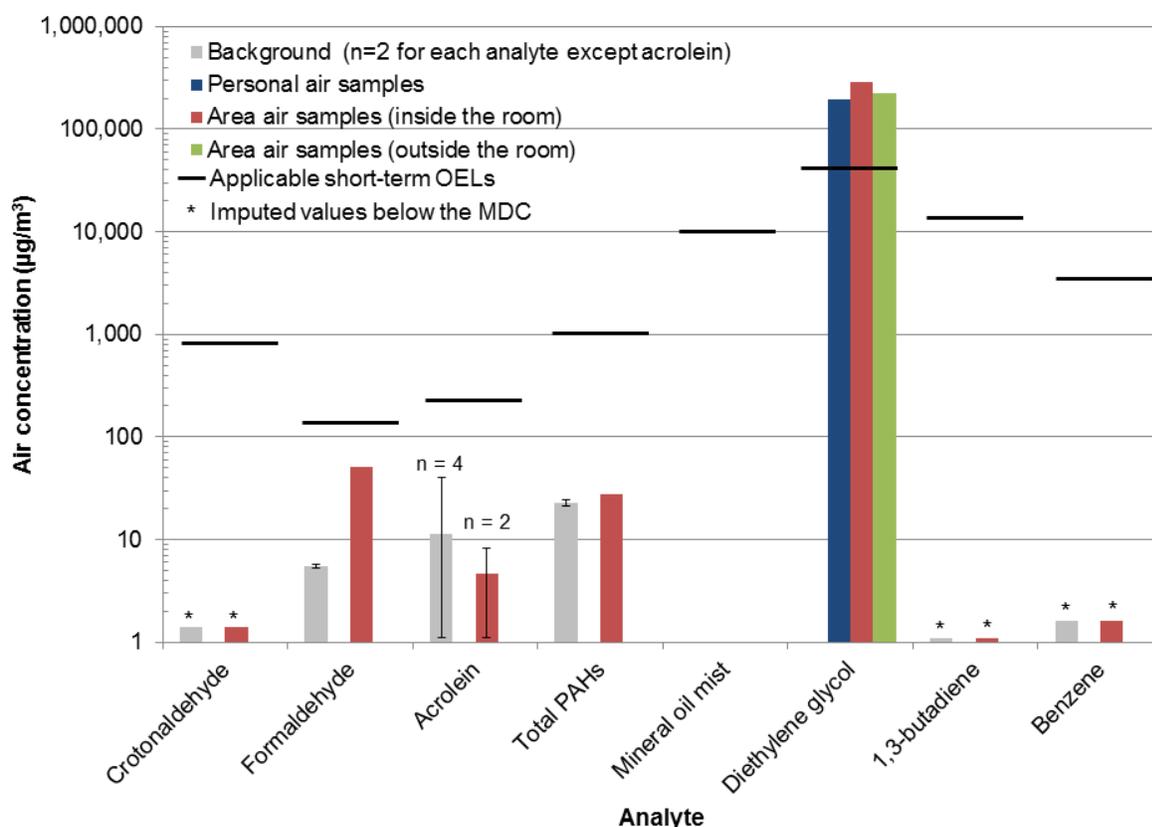
Figure 10. Air concentrations of diethylene glycol and its thermal decomposition products (including background levels) during Exercise 2. Average concentrations and error bars representing the minimum and maximum measurements are provided if more than one sample was collected. If no measurements were collected, then nothing is reported.

Figure 11 presents the air concentrations of the diethylene glycol aerosol by aerodynamic diameter measured inside the training room during Exercise 2. We neglected to include the impactor filter for aerosol 0.25–0.44 μm in aerodynamic diameter. The majority of the aerosol was < 0.44 μm. However, this may not accurately characterize the size distribution because diethylene glycol is semivolatile (vapor pressure = 0.07 millimeters of mercury [mmHg] at 68°F) and, therefore, the airflow through the cascade impactor could have caused some of the collected material to evaporate especially under elevated temperatures.
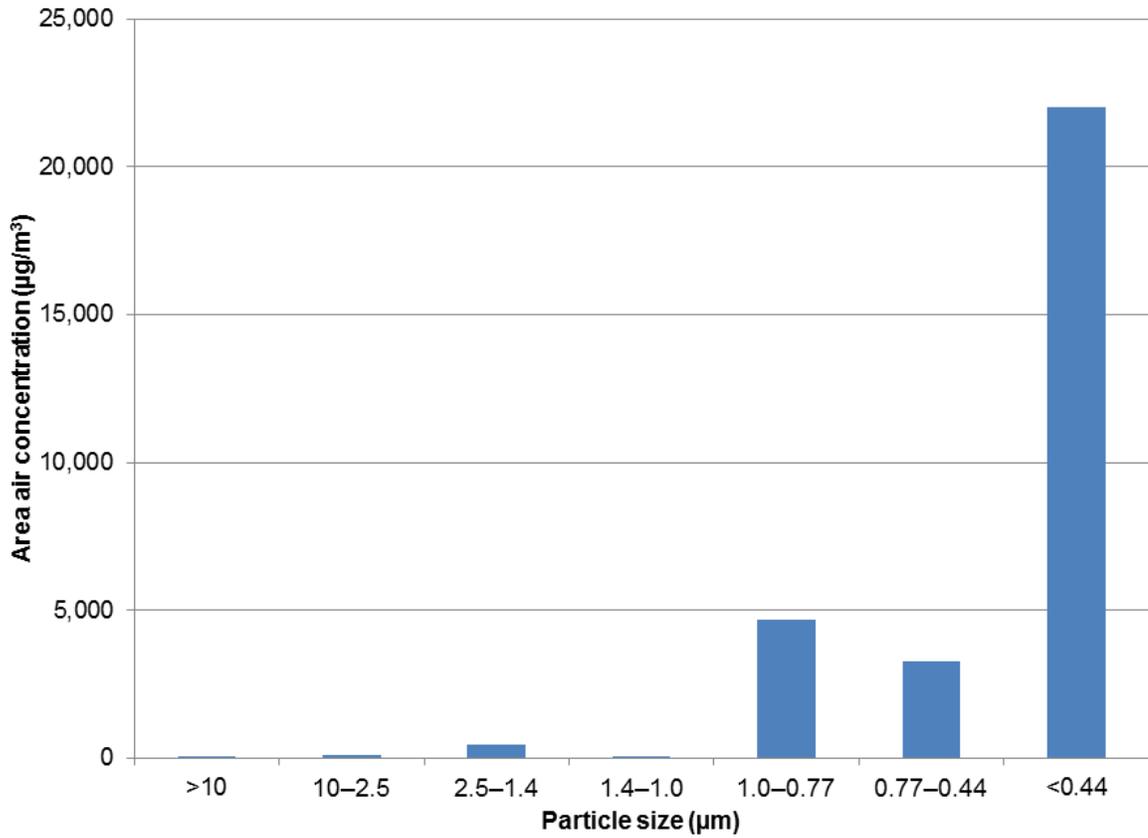
Figure 11. Area air concentrations of diethylene glycol aerosol by aerodynamic diameter inside the training room during Exercise 2.

Figure 12 presents the air sampling results for mineral oil mist and its thermal decomposition products during Exercise 3. The most protective short-term OELs for these compounds are also provided in this figure as horizontal lines. Personal air concentrations of formaldehyde, acrolein, and mineral oil mist exceeded the most protective short-term OELs [NIOSH 2010; ACGIH 2013]. Area air concentrations of formaldehyde outside the room exceeded the NIOSH ceiling limit [NIOSH 2010] despite the fact that the training room door was mostly closed during the exercise.
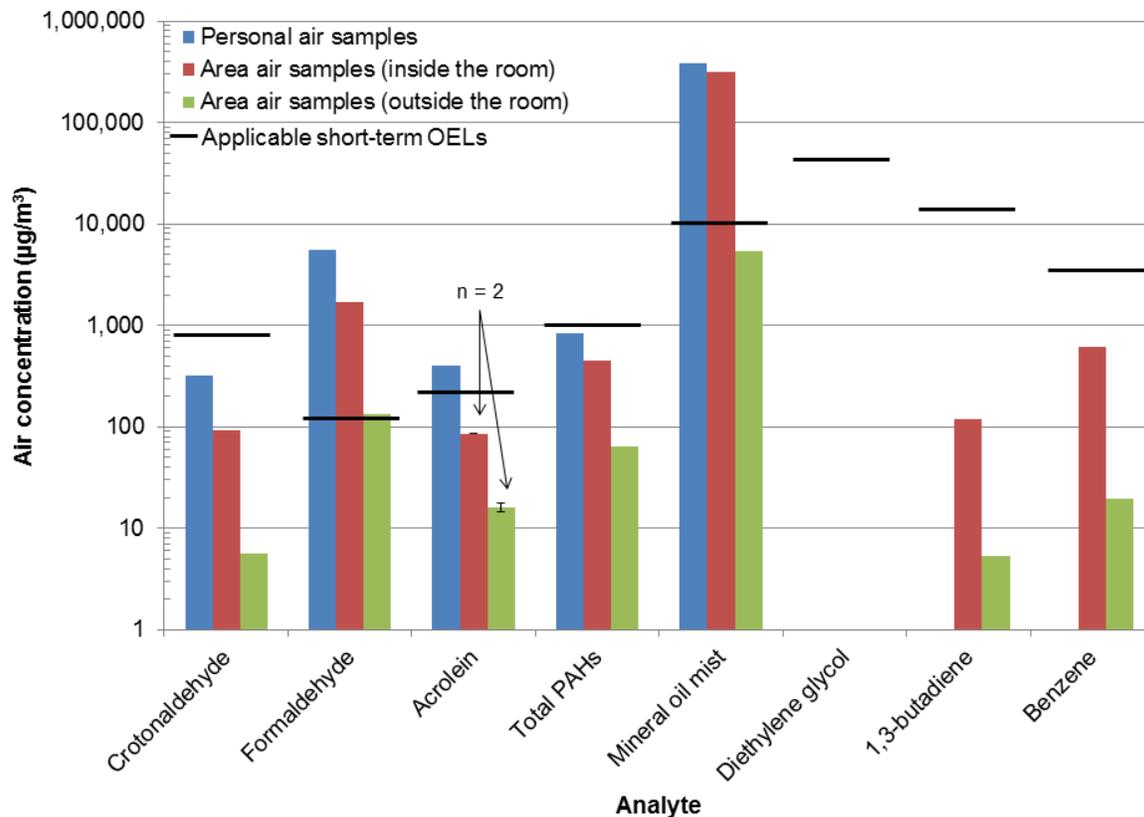

Figure 12. Air concentrations of mineral oil mist and its thermal decomposition products during Exercise 3. Average concentrations and error bars representing the minimum and maximum measurements are provided if more than one sample was collected. If no measurements were collected, then nothing is reported.

Exercise 4: Glycol-Based Smoke Simulant and Propane-Generated Heat and Fire

Figure 13 presents the air sampling results for diethylene glycol and its thermal decomposition products during Exercise 4. The most protective short-term OELs for these compounds are also provided in this figure as horizontal lines. The personal and area air concentrations of formaldehyde inside the room exceeded the NIOSH ceiling limit [NIOSH 2010]. The personal air concentration of diethylene glycol inside the room was > 50% of the AIHA excursion limit [AIHA 2011]. The area air concentrations outside the room were an order of magnitude below the most protective short-term OELs; the training room door was one fourth opened during this exercise.
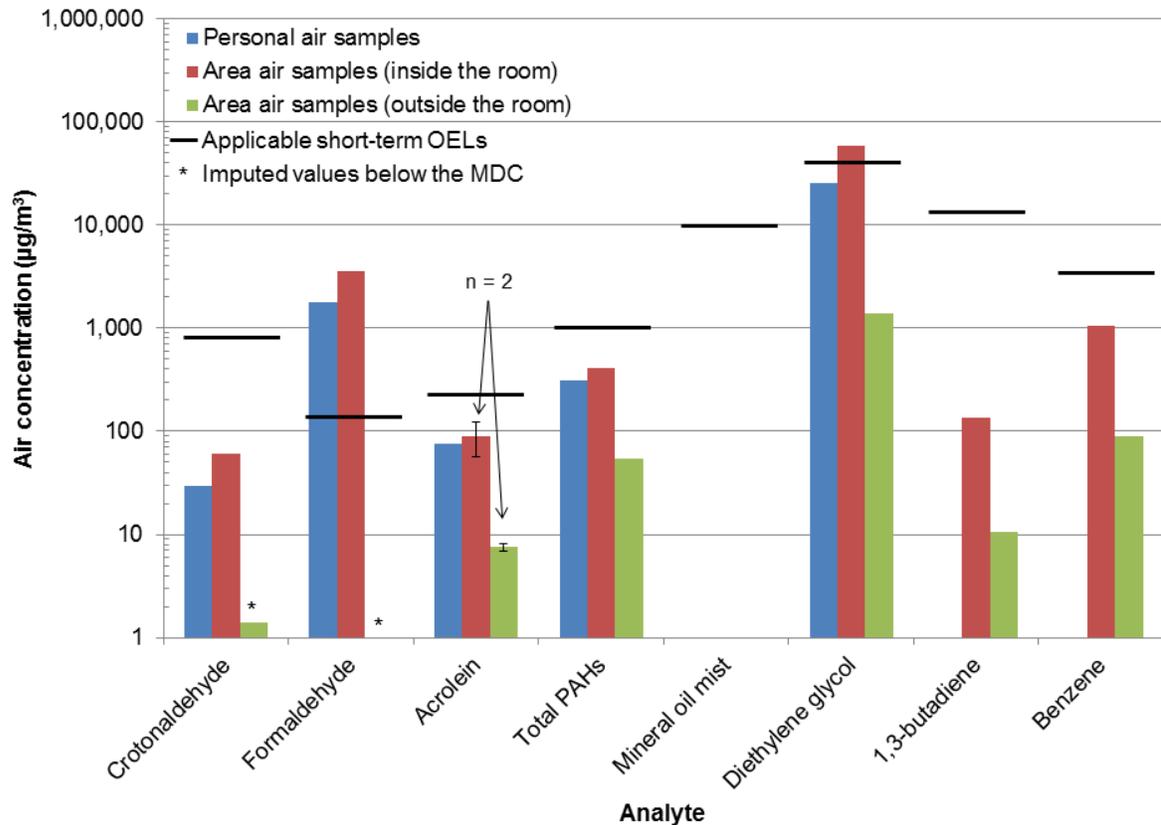

Figure 13. Air concentrations of diethylene glycol and its thermal decomposition products during Exercise 4. Average concentrations and error bars representing the minimum and maximum measurements are provided if more than one sample was collected. If no measurements were collected, then nothing is reported.

Exercise 5: Oil-Based Smoke Simulant, Glycol-Based Smoke Simulant, and Propane-Generated Heat and Fire

Figure 14 presents the air sampling results for mineral oil mist, diethylene glycol, and their thermal decomposition products during Exercise 5. The most protective short-term OELs for these compounds are also provided in this figure as horizontal lines. The personal air concentrations inside the room for formaldehyde, mineral oil mist, and diethylene glycol exceeded the most protective short-term OELs [NIOSH 2010; AIHA 2011; ACGIH 2013]. The area air concentrations of these compounds varied by measurement height inside the room. The area air samples inside the room were collected at two heights (2-foot and 5-foot) because the trainers told us that they occasionally stand or kneel during the exercises and the heat inside the room forced much of the smoke towards the ground (below about 3-foot height). The area air concentration of formaldehyde outside the room exceeded the NIOSH ceiling limit [NIOSH 2010]; the training room door was one fourth opened during this exercise.
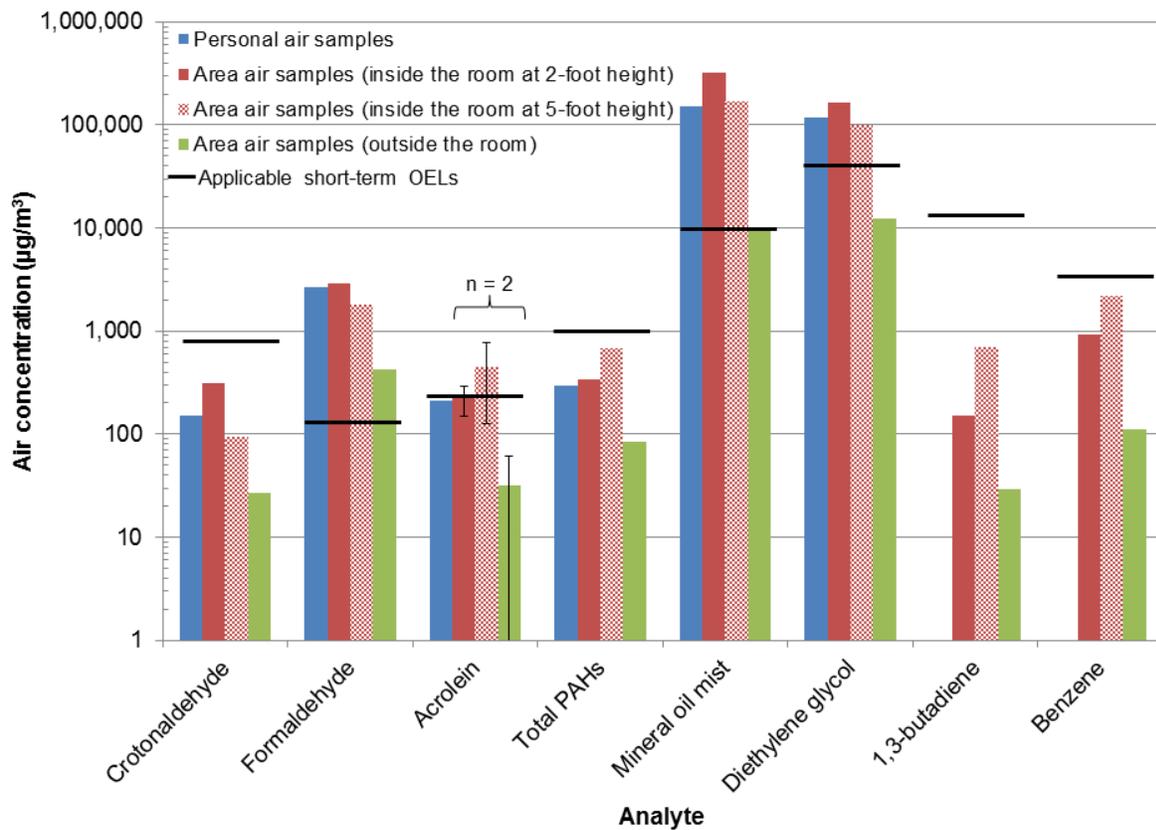

Figure 14. Air concentrations of mineral oil mist, diethylene glycol, and their thermal decomposition products during Exercise 5. Average concentrations and error bars representing the minimum and maximum measurements are provided if more than one sample was collected. If no measurements were collected, then nothing is reported.

Discussion

We faced some challenges during this evaluation. First, we did not sample all possible contaminants. Training exercises involving propane-generated heat and fire can produce thermal decomposition products beyond those we sampled. For example, oxides of nitrogen are produced during the combustion of propane [Arashidani et al. 1996]. Second, the potential for sampling errors increases with elevated ambient temperatures. In particular, the sampling pumps used have a maximum operating temperature of 113°F [SKC 2001]. This maximum temperature was probably exceeded at all sampling locations during the training exercises that contained propane-generated heat and fire. The ability of the pumps to accurately draw air at temperatures > 113°F (especially > 400°F) is unknown. The development of sampling pumps specially designed for these extreme temperatures is needed. Third, the two methods we used to measure acrolein in air have limitations. The EPA TO-11A method has been shown to underestimate the actual concentrations [EPA 1999a], while the EPA TO-15 method has been shown to overestimate the actual concentrations [EPA 2010]. Fourth, not all the polycarbonate filter samples could be analyzed by scanning electron microscopy because volatile compounds on the samples contaminated the sample chamber.

Despite these potential limitations, we believe the results provide reasonable estimates of exposure and other valuable information. For example, mineral oil mist has a boiling point (590°F) well above the maximum ambient temperatures inside the training room and thus should not evaporate or decompose as readily as diethylene glycol. The similarity between the air concentrations of mineral oil mist measured during training exercises with and without heat and fire suggests that the pumps performed as designed even in the high heat conditions. In addition, we obtained similar acrolein measurements from both the EPA TO-11A and EPA TO-15 methods. Finally, the absence of soot on the polycarbonate filter samples that were analyzed suggests that the thermal decomposition products formed during the training exercises were mostly volatile or semivolatile compounds.

We compared the 15-minute time-weighted average air concentrations to the most protective short-term OELs. Most of these OELs were ceiling or excursion limits that should not be exceeded at any time. Air concentrations can vary substantially over a 15-minute sampling period. In addition, 15-minute time-weighted average air concentrations can vary from one sampling period to the next. Therefore, overexposures are possible even if the 15-minute time-weighted average air concentration is below the short-term OEL. To account for this variability, action levels or some fraction of the OEL are sometimes used. Although we focus much of our discussion on the air concentrations above OELs; those within about 50% of the OELs may also represent potential overexposures.

In general, the magnitude of the air concentrations followed this pattern: area air concentrations inside the room were at or above personal air concentrations, which were at or above area air concentrations outside the room. The magnitude of the area air concentrations outside the room depended on how much the door to the room was opened. Differences between the area air concentrations inside the room and the personal air concentrations were

generally small (within a factor of 2) and may be explained by whether or not the trainers took measures to reduce their exposures, such as standing above the smoke layer.

For Exercises 1A, 1B, and 2 that involved only the oil-based or glycol-based smoke simulant, the personal and area air sampling results collected inside the room are relevant because the trainers did not always wear the appropriate respiratory protection during these exercises. We measured air concentrations of the parent compounds that were well above the short-term OELs. The thermal decomposition of diethylene glycol was probably the main source of formaldehyde in Exercise 2 (where the air concentration was > 40% of the NIOSH ceiling limit) and likely took place inside the portable fogging machine. According to the user guide for the FQ-100 Fog Generator, Atmospheres Fog Fluid is supposed to be used with the portable fog machine [High End Systems 2010]. This fog fluid is composed of triethylene glycol, propylene glycol, and deionized water [High End Systems 2007]. Propylene glycol has an ACGIH excursion limit of 50,000 $\mu g/m^3$ (same as the AIHA excursion limit for diethylene glycol) [ACGIH 2013]. Although these glycols are structurally different than diethylene glycol, similar thermal decomposition products may be expected.

For Exercises 3–5, the propane-generated heat and fire caused thermal decomposition of oil-based and glycol-based smoke simulant. The propane-generated fire forced the smoke simulant down toward the floor (Figure 4). This smoke-simulant boundary layer (about 3-foot height) could explain why the air concentrations varied between 2-foot and 5-foot sampling heights (Figure 14). The area air samples outside the room were always collected at 5-foot height because trainers typically stand when looking into the training room. This task, if done without appropriate respiratory protection, presents the potential for inhalation exposure. Personal and area air concentrations of many compounds measured inside the training room during these exercises exceeded short-term OELs. Therefore, trainers have the potential to be overexposed to certain chemicals any time they look inside the training room during an exercise. Our air sampling results suggest that air concentrations of formaldehyde, in particular, are likely to exceed short-term OELs outside the training rooms during exercises involving one or both of the smoke simulants and heat and fire.

On a mass basis, most of the mineral oil mist aerosol was measured in the size range of 0.25–0.77 μm in aerodynamic diameter, while the diethylene glycol aerosol was < 0.44 μm. The technical manual for the MDG Fog Generator System (mineral oil-based smoke simulant) reported a particle size range of 0.5–0.7 μm [MDG 2003], which agrees with our findings. However, the user guide for the FQ-100 Fog Generator (glycol-based smoke simulant) did not report a particle size range [High End Systems 2010]. Because diethylene glycol is semivolatile, some of the collected aerosol could evaporate during sampling. Therefore, the actual aerosol size distribution likely varies from our results. Despite this, it is likely that most of the glycol aerosols are < 1 μm in aerodynamic diameter. Aerosols in this range are able to penetrate deeply into the lungs where they are more difficult to clear [Hinds 1999].

The small size of the aerosols may also explain why we did not detect much mineral oil on the patch samples on the trainers' turnout gear and on the deposition filters in the middle of the training rooms during Exercises 1A and 1B. Aerosols < 1 μm have slow settling velocities

(estimated at < 0.006 feet per minute) and can remain airborne for long periods of time. It is plausible, therefore, that much of the mist was carried outdoors during the forced ventilation after the training exercises before it could deposit onto surfaces or coat surfaces by other mechanisms. The surface of the skin is different than the surface of the sampling media or turnout gear. Mineral oil mist could have a greater affinity for skin. Lipids in the skin could enhance the dermal absorption of the mineral oil mist. We did not investigate the surface contamination with glycol-based smoke simulant. However, because diethylene glycol is semivolatile, any surface contamination would likely evaporate over time.

Dermal exposure to poorly or mildly refined mineral oil can cause skin irritation such as dermatitis, oil acne, and lipid granuloma, but it is unclear whether dermal exposure to highly refined mineral oil could also cause skin irritation [ACGIH 2010]. Diethylene glycol does not significantly irritate the skin and is slowly absorbed through the skin [Cavender and Sowinski 1994]. Although three of the trainers reported feeling an oily residue on their skin following training exercises, none of the trainers reported experiencing rashes, acne, or other skin problems.

The primary route of exposure to the compounds we measured is inhalation. Because exposures are of short duration, acute health effects are most relevant. However, chronic health effects are also possible if trainers are exposed repeatedly without proper respiratory protection. The trainer, who suffered the acute respiratory injury in October 2011, was exposed to mineral oil mist. Short-term inhalation exposures to mineral oil mist can cause lipoid pneumonia or chemical pneumonitis [Spickard and Hirschmann 1994; IPCS 2006]. Lipoid pneumonia is an uncommon condition resulting from aspirating or inhaling lipid soluble substances, such as mineral oils [Spickard and Hirschmann 1994]. Other health effects from exposure to mineral oil mists may include eye, skin, and upper respiratory tract infection, central nervous effects, and respiratory distress associated with a chemical pneumonitis [NIOSH 1978]. However, many of these effects have been attributed to the poorly and mildly refined mineral oils used in industrial applications, but not necessarily the highly refined mineral oil used in the MDG Neutral Fluid [MDG 2003]. The safety data sheet for the MDG Neutral Fluid specifically states that "no acute or chronic health effects are known to occur when used in the MDG Fog Generator." However, the safety data sheet recommends that fire fighters (or trainers) wear protective equipment and SCBA [MDG 2003]. The findings from this evaluation support the physician's diagnosis of work-related pneumonitis/lipoid pneumonia for the trainer who suffered the acute respiratory injury.

Depending on the type of training exercise, trainers can also be exposed to diethylene glycol and thermal decomposition products of mineral oil and diethylene glycol. Short-term exposures to diethylene glycol can cause adverse effects to the blood, kidney, liver, and central nervous system; the generation of mists should be avoided if possible [IPCS 2007]. Short-term exposures to crotonaldehyde, formaldehyde, and acrolein can irritate the skin, respiratory tract, and eyes. Inhalation exposures to high concentrations of these aldehydes can cause pulmonary edema [IPCS 2001, 2003b, 2004]. Of these compounds, acrolein is the most potent irritant [IPCS 2001]. Short-term exposures to PAHs can irritate the eyes, skin, and respiratory tract [IPCS 2002]. Short-term exposures to 1,3-butadiene can irritate the eyes and respiratory tract and cause adverse effects on the central nervous system [IPCS 2000].

Short-term exposures to benzene can irritate the eyes, skin, and respiratory tract and cause adverse effects on the central nervous system [IPCS 2003a]. Many of the short-term OELs are based on the acute effects to the eyes and respiratory tract (Appendix B). Therefore, the ACGIH additive mixture formula could be used for these compounds because the health effect (irritation) and target organs (eyes and respiratory system) are the same [ACGIH 2013]. We did not do this analysis because it would not change our main conclusions and recommendations. Nevertheless, eye and respiratory tract irritation are likely during training exercises if the trainers are not adequately protected.

Most other studies investigating exposures to oil-based or glycol-based smoke simulants were performed in the theatrical industry. Investigators in these studies found average work-shift (about 4 hours) exposures to glycols ranging up to 7,000 $\mu g/m^3$, while average work-shift (about 4 hours) exposures to mineral oils ranged up to 60,000 $\mu g/m^3$; both levels are well below the short-term levels we measured [NIOSH 1994; Moline et al. 2000; Teschke et al. 2005]. Investigators in one of these studies also found detectable levels of aldehydes and PAHs [Teschke et al. 2005]. Acute and chronic respiratory health effects have been associated with exposures to theatrical smoke [Varughese et al. 2005].

The study that is most comparable to this evaluation investigated pilots' exposures to glycol-based smoke simulant during aviation emergency training [Wieslander et al. 2001]. In that study, short-term (1-minute) air concentrations of propylene glycol averaged 310,000 $\mu g/m^3$, which is similar to the short-term air concentrations of diethylene glycol we measured. The pilots did not wear respiratory protection. Following this brief exposure, self-reported eye and throat irritation and trouble breathing (dyspnea) increased. In addition, tear film stability increased and the ratio of forced expiratory volume in 1 second to forced vital capacity was slightly reduced [Wieslander et al. 2001].

Conclusions

Prior to the incident where a trainer suffered acute respiratory injury after being exposed to the oil-based smoke simulant, many of the trainers were under the assumption that the oil-based and glycol-based smoke simulants were not hazardous. However, the results of this evaluation indicate that air concentrations of mineral oil mist and diethylene glycol can exceed short-term OELs during training exercises involving oil-based smoke simulant, glycol-based smoke simulant, or both. If propane-generated heat and fire are added to the training exercises, thermal decomposition products can be produced, and the air concentrations of these products could also exceed short-term OELs. Overexposures are also possible if trainers open the training room and look inside without respiratory protection for even just a short time. If trainers are not adequately protected, these chemical exposures could cause eye and respiratory irritation or more serious acute respiratory effects.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the fire department to use a labor-management health and safety committee or working group to discuss the recommendations in this report and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the fire department.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Use the training tower's exhaust ventilation system immediately after completing a training exercise. Do not re-enter the tower without appropriate respiratory protection until all smoke simulant has visibly dissipated.

Administrative Controls

The term "administrative controls" refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Rotate training duties throughout a full day of training exercises. This will lessen each trainer's chemical exposures. Although not a focus of our evaluation, this would also lessen the physiological strain associated with repeated training exercises, particularly those involving heat, fire, and use of SCBA.

2. Encourage trainers to report health concerns or symptoms associated with work tasks to a supervisor. Irritation to the eyes or respiratory system may be the most common immediate symptom a trainer could experience if he/she is not adequately protected during the training exercises.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Wear full-structural fire-fighting ensembles (including SCBA) inside the training tower at all times during or when preparing for the training exercises involving propane-generated heat and fire. The ensembles (including SCBA) should be worn even if the trainer is outside the training room and only looks in the room briefly. This is because the SCBA provides optimal respiratory protection to the compounds we measured in addition to those we did not measure but could be present in air from thermal decomposition of the oil-based or glycol-based smoke simulant or the incomplete combustion of propane. In addition, the ensembles provide protection from heat, which would be especially important if an emergency were to occur that required the trainer to provide assistance inside the training room. SCBA could also be used for the other training exercises that do not involve heat and fire. However, the added weight of the SCBA increases the physical burden on the trainers. Therefore, we provide another respirator option below for the training exercises that do not involve heat and fire.

2. Wear NIOSH-approved full-facepiece air purifying respirators with NIOSH-approved cartridge/canisters that are effective against oil-based aerosol (i.e., P100 cartridge) and formaldehyde (i.e., formaldehyde cartridge) during or when preparing for the training exercises that involve oil-based or glycol-based smoke simulant or both (but not heat and fire). This type of respirator should also be worn inside the training tower during these exercises even if the trainer is outside the training room. Full-facepiece air purifying respirators have a NIOSH assigned protection factor of 50 [NIOSH 2004]. This means that they can be used for atmospheres not immediately dangerous to life and health when air concentrations are < 50 times the applicable OELs provided that the appropriate cartridge/canister is used and that they are fitted, worn, and maintained properly. All the air concentrations we measured were well below 50 times the most-protective short-term OELs. Full-facepiece respirators also protect the eyes from chemical irritants or other hazards that may be present during these training exercises. Cartridges/canisters that are effective against oil-based aerosol and formaldehyde may be available for use with existing respirators. Ensure that trainers are clean-shaven and that they check the seal of the tight-fitting respirators before using them. This is especially important for negative-pressure air-purifying respirators because an improper seal around the face will result in an increase of inward leakage of air and thereby an increase in inhalation of contaminants.

3. Conduct fit testing for the full-facepiece air purifying respirators under the configuration that they will be used as mandated in the OSHA comprehensive respiratory protection program standard [29 CFR 1910.134].

4. Determine a cartridge/canister change-out schedule based on the service life of the cartridge/canister under the conditions of use. The change-out schedule can be determined by using the information in this report along with the assistance of the respirator manufacturer (software or other tools) or by conducting service life tests.

5. Wear nitrile gloves when refilling the fog machine reservoirs with oil-based or glycol-based fluids.

6. Wash hands after each training exercise and shower at the end of a series of training exercises to rinse possible chemical contamination off the skin.

Appendix A: Additional Sampling and Analytical Information

Mineral Oil, Diethylene Glycol, Aldehydes, and Polycyclic Aromatic Hydrocarbons

Calibrated SKC Airchek 2000 pumps were used to draw 1 Lpm of air through media used for sampling mineral oil mist, diethylene glycol, aldehydes, and PAHs. The aldehyde media was stored in a −20°C freezer before and after sampling. These samples were analyzed using the published NIOSH or EPA methods (Table 2 on page 6).

Bulk samples of the mineral oil-based fluid and the diethylene glycol-based fluid were collected using 25-mL glass pipets to draw a 5-mL sample of each fluid from its reservoir. The fluid was then expelled into 20-mL glass vials. A sample of mineral oil condensate was collected by placing an open 20-mL vial near the built-in fog generator supply nozzle for 1 minute during Exercise 1A. The samples of the mineral oil fluid and condensate were prepared by dissolving in methylene chloride and analyzed using GC/MS. The sample of the diethylene glycol fluid was analyzed using NIOSH Method 5523 [NIOSH 2013] modified for the aqueous matrix.

Samples of mineral oil mist deposition were collected by placing the media into open petri dishes and positioning the open petri dishes on surfaces in the middle of each training room (during Exercises 1A and 1B). Patch samples to measure the levels of mineral oil mist on clothing during these exercises were made by placing the media inside paperboard holders with 75-mm openings. The patch samples were attached to the trainers' turnout gear with alligator clips. After the training exercises, the samples were collected. The patch samples were placed into 100-mm petri dishes. The petri dishes were closed and sealed with parafilm. These samples were analyzed using NIOSH Method 5523 [NIOSH 2013].

Volatile Organic Compounds

The evacuated canisters for sampling VOCs in air were equipped with orifices set to run for 15 minutes. The sampling port on the evacuated canisters were opened just prior to the start of each training exercise and closed just after the end of each training exercise. The samples were analyzed using EPA Method TO-15 [EPA 1999b]. Each canister was analyzed for 65 target compounds and the top 20 tentatively identified compounds by GC/MS.

Carbonaceous Particles (Scanning Electron Microscopy)

Calibrated SKC Airchek 2000 pumps were used to pull 1 Lpm of air through the polycarbonate filters. The samples were analyzed by scanning electron microscopy using NIOSH Method 7404 [NIOSH 2013] with modifications. These modifications included affixing the filters to aluminum stubs with colloidal silver to avoid adding carbon to the samples and using energy dispersive X-ray analysis. In addition, no quantitation was

performed. The samples were analyzed at magnifications ranging from 1,000 to 12,000 times. Images were obtained using the backscatter electron detector at an accelerating voltage of 20,000.

Aerosol Size Distribution

The cascade impactor plates were prepared with media using forceps and assembled in order. Thomas VTE vacuum pumps were used for pulling 100 Lpm through the cascade impactors. A Magnehelic® pressure gauge was used to set the inlet flow rate through the impactors at 100 Lpm. After sampling, the impactors were disassembled. Using forceps, the media was placed inside 100-mm petri dishes and sealed with parafilm. The samples were analyzed using NIOSH Method 5026 [NIOSH 2013].

Appendix B: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average exposure. A time-weighted average refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values. Unless otherwise noted, the STEL is a 15-minute time-weighted average exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.

- NIOSH recommended exposure limits are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH recommended exposure limits are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.

- Other OELs commonly used and cited in the United States include the TLVs, which are recommended by ACGIH, a professional organization, and the workplace environmental exposure levels, which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and workplace environmental exposure levels are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are

not consensus standards. TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2013]. Workplace environmental exposure levels have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2011].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/en/gestis/limit_values/index.jsp, contains international limits for more than 1,500 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Criteria for the Short-Term Occupational Exposure Limits Referenced in this Report

Of the short-term OELs referenced in this report (Table 4 on page 10), ACGIH TLV documentation exists for crotonaldehyde, formaldehyde, acrolein, and benzene; NIOSH criteria documentation exists for formaldehyde and benzene. The ACGIH TLV ceiling for crotonaldehyde is intended to minimize the potential for rapidly acting irritation of the eyes and upper respiratory tract [ACGIH 2001e]. Likewise, the ACGIH TLV STEL for formaldehyde is intended to minimize the potential for eye and upper respiratory tract irritation [ACGIH 2001f]. The NIOSH ceiling limit for formaldehyde was set in 1988

according to the NIOSH carcinogen policy at that time (i.e., lowest reliably quantifiable concentration) [NIOSH 1988]. Since then, sampling methods have become more sensitive and the quantity and quality of data for performing a risk assessment on formaldehyde has increased. NIOSH is currently in the process of evaluating and possibly revising this ceiling limit. The ACGIH TLV ceiling for acrolein is intended to minimize the potential for intense irritation of the eyes, mucous membranes, and respiratory tract and the development of pulmonary edema [ACGIH 2001b]. The ACGIH TLV STEL for benzene is intended to protect against the excess risk of leukemia due to the dose rate-dependent hematopoietic toxicity of benzene [ACGIH 2001c]. The NIOSH STEL for benzene is also intended to prevent leukemia from repeated exposures; however, this STEL was based on the analytical detection limits at the time it was set in 1974 [NIOSH 1974].

The basis for excursion limits is the variability in air concentrations throughout a workday. Air concentrations that are five times the work-shift OEL represent poorly controlled occupational environments [ACGIH 2013]. Although work-shift OELs are typically based on chronic health effects, maintaining exposures below excursion limits should also minimize acute health effects when such health effects are possible. Most the compounds we measured are capable of producing acute health effects from short-term exposures (pages 23–24 have an overview of these health effects). Maintaining intermittent exposures below excursion limits should also minimize chronic health effects. This is relevant for the trainers because repeated exposure to the smoke simulants and their thermal decomposition products are possible throughout the year. The ACGIH work-shift TLV for coal tar pitch volatiles (criteria we used for total PAHs) is intended to minimize the potential for an increase incidence of lung and other tumors [ACGIH 2001d]. The ACGIH work-shift TLV for mineral oil mist (pure, highly refined) is intended to prevent respiratory symptoms and pulmonary function changes and is mainly based on theatrical smoke exposures in the entertainment industry [ACGIH 2010]. The ACGIH work-shift TLV for 1,3-butadiene is intended to minimize the potential for cancer [ACGIH 2001a].

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