Evaluation of Diesel Exhaust Exposure at Two Fire Stations

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The employer is required to post a copy of this report for 30 days at or near the workplace(s) of affected employees. The employer must take steps to ensure that the posted report is not altered, defaced, or covered by other material.

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. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from the chief at a fire department with two stations. The chief was concerned about fire fighters' exposure to diesel exhaust in the living quarters of the fire stations. We visited the stations in April 2016. The larger station is referred to as station 1, the smaller as station 2.

What We Did

- We sampled in the living areas and apparatus bays of both stations for chemicals found in diesel exhaust.
- We measured airborne particle counts, carbon monoxide, temperature, and relative humidity.
- We looked at the ventilation systems at the fire stations to see if they were properly maintained.

What We Found

- We measured low levels of diesel exhaust in the apparatus bay at both stations.
- We measured low levels of diesel exhaust in living areas of station 1 and even lower levels at station 2.
- The airborne particle concentration in the kitchen at station 1 increased shortly after a diesel engine was started in the apparatus bay. This means that the use of a diesel engine in the bay is likely correlated with an increase in diesel exhaust in the living quarters.
- Air flowed from the apparatus bays and into the living quarters in both fire stations. This is opposite of what is preferred.
- Boxes and other supplies partially blocked the air intakes in the apparatus bay of station 1.
- The three air handlers serving station 1 had poorly fitting or missing air filters. We did not look at the air handlers serving station 2.

We evaluated diesel exhaust exposures at two fire stations. We measured substances that are present in diesel exhaust in the living quarters of both fire stations. We found low levels of diesel exhaust in all sampled areas of the two fire stations, with levels highest in the apparatus bay and living quarters of the larger of the two fire stations. At both stations we found that air flowed from the apparatus bays into the living quarters. We recommended hiring a ventilation engineer to evaluate the ventilation system to keep the amount of diesel exhaust that enters the living quarters to a minimum.

What the Employer Can Do

- Hire a licensed professional mechanical engineer to evaluate the ventilation at both stations.
- Ensure that air flows from the living quarters and into the apparatus bays at both stations.
- Install diesel control systems to decrease the amount of diesel exhaust in the apparatus bay.
- Remove items that block the air intake louvers in the apparatus bay at station 1.

- Replace missing or improperly fitting air filters in the three air handling units at station 1.
- Use the existing tailpipe exhaust hose for checking equipment in the apparatus bay.
- Install a chain across the opening to the mechanical room that contains the air handling units to prevent falls.

What Employees Can Do

- Open both apparatus bay doors when starting diesel engines inside the bay to increase ventilation.
- Close apparatus bay doors when equipment is running outside the bay.
- Run apparatus or equipment within the apparatus bay no longer than necessary.
- Keep doors connecting the living quarters and the apparatus bay closed.

Abbreviations

NIOSH	National Institute for Occupational Safety and Health

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Introduction

The Health Hazard Evaluation Program received a request from the chief at a fire department with two stations. The chief was concerned about diesel exhaust because some fire fighters had noticed exhaust odors in the living quarters after starting diesel powered equipment in the adjacent apparatus bay. These exhaust odors were more frequent in the larger and busier of the two fire stations. We visited the fire stations in April 2016. Shortly after our visit we sent letters to the employer and employee representative summarizing our activities.

Background

The two single-story fire stations were built in 1998 and were staffed by 16 full-time and 18 to 20 part-time volunteer fire fighters. Three squads of full-time fire fighters worked 24-hour alternating shifts, with 48 hours off in between. Three full-time fire fighters staffed the larger main station (station 1) per shift, and two full-time fire fighters staffed the smaller station 2. An additional one to three volunteer fire fighters were staffed at either station.

Station 1 was a pull-through station with bay doors on the front and back walls of the apparatus bay. Station 1 could hold up to seven vehicles, and the adjoining living quarters included a radio room, a kitchen and dining area, a bunk room, a gym, a meeting room, and offices. At the time of our evaluation, station 1 housed five emergency response vehicles. The station housed one fire engine (1992 Pierce Lance), one rescue (2016 Pierce Saber®), one tower (2003 Pierce Dash®), one medic unit (2007 International 4300), and one gasoline-powered truck (1996 Chevrolet).

Station 2 was a back-in fire station with a permanent back wall and apparatus bay doors facing the street. Station 2 was about one-third of the size of station 1 and had a bay that could hold two vehicles. The living quarters at station 2 included a living room, a kitchen, a bunk area, and a storage and mechanical room. At the time of our evaluation, station 2 housed two emergency response vehicles. The station housed one fire engine (1999 Pierce Saber®), and one medic unit (2005 International 4300).

The stations had powered wall-mounted exhaust fans providing general dilution ventilation in the bays. At station 1 passive air intake louvers and an exhaust fan were located on a side wall in a fenced storage area on the mezzanine level of the bay; a second exhaust fan was above the back bay doors (Figure 1). At station 2 the passive air intakes were above the bay doors, and wall exhaust fans were on the opposite wall. All exhaust fans were set to automatically run for 1 minute after the bay doors were opened or closed. If necessary the exhaust fans could be operated manually from a control box in each bay.

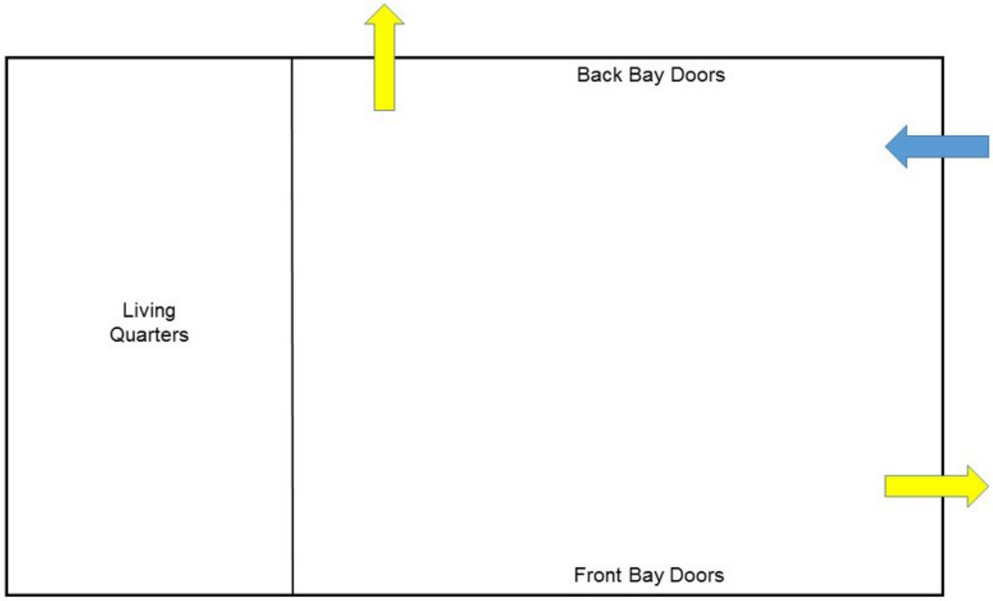

Figure 1. Diagram of station 1 (not to scale) showing the passive air intake louver (blue arrow) and the powered wall exhausts (yellow arrows).

Methods

The objectives of this evaluation were to (1) determine if diesel exhaust was entering the fire fighters' living quarters, and (2) evaluate the ventilation at the fire stations.

During the site visit, we observed work practices and workplace conditions and spoke with the fire fighters at each station. We took 14 full-shift area air samples for elemental carbon and six for 1-nitropyrene in the bay and living quarters of each fire station. We used elemental carbon as a surrogate for diesel exhaust exposure because diesel exhaust is a complex mixture of gases and particles comprised of more than 80% carbon. 1-nitropyrene is a nitrated polycyclic aromatic hydrocarbon that is present in the organic carbon component of diesel exhaust [Bamford et al. 2003], and thus could be a surrogate measure for diesel exhaust.

We also collected area air samples (4 for elemental carbon and 2 for 1-nitropyrene) outside of both fire stations to determine the environmental background levels of elemental carbon and 1-nitropyrene. We collected elemental carbon air samples using National Institute for Occupational Safety and Health (NIOSH) Method 5040 [NIOSH 2016]. We collected 1-nitropyrene air samples using NIOSH Method 2560 [NIOSH 2016], with a modification replacing the chemiluminescence detector with a nitrogen phosphorus detector.

We used TSI Q-Trak indoor air quality monitors to measure carbon dioxide, carbon monoxide (only at station 1), temperature, and humidity in the living quarters of the stations. Carbon dioxide is released by occupants and its levels in air are used to assess the effectiveness of ventilation systems. Carbon monoxide is a combustion product. We measured temperature and humidity because they can affect how a person perceives their indoor environment. Direct-reading BW Technologies GasAlert® Extreme meters were used to measure carbon monoxide in the bays, but the downloaded data from both stations were not appropriately saved and thus cannot be reported.

We measured particle concentrations throughout the day using a TSI DustTrak™ DRX 8533 Aerosol Monitor in the bays and living quarters of both fire stations. These monitors logged particle concentrations during the time that the elemental carbon and 1-nitropyrene samples were collected. More than 95% of diesel exhaust particulate is less than 1 micrometer in size and is respirable [NIOSH 2016]. Animal studies have shown that most of the harmful effects of diesel exhaust could be attributed to the particulate fraction [Birch 2016]. Appendix B provides information about health effects associated with diesel exhaust exposure.

We visually inspected the air handling units at the stations and used ventilation smoke tubes to observe the airflow direction between the bays and living quarters.

Results and Discussion

Diesel Exhaust, Carbon Monoxide, and Particulates

During our visit, we noticed a slight diesel exhaust odor in the radio room and kitchen area of the living quarters at station 1. These rooms were close to a door leading to the apparatus bay.

Table 1 shows the number of runs per diesel apparatus during our site visit. According to the chief, the number of runs during the same time frame is typically higher.

Table 1. Diesel engine apparatus runs during the sample period

Station	Diesel apparatus	Number of runs
1	Medic unit	2
	Tower truck	1
2	Medic unit	1
	Engine truck	2

The area air concentrations of elemental carbon are shown in Table 2. We collected area air samples for approximately 8 to 9 hours during the day. The average elemental carbon air concentrations in the fire stations ranged from 0.20 micrograms per cubic meter to 6.7 micrograms per cubic meter. Levels in the living quarters were less than half of the levels in the bays. Although these were area air samples, and their results are not directly comparable to occupational exposure limits, it is helpful to note that these concentrations would not have exceeded the recommended California elemental carbon occupational exposure limit of 20 micrograms per cubic meter if they had been personal air samples [California Department of Public Health 2002]. The lowest concentrations of elemental carbon were found outdoors.

Table 2. Area air concentrations of elemental carbon	
Location	Elemental carbon (micrograms per cubic meter)
Station 1	
Apparatus bay	6.7
Kitchen	1.9
Radio room	1.4
Bunk room	1.3
Outside	0.16
Station 2	
Apparatus bay	1.1
Living quarters	0.20
Outside	Not detected*

*Less than the minimum detectable concentration of 0.2 micrograms per cubic meter

We did not detect 1-nitropyrene in any area air sample (< 0.2 micrograms per cubic meter) in the living quarters at station 1 during the work day, and did not detect carbon monoxide (limit of detection, 1 ppm) in the living quarters at station 1. The temperature and relative humidity were within recommended thermal comfort guidelines for the summer season of 75°F to 80.5°F and below 65% relative humidity [ANSI/ASHRAE 2013]. Carbon dioxide concentrations in the living quarters ranged from 613 to 911 parts per million in station 1 and 423 to 795 parts per million in station 2. Carbon dioxide is a normal part of exhaled breath, and its concentration can be used to determine if enough outdoor air is being supplied to keep odors to an acceptable level. Indoor carbon dioxide concentrations no greater than 700 parts per million above outdoor carbon dioxide concentrations will satisfy about 80% of occupants [ANSI/ASHRAE 2016]. We did not take measurements of carbon dioxide concentrations outside of the stations. Carbon dioxide concentrations are typically 350–400 parts per million outdoors. Although most carbon dioxide concentrations were within recommended guidelines during this evaluation, both stations were sparsely occupied. Therefore, comparing indoor and outdoor carbon dioxide concentrations may not be a good indicator of ventilation adequacy in this instance. Measuring carbon dioxide concentrations when more fire fighters are working would be a better indicator of ventilation adequacy.

The fan setting on the thermostat in the living quarters was set to "auto," meaning that the heating, ventilation, and air-conditioning system's fan will only run when the system is heating or cooling the space. Once the desired indoor temperature is reached, the fan will shut off until the next heating or cooling cycle. Changing the fan setting to "on" will keep the fan running independently of heating and cooling cycles, and can improve air mixing in the living quarters.

In station 1, counts of airborne particles < 2.5 micrometers in diameter increased in the bay after a diesel engine was started, followed by lower particle count increases in the living quarters (Figure 2). For example, a diesel-powered vehicle was started around 7:45 a.m. in the bay, then driven out. During this event the particle counts in the bay increased within 5 minutes, followed by a particle count increase in the living quarters beginning around 8:00 a.m. After the equipment returned to the bay around 8:30 a.m., the particle counts in the bay and living areas steadily declined. The increase in particle counts was likely associated with diesel exhaust particulate. We found a similar pattern at station 2 (Figure 3).

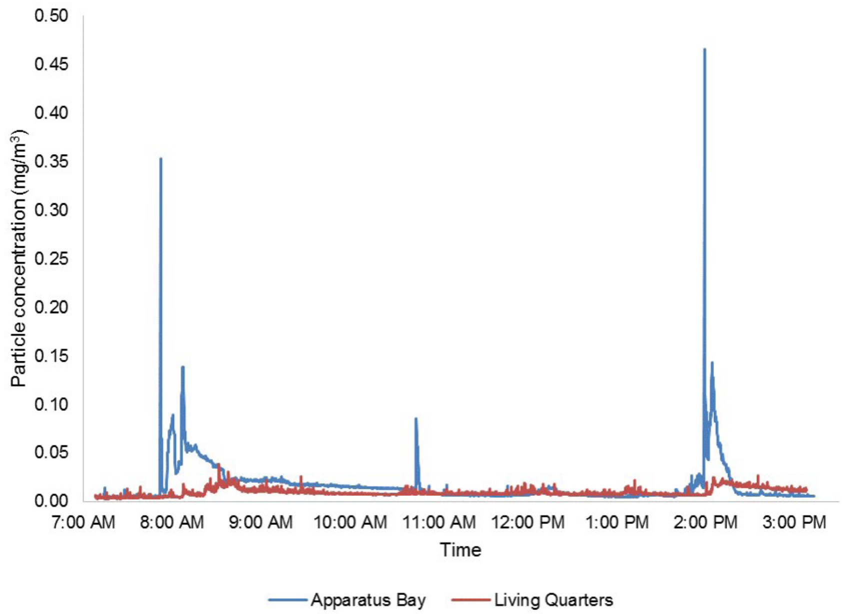

Figure 2. Concentrations of particles less than 2.5 micrometers in diameter at station 1.

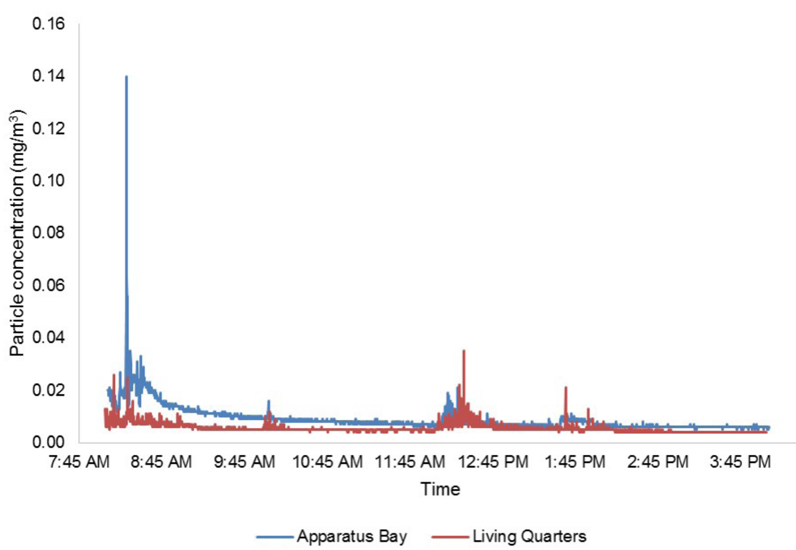

Figure 3. Concentrations of particles less than 2.5 micrometers in diameter at station 2.

Ventilation

Fire fighters operated diesel (and less commonly gasoline-powered) vehicles and equipment during weekly checks and during emergency responses. For the weekly checks fire fighters opened the front or back bay doors before starting diesel or gasoline powered vehicles. Weather permitting, the vehicle was then driven to the driveway just outside of the bay for inspection while it remained running. During inclement weather fire fighters performed these weekly checks with the vehicle running inside the bay, but with the bay door(s) open. We saw a tailpipe exhaust hose at station 1 that could have been used for equipment checks in the bay. The fire fighters indicated that this hose was used for maintenance that had to be done inside the bay, but it was not used during equipment checks in the bay.

The area near the air intakes in the apparatus bay of station 1 was used for storage of boxes and other supplies. These items impede airflow by blocking the air coming in from the intakes.

Using ventilation smoke tubes we determined that the living quarters at both stations were under negative pressure relative to the bays. This means that air flowed from the bay into the adjacent living quarters. This pressure relationship remained regardless of whether the ventilation systems in the living quarters or bays were operating or if the bay doors were opened or closed. In a fire station, it is preferable that the living quarters be kept under positive pressure compared to the bay to minimize the migration of diesel or gasoline engine exhaust into the living quarters.

Heating and air-conditioning for the living quarters at station 1 were provided by three air handlers. The air handlers were in a mechanical room adjacent to the bay. The room was about 8 feet off the bay floor (mezzanine level) and required climbing a ladder to access. Air filters were installed in two of the three air handlers (#1 and #2), but there were gaps between the filters and the filter frame, thus allowing unfiltered air to pass and then enter the living quarters. No air filters were installed in air handler #3. The air filters were a low-efficiency bulk fiberglass roll material (unknown minimum efficiency reporting value) that was cut to fit the filter opening in the air handlers. The location and design of the three air handlers made it difficult to check and replace the air filters, factors that likely contributed to the poor condition of the air filters that we observed. The outdoor air intake for the living quarters was on an exterior wall that was not near any potential sources of contaminants such as the exhaust fans in the bay.

At the smaller station 2, the air handler was located in a utility room off the living quarters, and the outdoor air intake was on the rear wall of the station that was remote from any potential contaminant sources.

Other Observations

The opening to the mechanical room containing the air handling units at station 1 is approximately 8 feet off of the bay floor and only accessible by a fixed ladder (Figure 4). The opening has curtains that were not used or were not functional, resulting in a potential fall hazard.

Figure 4. Ladder and opening to the mechanical room containing the three air handling units that supplied air to the living quarters.

Conclusions

We measured elemental carbon in the living quarters of station 1, indicating the presence of diesel exhaust. In contrast, the levels of elemental carbon in the living quarters of station 2 were similar to levels found outside of station 1.

We saw an increase in airborne particles in the living quarters of station 1 shortly after diesel-engine-powered equipment was started in the bay, suggesting that exhaust was migrating into the living areas. At both stations we found that air flowed from the bays and into the living quarters, the opposite of what is needed to minimize contaminants from migrating into the living quarters. The air handlers at station 1 had poorly installed or missing air filters, and the location and design of the air handlers made maintaining the ventilation systems difficult. The air handlers were also in a mechanical room that opened to the bay, thereby creating an opportunity for vehicular exhaust to enter the ventilation systems serving the living areas.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the fire station to use an employee-management health and safety committee or working group to discuss our recommendations 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 station.

Our recommendations are based on an approach known as the hierarchy of controls. 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. Hire a professionally licensed mechanical engineer to evaluate the ventilation at both stations. One objective would be to ensure that the living quarters are kept under positive pressure relative to the bays at all times and under all ventilation conditions, including bay doors open. This means that air should flow out from the living quarters and into the bays. Another objective would be to evaluate the ability of the air handling systems to use higher efficiency air filters that can remove more of the fine particles in the air.
2. Install a door or flexible strip curtain to block the opening between the mechanical room (housing the air handlers) and the bay at station 1. This should reduce the chance for contaminants from the bay to enter the air handlers providing ventilation for the living quarters.
3. Use the tailpipe exhaust hose at station 1 when conducting equipment checks in the bay.
4. Install properly fitting air filters in the air handlers at station 1.
5. Install a chain across the opening to the air handler mechanical room to prevent falls.

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. Keep personnel doors between the living quarters and bays closed. Also check for openings around doors and windows where diesel exhaust could enter the living areas, and repair or replace items such as damaged weather-stripping and door sweeps.
2. Open the front and back bay doors when using and checking diesel equipment. The increase in ventilation should help dilute diesel exhaust in the apparatus bay.
3. Keep bay doors open after operating gasoline or diesel-powered equipment until odors are gone.
4. Set fan setting on thermostat in the living quarters to "on."

Appendix: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits for chemical, physical, and biological agents when evaluating workplace hazards. These limits have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, occupational exposure limits 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 occupational exposure limits address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most occupational exposure limits are expressed as a time-weighted average exposure. This refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit 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, occupational exposure limits have been established by federal agencies, professional organizations, state and local governments, and other entities. Some are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor Occupational Safety and Health Administration 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.
- The National Institute for Occupational Safety and Health 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. These are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. The National Institute for Occupational Safety and Health 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 occupational exposure limits commonly used and cited in the United States include the threshold limit values, which are recommended by the American Conference of Governmental Industrial Hygienists, a professional organization, and the

workplace environmental exposure levels, which are recommended by the American Industrial Hygiene Association, another professional organization. These limits are developed by committee members of these associations from a review of the published, peer-reviewed literature and are not consensus standards. The threshold limit values 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 2016]. The workplace environmental exposure levels have been established for some chemicals “when no other legal or authoritative limits exist” [AIHA 2016].

Outside the United States, occupational exposure limits 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 occupational exposure limits from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

The Occupational Safety and Health Administration 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 occupational exposure limit. It also is important to keep in mind that occupational exposure limits may not reflect current health-based information.

When multiple occupational exposure limits exist for a substance or agent, the National Institute for Occupational Safety and Health investigators generally encourage employers to use the lowest occupational exposure limit when making risk assessment and risk management decisions. We 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 occupational exposure limits have not been established or can be used to supplement existing limits.

Diesel Exhaust

Diesel exhaust is a complex mixture of various gases and fine particles. Diesel exhaust is typically black in color with a low odor threshold (odors easily detected at low concentrations) and contains more than 40 toxic compounds [Environmental Protection Agency 2002]. The gases in diesel exhaust include hydrocarbons and oxides of carbon, sulfur, and nitrogen [NIOSH 1988; Occupational Safety and Health Administration 1988]. The particles mainly consist of organic carbon compounds adsorbed onto cores of microscopic elemental carbon. More than 95% of these particles are less than 1 micrometer in size and are respirable [NIOSH 2016]. Because of their small size, diesel exhaust particles can be inhaled deeply into the lungs and even into the bloodstream.

Diesel exhaust exposure is associated with acute health effects, such as eye, nose, throat, and lung irritation; cough; headache; lightheadedness; and nausea [Gamble et al. 1987; Pronk et al. 2009; Reger and Hancock 1980; Sydbom et al. 2001]. Diesel exhaust exposure is also associated with lung inflammation, can aggravate asthma and other chronic respiratory conditions, and make allergenic responses worse [Sydbom et al. 2001, Ulfvarson and Alexandersson 1990]. Whether a person experiences these acute or chronic health effects depends on the duration and magnitude of the exposures and on individual susceptibility.

Research from NIOSH has shown an increased risk of death from lung cancer in underground miners [Attfield et al. 2011]. The International Agency for Research on Cancer has concluded, with sufficient evidence, that diesel exhaust is a Group 1 human carcinogen that causes lung cancer, and is positively associated, with limited evidence, with an increased risk of bladder cancer [International Agency for Research on Cancer 2012]. NIOSH considers diesel exhaust emissions a potential occupational carcinogen and recommends exposure be kept at the lowest feasible concentration. NIOSH is currently developing quantitative recommended exposure limits based on human and/or animal data, with consideration to the availability of workplace exposure controls. The Occupational Safety and Health Administration does not have a permissible exposure limit for diesel exhaust. 1-nitropyrene is a nitrated polycyclic aromatic hydrocarbon, which is also a component of diesel exhaust [Bamford et al. 2003], and has been used a surrogate measurement of exposure to diesel particulate matter [Galaviz et al. 2015; Miller-Schulze et al. 2010]. We measured carbon monoxide because it is a component of most combustion processes. The International Agency for Research on Cancer classified 1-nitropyrene as a Group 2A carcinogen, or “probably carcinogenic to humans” [International Agency for Research on Cancer 2014]. 1-nitropyrene has also been identified as a potential mutagen [Chan 1996; Scheepers et al. 1995]. Other health effects from 1-nitropyrene exposure are not well known.

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Availability of Report

Copies of this report have been sent to the employer, union, and employees at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

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