HHE Health Hazard Evaluation Program

Evaluation of Diesel Exhaust Control Methods at a Fire Station in a City Fire Department

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Program Description

The National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 [29 USC 669a(6)]. The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations [42 CFR Part 85].

Disclaimer

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Availability of Report

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

Recommended Citation

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Introduction

Request

The Health Hazard Evaluation Program received a request from management at a city fire department. The fire marshal was concerned about firefighters' exposure to diesel exhaust when fire apparatuses are running in the apparatus bay.

Workplace

The two-story fire station had six pull-through apparatus bays with bay doors on the front and back walls. Adjoining living quarters on the first floor included a kitchen and dining area, a captain's office, a gym, and three work offices. The dormitory was located on the second floor, with locker rooms and a separate bedroom for the station's captain. At the time of our evaluation, the station housed five emergency response vehicles. The station housed one diesel-powered fire engine (2014 Rosenbauer), one diesel-powered tower truck (2019 Sutphen), one diesel-powered medic unit (2018 Ford F-550), one gasoline-powered SUV, and one gasoline-powered pickup truck.

The apparatus bay of the station was equipped with an air filtration system consisting of six ceiling-mounted units. The apparatus bay had a ceiling height of 32 feet (ft), with each of the six air filtration units installed approximately 24 ft above the floor. Each unit included a direct-drive blower, an auto-roll pre-filter media, a particle filter of Minimum Efficiency Reporting Value (MERV) 15, and a carbon/alumina filter. The bay also had two exhaust fans at the far end of the apparatus bay away from the living quarters. The exhaust system discharged air to the outdoors. A louvered outdoor air intake, designed to replace the air exhausted from the bay by these fans, was installed on the opposite wall of the bay near the roof and adjacent to the living quarters. Figure A1 shows the position of the air filtration system in the apparatus bay.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

We conducted an initial walkthrough of the facility in August 2024 to tour the facility and gather information to prepare for a follow-up visit. We returned in July 2025, and we did the following activities:

- Observed work processes and practices.
- Collected area air samples of diesel particulate during one 12-hour period and one 8-hour period in the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors.

- Measured real-time concentrations of carbon monoxide, carbon dioxide, and particulates over an approximately 32-hour period in the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors.
- Conducted a ventilation assessment at the station.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Levels of diesel particulate and other components of diesel exhaust were low in the apparatus bay and living quarters

- Air concentrations of carbon monoxide, carbon dioxide, and particulates were well below occupational exposure limits. While these were not personal samples, the samples were collected near where employees typically worked.
- Although air concentrations were low, some exhaust fans needed repair. Making sure exhaust fans are working properly can help keep air concentrations low.
- Industrial air cleaners provided effective filtration in the apparatus bay but had insufficient runtime, allowing diesel-related particle concentrations to remain elevated for up to two hours after vehicle operation. Extending the air cleaners' runtime and restoring the additional exhaust fan would improve ventilation performance in the bay.

Air flowed from the living quarters into the apparatus bay

- This ventilation setup is recommended for keeping exposures to vehicle exhaust low.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The potential benefits of improving workplace health and safety are:

↑ Improved worker health and well-being	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier employee recruiting and retention	↑ Increased overall cost savings

The recommendations below are based on the findings of our evaluation. These recommendations are workplace-specific, based on the information available for the workplace evaluated, and are intended to improve this workplace's conditions. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls is a way of determining which actions will best control exposures. In most cases, the preferred approach is to eliminate hazards or to replace the hazard with something less hazardous (i.e., substitution). Installing engineering controls to isolate people from the hazard is the next step in the hierarchy. Until such controls are in place, or if they are not effective or practical, administrative controls and personal protective equipment might be needed. Read more about the hierarchy of controls on the NIOSH website.

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in OSHA's Recommended Practices for Safety and Health Programs.

Recommendation 1: Reduce firefighters' exposures to diesel exhaust in the apparatus bay as much as possible

Why? Reducing exposure to diesel exhaust would help keep eyes and respiratory systems from getting irritated, especially among workers who are sensitive to diesel exhaust, such as people with asthma.

Breathing in diesel exhaust at work has been associated with eye, nose, throat, and lung irritation. Diesel exhaust is a carcinogen, and exposure is also associated with lung inflammation, can aggravate asthma and other chronic respiratory conditions, and make allergic responses worse.

While air concentrations of components of diesel exhaust were lower than occupational exposure limits, the following recommendations could further reduce diesel exhaust exposure.

How? At your workplace, we recommend these specific actions:

Repair both exhaust fans in the apparatus bay and the second-story pole enclosure

Consider source control in addition to air cleaners in the apparatus bay

- Although additional air cleaner runtimes could marginally increase total air cleaning, the six ceiling-mounted units were not close enough in proximity to the diesel emissions sources to prevent the buildup of particles in the bay. Consider installing source-capture systems in addition to restoring mechanical exhaust fans within the bay. The air cleaners may supplement overall filtration but are not effective as a primary source control for diesel particulate in a large bay.

Close apparatus bay doors when equipment is running outside of the bay

- This is especially important if apparatuses are high idling outside of the bay.

Recommendation 2: Address other health and safety issues we identified during our evaluation

Why? A workplace can have multiple health hazards that cause worker illness or injury. Similar to the ones identified above, these hazards can potentially cause serious health symptoms, lower morale and quality of life for your employees, and possibly increased costs to your business. We saw the following potential issues at your workplace:

- We found a bird's nest in the outdoor air intake louvers connected to the duct that supplies air for filling the self-contained breathing apparatus tanks.

Although they were not the focus of our evaluation, these hazards could cause harm to your workers' health and safety and should be addressed.

How? At your workplace, we recommend these specific actions:

Remove the bird's nest from the outdoor air intake louvers

- Prevent birds from entering the intakes by installing screens, mesh, or netting.

Supporting Technical Information

Evaluation of Diesel Exhaust Control Methods at a Fire Station in a City Fire Department

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Section A: Workplace Information

The two-story fire station was built in 2013 and was staffed by nine full-time firefighters. Squads of firefighters worked 24-hour alternating shifts, with 48 hours off in between. All employees belonged to a union. During our initial walkthrough, this station was identified as the busiest station in the department. The apparatus bay volume was approximately 270,000 cubic feet (ft^3).

The building used a geothermal heating and cooling system, with mechanical equipment located inside the second floor of the building for noise reduction and longer equipment life. The living quarters ventilation was provided by a dedicated outdoor-air system (DOAS) with an energy recovery ventilator that introduced conditioned outdoor air to the building through an intake located on the back side of the building and discharged exhaust air to the front side of the building. Zone-level conditioning in the living quarters was provided by ceiling-mounted, ducted water-source heat pumps (WSHP) connected to the building's geothermal loop. Consistent with hot-/warm-/cold-zone design principles for fire stations, the heating, ventilation, and air-conditioning (HVAC) systems were sequenced to keep the apparatus bay under negative pressure relative to the living quarters to limit migration of vehicle exhaust and contaminated air into the living quarters. Supply air to the apparatus bay was delivered by this same system through five diffusers along a duct that ran parallel to the bay doors and was installed in the middle line of the space near the ceiling.

The apparatus bay had two dedicated exhaust systems. They were designed to enhance air changes in the apparatus bay and to maintain the bay under negative pressure relative to the living quarters. One exhaust system was provided by the same DOAS described above with ductwork containing five air intake grilles running along the ceiling by the wall separating the apparatus bay from the living quarters. The other exhaust system included two exhaust fans at the far end of the apparatus bay away from the living quarters and wall-mounted ductwork with upper and lower intake grilles, which directed airflow outdoors through wall-penetrating ductwork. These two exhaust fans were designed to be activated when air concentrations of carbon monoxide reached a certain level in the bay or could be manually turned on. In addition, space heating to the apparatus bay was provided by radiant equipment appropriate for large-volume bays.

The apparatus bay had a ceiling height of 32 ft, with six air cleaners installed approximately 24 ft above the floor. Each air cleaner had a three-stage filtration process designed to capture particulates and other airborne contaminants. Each unit had a 3,000 cubic feet per minute (cfm) direct-drive blower, an auto-roll pre-filter media, a MERV 15 particle filter, and a carbon/alumina filter. Air from the bay was drawn into the air cleaner baffle box attachment, passed through the filters, and then recirculated back into the facility. Sensors positioned near the top of each overhead bay door were configured to detect vehicle entry or exit to initiate operation of all six ceiling-mounted air cleaners. During the evaluation, the programmed cycle time was set for the air cleaners to run for approximately 9–10 minutes after each sensor activation.

There were five doorways that separated the living quarters from the apparatus bay. Three of these doorways were located on the first floor, providing direct passage between the administrative/dayroom spaces and the apparatus bay. The remaining two openings housed fire poles connecting the second-floor sleeping quarters to the apparatus bay. Both second-story pole enclosures were equipped with dedicated small exhaust fans designed to activate when enclosure doors were opened. These fans were intended to draw air from the fire pole enclosure directly into the apparatus bay to prevent vehicle exhaust and other contaminants from migrating into the sleeping quarters.

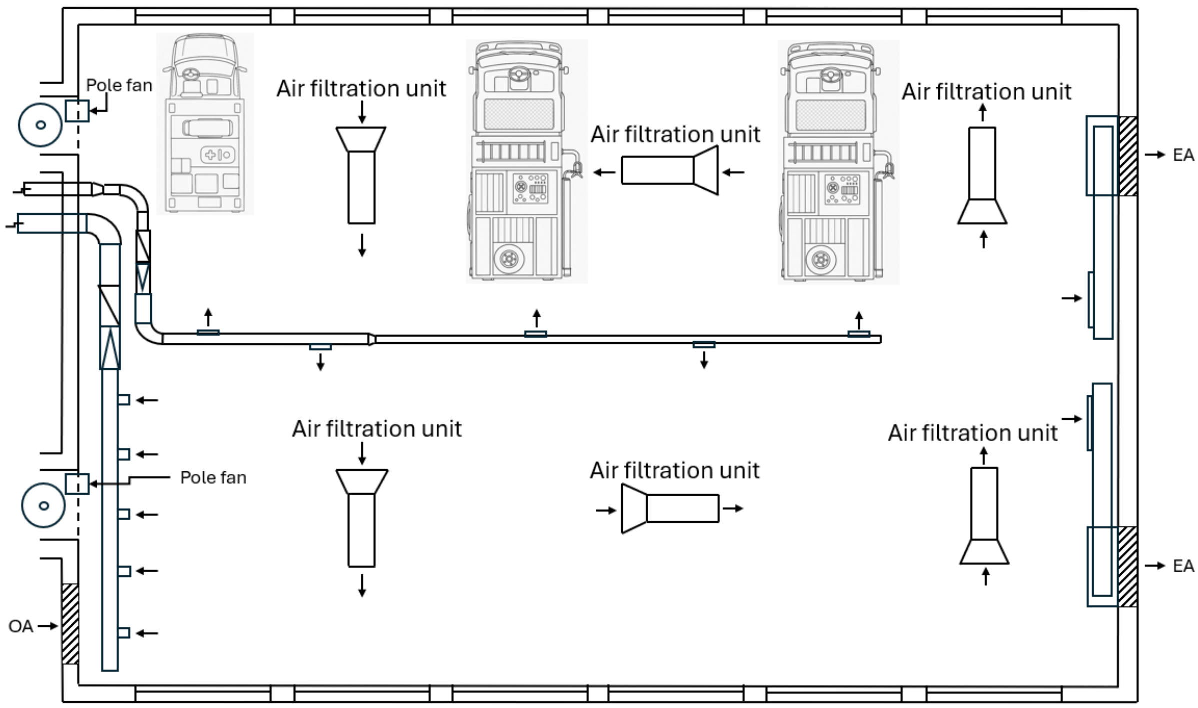

Figure A1. Positions of the air filtration units in the apparatus bay.

EA = exhaust air, OA = outdoor air.

Section B: Methods, Results, and Discussion

Methods: Observations of Work Processes, Practices, and Conditions

We collected information on the following during our site visit:

- Number of runs made
- Work processes
- Workplace conditions

Results: Observations of Work Processes, Practices, and Conditions

Table C1 shows the number of runs per diesel apparatus during our site visit. This run list does not include those instances when a crew went out for reasons other than incident response, including training, hydrant testing, or grocery runs.

- We observed an ambulance high idling less than 10 ft from rear bay doors for about 20 minutes during the morning of the first sampling day. The apparatus bay doors closest to the vehicle were open during this time.
- During our ventilation assessment, we observed that there was a bird's nest in the duct that supplies outdoor air for filling self-contained breathing apparatus (SCBA) tanks.

Methods: Exposure Assessment

Particulates

Diesel Particulate Matter (as Elemental Carbon)

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. Due to the emergency response nature of their jobs and the importance of quickly putting on firefighter turnout gear to leave the station, personal samples were determined to be impractical and could have potentially impeded their ability to perform their emergency response duties. Although we did not collect personal samples, we placed the area samples in locations where firefighters typically worked or resided within the station. We collected area air samples for diesel particulate matter (as elemental carbon) from the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors. Firefighters can have diesel exhaust exposures away from the fire station; however, the scope of this HHE was on evaluating exposures within the station. We collected the air samples at a flow rate of 2 liters per minute on a three-piece, 37-milimeter diameter open-faced cassette with a heat-treated quartz-fiber filter supported on a cellulose pad.

- We analyzed each sample for elemental carbon using NIOSH Method 5040, using thermal-optical analysis [NIOSH 2025].
- We calculated area air concentrations of elemental carbon at each of the sampling locations.

DustTrak Monitors

We measured particulates using DustTrak™ DRX 8533 aerosol monitors (TSI, Inc.) in the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors. All monitors were set to log particle mass concentrations every 30 seconds in different size groups: particulate matter (PM) smaller than 1 micron (µm) (PM_1); PM smaller than 2.5 µm ($PM_{2.5}$); respirable (less than 4 µm); PM smaller than 10 µm; and total PM (less than 100 µm). The data output was expressed as the mass concentration of particles per cubic meter (mg/m^3) of the sampled air. The lower instrument range was less than 0.001 mg/m^3.

Condensation Particle Counters

We also measured particulates using TSI® Model 3007 handheld condensation particle counters (CPCs) in the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors. All CPCs were set to log particle number concentrations every second in the size range of 0.01 to >1 µm, including ultrafine particles (smaller than 0.1 µm). The data output was expressed as the total number of particles per cubic centimeter (p/cm^3) of the sampled air. The detectable concentration for the CPC ranged from 0 to 100,000 p/cm^3.

Carbon Monoxide and Carbon Dioxide

We used TSI Q-Trak™ indoor air quality monitors to measure carbon dioxide, carbon monoxide, temperature, and relative humidity in the apparatus bay, captain's office, dormitory hallway, kitchen, and outdoors. Carbon dioxide is released by occupants and its levels in air can be used to assess the effectiveness of ventilation systems. Carbon monoxide is a component of most combustion processes. The monitors were set to log data every 30 seconds. While we were able to observe near real-time carbon monoxide air concentrations in the sampling locations, not all of the carbon monoxide data from the Q-Traks were appropriately saved and thus summary data for the apparatus bay, captain's office, and dormitory hallway cannot be reported.

Results: Exposure Assessment

Particulates

We collected area air samples for diesel particulate matter for approximately 12 hours on the first sampling day and eight hours on the second day. Elemental carbon was not detected in any of the samples. Tables C2 through C4 summarize particle concentrations, reported as milligrams per cubic meter of air (mg/m^3), in different size groups during the sampling period. Respirable particle concentrations ranged from 0.024–0.070 mg/m^3 in the apparatus bay, 0.011–0.036 mg/m^3 in the captain's office, 0.004–0.512 mg/m^3 in the kitchen, less than 0.001–0.046 mg/m^3 in the dormitory hallway, and less than 0.001–0.069 mg/m^3 outdoors. The Occupational Safety and Health Administration (OSHA) has a permissible exposure limit (PEL) for respirable dust of 5 mg/m^3 time-weighted average (TWA). This limit is intended for nuisance dust that is known to not contain harmful components. Additionally, area samples cannot be compared to occupational exposure limits since these limits are based on personal exposure levels.

Concentrations of airborne ultrafine particles (less than 0.1 µm in diameter) increased in the bay while diesel engines were running, but not in the living quarters. Figure B1 shows the concentrations of ultrafine particles in the sampling locations after an ambulance high idled outside of the apparatus bay when the bay doors were open. While the concentration of ultrafine particles increased in the bay, there was not a corresponding increase in concentration in the living quarters. After the ambulance pulled through the bay and left the station, the ventilation in the bay turned on and the concentration of ultrafine particles in the bay steadily declined over the next two hours to just above outdoor levels. The bay doors were closed for the majority of this time, except for when apparatus entered and exited the bay. We also noticed an increase and then decrease in the concentration of ultrafine particles in the kitchen related to cooking activities using the station's gas stove.

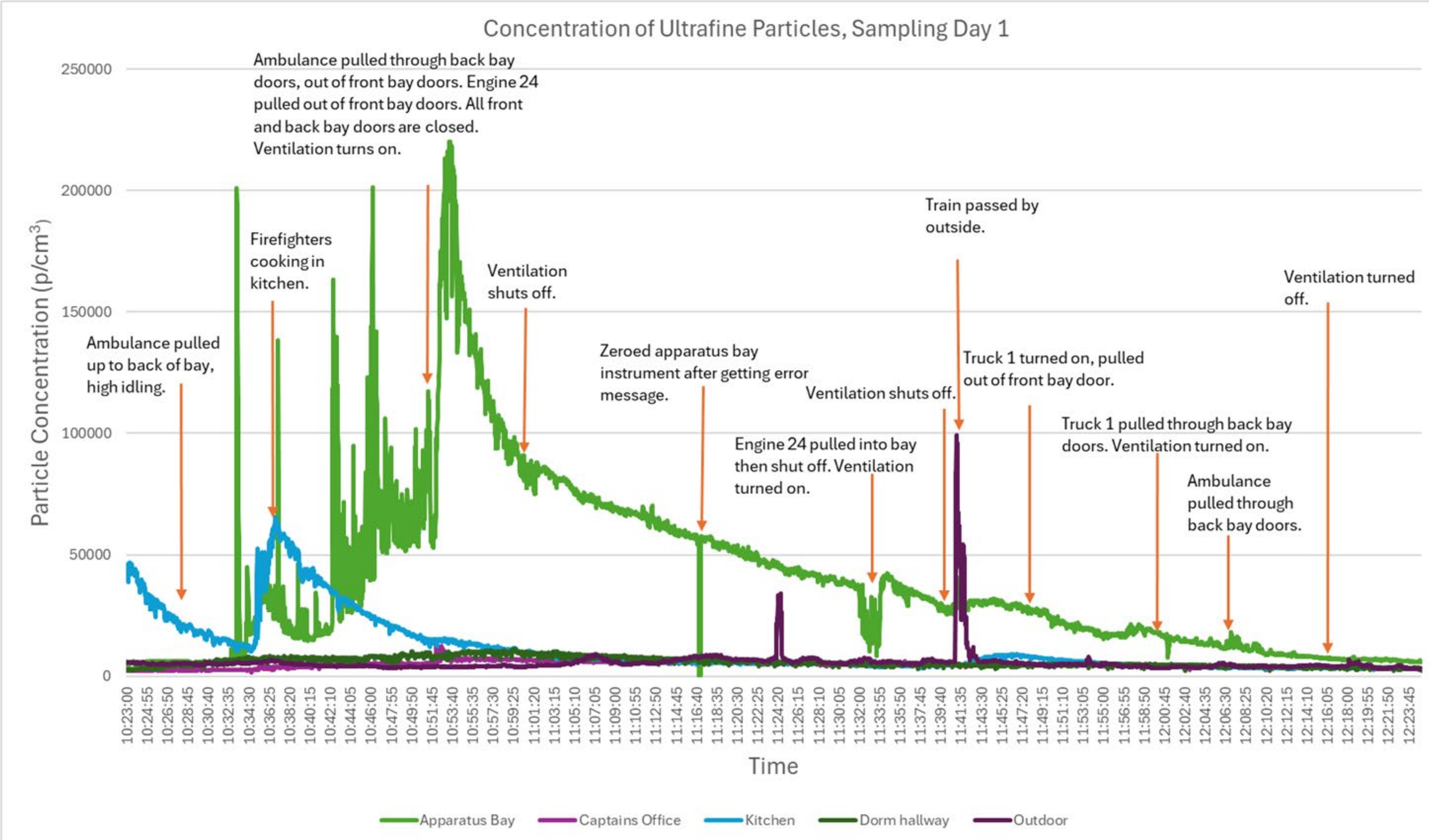

Figure B1. Concentration of ultrafine particles during and after an ambulance high idled outside the back of the apparatus bay. Figure by NIOSH.

Carbon Monoxide and Carbon Dioxide

Table C5 summarizes carbon monoxide concentration in parts per million of air (ppm) in the kitchen and outdoors during the sampling period. The average carbon monoxide concentration in the kitchen was 0.1 ppm (range: <0.1 ppm to 2.6 ppm), similar to outdoor levels. For perspective, in industrial settings OSHA has a PEL for carbon monoxide of 50 ppm TWA, and the NIOSH recommended exposure limit (REL) is 35 ppm, TWA [NIOSH 2019; OSHA 2025].

Carbon dioxide concentrations ranged from 343–2,246 ppm in the apparatus bay, 408–1,130 ppm in the captain's office, 405–1,051 ppm in the kitchen, 434–762 ppm in the dormitory hallway, and 323–470 ppm outdoors. OSHA and NIOSH have a PEL and REL for carbon dioxide of 5,000 ppm TWA, respectively.

Methods: Ventilation Assessment

We reviewed ventilation system operational parameters by doing the following: (1) reviewed mechanical drawings; (2) assessed the contribution to the air change rate in the apparatus bay from the air filtration system, dedicated exhaust fans, and exhaust through the air handling unit; (3) assessed pressure differences between the apparatus bay and the living quarters; and (4) determined the particulate filtration efficiency of one of the ceiling-mounted air-cleaning units.

We used a TSI Velocicalc® with an attached rotating vane anemometer for ventilation measurements of the apparatus bay exhaust system. Air velocity readings were taken across the face of each exhaust grille, and the measured average velocity was multiplied by the free area of the opening to calculate volumetric airflow. The calculated volumetric airflow measurements were compared to the original design drawings.

Airflow from the ceiling-mounted industrial air cleaners was measured by removing the downstream access cover and positioning a TSI® Alnor® flow hood with a 2 ft × 2 ft skirt directly over the unit outlet. This setup allowed for a direct volumetric airflow reading to be obtained at the discharge of the air cleaner. Particulate filtration efficiency was estimated by measuring upstream and downstream particle counts with a TSI® Model 3007 CPC.

A micromanometer was used to measure differential pressure across all five doorways that separate the living quarters from the apparatus bay. To supplement the quantitative pressure readings, smoke tracer tests were conducted at each doorway to observe airflow direction and confirm pressurization relationships. This method provided a visual verification of the micromanometer results, particularly at transient points such as the fire pole enclosures.

Results: Ventilation Assessment

The total air change rate in the apparatus bay was 3.9 air changes per hour (ACH), meaning air was exchanged once every 15–16 minutes if the air was effectively mixed when all the bay doors are closed. The air filtration units have a manufacturer-rated fan capacity of 3,000 cfm. The unit we measured was operating at 2,200 cfm, which is expected considering the pressure resistance from the three layers of filters used for the system. Measurement of upstream and downstream particle counts showed that the evaluated air filtration unit achieved an 87% reduction in particle concentrations (in the size range of 0.01 to >1 µm) as air passed through the filters, thus allowing the six air cleaners to contribute approximately 2.6 ACH in total. Although our particle measurements were in the size range of 0.01 to

>1 μm and do not align exactly with the ASHRAE Standard 52.2 size bins used for MERV ratings, the observed 87% reduction is consistent with the expected performance of a MERV 15 filter, which is rated to capture ≥85% of particles 0.3–1.0 μm, ≥90% of particles 1.0–3.0 μm, and ≥95% of particles 3.0–10 μm [ANSI/ASHRAE 2017]. During the site visit, one exhaust fan was not in service, and the other exhaust fan was operating continuously. The operating fan was measured to have 4,000 cfm, the same as the mechanical drawing indicated, which contributed 0.9 ACH. ASHRAE Standard 62.1 lists minimum exhaust rates of 0.75 cfm/ft^2 for parking garages, which equates to about 6,300 cfm for the apparatus bay [ANSI/ASHRAE 2025]. With both 4,000 cfm exhaust fans, the system has more than the minimum exhaust rates listed in the standard. Additionally, the exhaust that returned air from the apparatus bay to the DOAS was measured at the air intake grilles with a total flow of 1,870 cfm, contributing an additional 0.4 ACH.

Smoke tracer tests verified the negative pressure in the apparatus bay relative to the living quarters at all five doorways that separated the two spaces. The pressure difference was measured at -0.007 and -0.015 inches of water column (in. w.c.) for two doorways on the first floor (note that the measurement was not conducted at the third doorway due to the tight fitting of the door gap); and at -0.014 and -0.015 in. w.c. for the two doorways on the second floor. Also, at the time of evaluation, one of the pole enclosure exhaust fans was observed to be non-functional.

Discussion

There are a variety of different strategies fire departments use to control diesel exhaust emissions into fire stations. These include exhaust filtration systems, tailpipe exhaust ventilation, and dilution ventilation. Engine exhaust filters work by removing particulates from the diesel exhaust. The filters are installed in the vehicle's exhaust system or at the tailpipe. These systems are typically on a timer and operate for a preset amount of time (from a few seconds to a couple of minutes) to allow the vehicle to exit the station. Tailpipe exhaust ventilation involves attaching an exhaust hose to the tailpipe with the exhaust hose connected to a fan that discharges diesel exhaust to the outside. An advantage of using an exhaust hose is that it removes both gaseous and particulate emissions in the diesel exhaust. Dilution ventilation relies on a fan to exhaust contaminated air to the outside while fresh outside makeup air flows into the bay through open doors or supply-air openings. Unlike the other two strategies, dilution ventilation does not capture emissions at the source [Roegner et al. 2002]. The station we evaluated used a combination of dilution ventilation and air cleaning to control indoor diesel exhaust emissions.

Tables C2 through C4 summarize particle concentrations, reported as milligrams per cubic meter of air (mg/m^3), in different size groups during the sampling period. Most of the particles were smaller than 1 μm in diameter. In general, average particle concentrations were higher in the apparatus bay compared to the other sampling locations. When the apparatus entered or exited the station, we did not find any corresponding increase in particle concentrations in the living quarters. We also did not observe any increases (more than twice the background level) in CO concentrations within the living quarters during apparatus run times. This finding, along with the average CO concentrations reported in Table C5, suggests that exhaust from the diesel apparatus was not entering the living and sleeping quarters. In addition, we observed a negative pressure relationship between the apparatus bay and the living quarters. These findings indicate that air did not flow from the apparatus bay into the living quarters, which is preferred.

Particles larger than 100 μm in diameter may be too big to enter the deepest areas of the lungs but can enter the nose, mouth, and upper airways during breathing. Particles smaller than 4 μm in diameter are respirable and can penetrate deeply into the lower respiratory system [ACGIH 2025]. Fine particles (less than 2.5 μm in diameter) and ultrafine particles (less than 100 nanometers (nm) in diameter) are primarily deposited in the small airways and alveoli [EPA 2025]. Ultrafine particles are small enough to pass through the alveoli into the bloodstream [American Lung Association 2025]. Acute and chronic exposure to respirable particles have been linked with adverse health effects, including cardiovascular disease, respiratory disease, developmental and reproductive effects, and lung cancer [EPA 2025]. Most particles in diesel exhaust are within the respirable size fraction and most are ultrafine, in terms of particle counts [Debia et al. 2016].

OSHA has a PEL of 5 mg/m^3 for respirable dust over an 8-hour TWA [OSHA 2025]. This PEL is for particulates not otherwise regulated, including nuisance dust or inert dust. For dust containing diesel particulate, this PEL may not be applicable. The American Conference of Governmental Industrial Hygienists (ACGIH®) recommends that airborne concentrations of respirable dust be kept below 3 mg/m^3 [ACGIH 2025]. Currently, neither OSHA nor NIOSH has occupational exposure limits for exposure to diesel particulate matter (as elemental carbon) or ultrafine particles of nuisance dust. We did not detect elemental carbon in any of the samples.

The six ceiling-mounted industrial air cleaners were effective at single pass particle filtration and contributed to reductions in particle concentrations within the apparatus bay. Immediately following vehicle operation, however, CPC measurements taken at locations more than 40 ft from the apparatus occasionally exceeded the instrument's upper limit of 100,000 particles per cubic centimeter of air, depending on the number of bay doors open. Although the air cleaners were programmed to operate for approximately 9–10 minutes after activation, particle concentration data, as shown in Figure B1, indicated that it sometimes required approximately two hours for the particle concentration to return to background levels. This suggests that the air cleaners were insufficient to fully address the diesel exhaust burden in the apparatus bay. Increasing the air cleaners' run time may marginally improve ventilation in the bay and implementing source control may be more effective. Furthermore, bringing the other exhaust fan back into service would be expected to increase the air change rate in the apparatus bay by another 0.9 ACH.

During our ventilation assessment, we observed that there was a bird's nest in the duct that supplies outdoor air for filling SCBAs. Exposures to birds as well as other allergens have been associated with respiratory diseases, including hypersensitivity pneumonitis. A fungus, *Histoplasma capsulatum,* is also associated with bird droppings. This fungus, when present in soil, can flourish when bird droppings provide nutrients for its growth [NIOSH 2004; Wheat and Kauffman 2003]. Birds can also carry the fungi on their wings, feet, and beaks [NIOSH 2004]. *Histoplasma capsulatum* tends to be present in geographic cluster areas. In the United States, *Histoplasma capsulatum* is most common (endemic) along the Ohio and Mississippi valleys [Kauffman 2006]. However, even in regions where *Histoplasma capsulatum* is not considered highly endemic, outbreaks of histoplasmosis from inhaling spores of

Histoplasma capsulatum have resulted from work-related activities in bird roosts which caused contaminated dust to become airborne [DiSalvo and Johnson 1979; Morse et al. 1985; NIOSH 2004].

It is important to prevent birds from roosting or nesting in outdoor air intakes or ductwork to prevent potential exposure to allergens or diseases. Strategies to keep birds out of these spaces include blocking openings with screens or mesh and regular inspection of roof and HVAC systems to identify intrusion.

Limitations

This evaluation is subject to several limitations. Industrial hygiene sampling can only document exposures and conditions in the locations evaluated on the days that the evaluation occurred. These results may not be representative of conditions during other days due to the nature of the work or change in season. It is important to note that we only collected area samples where employees typically worked. We did not collect any personal exposure measurements and so cannot directly compare our results with occupational exposure limits, which are for personal exposures.

Conclusions

Levels of diesel exhaust particulate (as elemental carbon) and other components of vehicle exhaust were low in the apparatus bay and living quarters. Our results showed that most of the particulate in the apparatus bay was smaller than 1 μm in diameter. Ultrafine particle concentrations in the apparatus bay consistently spiked above the upper limit of our direct reading instrument during engine start events and took approximately two hours to return to background levels. Further evaluation is recommended to assess whether extending air cleaner runtimes or implementing combined control technologies, such as source control, could more effectively reduce particulate concentrations from vehicle exhaust in the apparatus bay.

Section C: Tables

Table C1. Daily diesel engine apparatus runs

Diesel apparatus	Sampling Day 1	Overnight	Sampling Day 2
Medic unit	6	6	5
Fire engine	5	3	2
Fire truck	1	1	1
Total	11	10	8

Table C2. Average particle concentrations (mg/m^3) during the first sampling day

	Bay Average (range)	Captain's office Average (range)	Kitchen Average (range)	Dorm hallway Average (range)	Outdoors Average (range)
PM_1	0.044 (0.019–0.064)	0.021 (0.019–0.035)	0.016 (0.012–0.073)	0.008 (0.005–0.026)	0.027 (ND*–0.067)
$PM_{2.5}$	0.045 (0.020–0.066)	0.021 (0.019–0.035)	0.016 (0.013–0.073)	0.008 (0.005–0.028)	0.027 (ND–0.068)
Respirable	0.047 (0.024–0.070)	0.022 (0.019–0.036)	0.016 (0.013–0.073)	0.008 (0.005–0.032)	0.027 (ND–0.069)
PM_{10}	0.051 (0.029–0.077)	0.022 (0.019–0.036)	0.017 (0.013–0.074)	0.009 (0.005–0.054)	0.027 (ND–0.070)
Total	0.053 (0.032–0.083)	0.024 (0.019–0.047)	0.018 (0.013–0.077)	0.010 (0.006–0.066)	0.027 (ND–0.070)

* ND = non-detect, less than the instrument's limit of detection, 0.001 mg/m^3

Range = minimum – maximum

Table C3. Average particle concentrations (mg/m^3) overnight, between the first and second sampling day

	Bay Average (range)	Captain's office Average (range)	Kitchen Average (range)	Dorm hallway Average (range)
PM_1	0.044 (0.037–0.057)	0.017 (0.011–0.030)	0.010 (0.004–0.021)	0.005 (ND*–0.023)
$PM_{2.5}$	0.044 (0.037–0.058)	0.017 (0.011–0.030)	0.010 (0.004–0.021)	0.005 (ND–0.023)
Respirable	0.045 (0.037–0.059)	0.017 (0.011–0.030)	0.010 (0.004–0.021)	0.005 (ND–0.023)
PM_{10}	0.047 (0.038–0.064)	0.017 (0.011–0.031)	0.010 (0.004–0.023)	0.005 (ND–0.024)
Total	0.048 (0.038–0.069)	0.018 (0.011–0.065)	0.011 (0.004–0.040)	0.006 (ND–0.024)

* ND = non-detect, less than the instrument's limit of detection, 0.001 mg/m^3

Range = minimum – maximum

Table C4. Average particle concentrations (mg/m³) during the second sampling day

	Bay Average (range)	Captain's office Average (range)	Kitchen Average (range)	Dorm hallway Average (range)	Outdoors Average (range)
PM_1	0.041 (0.037–0.046)	0.014 (0.011–0.020)	0.040 (0.004–0.492)	0.010 (0.001–0.044)	0.007 (ND*–0.019)
$PM_{2.5}$	0.041 (0.038–0.047)	0.014 (0.011–0.020)	0.040 (0.004–0.505)	0.011 (0.001–0.045)	0.007 (ND–0.019)
Respirable	0.042 (0.038–0.047)	0.014 (0.012–0.020)	0.041 (0.004–0.512)	0.011 (0.001–0.046)	0.008 (ND–0.019)
PM_{10}	0.043 (0.039–0.053)	0.014 (0.012–0.020)	0.042 (0.004–0.534)	0.011 (0.001–0.048)	0.009 (ND–0.025)
Total	0.044 (0.039–0.057)	0.016 (0.012–0.038)	0.045 (0.004–0.568)	0.011 (0.001–0.049)	0.009 (ND–0.042)

* ND = non-detect, less than the instrument's limit of detection, 0.001 mg/m³

Range = minimum – maximum

Table C5. Average carbon monoxide concentrations (ppm)

Sampling day	Kitchen Average (range)	Outdoors Average (range)
Day 1	0.1 (ND*–1.4)	0.4 (0.1–1.0)
Overnight	ND	—
Day 2	0.1 (ND–2.6)	0.1 (ND–0.6)

* ND = non-detect, less than the instrument's limit of detection, 0.1 ppm

Range = minimum – maximum

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits (OELs) for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to decrease the risk of 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 preexisting 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 (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA 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.

- OSHA, an agency of the U.S. Department of Labor, publishes permissible exposure limits [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These legal limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970. The Occupational Safety and Health Act requires employers to provide a safe workplace.
- NIOSH recommended exposure limits (RELs) 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 RELs are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2007]. 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.
- Another set of OELs commonly used and cited in the United States includes the threshold limit values or TLVs, which are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They 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 2025].

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 contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) 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. 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.

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 [EPA 2002]. The gases in diesel exhaust include hydrocarbons and oxides of carbon, sulfur, and nitrogen [NIOSH 1988; OSHA 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 exposed to diesel exhaust [Attfield et al. 2012]. The International Agency for Research on Cancer (IARC) 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 [IARC 2012]. NIOSH considers diesel exhaust emissions a potential occupational carcinogen and recommends exposure be kept at the lowest feasible concentration. The Occupational Safety and Health Administration does not have a permissible exposure limit for diesel exhaust.

Carbon Monoxide

CO is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials, e.g., gasoline. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma or death may occur if high exposures continue. Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb) [ACGIH 2025; NIOSH 1972, 1977, 1979, 2007; Proctor et al. 1988]. The NIOSH REL for CO is 35 ppm for an 8-hour TWA exposure, with a ceiling limit of 200 ppm that should not be exceeded [NIOSH 2007]. The NIOSH REL is designed to protect workers from health effects associated with COHb levels in excess of 5% [NIOSH 1972]. ACGIH recommends a TLV of 25 ppm as an 8-hour TWA. This is designed to protect workers from health effects associated with COHb levels in excess of 3.5% [ACGIH 2025]. The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure [29 CFR 1910.1000].

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