Control of Diesel Exhaust at a Municipal Fire Station

HHE Report No. 2023-0106-3432

April 2026

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Keywords: North American Industry Classification System (NAICS) 922160 (Fire Protection), Diesel Exhaust, Elemental Carbon, Ventilation, Engine Exhaust Filter, Fire Station, Firefighters, Iowa

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].

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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 have also received a copy. This report is not copyrighted and may be freely reproduced.

Recommended Citation

NIOSH [2026]. Control of diesel exhaust at a municipal fire station. By Echt H, Qi C, Hammond D, Niemeier-Walsh M. Cincinnati, OH: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 2023-0106-3432, https://www.cdc.gov/niosh/hhe/reports/pdfs/2023-0106-3432.pdf.

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Introduction

Request

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

Workplace

The two-story fire station had a large apparatus bay that held two back-in-only bays and four pull-through bays. Doors on the front and back walls of the apparatus bay allowed vehicles to drive through. The first floor included a kitchen and dining area, report office, gym, turnout gear storage room, and several administrative offices for department leadership and staff. The dormitory and locker rooms were on the second floor. At the time of our evaluation, the station housed one gasoline-powered pickup truck, two diesel-powered fire engines (2010 Spartan and 2003 Becker), one diesel-powered tower ladder truck (2011 Pierce), two diesel-powered ambulances (2022 and 2024 Ford F-550s), a diesel-powered water tender, and a diesel-powered brush truck.

All diesel-powered apparatuses built after 2007 were equipped with ceramic diesel particulate filters. These are designed to remove diesel particulate from the exhaust stream upon vehicle startup. The system is installed directly on the muffler and does not require a diverter valve. The 2003 fire engine was equipped with an older model engine exhaust filter. Upon startup, this system diverted engine exhaust through a filter instead of the muffler and tailpipe. The system filtered the exhaust for a preset amount of time, from 10–99 seconds, allowing the engine time to leave the bay. Afterward, the exhaust was redirected through the muffler and tailpipe.

Both systems require regular cleaning (called regeneration) of their filters. During this process, diesel particulate is removed from the filter using heat from the exhaust system. This cleaning process takes about 30–45 minutes, and the truck is out of service during this time. The water tender and brush truck did not have engine exhaust filters.

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

Our Approach

We first toured the facility in August 2024 and gathered information for a follow-up visit. We returned in July 2025 and completed the following activities:

- Observed work processes and practices.

- Collected area air samples of diesel particulate (as elemental carbon) during one 12-hour period and one 8-hour period in the apparatus bay, report room, dormitory hallway, kitchen, and outdoors.
- Measured real-time concentrations of carbon monoxide, carbon dioxide, and particulates over about a 32-hour period in the apparatus bay, report room, dormitory hallway, kitchen, and outdoors.
- Measured real-time particle concentrations at vehicles' tailpipes while their engines were running. This was either before leaving or when returning from a call, during daily equipment checks, or when engine exhaust filters were regenerating for routine maintenance.
- 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 exhaust components 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.
- Ultrafine particle levels were much lower in this fire station's apparatus bay than in the apparatus bays at two other local fire stations. This station used on-engine exhaust filters while the other two stations did not.

Air flowed from the living quarters into the apparatus bay

- This ventilation setup is preferred to lower worker exposures to vehicle exhaust.

Air flowed from the turnout gear room into the living quarters and apparatus bay

- This occurred when the supply air in the turnout gear room was on and the exhaust air was off.
- This ventilation setup is not preferred because it may increase exposures if off-gassing chemicals from turnout gear move to the other areas.

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

Our Recommendations

Potential benefits of improving workplace health and safety include:

↑ 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.

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 when possible

Why? Reducing exposure to diesel exhaust would help keep eyes and respiratory systems from getting irritated, especially among workers who are sensitive to the presence of diesel exhaust, such as people with asthma. Breathing in diesel exhaust at work has been associated with eye, nose, throat, and lung irritation. Exposure can inflame the lungs, aggravate asthma and other chronic respiratory conditions, and worsen allergies.

Diesel exhaust is a carcinogen, meaning it can cause cancer. Because there is no known safe level for most cancer-causing hazards, it is important to reduce exposures to as low as possible. While the levels of diesel exhaust components were lower than occupational exposure limits, the following recommendations could further reduce exposure.

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

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

- This is especially important during filter regeneration as vehicles sit idling outside.

Keep bay doors open when diesel-powered equipment is operated inside the apparatus bay.

- This is especially important during morning equipment checks when multiple engines may be operating for extended periods.
- Perform morning equipment checks outside the apparatus bay with the bay doors closed whenever possible.

Train firefighters regularly how to use engine exhaust filters correctly and follow best practices.

- Include engine exhaust filter training into formal apparatus operator training and annual refresher programs.
- Create a checklist to use during routine apparatus inspections. Record the findings in maintenance logs to strengthen accountability and help find equipment issues early.
- Develop and adopt a standard operating procedure (SOP) for how to use the exhaust filter system and what to do if the system fails. The SOP should define operational guidance, such as having the system on during station start-ups and on-scene idling. The SOP can include how to report malfunctions and get repairs done.

Recommendation 2: Reduce firefighters' exposures to off-gassing chemicals from turnout gear

Why? Firefighters' turnout gear can pick up harmful chemicals during firefighting. Later, some of these chemicals can off-gas (be released as vapors), and firefighters could breathe them in.

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

Coordinate the supply and exhaust airflow controls in the turnout gear room to keep continuous negative pressure relative to nearby spaces.

- When the exhaust and supply air in the turnout gear room were both on, air flowed from the living quarters and apparatus bay into the turnout gear room. This prevented airborne chemicals from getting out of the turnout gear room into other areas.

However, when the supply air in the turnout gear room was on and the exhaust air was off, air flowed from the turnout gear room into the living quarters and apparatus bay.

- The turnout gear room should be configured with an exhaust system that automatically turns on whenever supply air is provided to the room. The system should be sized and balanced to maintain negative pressure in the turnout gear room relative to these nearby spaces. This would mean that the pressure in the turnout gear room would be lower so the air flows into it rather than out of it.
- Manual timers should not be used as the primary means of exhaust control, as this may allow periods of positive pressure and contaminant migration into living quarters.

Recommendation 3: 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 observed the filters in the air handling unit for the energy recovery ventilator were folded. This could allow air to bypass the filters.
- We observed containers of flammable liquid stored outside their designated safety cabinet in the alcove of the apparatus bay.

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:

Add vertical support bars to the filter holder in the air handling unit. These will support the filters and keep them from bending or folding.

Whenever combustible or flammable liquids are not being used, store them in a designated flammable materials storage cabinet.

Supporting Technical Information

Control of Diesel Exhaust at a Municipal Fire Station

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Section A: Workplace Information

Employee Information

During our initial walkthrough, this station was identified as the busiest in the department. It was staffed by a mix of career and on-call firefighters who rotated between different stations in the department. Squads of firefighters worked 24-hour alternating shifts. All employees belonged to a union.

Building/Worksite

This fire station was built in 2013. The apparatus bay was approximately 8,000 square feet (ft^2) with a ceiling height of 19.25 ft and volume of approximately 154,000 cubic feet (ft^3).

A water-source heat pump with an integrated air handling unit (AHU) and an energy recovery ventilator (ERV) provided ventilation to the living quarters by introducing conditioned outdoor air and discharging exhaust. Upstream of the energy recovery wheel were two Minimum Efficiency Reporting Value (MERV) 10 air filters. Downstream of the wheel were four MERV 10 air filters.

Ceiling-mounted heat pumps provided zone-level conditioning in the living quarters. The turnout gear storage room, located between the living quarters and apparatus bay, had a volume of approximately 10,000 ft^3. It had one doorway that opened to a hallway across from the kitchen and two doorways that opened to the apparatus bay. The supply air in the turnout gear room operated via on-demand-controlled ventilation. A rooftop exhaust fan, controlled by a wall-mounted timer switch, supplied the exhaust air.

Two rooftop exhaust fans ventilated the bay area through two sets of wall-mounted ductwork at the near and far side of the bay relative to the living quarters. Each set of ductwork had three upper intake grilles near the ceiling and three lower grilles near the floor. These 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.

All the exhaust fans discharged their air outdoors at the rooftops, away from the intake of the ERV serving the living quarters. In addition to the two doorways to the turnout gear room, three doorways connected the bay area to the living quarters. These three doors led to the fitness room, the record room, and a corridor connected to the record room.

Section B: Methods, Results, and Discussion

Methods: Observations of Work Processes, Practices, and Conditions

We evaluated 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. The call system only logs incident response runs; therefore 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.

- On the morning of the first sampling day, we observed firefighters performing their daily apparatus checks inside the bay while the doors were closed.
- On the second sampling day, we observed firefighters regenerating the filter on the tower ladder truck outside the back of the apparatus bay while the back bay doors were open.
- When asked about the engine exhaust control system, firefighters and paramedics reported a range of understanding from not being familiar with the system, not knowing which vehicles had engine exhaust controls installed, to having a detailed understanding.
- During our ventilation assessment, we observed folded filters in the AHU for the ERV.

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. Because firefighters need to respond quickly and put on their turnout gear rapidly, personal samples were determined to be impractical. Doing so might have slowed them down and possibly impeded their ability to perform their emergency response duties.

Although we did not collect personal samples, we placed the area samples where firefighters typically worked or resided within the station. We collected air samples for diesel particulate matter (as elemental carbon) from the apparatus bay, report room, dormitory hallway, kitchen, and outdoors. Firefighters can have diesel exhaust exposures away from the fire station; however, our focus 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, which employs thermal-optical analysis [NIOSH 2026]. We then 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, report room, dormitory hallway, kitchen, and outdoors. All monitors were set to log particle mass concentrations every 30 seconds in different size groups: particulate matter (PM) less than 1 micron (μm) (PM_1); PM less than 2.5 μm ($PM_{2.5}$); respirable (less than 4 μm); PM less than 10 μm (PM_{10}); and total PM (less than 100 μm). The data output was expressed as the mass concentration in milligrams of particles per cubic meter (mg/m^3) of the sampled air. The lower instrument range was less than 0.001 mg/mg^3.

Condensation Particle Counters

We also measured particulates using TSI Model 3007 handheld condensation particle counters (CPCs) in the apparatus bay, report room, dormitory hallway, kitchen, and outdoors. These CPCs were set to log particle number concentrations every second in the size range of 0.01 to greater than 1 μm, including ultrafine particles (less than 0.1 μm in diameter). The data output was expressed as the total number of particles per cubic centimeter (p/cc) of the sampled air. The detectable concentration for the CPC ranged from 0 to 100,000 p/cc.

Carbon Monoxide

We used TSI Q-Trak™ indoor air quality monitors to measure carbon dioxide, carbon monoxide, temperature, and relative humidity in the apparatus bay, report room, dormitory hallway, kitchen, and outdoors. Carbon dioxide released by occupants (through breathing) is a key indicator of ventilation system effectiveness. 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 Q-Trak carbon monoxide data were saved correctly. Therefore, summary data for the report room, kitchen, 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 mg/m^3, in different size groups during the sampling period. Respirable particle concentrations ranged from 0.006–0.093 mg/m^3 in the apparatus bay, less than 0.001–0.151 mg/m^3 in the report room, less than 0.001–0.368 mg/m^3 in the kitchen, less than 0.001–0.018 mg/m^3 in the dormitory hallway, and 0.003–0.062 mg/m^3 outdoors.

Figures 1 and 2 show the concentrations of ultrafine particles (less than 0.1 μm in diameter) in the sampling locations during the first and second sampling day. The highest peaks in the apparatus bay for both days occurred during morning equipment checks.

On the first sampling day, the concentration of ultrafine particles increased around 6:40 a.m. This was the time when firefighters checked the tower ladder truck, fire engine, water tender, and brush truck inside the bay while the bay doors were closed. A few minutes after checking the last apparatus, ultrafine particle concentrations decreased to background levels. On the second sampling day, the concentration of ultrafine particles increased around 6:42 a.m. when firefighters regenerated the engine exhaust filter on the tower ladder truck outside of the bay while the bay doors were open. The engine exhaust filter does not operate to filter particulates during this regeneration process.

We also noticed an increase and then a decrease in the concentration of ultrafine particles in the kitchen related to cooking activities using the station's gas stove. Peaks in outdoor particle concentrations on the second day were likely related to landscaping activities.

We took several point-source measurements at vehicles' tailpipes while their engines were running, either before leaving for a call, after returning from a call, or during daily equipment checks or filter regeneration. The water tender and brush truck were not equipped with engine exhaust filters.

Table C6 summarizes ultrafine particle concentrations taken at vehicles' tailpipes. Concentrations of ultrafine particles were much higher in vehicles without engine exhaust filters than in vehicles with the filters. We also observed ultrafine particle concentrations were higher during filter regeneration compared to routine engine starts.

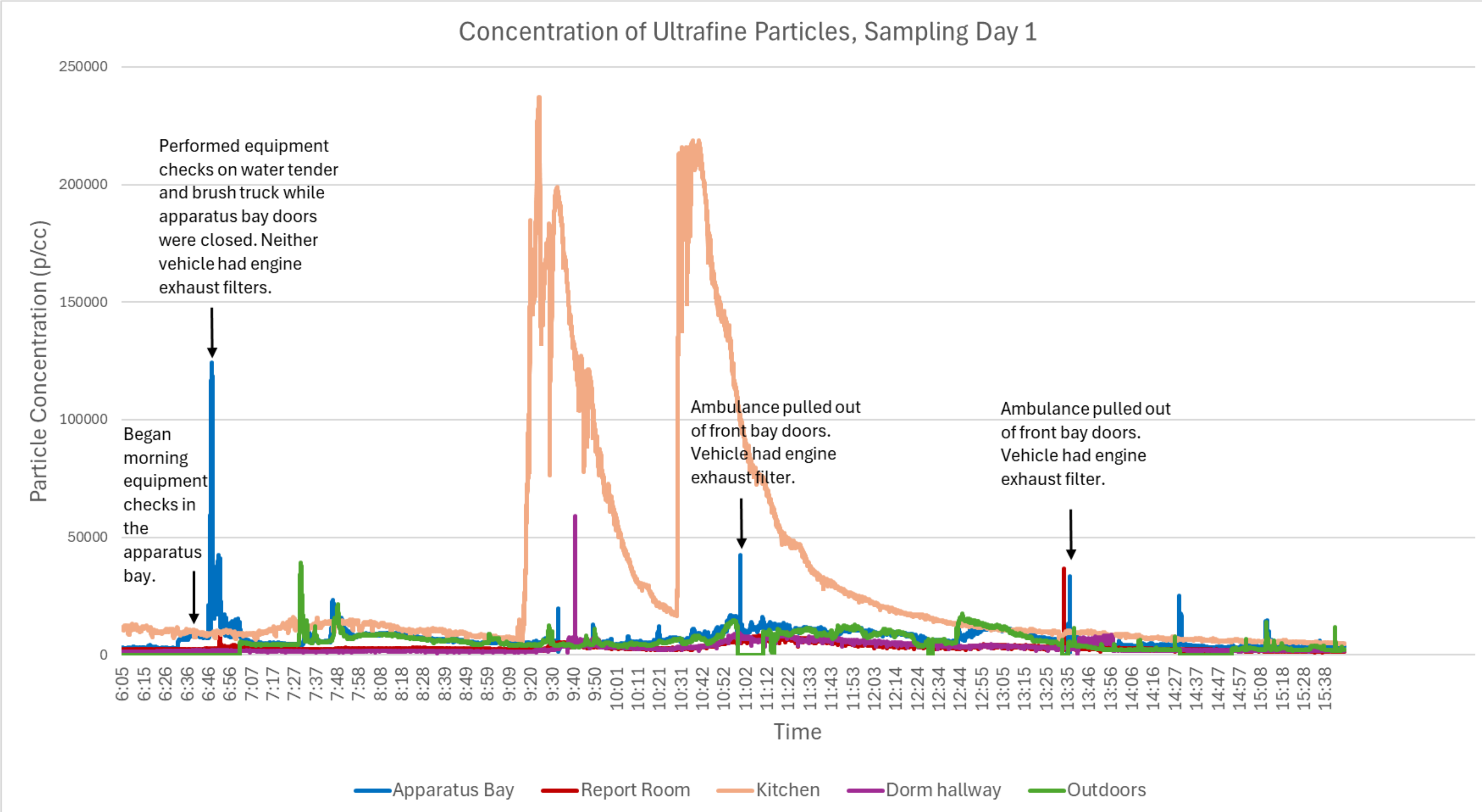

Figure B1. Concentration of ultrafine particles during the first sampling day. Figure by NIOSH.

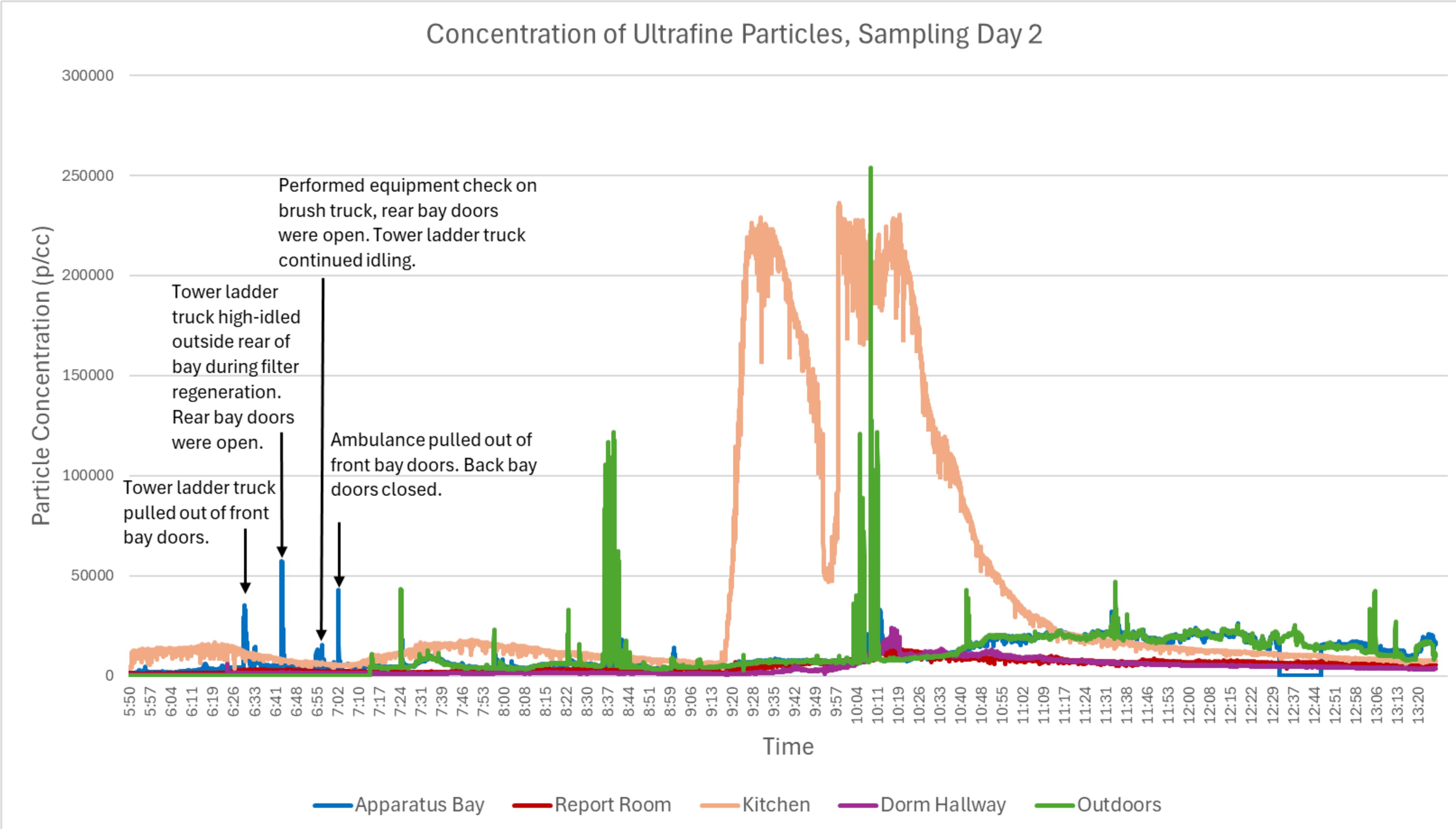

Figure B2. Concentration of ultrafine particles during the second sampling day. Figure by NIOSH.

Carbon Monoxide

Table C5 summarizes carbon monoxide concentration in parts per million of air (ppm) in the apparatus bay and outdoors during the sampling period. The average carbon monoxide concentration in the apparatus bay was 0.1 ppm (range: < 0.1 ppm to 4.8 ppm), which was similar to outdoor levels. For perspective, in industrial settings the Occupational Safety and Health Administration (OSHA) has a permissible exposure limit (PEL) for carbon monoxide of 50 ppm, time-weighted average (TWA), and the NIOSH recommended exposure limit (REL) is 35 ppm, TWA [NIOSH 2019; OSHA 2026].

Carbon dioxide concentrations ranged from 344–580 ppm in the apparatus bay, 420–807 ppm in the report room, 464–1,254 ppm in the kitchen, 484–1,461 ppm in the dormitory hallway, and 398–586 ppm outdoors. The carbon dioxide OSHA PEL and NIOSH REL are both 5,000 ppm TWA [NIOSH 2019; OSHA 2026].

Methods: Ventilation Assessment

We evaluated the operational parameters for the ventilation system by (1) measuring the contribution of the exhaust fans to the air change rate in the apparatus bay; (2) measuring the contribution to the air change rate in the turnout gear storage room; (3) determining the pressure differences between the apparatus bay, the turnout gear storage room, and the living quarters; and (4) assessing the AHU of the ERV.

Ventilation measurements were performed using a TSI Velocicalc® with an attached rotating vane anemometer. Velocity readings were taken across the face of the discharge outlet of each exhaust fan, the supply air diffusers and exhaust grilles in the turnout gear storage room, and the inlet and outlet of the ERV's AHU. The average velocity measured was multiplied by the free area of the corresponding opening to calculate volumetric airflow.

A micromanometer was used to measure differential pressure across the doorways separating the apparatus bay and turnout gear storage room from the living quarters. 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.

Results: Ventilation Assessment

The two apparatus bay exhaust fans, when operating, discharged 6,500 and 6,340 cubic feet per minute (cfm), respectively. Combining both fans would provide 5.3 air changes per hour (ACH), meaning air was exchanged once every 11–12 minutes if the air was effectively mixed when all the bay doors are closed.

Smoke tracer tests verified the negative pressure in the apparatus bay relative to the living quarters at the three doorways separating the two spaces. The pressure difference was measured at –0.002 and –0.005 inches of water column (in. w.c.) among these doorways. The lowest reading of –0.002 in. w.c. was recorded when the nearby bay door was open, and it was windy outside. The exhaust air in the turnout gear storage room, when operating, provided 1,230 cfm airflow with 7.4 ACH. This established good negative air pressure (–0.012 in. w.c.) with regards to the living quarter and apparatus bay.

The AHU for the ERV provided about 2,000 cfm of airflow, measured at both its inlet and outlet. The two MERV 10 supply air filters (measuring 20 in. × 25 in. × 2 in.) upstream of the energy recover wheel should withstand this flow rate according to the manufacturer (3,500 cfm for two filters). During our ventilation assessment, we observed that the filters had folded in the AHU for the ERV. To address this issue, consider adding vertical support bars at the exit of the filter holder to support the filters and prevent them from folding.

Discussion

Fire departments use a variety of different strategies to control diesel exhaust emissions in fire stations. These include exhaust filtration systems, tailpipe exhaust ventilation, and dilution ventilation. Dilution ventilation relies on a fan to exhaust contaminated air to the outside while outdoor 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.

Tailpipe exhaust ventilation involves attaching an exhaust hose to the tailpipe, which is connected to a fan that discharges diesel exhaust to the outdoors. An advantage of using an exhaust hose is that it removes both gaseous and particulate emissions in the diesel exhaust. The disadvantage is that it requires the firefighter to remember to attach the hose to the apparatus when the vehicle returns to the station.

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 for the vehicle to exit the station. While studies have shown that engine filters are effective at removing particulates from the exhaust stream, they do not remove gases [Baldwin et. al 2011; Roegner et. al 2002]. The station we evaluated used in-engine exhaust filtration to control indoor diesel exhaust emissions. Average carbon monoxide and carbon dioxide measurements taken at this station were well below their respective occupational exposure limits.

Tables C2 through C4 summarize particle concentrations, reported as mg/m^3, in different size groups during the sampling period. Most of the particles were less than 1 μm in diameter. In general, average particle concentrations were higher in the apparatus bay compared with the other sampling locations. Concentrations of ultrafine particles were between 10 to 15 times higher in vehicles that did not have engine exhaust filters than in vehicles with the filters. We also observed that concentrations of ultrafine particles were higher during filter regeneration compared with routine engine starts.

When apparatuses entered or exited the station, we did not find any corresponding increase in particle concentrations in the living 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 less than 4 μm in diameter are respirable and can penetrate deeply into the lower respiratory system [ACGIH 2026]. 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].

Diesel exhaust is a complex mixture of gases and very fine particles. Neither Occupational Safety and Health Administration (OSHA) nor NIOSH have occupational exposure limits for exposure to total diesel exhaust as a mixture, or for elemental carbon which is commonly used as a surrogate measure of exposure. We did not detect elemental carbon in any of our measurements. Other component-specific limits (e.g., carbon monoxide, particulates) are also sometimes used as surrogates. NIOSH classifies diesel exhaust as a potential occupational carcinogen and recommends that exposures be reduced to the lowest feasible concentration [NIOSH 1988]. OSHA has a permissible exposure limit (PEL) of 5 mg/m^3 for respirable dust, as an 8-hour TWA [OSHA 2026]. This PEL is for particulates not otherwise regulated, including nuisance dust or inert dust not known to contain harmful components. The American Conference of Governmental Industrial Hygienists (ACGIH®) recommends that airborne concentrations of respirable dust be kept below 3 mg/m^3 [ACGIH 2026]. Area samples cannot be directly compared with occupational exposure limits because these limits are based on personal exposure measurements taken in a worker's breathing zone. Furthermore, these limits are TWAs based on exposures over an 8–10 hour workday, and so may not fully represent risks for firefighters who typically work much longer, varied shifts.

The pressure difference between the turnout gear storage room and the adjacent spaces varied depending on the operation status of its ventilation. When the supply air in the turnout gear storage room was on and the exhaust air was off, the airflow was approximately 450 cfm with 2.7 ACH in the room. This created either neutral or slightly positive pressure compared with the apparatus bay and living quarters. This condition is undesirable because chemicals off-gassing from turnout gear can move to these other areas.

To mitigate this, we recommend synchronizing supply and exhaust airflow controls in the turnout gear room to maintain continuous negative pressure relative to adjacent spaces. Manual timers should not be used as the primary means of exhaust control, as this may allow periods of positive pressure and contaminant migration into living quarters. However, it may be useful to have additional exhaust air in the turnout gear room activated by a switch when turnout gear is likely to be more contaminated and off-gassing, such as after a fire event.

Limitations

This evaluation is subject to several limitations. We did not evaluate the relative effectiveness of on-engine exhaust filters compared with the emissions controls that come standard on newer fire engines and ambulances. A focused follow-up study could be conducted to evaluate this question. However, ultrafine particle concentrations in the apparatus bays at two other fire stations frequently exceeded the instrument measurement range, sometimes requiring up to two hours to decay. Concentrations in this apparatus bay remained substantially lower [NIOSH 2026a,b].

Additionally, this study did not directly compare vehicles equipped with and without the engine exhaust filters, making it difficult to determine the system's impact in reducing diesel emissions. Also, 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, so we cannot directly compare our results with occupational exposure limits, which are for personal exposures.

Conclusion

Our results showed that levels of diesel exhaust particulate (as elemental carbon) and other components of vehicle exhaust were low in the apparatus bay and the living quarters. Most of the particulate in the apparatus bay were ultrafine particles, less than 1 μm in diameter. We observed consistent peaks in ultrafine particle concentrations in the apparatus bay during engine start events, but these levels returned to background within a few minutes. Future evaluations could include testing a new fire engine or ambulance with and without the engine exhaust filter system to directly assess its effectiveness compared with standard factory-installed diesel emission controls in newer fire engines or ambulances.

Section C: Tables

Table C1. Daily diesel engine apparatus runs

Diesel apparatus	Sampling day 1	Overnight	Sampling day 2
Ambulance	4	5	3
Tower ladder truck	4	4	3

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

.	Bay average (range)	Report room average (range)	Kitchen average (range)	Dorm hallway average (range)	Outdoors average (range)
PM_1	0.027 (0.005–0.065)	0.010 (0.007–0.015)	0.012 (0.005–0.286)	0.004 (0.003–0.010)	0.008 (0.004–0.015)
$PM_{2.5}$	0.027 (0.006–0.065)	0.010 (0.007–0.015)	0.012 (0.005–0.307)	0.004 (0.003–0.010)	0.008 (0.004–0.015)
Respirable	0.027 (0.006–0.065)	0.010 (0.007–0.015)	0.013 (0.005–0.331)	0.004 (0.003–0.010)	0.008 (0.004–0.015)
PM_{10}	0.029 (0.006–0.066)	0.010 (0.007–0.016)	0.014 (0.005–0.397)	0.004 (0.003–0.013)	0.009 (0.005–0.018)
Total	0.029 (0.006–0.067)	0.011 (0.007–0.038)	0.015 (0.005–0.411)	0.005 (0.003–0.037)	0.010 (0.005–0.035)

Range = minimum–maximum

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

.	Bay average (range)	Report room average (range)	Kitchen average (range)	Dorm hallway average (range)
PM_1	0.034 (0.021–0.091)	0.015 (ND–0.022)	0.011 (ND–0.022)	0.009 (ND–0.014)
$PM_{2.5}$	0.035 (0.021–0.092)	0.015 (ND–0.022)	0.011 (ND–0.022)	0.009 (ND–0.014)
Respirable	0.035 (0.021–0.093)	0.015 (ND–0.022)	0.011 (ND–0.023)	0.009 (ND–0.015)
PM_{10}	0.036 (0.021–0.094)	0.015 (ND–0.024)	0.011 (ND–0.038)	0.009 (ND–0.016)
Total	0.037 (0.022–0.096)	0.015 (ND–0.058)	0.012 (ND–0.054)	0.010 (ND–0.053)

*ND = non-detect, less than the instrument's limit of detection, 0.001 milligrams per cubic meter (mg/m^3)
Range = minimum–maximum

Table C4. Average particle concentrations (mg/m^3) during the second sampling day

.	Bay average (range)	Report room average (range)	Kitchen average (range)	Dorm hallway average (range)	Outdoors average (range)
PM_1	0.026 (0.021–0.031)	0.011 (0.010–0.147)	0.023 (0.003–0.362)	0.004 (0.001–0.018)	0.009 (0.003–0.061)
$PM_{2.5}$	0.026 (0.021–0.032)	0.012 (0.010–0.147)	0.023 (0.003–0.365)	0.004 (0.001–0.018)	0.009 (0.003–0.061)
Respirable	0.027 (0.022–0.034)	0.012 (0.010–0.151)	0.024 (0.003–0.368)	0.004 (0.001–0.018)	0.010 (0.003–0.062)
PM_{10}	0.029 (0.023–0.043)	0.012 (0.010–0.197)	0.025 (0.003–0.383)	0.004 (0.001–0.023)	0.012 (0.003–0.065)
Total	0.030 (0.024–0.055)	0.016 (0.010–0.612)	0.026 (0.003–0.393)	0.007 (0.001–0.182)	0.013 (0.003–0.068)

Range = minimum–maximum

Table C5. Average carbon monoxide concentrations (ppm)

Sampling day	Bay average (range)	Outdoors average (range)
Day 1	ND* (ND–4.8)	0.1 (ND–1.0)
Overnight	0.1 (ND–1.2)	NA†
Day 2	ND (ND–0.8)	0.3 (ND–13.6)

*ND = non-detect, less than the instrument's limit of detection, 0.1 parts per million (ppm)

†NA = not applicable. Instrumentation was not used outside overnight

Range = minimum–maximum

Table C6. Average ultrafine particle concentrations (p/cc) from measurements taken at vehicle tailpipes during both sampling days

Vehicle	Sample date, time	Sample length (seconds)	Task	Average (minimum–maximum)
Tower truck 132	7/27/25, 1230	12	Going on a call	14,000 (6,700–39,000)
Ambulance A113*	7/27/25, 1334	10	Going on a call	12,000 (6,100–20,000)
Tower truck 132	7/27/25, 1547	16	Returning from a call	16,000 (2,000–21,000)
Ambulance A113	7/27/25, 1638	8	Going on a call	16,000 (1,400–38,000)
Tower truck 132	7/28/25, 0645	15	Filter regeneration	110,000† (72,000–140,000)
Tower truck 132	7/28/25, 0647	15	Filter regeneration	130,000 (120,000–160,000)
Tower Truck 132	7/28/25, 0649	14	Filter regeneration	170,000 (140,000–190,000)
Engine 123	7/28/25, 0653	16	Morning check	240,000 (4,500–260,000)
Engine 123	7/28/25, 0653	7	Morning check	260,000 (120,000–290,000)
Engine 123	7/28/25, 0654	10	Morning check	300,000 (220,000–310,000)
Water tender 141‡	7/28/25, 0657	12	Morning check	300,000 (220,000–310,000)
Water tender 141	7/28/25, 0658	12	Morning check	310,000 (230,000–320,000)
Ambulance A113*,§	7/28/25, 0659	12	Morning check	330,000 (320,000–330,000)
Brush truck 141	7/28/25, 0701	10	Morning check	310,000 (290,000–320,000)
Ambulance 123	7/28/25, 1233	27	Idling outside rear bay	18,000 (17,000–19,000)

*Ambulance number may not be accurate. We learned in the closing meeting that multiple ambulances may share the same marked number on their bodies while their specific numbers are at the driver-side doors.
†Concentration range of the instrument is 0 to 100,000 parts per cubic centimeter (p/cc). For concentrations > 100,000 p/cc, the instrument is likely underestimating the concentration.
‡Neither the water tender nor the brush truck were equipped with engine exhaust filters. All other apparatuses were equipped with filters.
§The high concentration for this ambulance was likely because the diesel exhaust filtration was not activated during this morning check.

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 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 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 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. For extended work shifts, the OEL-TWA can be adjusted by using an OEL reduction factor [ACGIH 2026; Brief and Scala 1986]. The American Conference of Governmental Industrial Hygienists (ACGIH®) has additional information on adjusting OELs for unusual work schedules [ACGIH 2026].

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, PPE, 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 ACGIH. The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peerreviewed 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 2026].

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]. 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. 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. NIOSH is currently considering developing quantitative RELs based on human and/or animal data, with consideration to the availability of workplace exposure controls. OSHA does not have a PEL 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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