Controlling Diesel Exhaust Exposure Inside Firehouses

BY TOMMY N. BALDWIN, THOMAS R. HALES, AND MAUREEN T. NIEMEIER

DIESEL EXHAUST IN FIREHOUSES HAS BEEN AND continues to be a problem for many firefighters. A diesel-powered apparatus generates exhaust whenever it leaves or returns to a station. If not properly captured, this exhaust will enter not only the apparatus bay but also the firefighters' living quarters. As a result, firefighters can be exposed to diesel exhaust for a significant portion of their shifts. Scientific evidence suggests an association between lung cancer and occupational exposure to diesel exhaust emissions. Safety and health professionals at the National Institute for Occupational Safety and Health (NIOSH) have evaluated several fire stations for diesel exhaust through its Health Hazard Evaluation (HHE) program (see box at right). Below, we address the health effects of diesel exhaust, the amount of diesel exhaust typically found in fire stations, and the controls and work practices that can reduce firefighters' exposure.

HEALTH EFFECTS

Diesel engine exhaust is a complex mixture of gases and particles (particulate). The composition of the mixture varies greatly with fuel and engine type, load cycle, maintenance, tuning, and exhaust-stream treatment.[1,2] The gaseous chemicals include carbon dioxide, carbon monoxide, oxides of nitrogen, oxides of sulfur, and hydrocarbons.[3] The part of diesel exhaust that is particulate (soot) is made up of microscopic carbon (in its pure or elemental state), onto which thousands of different substances can attach/absorb.[2,4] The absorbed material contributes 15 to 65 percent of the total particulate mass and includes compounds such as polynuclear aromatic hydrocarbons (PAHs), which are carcinogenic.[2,4,5] Almost all of the particles are extremely small and can reach the deep regions of the human lung when inhaled. These respirable particles are considered more hazardous than larger particles, which are efficiently trapped in higher regions of the respiratory tract and removed. These larger particles are similar to the black-tinged sputum that some firefighters cough up for several hours or days after fighting a fire. This sputum contains soot particles from incomplete combustion at the fire scene.

Based on the results of laboratory animal and human studies, NIOSH considers whole diesel exhaust emissions to be a potential occupational carcinogen.[2] The term "whole" distinguishes the complete mixture from its individual components, which have been separately studied. Human studies *suggest* an association between occupational exposure to whole diesel exhaust emissions and lung cancer, while studies of rats and mice exposed to whole diesel exhaust (especially the particulate portion) *confirm* an association with lung tumors.[2,4,5,6] In addition to the potential carcinogenic effects, eye irritation and reversible lung function changes have been experienced by workers exposed to diesel exhaust.[2,5,7,8,9] These adverse health effects may be associated with individual constituents of diesel exhaust, such as lung irritation from oxides of nitrogen, eye and mucous membrane irritation from sulfur dioxide and aldehyde compounds, and chemical asphyxiation effects from carbon monoxide.[10] The Occupational Safety and Health Administration (OSHA) regulates workplace levels of carbon dioxide, carbon monoxide, nitrogen dioxide, and sulfur dioxide; however, OSHA has not adopted standards for "whole" diesel exhaust.[11] NIOSH, on the other hand, has taken a position. Because of its potential as a human carcinogen, NIOSH recommends that workers' exposures to diesel exhaust be reduced to the lowest feasible concentration.[2]

The Health Hazard Evaluation (HHE) Program

Based on a federal law, NIOSH conducts Health Hazard Evaluations (HHEs) to investigate possible workplace health hazards. Employees, employers, or union representatives can ask our comprehensive team of experts to investigate their health and safety concerns by requesting an HHE. Our team contacts the requestor and discusses the problems and how to solve them. This may result in sending the requestor information, referring him to a more appropriate agency, or making a site visit (which may include environmental sampling and medical testing). If we make a site visit, the end result is a report of our investigations that includes recommendations specific to the problems found, as well as general guidance for following good occupational health practices. These HHE reports are available on the Internet (http://www.cdc.gov/niosh/hhe/).

NIOSH has received many requests for HHEs regarding diesel exhaust in firehouses, and our occupational safety and health professionals have evaluated several fire stations for this hazard. These reports are publicly available online and can be accessed for more specific information [http://www.cdc.gov/niosh/hhe/].

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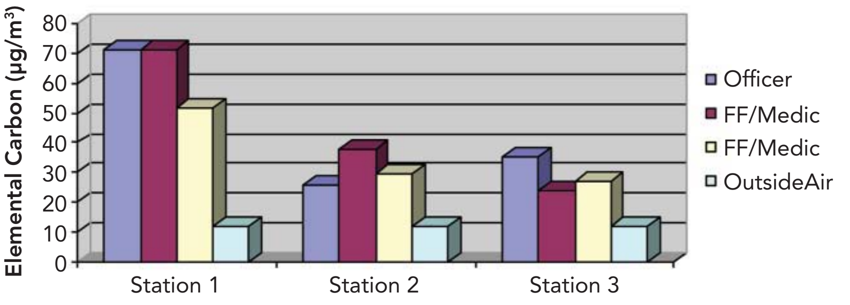
In addition to its effect on the lungs, mucous membranes, and potential for causing cancer, diesel exhaust may also be associated with heart disease. A study in the *New England Journal of Medicine* studied ischemic (decreased blood flow because of vessel tightening) and thrombotic (blockage of blood flow because of clotting) effects of dilute diesel exhaust inhalation in men with coronary heart disease. It suggests: "Exposure to combustion-derived air pollution is associated with adverse cardiovascular events, including acute myocardial infarction."[12] One component of diesel exhaust, carbon monoxide, might increase myocardial ischemia (a painful heart condition caused by lack of blood flow to the heart) and, therefore, may represent an additional risk to the firefighter with coronary heart disease.[10] Furthermore, since carbon monoxide in the blood reduces the amount of oxygen delivered to body organs and tissues, exposure to elevated levels of it can impair visual perception, manual dexterity, learning ability, and the performance of complex tasks.[3]

Figure 1. Fire Department 1, Day 1: Personal Breathing Zone Air[13]



Elemental carbon concentration in micrograms per cubic meter (µ/m³).
Source: National Institute for Occupational Safety and Health.

DIESEL EXHAUST LEVELS IN FIRE STATIONS

In the 1990s, NIOSH evaluated seven fire stations from three fire departments for diesel exhaust contamination. Researchers took personal breathing zone (PBZ) air samples for elemental carbon (a surrogate for diesel exhaust) from firefighters and took a number of samples from areas around the station.

Fire Department 1. PBZ and area air samples for elemental carbon were taken from three stations on two consecutive days (Figures 1-4).[13] None of the three stations had a mechanical ventilation system.

At Station 1 on the first evening of sampling, the station's diesel-powered truck was started and moved out of the apparatus bay one time. On the second evening of sampling, neither the station's engine or truck was started. The PBZ and

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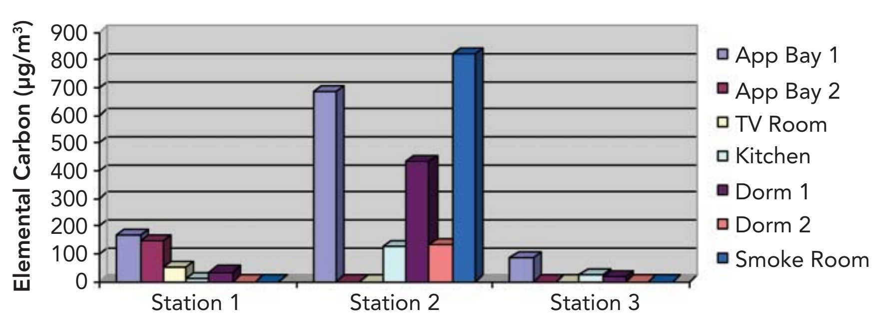
area air samples for elemental carbon indicated higher levels of elemental carbon during the first evening.

At Station 2 on the first evening of sampling, both the diesel-powered truck and ambulance made one emergency run. On the second evening of sampling, the engine made two runs; the ambulance made five. Surprisingly, the levels of elemental carbon were less than Day 1 even though there were several more responses. Another interesting aspect of these results is how high elemental carbon levels are in the smoking room, which is a reason to restrict smoking inside stations.

Figure 2. Fire Department 1, Day 1: Area Air[13]



Elemental carbon concentration in micrograms per cubic meter (µ/m³).
Source: National Institute for Occupational Safety and Health.

At Station 3 on the first evening of sampling, the station's diesel-powered engine and truck were both started and driven outside of the apparatus bay for cleaning. On the second evening of sampling, the engine made one emergency call; the diesel-powered ambulance made two runs. Elemental carbon levels in the apparatus bay increased 136 percent because of the additional responses.

Fire Department 2. PBZ and area air samples for elemental carbon were collected at two fire stations (Stations 5 and 8) on two consecutive days. The stations were equipped with general exhaust ventilation systems designed to remove exhaust emissions from the apparatus bay. Although Station 5's apparatus made one emergency run on the first evening and two runs the second evening, no elemental carbon was detected for any of its PBZ or area samples. [Note: Analysis cannot detect samples with elemental carbon concentrations <4 µg/m³ (micrograms per cubic meter).] Station 8's rescue unit had one run on both days, but only one area sample was above the limit of quantification (16 µg/m³), and only two of the PBZ samples were above the lab's limit of detection (between 4 and 10 µg/m³).[14]

Fire Department 3. Fire Department 3 was planning to install diesel exhaust filtration systems on some of its apparatus and requested that NIOSH document their effectiveness in reducing diesel soot. NIOSH investigators conducted precon-

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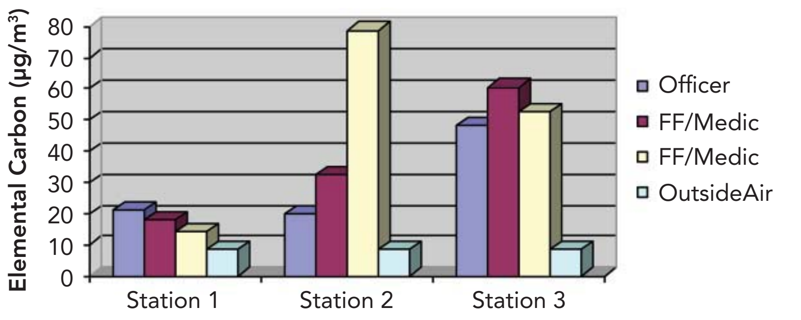
Figure 3. Fire Department 1, Day 2: Personal Breathing Zone Air[13]



Elemental carbon concentration in micrograms per cubic meter (μ/m³).
Source: National Institute for Occupational Safety and Health.

trol evaluations for three consecutive days in two fire stations (Station 3 and Station 5) to provide baseline data and follow-up evaluations after the ceramic filters were installed on the engines (see below for more information on engine exhaust filters). Despite multiple runs by both Station 3 and Station 5's engines and ambulances, only trace concentrations of elemental carbon were measured in PBZ samples. Area samples collected in the apparatus bay ranged from none detected to 23.5 μg/m³.[15] Geometric mean elemental carbon concentrations in the apparatus bays of both stations were significantly reduced after installation of the engine exhaust filters (76 percent in Station 3, and 91 percent in Station 5).

ENGINEERING CONTROLS

Several engineering control options are available to control fire apparatus diesel exhaust emissions. We present three potentially effective options: (1) engine exhaust filters, (2) local tailpipe exhaust ventilation, and (3) dilution ventilation. Industrial hygiene principles suggest that tailpipe capture devices would be the most effective way to reduce firefighters' exposure to occupational diesel exhaust. This type of device captures the exhaust before it enters the personal breathing zone, but studies have not been conducted to confirm this finding.

Engine exhaust filters. Engine exhaust filters are designed to remove particulate from the exhaust stream. The filters are installed in the exhaust system or at the tailpipe.

One commercially available filter system consists of a porous ceramic filter, a diverter valve, and an electronic control module. The diverter valve is installed in the exhaust pipe and directs the exhaust through a ceramic filter when the engine is started. This filter "cleans" the exhaust of diesel exhaust particulate. After about 20 seconds to three minutes (enough time

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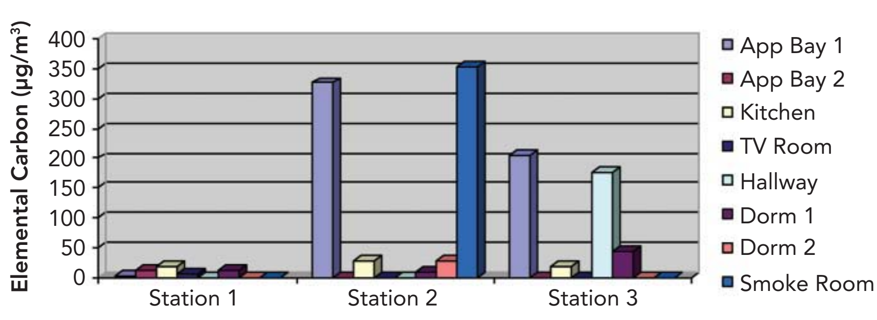
Figure 4. Fire Department 1, Day 2: Area Air[13]



Elemental carbon concentration in micrograms per cubic meter (µ/m³).
Source: National Institute for Occupational Safety and Health.

for the engine/truck to exit the apparatus bay), the electronic control bypasses the filter and vents the exhaust directly into the exhaust pipe. When the vehicle is shifted into reverse to back into the garage, the electronic control again routes the exhaust fumes through the filter. The ceramic filter weighs between 20 and 30 pounds and collects about two pounds of particulate before requiring servicing (approximately every 30 operating hours). Ceramic filters have reduced diesel particulate concentrations by 90 percent in the mining industry[16]; however, their efficacy for diesel-powered fire vehicles has not been reported in the literature.[17]

Engine exhaust filters have the advantage of removing particulate from the exhaust stream, but the disadvantage is that only the particulate portion of the exhaust stream is unfiltered—in other words, not the gases. They also have a relatively high per-vehicle cost. The approximate cost for one filter system was $10,000 in 2009.[18,19]

Another version of the particulate filter, a filter trap, developed by the Donaldson Company in Minnesota, reports to reduce diesel particulate levels by ≥80%.[20] The cost of this filter trap was about $5,000 to $10,000 in 2009.[20]

A third version of the particulate filter is a two-stage diesel emission control system designed to regulate emissions based on proximity, or "Smog Free Zones."[21] Diesel exhaust capture occurs at the tailpipe before it can enter the breathable air.[21] Radio signals automatically activate the filtration mode when the vehicle enters the Smog Free Zone and continues to filter emissions until the vehicle drives out of range.[21] Filtration occurs any time the vehicle is within a 100-meter range of a radio frequency transponder (installed at a fire station, a trauma center, a schoolyard, or a repair shop), not just on engine startup or when backing up, and is not limited to 100 seconds (or less).[21] Filtration occurs when the apparatus is idling or in any forward or reverse gear for as long as needed.[21] Within the proximity of radio frequency transponders, diesel exhaust is diverted downstream of the muffler into the filter, effectively reducing emissions by 99 percent (EPA Level 3).[21] The muffler acts as both a silencer and a spark arrester.[21] The filter is downstream of the muffler and is the final exhaust trap, which does not affect the engine's warranty.[21]

Local tailpipe exhaust ventilation. The second type of engineering control is local tailpipe exhaust ventilation. This works by attaching a hose to the tailpipe and connecting it to a fan, which discharges the exhaust outside the station.

To adequately remove the exhaust, one manufacturer recommends the fan exhaust 600 cubic feet per minute (cfm) for each vehicle. The exhaust hoses can be purchased with several options. One is an automatic disconnect feature, which automatically disconnects the hose from the vehicle exhaust pipe as the vehicle pulls out of the garage. Installing an overhead rail to keep hoses off the floor is another option. The hoses are suspended from the rail by a balancer that automatically retracts the hose when it is not in use. Various hose diameters are available for different sizes of exhaust pipes. Costs vary with length of hose, type of overhead mounting, and number of options purchased.

An advantage of the local tailpipe exhaust hose and ventilation is that it removes not only the diesel particulates but also the gaseous emissions, such as nitrous oxides and sulfur oxides. The tailpipe exhaust hose captures the exhaust emissions when the vehicle exits the fire station but affords no control when the vehicle reenters the station unless the firefighters reattach the exhaust hose to the fire vehicle in the driveway. A disadvantage is that the system requires individual firefighters to remember to attach the hose to the apparatus tailpipe.

Dilution ventilation (exhaust fan). With dilution ventilation, the air contaminated with diesel fumes is exhausted to the outside while fresh outside makeup air flows into the garage through open doors or supply air openings. Air is exhausted using a roof or wall fan. The fan can be integrated into the fire alarm system so that it turns on before the fire trucks are started. It may also be worthwhile to turn the fan on for a few minutes after the fire trucks have returned to the garage.

The exhaust fan should be toward the rear of the fire station garage opposite the garage doors so that outside air flows through the open garage doors, sweeping the entire length of the building before being exhausted. The exhaust fans should be high in the wall (or in the ceiling). If the garage doors cannot be kept open while the exhaust fan is running, a supply air fan can be installed at the opposite side of the building from the exhaust fan to bring fresh air into the garage.

The major drawbacks to using dilution ventilation are the cost of cooling the makeup air during warm weather months and warming the makeup air during cold weather months. In addition, dilution ventilation doesn't capture emissions at the source. Thus, firefighters

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can be exposed to some, albeit lower, amounts of diesel exhaust. The principal advantage of this system is the relatively low purchasing and installation costs.

Air filtration. An air filtration system can be installed above the fire apparatus. The system contains a carbon monoxide detector that activates the system when the carbon monoxide level reaches a predetermined setting and remains in operation until the level falls below that predetermined setting. This system is a multistage progressive filtration system designed to capture airborne particulates, contamination, and gaseous pollutants.[21] It is powered by a direct drive blower that is rated at 3,000 cfm. The blower draws diesel exhaust and pollutants into the filtration media.[21] The purified airflow is reintroduced into the engine bay through a baffle box attachment that deadens noise levels while diffusing and dissipating the clean filtered air.

Other controls. Other strategies for controlling diesel exhaust emissions in fire stations include the engineering controls listed below and described in detail in a brochure prepared by the New Jersey Public Employees Occupational Safety and Health (PEOSH) Program, "Diesel Exhaust in Fire Stations":[22]

- Modify weatherstripping on all doors leading from the garage to the offices and living quarters to prevent infiltration of diesel fumes.
- Permanently seal all pole holes that aren't essential. Active pole holes should have flexible covers with air tight seals.
- Install ventilation to control exhaust (for example, exhaust fans near the ceiling, a supply of makeup air to replace air exhausted by the fan, and situate the exhaust to prevent reentry through windows or fresh air intakes). Consider the American Conference of Governmental Industrial Hygienists (ACGIH) exposure limits depending on the number of trucks in the firehouse and their horsepower.[23] The ACGIH recommends a dilution ventilation rate of 100 cfm per horsepower for diesel engines that are idling.

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- Keep the living quarters under positive pressure to prevent entry of exhaust into them (use window-mounted air-conditioners or fans to bring fresh outside air into these areas).
- Perform regular maintenance on the building's furnace and air-handling system and install humidifiers.[24]

WORK PRACTICES

In addition to engineering controls, improved work practices may help reduce diesel emissions and subsequent personal exposures to diesel particulates. Consider following these suggested work practices (mentioned in the PEOSH brochure):[22]

- Always open the garage doors before starting vehicles.
- Keep vehicle operation inside the garage to an absolute minimum (in other words, minimize engine idling time inside apparatus bays).
- Keep garage doors open (weather permitting) for at least 10 minutes following vehicle operation.
- Keep doors between the garage and other areas of the firehouse closed (consider installing automatic door closers).
- Perform regular engine maintenance on the vehicles to minimize diesel particulate emissions (for example, place additives in fuel tanks to combat contaminants, change fuel injectors).
- Consider a retrofit program to rebuild diesel engines to generate less diesel particulate when they require major overhauls. The U.S. Fire Administration offers grants for equipment modifications of this kind (refer to its Web site http://www.firegrantsupport.com/ for more information).
- Consider both mechanical performance and emissions data when selecting new engines. ●

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