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Case Studies

Evaluation of Diesel Exhaust Controls

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Reported by Kevin Roegner, W. Karl Sieber, and Alan Echt

The National Institute for Occupational Safety and Health (NIOSH) received a request from a fire department to conduct a health hazard evaluation (HHE). The department was planning to install diesel exhaust filtration systems on some of its fire apparatus and wanted NIOSH to evaluate the effectiveness of the control.

In response to the request, NIOSH worked with the department to select stations within the department that would be most appropriate for the study. NIOSH then conducted pre- and post-control evaluations of diesel exhaust in two fire stations. Site visits were made to document levels of the gas-phase and particulate-phase (soot) constituents of the diesel exhaust, and to evaluate the control's effectiveness in reducing soot exposures at the stations. Airborne concentrations were obtained for elemental carbon (C_e), sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs). The first site visit was conducted before the ceramic filters were installed on the engines, and a post-control evaluation was conducted four months later.

Health Effects of Diesel Exhaust

Diesel engines function by combusting liquid fuel without spark ignition. Air is compressed in the combustion chamber, fuel is introduced, and ignition is accomplished by the heat of compression. The emissions from diesel engines consist of a complex mixture of gaseous and particulate fractions. The composition of the mixture varies greatly with fuel and engine type, load cycle, maintenance, tuning, and exhaust gas treatment. The gaseous constituents include carbon dioxide (CO_2), carbon monoxide (CO), NO, NO_2, SO_2, and VOCs (e.g., ethylene, formaldehyde, methane, benzene, phenol, acrolein, and polynuclear aromatic hydrocarbons).[1–4] The particulate fraction (soot) is composed of solid carbon cores, produced during the combustion process, that tend to combine to form chains of particles or aggregates, the largest of which are in the respirable range (more than 95% are less than 1 micron in size).[5] Estimates indicate that as many as 18,000 different substances resulting from the combustion process may be adsorbed onto these particulates.[6] The adsorbed material contains 15 to 65 percent of the total particulate mass, and includes compounds such as polynuclear aromatic hydrocarbons, a number of which are known mutagens and carcinogens.[4,5,7,8]

Many of the individual components of diesel exhaust are known to have toxic effects. The following health effects have been associated with some of these components: 1) pulmonary irritation from oxides of nitrogen; 2) irritation of the eyes and mucous membranes from SO_2, phenol, sulfuric acid, sulfate aerosols, and acrolein; and 3) cancer in animals from polynuclear aromatic hydrocarbons. Several studies confirm an association between exposure to whole diesel exhaust and lung cancer in rats and mice.[5] Limited epidemiological evidence suggests an association between occupational exposure to diesel exhaust emissions and lung cancer.[9] The agreement of current toxicological and epidemiological evidence led NIOSH, in 1988, to recommend that whole diesel exhaust be regarded as a "potential occupational carcinogen," as defined in the Occupational Safety and Health Administration's (OSHA) Cancer Policy ("Identification, Classification, and Regulation of Potential Occupational Carcinogens," 29 CFR 1990).[5] Accordingly, NIOSH recommends that exposures be controlled to the lowest feasible concentration. Although OSHA has exposure limits for some of the individual components of diesel exhaust (i.e., NO_2, xylene, and CO), a permissible exposure limit (PEL) has not been established for whole diesel exhaust. The American Conference of Governmental Industrial Hygienists (ACGIH®) has proposed, but not yet adopted, a Threshold Limit Value (TLV®) of 20 micrograms per cubic meter ($\mu g/m^3$) for diesel exhaust emissions.[10]

Engineering Control Options

There are technologies available for controlling diesel exhaust emissions into fire stations. These technologies include exhaust filtration systems, tailpipe exhaust ventilation, and dilution ventilation systems. A summary of each technology is offered below.

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 the ceramic filter when the engine is started. After a preset time, usually between 20 seconds and three minutes, the electronic control vents the exhaust to the exhaust pipe, bypassing the ceramic filter. The timer should be set to allow enough time for the truck to exit the fire station. When the truck 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. The approximate cost for one filter system is $10,000.[11]

A report by researchers at the U.S. Bureau of Mines showed that the ceramic filter reduced diesel particulate concentrations by at least 90 percent on a load-haul-dump vehicle in a mine.[12] No documentation on the performance of the ceramic filter specifically for diesel-powered fire trucks was found in the literature. Engine exhaust filters have the advantage of removing particulate from the exhaust stream. However, they filter only the particulate portion of the exhaust stream, and have a relatively high per-vehicle cost.

A local exhaust ventilation control for diesel emissions from a truck's engine running in the fire station is the tailpipe exhaust hose (also called an exhaust extractor). A hose attaches to the tailpipe and connects to a fan that discharges the diesel exhaust to the outside. One manufacturer of these controls recommends an exhaust rate of 600 cubic feet per minute (cfm) for each vehicle. The hoses can be purchased with several options. One option is an automatic disconnect feature, which automatically disconnects the hose from the vehicle exhaust pipe as the vehicle pulls out of the garage. Another option is to install an overhead rail to keep hoses off of the floor. 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-sized exhaust pipes. Costs will vary with length of hose, type of overhead mounting, and number of options purchased.

An advantage of the tailpipe exhaust hose is that it removes both gaseous and particulate emissions in the diesel exhaust. 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 exhaust hose is reattached to the fire truck in the driveway.

Another control option is to use dilution ventilation. With dilution ventilation, the air contaminated with diesel fumes is exhausted to the outside, while fresh outside makeup air flows into the bay 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 located toward the rear of the apparatus bay, opposite the bay doors, so that outside air flows through the open bay doors, sweeping the entire length of the building before being exhausted. The exhaust fans should be located 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 located on the opposite side of the building from the exhaust fan can be installed to bring fresh air into the bay.

The principal advantage of using a dilution ventilation system is the relatively low initial cost required. The major drawbacks to using dilution ventilation are the cost of heating/cooling the makeup air during times of temperature extremes, and the fact that dilution ventilation does not capture emissions at the source.

As the science of the health effects associated with exposure to diesel exhaust has evolved, so have the control technologies. The manufacturers of the different types of controls make claims about the effectiveness of each of their controls. A review of the literature, however, did not identify any objective scientific studies that have been conducted to evaluate the efficacy of the control technologies. Accordingly, this study was conducted to provide an objective evaluation of ceramic filters for controlling diesel exhaust.

Methods

Station Selection

The fire department was composed of six fire stations, of which two were selected for this study. NIOSH representatives believed, based on recent diesel exhaust sampling efforts at other fire stations, that to make a determination as to the effectiveness of the engineering controls, stations with the highest potential exposures should be selected for the study. To determine which stations would be expected to have the greatest potential diesel exhaust exposures, NIOSH looked at the following variables: age of the diesel-powered apparatus operating at each of the stations, the number of diesel-powered apparatus operating at each station, and the level of activity (number of calls) at each station. Based on these variables for the six different stations, NIOSH selected two stations in which the potential for diesel exhaust exposures was greatest.

Environmental Sampling

Pre- and post-control air sampling was conducted for diesel exhaust constituents in two fire stations. Samples were collected to characterize exposures occurring at the fire stations, and to provide data for determining the effectiveness of the ceramic filters. During the pre-control evaluation, personal breathing zone (PBZ) and area samples were collected for C_e, a surrogate measure for whole diesel exhaust. A minimum of four PBZ samples were collected at each station during each sampled tour of duty. Area samples for C_e were collected in the apparatus bay and in the living quarters. Additionally, area samples were collected in the apparatus bay for oxides of nitrogen and VOCs, and grab samples were obtained for SO_2. Three tours were sampled during the three-day sampling effort. In order to evaluate only the exposure that occurred at the fire stations, rather than that which occurred while riding in the emergency vehicles, NIOSH personnel collected sampling pumps from the employees as they departed the station. These pumps were paused until the employees returned to the station, at which time they were promptly restarted and given back to the employees.

Post-control sampling was conducted on four tours over a four-day sampling period. This sampling was limited to area C_e samples collected in the apparatus bay. This decision was made because PBZ sampling for C_e and area samples for the gas-phase constituents yielded very low (or none detected) concentrations in the pre-control evaluation.

Air samples for C_e were collected and analyzed in accordance with NIOSH Method 5040.[13] The samples were collected on quartz-fiber filters in 37-millimeter (mm) diameter cassettes, connected via Tygon tubing to battery-powered air sampling pumps, which were operated at a flow rate of three liters per minute (Lpm). PBZ and general area samples were collected over the three days of pre-control sampling. Additionally, one background sample was collected each day, away from sources of diesel exhaust emissions. Samples obtained after the installation of the ceramic filter were collected using the same methods, but on 25-mm filters. The smaller filters provide increased sensitivity, due to the reduced volume of solvent needed to extract the smaller filter.

Grab samples for SO_2 were obtained when a diesel-powered apparatus entered or departed the station. These measurements were obtained using Sensidyne 5LC colorimetric detector tubes (Sensidyne, Inc., Clearwater, FL). These colorimetric tubes measure SO_2 in a concentration range from 0.1 to 25 parts per million (ppm).

Area air samples for oxides of nitrogen were collected and analyzed in accordance with NIOSH method 6014.[13] This method utilizes two triethanolamine (TEA)-treated molecular sieve sorbent tubes in series, separated by a chromate oxidizer tube, attached via Tygon tubing to a battery-powered sampling pump. NO_2 is collected on the first TEA sorbent tube, and is thereby separated from NO, which is oxidized by the chromate oxidizer tube, and is then collected on the second TEA sorbent tube. Samples to assess the time-weighted average exposure to oxides of nitrogen were collected at a flow rate of 25 milliliters per minute (ml/min) in the apparatus bay.

To screen for VOCs, area air samples were collected using thermal desorption tubes in accordance with NIOSH method 2459.[13] Thermal desorption tubes contain three sorbent beds in consecutive layers from front to back (Carbopack Y, Carbopack B, and Carboxen 1003), which are used to capture organic compounds over a wide range of volatility. Substances such as acetone, toluene, pentane, and hexane will be trapped with this sorbent tube. This method is an extremely sensitive and specific screening technique; it will identify the compounds present on the sample in the parts per billion range. Samples were collected in the apparatus bay, beginning when the vehicles departed the station in response to an emergency dispatch, and the pumps were allowed to run for about two hours. The thermal desorption tubes were connected via Tygon tubing to battery-powered sampling pumps that were operating at a calibrated flow rate of 50 ml/min. Samples were analyzed using an automatic thermal desorption system interfaced directly with a gas chromatograph and mass selective detector (GC-TD-MSD). Stock solutions in methanol containing known amounts of several compounds present in vehicle exhaust were used to prepare spikes to estimate the concentrations of solvents collected on the air samples.

To quantify compounds identified during the analysis of thermal desorption samples, samples were collected on charcoal tubes side-by-side with the thermal desorption tubes. The charcoal tubes were placed in plastic holders connected via Tygon tubing to battery-powered sampling pumps that were operating at a flow rate of 200 ml/min. Sampling times matched those of the thermal desorption tubes. Based on the results of the analysis of the thermal desorption tubes, the charcoal tubes were quantitatively analyzed for benzene, toluene, and xylene, using NIOSH method 1501.[13]

Ventilation Assessment

A qualitative ventilation assessment was conducted at each fire station to determine the pressure differentials between the apparatus bay and the living quarters. The assessment included an overview of the heating, ventilating, and air conditioning (HVAC) system's modes of operation, and a determination of the operating mode's effects on relative pressures between the living quarters and the bay. Smoke tubes were used to observe relative pressures through doorways separating the apparatus bay from the living quarters.

Statistical Methods

Preliminary determinations of the number of area samples required to detect a reduction of 50 percent or more in concentrations of C_e were made using levels found in a previous HHE. Power calculations indicated that a minimum of 26 C_e samples (13 pre-control and 13 post-control) from each fire station would be needed to detect the 50 percent reduction in levels of elemental carbon with 90 percent power, at a level of significance of $\alpha = 0.050$. Subsequent power calculations using measured pre-control data indicated that 12 samples from each station would be sufficient. Concentrations in the pre-control data were found to follow a lognormal distribution; therefore, logarithms of concentrations were used for all calculations and statistical tests.

Several sample concentrations were below the method limit of detection (LOD). To be included in statistical analyses, these samples were assigned values equal to LOD divided by the square root of two.[14] All transformations and calculations were done using the Statistical Analysis System (SAS) v8.0, and plots were prepared using S-Plus v4.0.

Plots of concentrations of C_e by numbers of calls per day were made for each

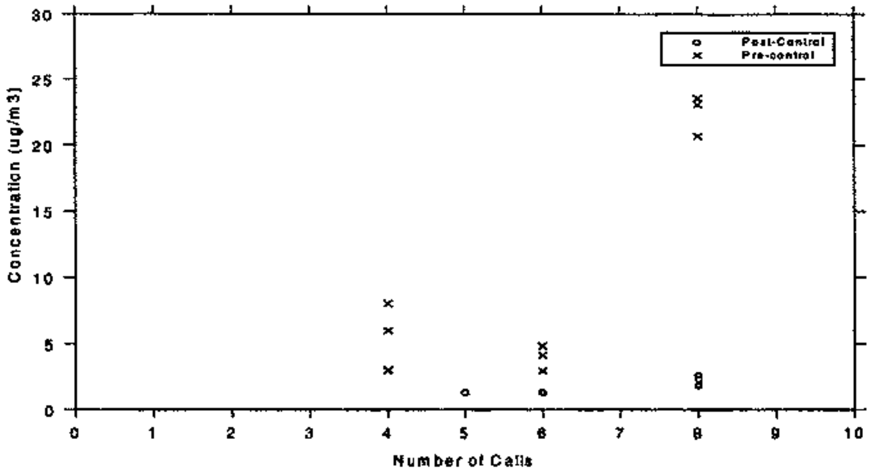

FIGURE 1
Comparison of pre- and post-control concentrations, Fire Station 3.

station, pre- and post-intervention. These are identified in Figures 1 and 2.

Results

Pre-Control

Station 3. One 1989 E-One medic engine and one 1989 Quint were housed in station 3 during this study. The medic engine was powered by an eight-cylinder series 92-T Detroit Diesel engine. This engine was installed in 1998. The Quint was powered by an eight-cylinder series 92 Detroit Diesel engine, which was installed in 1994. All diesel engines used No. 2 Diesel Fuel.

During the sample period on day 1, the Quint made two runs, and the medic engine made four runs. On day 2, the Quint made three runs, and the medic engine made five runs. On day 3, the Quint and the medic engine each made two runs.

Elemental carbon A trace C_e concentration was detected on one of 12 (8%) PBZ samples collected during the three-day sampling campaign. No C_e was detected on the other 11 PBZ samples. Area samples collected in the apparatus bay ranged from none detected to 23.5 $\mu g/m^3$. These 12 samples had a geometric mean (GM) of 6.1 $\mu g/m^3$ (geometric standard deviation [GSD] 2.3). A trace concentration of C_e was detected on seven of 30 (23%) samples collected in the living quarters of the fire station.

Sulfur dioxide Sulfur dioxide was not detected in any grab samples collected in the apparatus bay. This indicates that the concentration of SO_2 in the bay did not exceed 0.1 ppm as the apparatus entered and departed the station.

Nitrogen oxides Oxides of nitrogen samples collected on day 1 were not valid and, therefore, were not reported. Trace concentrations of nitrogen dioxide were measured in the bay on days 2 and 3. The measurements indicated that concentrations in the bay were less than 0.041 ppm as an 8-hour TWA. These concentrations were well below current exposure criteria. Nitrogen dioxide measurements were obtained during four-hour sampling periods. These sampling periods were too long to permit direct comparison against the short-term exposure criteria that are established for NO_2. The concentrations do, however, offer a general idea as to the levels that may have existed during apparatus departures, if assumptions are made about the time-concentration pattern. Concentrations during the four-hour sampling periods ranged from none detected to trace, indicating that NO_2 was detected in the apparatus bay at an average concentration of less than 0.27 ppm. These concentrations are averaged over four-hour sampling periods, and suggest that the 1 ppm TLV could have been exceeded when apparatuses departed the station.

Volatile organic compounds Low concentrations of several organic chemicals were identified in the analysis of the thermal desorption tubes. Identified chemicals included methyl t-butyl ether, C_4-C_7 alkanes, benzene, toluene, and xylenes. Toluene was also identified on the field blanks. Toluene and xylenes were present in the greatest abundance. Accordingly, the charcoal tube samples were analyzed for toluene and xylenes,

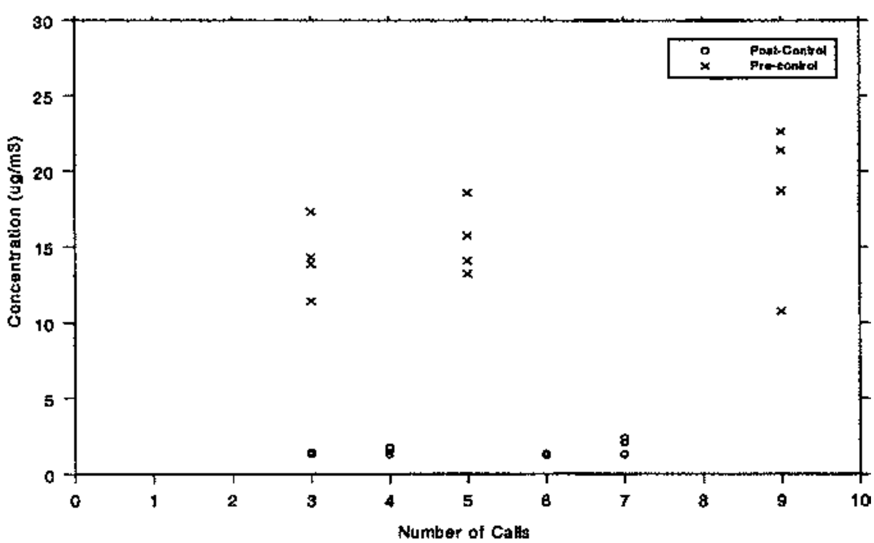

FIGURE 2
Comparison of pre- and post-control concentrations, Fire Station 5.

as well as for benzene, due to its toxicity. Analysis of charcoal tubes recovered undetectable to trace quantities of benzene, corresponding to airborne concentrations of less than 0.003 ppm. The concentration of xylenes in the apparatus bay ranged from undetectable to 0.004 ppm. Field blanks were contaminated with toluene, which precluded accurate quantitation of toluene concentrations in the bay. The measured concentrations of benzene and xylenes were well below current exposure criteria.

Ventilation assessment The HVAC system in Station 3 supplies air to the living quarters of the fire station. Air is not mechanically supplied to the apparatus bay. The evaluation was made with the HVAC manually turned to the "fan on" position, and again with the fans in the "off" position. Air consistently moved from the living quarters into the bay when the fans were operating. This condition is ideal for keeping diesel exhaust from migrating into the living quarters. When the fans were off, there was slight air movement from the bay into the living quarters.

Station 5. A 1997 E-One medic engine and a 1983 Crown Maxum truck were housed at Station 5. The E-One was powered by a 1997 series 60 six-cylinder Detroit Diesel engine. The truck was powered by a six-cylinder 92 non-computerized Detroit Diesel engine.

During the sample period on day 1, the truck made four runs, and the medic engine made five runs. On day 2, the truck made one run, and the medic engine made four runs. On day 3, the truck made one run, and the medic engine made two runs.

Elemental carbon Trace concentrations of C_e were detected on 4 of 15 PBZ samples collected during the three-day sampling campaign, indicating exposures in the range of 3 to 24 μg/m^3. Area samples collected in the apparatus bay ranged from none detected to 22.6 μg/m^3. The GM concentration for the 12 samples collected in the apparatus bay was 15.6 μg/m^3 (GSD 1.3). Trace concentrations of C_e were detected on 10 of 28 samples collected in the living quarters of the fire station. No C_e was detected on the other 18 samples.

Nitrogen oxides Nitric oxide was not detected in three of six samples collected over the three-day period. Three samples had trace quantities, indicating that NO concentrations in the bay were less than 0.41 ppm as an 8-hour TWA. The measured concentrations were well below current exposure criteria. Nitrogen dioxide measurements were obtained during four-hour sampling periods. Concentrations during these periods ranged from none detected to trace, which equate to concentrations of less than 0.09 ppm to 0.27 ppm in the bay.

Volatile organic compounds Low concentrations of the organic chemicals identified in Station 3 were also identified in samples collected in Station 5. Toluene was also identified on the field blanks. The charcoal tube samples were analyzed for toluene, xylenes, and benzene. Analysis of charcoal tubes recovered none detected to trace quantities of benzene, corresponding to airborne concentrations of less than 0.003 ppm. The concentration of xylenes in the bay ranged from 0.004 to 0.009 ppm. Field blanks were contaminated with toluene, which precluded accurate quantitation of toluene concentrations in the bay. Concentrations of benzene and xylene in the bay were well below current exposure criteria.

Sulfur dioxide Sulfur dioxide was not detected in any grab samples collected in the apparatus bay. This indicates that the concentration of SO_2 in the bay did not exceed 0.1 ppm as the apparatus entered and departed the station.

Ventilation assessment As with Station 3, the HVAC system in Station 5 supplies air to the living quarters of the fire station, but does not supply air to the apparatus bay. The evaluation was made with the HVAC manually turned to the "fan on" position, and again with the fans in the "off" position. Air consistently moved from the bay into the living quarters when the fans were turned off. When the fans were on, there was slight air movement from the bay into the living quarters. This is opposite to the more desirable condition noted at Station 3.

Post-Control

Elemental carbon.

Station 3 During the sample period on day 1, the Quint and the medic engine each made four runs. On day 2, the Quint made one run, and the medic engine made five runs. On day 3, the Quint made no runs, and the medic engine made six runs. The Quint made no runs on day 4, while the medic engine made five runs. See Figure 1 for an illustration of the number of runs against the C_e concentrations, before and after the controls were installed.

Trace concentrations of C_e were detected on 4 of 16 area samples collected in the bay during the four-day sampling campaign. Four area samples collected on day 1 had trace amounts of C_e, indicating that C_e concentrations in the bay ranged from 1.3 to 5.1 μg/m^3. The 16 samples had a GM C_e concentration of 1.5 μg/m^3. Geometric mean C_e concentrations were reduced by 76 percent from pre-control levels.

Station 5 During the sample period on day 1, the truck and medic engine each made three runs. On day 2, the truck made three runs, and the medic engine made four runs. On day 3, the truck made no runs, and the medic engine made three runs. The truck made no runs on day 4, while the medic engine made four runs.

Trace C_e was detected on five of 16 area samples collected during the four-day sampling campaign. C_e was detected in two area samples collected on day 2, and in three area samples collected on day 4, indicating that C_e concentrations for these samples ranged from 1.3 to 5.1 μg/m^3. The 16 samples had a GM C_e concentration of 1.4 μg/m^3. Geometric mean C_e concentrations were reduced by 91 percent from pre-control levels.

Discussion

In the two stations studied, which were deemed *a priori* to have the greatest potential diesel exhaust exposure, personal C_e exposures were low. Two factors likely played a role in keeping these PBZ exposures low. First, C_e concentrations measured in the apparatus bay of each station were moderate compared to concentrations that have been measured in other settings.[15–17] Second, fire fighters and paramedics spent very little time in the apparatus bay.

The low concentrations of gas-phase constituents measured at the stations are consistent with the findings of previous NIOSH evaluations of diesel exhaust.[15–17] These findings suggest that gas-phase components would not be likely to approach the evaluation criteria, with the exception of NO_2 in extreme exposure scenarios. Through previous research and field studies of diesel exhaust, it has been documented that although CO is generated by diesel engines, the levels are notably less than those generated by gasoline engines.[18,19] The small amounts of CO generated by diesel engines have not been found to create a significant CO hazard in open spaces such as an apparatus bay. For this reason, CO was not measured in this study.

In addition to the previously noted factors (i.e., age and number of engines, level of activity, and size of station) that may affect diesel exhaust exposures in fire stations, an additional factor was noted during this study that should be considered when referencing the findings of this study as a basis for decision-making with regard to installing ceramic filter controls at other fire stations. Both of the stations studied had pull-through apparatus bays. Apparatus movement in and out of a fire station bay generally occurs in one of two ways. For bays having doors at the front and back, the apparatus may pull out through the front doors when departing the station, and pull forward through the back doors when returning. In contrast, a station having doors only at the front of the bay would require the apparatus to stop and back into the bay. Since pulling forward through the bay is a decelerating action, it typically requires little or no effort from the engine. In fact, some of the engineers shut off their engines, and coasted into the bay. Backing into the bay typically requires the engineer to stop in the street or driveway, and accelerate the engine through the threshold of the bay. This acceleration would be expected to generate more exhaust than would deceleration.

The ceramic diesel exhaust filtration system installed at the department included a switch in the cab that allowed the engineer to override the system. At Station 3, on post-control day 2, the NIOSH industrial hygienists found the exhaust diverter switch in the "off" position. The engineer on the apparatus routinely turns all switches off at the end of each run. Consequently, the switch for the diesel exhaust control had been inadvertently disengaged. The switch had remained off during the second run. The engineer was consulted, and thereafter indicated that he would leave the exhaust control switch on. This may have contributed to the small amount of C_e that was measured in the Station 3 bay on post-control day 2. More importantly, this episode points out the need for information about the new engineering control and its operation to be provided to fire department personnel at the time of installation. Reportedly, this information was casually passed along by word of mouth from tour to tour.

Recommendations

The NIOSH environmental assessment of diesel exhaust in two fire stations found that concentrations of gas-phase components of diesel exhaust were well below their respective evaluation criteria prior to the installation of engineering controls. Personal exposures to diesel exhaust particulates in these two fire stations were also low, because the quantities of C_e generated were moderate, and because firefighters and paramedics did not spend much time in the apparatus bay. Concentrations of diesel soot (measured as C_e) in the bays were reduced by 76 and 91 percent in Stations 3 and 5, respectively, after the ceramic diesel exhaust filters were installed. NIOSH researchers concluded that, in stations with pull-through apparatus bays, the ceramic filters are effective at reducing the emission of diesel soot into the apparatus bay. Further study is needed to determine the effectiveness of this and other controls for reducing diesel exhaust at stations where the apparatuses are required to back into the station. Although this study suggests that gas-phase components of diesel exhaust do not build up to unhealthful levels in closed apparatus bays without the filter controls, additional study may be warranted to determine the effectiveness of this and other engineering controls at limiting gas-phase components in environments where they may accumulate.

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EDITORIAL NOTE: Kevin Roegner and W. Karl Sieber are with the Hazard Evaluation and Technical Assistance Branch of NIOSH, and Alan Echt is with the Engineering and Physical Hazards Branch of NIOSH. More detailed information on this evaluation is contained in Health Hazard Evaluation Report No. 99-0266-2850, available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (800) 35-NIOSH; fax: (513) 533–8573.