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Costa Mesa Fire Department
Costa Mesa, California

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PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Kevin C. Roegner of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Alan Echt of the Engineering and Physical Hazards Branch, Division of Applied Research Technology; Joshua Harney, Robert McCleery, and Kristin Gwin of HETAB, DSHEFS. Analytical support was provided by DataChem Laboratories. Desktop publishing was performed by Ellen Blythe and David Butler. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Diesel Exhaust Controls

The Costa Mesa Fire Department asked NIOSH to evaluate the effectiveness of ceramic diesel exhaust filters installed on department vehicles at controlling diesel exhaust exposures in fire stations.

What NIOSH Did

- **We conducted a study in stations 3 and 5.**
- **We collected air samples for diesel soot and gases emitted from the apparatuses before the filters were installed.**
- **We collected samples for diesel soot after the filters were installed.**
- **We compared the amount of soot before filter installation to the amount after filter installation.**
- **We observed the number of runs that each apparatus made during the survey.**
- **We looked at the ventilation systems in each station.**

What NIOSH Found

- **The greatest soot concentrations were in the apparatus bay. Firefighter exposures to the exhaust were low before the filter installation.**
- **With the possible exception of nitrogen dioxide (NO_2), gas concentrations in the bay were low before the filters were installed.**
- **Installation of the ceramic filters reduced diesel soot concentrations in the bay by roughly 75–90%.**
- **The ventilation system in station 3 kept the living quarters under positive pressure all of the time. The ventilation system in station 5 kept the living quarters under positive pressure some of the time.**

What Costa Mesa Fire Department Can Do

- **If diesel exhaust is a concern at other stations, consider installing ceramic diesel exhaust filters at those stations.**
- **Provide more structured training and information exchange in the future if diesel exhaust controls are installed at other stations.**

What the Costa Mesa Firefighters Can Do

- **Leave the toggle switch for the ceramic filter controls in the "on" position.**

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National Institute for Occupational Safety and Health NIOSH

Health Hazard Evaluation Report 99-0266-2850
Costa Mesa Fire Department
Costa Mesa, California
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SUMMARY

On August 4, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Costa Mesa Fire Department (CMFD), located in Costa Mesa, California, to conduct a health hazard evaluation (HHE). The CMFD was planning to install diesel exhaust filtration systems on some of their apparatus and wanted NIOSH to evaluate the effectiveness of the controls.

In response to the request, NIOSH conducted pre- and post-control evaluations of diesel exhaust in two fire stations. The pre-control evaluations were conducted on November 8–11, 1999. Samples were collected to characterize contaminant concentrations at the fire stations, and to provide base line data for determining the effectiveness of the ceramic exhaust filters at controlling these contaminants. Airborne concentrations of elemental carbon (C_e), sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs) were measured. After the ceramic filters were installed on the engines, a follow-up evaluation was conducted on March 14–17, 2000, to determine the control's effectiveness in reducing diesel soot (measured as C_e) in the fire stations.

In the initial survey, only trace concentrations of C_e were measured in personal breathing zone (PBZ) samples at each station. Concentrations of C_e in the living quarters of each station were mostly in the none detected to trace range as well. The 12 C_e area samples collected in the apparatus bay of each station had mean concentrations of 6.1 micrograms per cubic meter ($\mu g/m^3$) in station 3, and 15.6 $\mu g/m^3$ in station 5.

SO_2 was not detected in any spot samples collected in the apparatus bay of either station. 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.

NO concentrations in the apparatus bay of both stations were all below the minimum detectible concentration (MDC). This indicates that all concentrations were below 0.5 ppm as an 8-hour time weighted average, which is well below the current evaluation criteria.

Low concentrations of several organic chemicals were identified. Identified chemicals included methyl t-butyl ether, C_4–C_7 alkanes, benzene, toluene, and xylenes. Concentrations of benzene and xylene were quantified, and were well below current exposure criteria.

In the post-control evaluation, C_e was not detected on 12 of 16 area samples collected in the bay of station 3. Four area samples had a trace amount of C_e, indicating that C_e concentrations in the bay were between the MDC of 1.3 $\mu g/m^3$ and the minimum quantifiable concentration (MQC) of 5.1 $\mu g/m^3$. C_e was not detected on 11 of 16 area samples collected during the post-control sampling campaign at station 5. Trace concentrations of C_e were detected in four area samples, indicating that C_e concentrations for these samples ranged from 1.3 to 5.1 $\mu g/m^3$. A significant reduction in geometric mean C_e concentrations in the apparatus bay of both stations was evident in the data. The reductions were 76% in station 3 and 91% in station 5.

The NIOSH environmental assessment of diesel exhaust in two fire stations found that concentrations of diesel exhaust gas-phase components were low prior to the installation of engineering controls. Personal exposures to diesel exhaust particulate-phase components 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 very much time in the apparatus bay. However, geometric mean concentrations of C_e in the two bays were reduced by 76% and 91% 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.

Recommendations were made for maintaining positive pressure in the living quarters relative to the bay and for a more formalized means of training and information exchange about engineering controls, should they be installed at other stations.

Keywords: SIC 9224 (Fire Protection), diesel exhaust control, fire stations, ceramic filters, elemental carbon

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INTRODUCTION

On August 4, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Costa Mesa Fire Department (CMFD), located in Costa Mesa, California, to conduct a health hazard evaluation (HHE). The CMFD was planning to install diesel exhaust filtration systems on some of their apparatus and wanted NIOSH to evaluate the effectiveness of the control.

In response to the request, NIOSH worked with the CMFD to select stations within the department that would be most appropriate for the study. NIOSH then conducted a pre- and a post-control evaluation 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 at reducing soot exposures at the fire 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 on November 8–11, 1999, before the ceramic filters were installed on the engines housed at two stations. A post-control evaluation was conducted on March 14–17, 2000.

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, including 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).[1,2,3,4] The particulate fraction (soot) is composed of solid carbon cores, produced during the combustion process, which 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 15–65% 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 the components of diesel exhaust: (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 3 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 2 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% 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, but filter only the particulate portion of the exhaust stream and have 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 which 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 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 size exhaust pipes. Costs will vary with length of hose, type of overhead mounting, and with the 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 at 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 about 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 their control's effectiveness, but a review of the literature 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 CMFD is comprised 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 different CMFD 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) samples 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 living quarters (see Figures 1–4 for sampling locations). 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 from 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 a length of Tygon® tubing to battery-powered air sampling pumps operated at a flow rate of 3 liters per minute (Lpm). PBZ samples and general area samples were collected over the three days of sampling. Additionally, one background sample was collected each day away from sources of diesel exhaust emissions. Samples obtained after the ceramic filter installation were collected using the same methods, but on 25-mm filters because 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, Florida). 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 a very 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 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 operating at a flow rate of 200 mL/min. Sampling times matched those of the thermal desorption tubes. Based upon 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% or more in concentrations of C_e were made using levels found in HETA 92-0160-2360, City of Lancaster, Division of Fire. Power calculations indicated that a minimum of 26 C_e samples (13 pre-control and 13 post-control samples) would be needed at each fire station to detect the 50% reduction in levels of elemental carbon with 90% power and level of significance of $\alpha = 0.050$. Subsequent power calculations using measured pre-control data at Costa Mesa indicated that 12 samples at each station would be sufficient. Concentrations in the pre-control data were found to follow a log-normal distribution, so 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) v. 8.0, and plots were prepared using S-Plus v. 4.0.

Plots of concentrations of C_e by numbers of calls per day were made for each station pre- and post-intervention. These are identified as Figures 5 and 6 at the end of the report.

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 sampled period on November 9, the Quint made two runs and the medic engine made four runs. On November 10, the Quint made three runs and the medic engine made five runs. On November 11, the Quint and the medic engine each made two runs.

Elemental Carbon

Results of C_e sampling in station 3 prior to the installation of ceramic filters are summarized in Table 1. A trace C_e concentration was detected on 1 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] of 2.3). A trace concentration of C_e was detected on seven of thirty (23%) samples collected in the living quarters of the fire station.

Sulfur Dioxide

SO_2 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

Results of nitrogen oxides sampling in station 3 prior to the installation of ceramic filters are summarized in Table 2. Samples collected on November 9 were not valid and therefore are not reported. Trace concentrations of NO_2 were measured in the bay on November 10 and 11. This 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 noted in Table 2. NO_2 measurements were obtained during four-hour sampling periods. These sampling periods are too long to permit direct comparison against the short-term exposure criteria that are established for NO_2. The concentrations do 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

Results of VOC sampling in station 3 prior to the installation of ceramic filters are summarized in Table 3. 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, and benzene as well 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 noted in Table 3.

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 both with the HVAC manually turned to the "fan on" position, and again with the fan in the off position. Air consistently moved from the living quarters and 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 sampled period on November 9, the truck made four runs and the medic engine made five runs. On November 10, the truck made one run and the medic engine made four runs. On November 11, the truck made one run and the medic engine made two runs.

Elemental Carbon

Pre-control C_e sampling results are summarized in Table 4. 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 $\mu g/m^3$. Area samples collected in the apparatus bay ranged from none detected to 22.6 $\mu g/m^3$. The GM concentration for the 12 samples collected in the apparatus bay was 15.6 $\mu g/m^3$ (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 18 samples.

Nitrogen Oxides

Results of nitrogen oxides sampling in station 5 prior to the installation of ceramic filters are summarized in Table 5. NO 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. NO_2 measurements were obtained during four-hour sampling periods. Concentrations during the four-hour sampling 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

Results of VOC sampling in station 5 prior to the installation of ceramic filters are summarized in Table 6. Low concentrations of the same 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

SO_2 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 supplies no 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 and into the living quarters when the fans were in the off position. 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 sampled period on March 14, the Quint and the medic engine each made four runs. On March 15, the Quint made one run and the medic engine made five runs. On March 16, the Quint made no runs and the medic engine made six runs. On March 17, the Quint made no runs and the medic engine made five runs. See Figure 5 for an illustration of the number of runs against the C_e concentration before and after the controls were installed.

Post-control C_e sampling results from station 3 are summarized in Table 8. 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 March 14 had a trace amount 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% from pre-control levels.

Station 5

During the sampled period on March 14, the truck and medic engine each made three runs. On March 15, the truck made three runs and the medic engine made four runs. On March 16, the truck made no runs and the medic engine made three runs. On March 17, the truck made no runs and the medic engine made four runs. See Figure 6 for an illustration of the number of runs against the C_e concentration before and after the controls were installed.

Post-control C_e sampling results from station 5 are summarized in Table 9. Trace C_e was detected on 5 of 16 area samples collected during the four-day sampling campaign. C_e was detected in two area samples collected on March 15, and in three area samples collected on March 17, 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% from pre-control levels.

DISCUSSION

In the two stations, 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.[15,16,17] Second, fire fighters and paramedics spent very little time in the apparatus bay. Summary results of the PBZ samples are reported in Tables 10 and 11 for stations 3 and 5, respectively. The post-control area sample results are presented in Tables 12 and 13.

The low concentrations of gas-phase constituents measured at the CMFD stations are consistent with the findings of previous NIOSH evaluations of diesel exhaust.[15,16,17] These findings suggest that gas-phase components would not 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, the levels generated 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, 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 the back, 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 CMFD engineers shut off the engine 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 CMFD included a switch in the cab, which allowed the engineer to override the system. At station 3 on March 14, 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 in the off position during the second run. The engineer was consulted and 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 March 14. More importantly though, this episode points out the need for information about the new engineering control and its operation 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.

CONCLUSIONS

The NIOSH environmental assessment of diesel exhaust in two CMFD 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% in stations 3 and 5, respectively, after the ceramic diesel exhaust filters were installed. NIOSH researchers conclude 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 suggested 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 from environments where they may accumulate.

RECOMMENDATIONS

The following recommendations are offered to further minimize the potential for diesel exhaust at the CMFD:

1. When ceramic filters or other engineering controls are installed in fire apparatus at other stations, it is recommended that a more formalized means of

training be established to communicate information about the control to CMFD personnel.

2. In station 5, the NIOSH industrial hygienist observed that air moves from the apparatus bay into the living quarters when the HVAC system is not circulating air. The cause for this was not identified at the time of the survey. One explanation is that the exhaust vents in the kitchen and bathrooms may be moving enough air from the living quarters to create low pressure relative to the apparatus bay. The ideal relationship for keeping diesel exhaust out of the living quarters, as observed in station 3, is for air to move from the living quarters into the bay. It is recommended that the air flow from the bathroom and kitchen exhaust fans and the air supply fans be balanced to minimize the migration of diesel exhaust into the living quarters.

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Table 1. Results of air sampling for elemental carbon at fire station 3 prior to the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Area	Sample Location or Job Title	Sample Time (minutes)	Concentration in air (µg/m^3)
Personal Breathing Zone Samples				
November 9	Living quarters/apparatus	Engineer	267	ND[1]
	Living quarters/apparatus	Engineer	391	ND
	Living quarters/apparatus	Firefighter/paramedic	389	ND
	Living quarters/apparatus	Firefighter/paramedic	235	ND
	Living quarters/apparatus	Captain	368	ND
November 10	Living quarters/apparatus	Engineer	365	ND
	Living quarters/apparatus	Firefighter/paramedic	367	ND
	Living quarters/apparatus	Captain	363	ND

November 11	Living quarters/apparatus	Engineer	246	ND
	Living quarters/apparatus	Engineer	267	ND
	Living quarters/apparatus	Firefighter/paramedic	192	14.8t[2]
	Living quarters/apparatus	Firefighter/paramedic	225	ND
General Area Air Samples				
November 9	Apparatus Bay	Center	482	4.1t
	Apparatus Bay	Rear center	481	ND
	Apparatus Bay	Generator door	471	4.8t
	Apparatus Bay	North wall ladder	481	ND
	Dining room	on table	487	ND
	Dormitory	on locker 19	484	ND
	Dormitory	on locker 13	482	ND

	Dormitory	on locker 10	494	ND
	Kitchen	on television	484	ND
	Kitchen	on refrigerator	485	ND
	Dormitory	on locker 26	487	ND
	Library	on bookcase	485	ND
	Office	on desk by window	486	ND
	Office	on table by portraits	487	ND
	Outside	Fence line	479	ND
November 10	Apparatus Bay	Center	481	23.5
	Apparatus Bay	Rear center	485	23.1
	Apparatus Bay	Generator door	482	20.7
	Apparatus Bay	North wall ladder	484	20.8
	Dining room	on table	484	3.0t
	Dormitory	on locker 19	478	ND
	Dormitory	on locker 13	483	ND
	Dormitory	on locker 10	486	ND
	Kitchen	on television	506	ND
	Kitchen	on refrigerator	487	3.2t
	Dormitory	on locker 26	487	ND
	Library	on bookcase	486	4.1t
	Office	on desk by window	486	ND
	Office	on table by portraits	480	3.0t
	Outside	Fence line	483	ND
November 11	Apparatus Bay	Center	478	6.0t
	Apparatus Bay	Rear center	477	ND
	Apparatus Bay	Generator door	473	8.0t
	Apparatus Bay	North wall ladder	478	6.0t

	Dining room	on table	479	ND
	Dormitory	on locker 19	478	ND
	Dormitory	on locker 13	479	ND
	Dormitory	on locker 26	478	ND
	Dormitory	on locker 10	487	3.2t
	Kitchen	on television	479	ND
	Kitchen	on refrigerator	479	3.6t
	Library	on bookcase	480	ND
	Office	on desk by window	478	3.6t
	Office	on table by portraits	480	3.0t
	Outside	Fence line	477	4.8t

[1] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for this sample set was 0.5 micrograms (µg) of C_e per sample. Due to the relatively small sample volumes, the minimum detectable concentrations (MDC) for the subset of PBZ samples ranged from 11 to 19 $\mu g/m^3$. For area samples the MDC was 3 $\mu g/m^3$.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

Table 2. Results of air sampling in the apparatus bay for oxides of nitrogen at fire station 3 before the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Sample Location	Sample Time[1]	Concentration in air (ppm)		
			Nitrogen Dioxide	Nitric Oxide	
General Area Air Samples					
November 9	Center of Bay	--samples not valid--			
	North wall ladder	--samples not valid--			
November 10	Center of Bay	0829-1332	.18t[2]	.28t	.14t[4]
		1338-1616	ND[3]	ND	
	North wall ladder	0828-1339	.27t	.28t	.14t
		1346-1616	ND	ND	
November 11	Center of Bay	0741-1128	.09t	.14t	.07t
		1128-1540	ND	ND	
	North wall ladder	0742-1130	.09t	.14t	.07t
		1130-1537	.09t	ND	
OSHA PEL					25
NIOSH REL					25

[1] Times are reported in military time.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.
[3] "ND" means none of the analyte was detected in this sample. The limit of detection for this sample set is 0.8 μg/sample.
[4] Values in this column are 8-hour time weighted averages (TWAs).

Table 3. Results of air sampling for volatile organic compounds at fire station 3 before the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Sample Location	Sample Time (min.)	Concentration in air (ppm)	
			Benzene	Xylenes
General Area Air Samples				
November 9	Center of Bay	474	ND[1]	ND
	North wall ladder	464	ND	ND
November 10	Center of Bay	477	ND	.004
	North wall ladder	477	ND	.002t[2]
November 11	Center of Bay	481	.002t	.004
	North wall ladder	480	.002t	.004
OSHA PEL			1	100
NIOSH REL			0.1	100

[1] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for benzene and xylenes was 0.4µg/sample, corresponding to MDCs of 0.001 ppm.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

Table 4. Results of air sampling for elemental carbon at fire station 5 prior to the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Area	Sample Location or Job Title	Sample Time (min.)	Concentration in air (µg/m^3)
Personal Breathing Zone Samples				
November 9	Living quarters/ apparatus	Engineer	213	ND[1]
	Living quarters/ apparatus	Engineer	237	7.1t[2]
	Living quarters/ apparatus	Firefighter/Paramedic	267	ND
	Living quarters/ apparatus	Firefighter/Paramedic	232	ND
	Living quarters/ apparatus	Firefighter/Paramedic	232	ND
	Living quarters/ apparatus	Captain	274	ND
November 10	Living quarters/ apparatus	Engineer	273	ND
	Living quarters/ apparatus	Firefighter/Paramedic	290	5.9t
	Living quarters/ apparatus	Firefighter/Paramedic	273	ND
	Living quarters/ apparatus	Captain	273	ND
November 11	Living quarters/ apparatus	Engineer	361	ND
	Living quarters/ apparatus	Firefighter/Paramedic	467	4.3t
	Living quarters/ apparatus	Firefighter/Paramedic	361	5.4t
	Living quarters/ apparatus	Captain	363	ND
	Living quarters/ apparatus	Tillerman	365	ND
General Area Air Samples				
November 9	Apparatus Bay	Center	493	22.6
	Apparatus Bay	NE ladder	471	21.4
	Apparatus Bay	SE ladder	473	10.8t
	Apparatus Bay	SW ladder	484	18.7

	Dining room	on table	487	ND
	East Dormitory	on window sill	474	ND
	East Dormitory	on locker 29	474	ND
	West Dormitory	on window sill	475	ND
	West Dormitory	on locker 18	474	ND
	Kitchen	on counter	486	ND
	Kitchen	on refrigerator	490	ND
	Television room	on table	476	ND
	Office	on window sill	493	3.1t
	Office	on filing cabinet	493	3.0t
	Outside	on fence	471	ND
November 10	Apparatus Bay	Center	477	18.6
	Apparatus Bay	NE ladder	481	15.7
	Apparatus Bay	SE ladder	483	13.3
	Apparatus Bay	SW ladder	482	14.1
	Dining room	on table	446	3.4t
	East Dormitory	on window sill	478	ND
	East Dormitory	on locker 29	478	ND
	West Dormitory	on window sill	475	ND
	West Dormitory	on locker 18	474	ND
	Kitchen	on counter	480	3.8t
	Kitchen	on refrigerator	307	ND
	Television room	on table	435	ND
	Office	on window sill	480	ND
	Office	on filing cabinet	480	3.5t
	Outside	on fence	466	ND
November 11	Apparatus Bay	Center	486	13.9
	Apparatus Bay	NE ladder	486	17.3
	Apparatus Bay	SE ladder	496	14.3

	Apparatus Bay	SW ladder	496	11.5t
	Dining room	on table	486	ND
	East Dormitory	on window sill	481	3.0t
	East Dormitory	on locker 29	481	ND
	West Dormitory	on window sill	486	ND
	West Dormitory	on locker 18	486	2.9t
	Kitchen	on counter	490	ND
	Television room	on table	482	ND
	Office	on window sill	465	3.1t
	Office	on filing cabinet	465	3.7t
	Outside	on fence	479	ND

[1] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for this sample set was 0.5 micrograms (µg) of C_e per sample. Due to the relatively small sample volumes, the MDCs for the subset of PBZ samples ranged from 11 to 19 µg/m^3. For area samples the MDC was 3 µg/m^3.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

Table 5. Results of air sampling in the apparatus bay for oxides of nitrogen at fire station 5 before the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Sample Location	Sample Time[1]	Concentration in air (ppm)		
			Nitrogen Dioxide	Nitric Oxide	
General Area Air Samples					
November 9	Center of Bay	0840-1239	ND[2]	.12t[3]	.13t[4]
		1239-1640	.09t	.14t	
	NE ladder	0842-1235	ND	ND	ND
		1235-1638	ND	ND	
November 10	Center of Bay	0738-1138	.09t	.28t	.20t
		1138-1540	.09t	.12t	
	NE ladder	0739-1142	ND	ND	ND
		1142-1541	ND	ND	
November 11	Center of Bay	0743-1227	ND	ND	ND
		1227-1553	ND	ND	
	NE ladder	0743-1227	.18t	.28t	.14t
		1227-1553	.09t	ND	
OSHA PEL					25
NIOSH REL					25

1 Times are reported in military time.
2 "ND" means none of the analyte was detected in this sample. The limit of detection for this sample set is 0.8 µg/sample.
3 A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.
4 Values in this column are 8-hour time weighted averages (TWAs).

Table 6. Results of air sampling for volatile organic compounds at fire station 5 before the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Sample Location	Sample Time (min.)	Concentration in air (ppm)	
			Benzene	Xylenes
General Area Air Samples				
November 9	Center of Bay	481	ND[1]	.004
	NE ladder	476	ND	.005
November 10	Center of Bay	481	ND	.004
	NE ladder	482	ND	.004
November 11	Center of Bay	486	.003t[2]	.009
	NE ladder	488	.003t	.009
OSHA PEL			1	100
NIOSH REL			0.1	100

[1] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for benzene and xylenes was 0.4µg/sample, corresponding to MDCs of 0.001 ppm.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

Table 7. Results of air sampling for sulfur dioxide at fire station 5 before the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Sample Location	Time of Collection[1]	Concentration in air (ppm)
November 9	Apparatus Bay	0930	ND[2]
	Apparatus Bay	1007	ND
	Apparatus Bay	1144	ND
	Apparatus Bay	1310	ND
	Apparatus Bay	1408	ND
	Apparatus Bay	1504	ND
	Apparatus Bay	1547	ND
	Apparatus Bay	1606	ND

[1] Times are reported in military time.
[2] "ND" means none of the analyte was detected in the sample, indicating that SO_2 concentrations were less than 0.1 ppm.

Table 8. Results of air sampling for elemental carbon at fire station 3 after the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Area	Sample Location or Job Title	Sample Time	Concentration in air ($\mu g/m^3$)
General Area Air Samples				
March 14	Apparatus Bay	Center	484	1.8t[1]
	Apparatus Bay	Rear center	484	2.6t
	Apparatus Bay	Generator door	483	2.8t
	Apparatus Bay	North wall ladder	484	1.9t
	Outside	Fence line	484	ND[2]
March 15	Apparatus Bay	Center	478	ND
	Apparatus Bay	Rear center	477	ND
	Apparatus Bay	Generator door	478	ND
	Apparatus Bay	North wall ladder	478	ND
	Outside	Fence line	475	ND
March 16	Apparatus Bay	Center	480	ND
	Apparatus Bay	Rear center	480	ND
	Apparatus Bay	Generator door	480	ND
	Apparatus Bay	North wall ladder	480	ND
	Outside	Fence line	480	ND
March 17	Apparatus Bay	Center	480	ND
	Apparatus Bay	Rear center	480	ND
	Apparatus Bay	Generator door	480	ND
	Apparatus Bay	North wall ladder	480	ND
	Outside	Fence line	479	ND

[1] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

[2] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for this sample set was 0.5 micrograms (µg) of C_e per sample. The MDC for this sample set was 1.3 $\mu g/m^3$.

Table 9. Results of air sampling for elemental carbon at fire station 5 after the installation of ceramic filter controls. Costa Mesa Fire Department. (HETA 99-0266)

Date	Area	Sample Location or Job Title	Sample Time	Concentration in air (µg/m³)
General Area Air Samples				
March 14	Apparatus Bay	Center	496	ND[1]
	Apparatus Bay	NE ladder	498	ND
	Apparatus Bay	SE ladder	492	ND
	Apparatus Bay	SW ladder	495	ND
	Outside	On fence	489	ND
March 15	Apparatus Bay	Center	495	ND
	Apparatus Bay	NE ladder	498	2.0t[2]
	Apparatus Bay	SE ladder	494	2.3t
	Apparatus Bay	SW ladder	482	ND
	Outside	On fence	499	ND
March 16	Apparatus Bay	Center	484	ND
	Apparatus Bay	NE ladder	485	ND
	Apparatus Bay	SE ladder	485	ND
	Apparatus Bay	SW ladder	482	ND
	Outside	On fence	485	ND
March 17	Apparatus Bay	Center	495	ND
	Apparatus Bay	NE ladder	492	1.5t
	Apparatus Bay	SE ladder	493	1.2t
	Apparatus Bay	SW ladder	492	1.7t
	Outside	On fence	492	ND

[1] "ND" means none of the analyte was detected in this sample. The analytical limit of detection for this sample set was 0.5 micrograms (µg) of C_e per sample. The MDC for this sample set was 1.3 µg/m³.
[2] A "t" next to the value indicates that the analyte was detected at trace concentrations. Concentrations in the trace range are semi-quantitative.

Table 10. Descriptive statistics of PBZ and area elemental carbon concentrations before control, by location at fire station 3. Nondetectable values replaced by LOD. Costa Mesa Fire Department. (HETA 99-0266)

Location/Job	N=	Arithmetic Mean	Arithmetic Standard Deviation	Geometric Mean	Geometric Standard Deviation
Captain	2	3.9203	0.10140	3.9197	1.02620
bay	12	8.7583	8.41356	6.0656	2.34047
engine	1	5.8134		5.8134	
Engineer	2	4.6286	0.85388	4.5891	1.20386
FF	3	8.2568	5.80592	7.0361	1.98043
FF/Paramedic	1	3.6511		3.6511	
in rig	1	10.5290		10.5290	
living quarters	30	3.6887	3.25178	3.2852	1.43632
Med Engineer	1	5.3371		5.3371	
outside	2	2.9726	0.03154	2.9725	1.01067
Paramedic/FF On	2	5.5683	1.08189	5.5155	1.21596
Quint Engineer	1	5.7927		5.7927	

Table 11. Descriptive statistics of PBZ and area elemental carbon concentrations before control, by location at fire station 5. Nondetectable values replaced by LOD. Costa Mesa Fire Department. (HETA 99-0266)

Location/Job	N=	Arithmetic Mean	Arithmetic Standard Deviation	Geometric Mean	Geometric Standard Deviation
bay	12	16.0135	3.74960	15.6187	1.26297
Captain on truck	3	4.7820	0.74175	4.7411	1.17758
Engineer	1	5.2198		5.2198	
Engineer on engine	1	7.1438		7.1438	
Engineer on truck	2	5.3188	1.93943	5.1389	1.45217
FF on engine	1	5.4003		5.4003	
FF on truck	1	5.3317		5.3317	
FF/Medic on engine	2	5.5582	0.47855	5.5479	1.09003
FF/Medic on truck	2	6.1422	0.00000	6.1422	1.00000
FF/Paramedic	1	4.2719		4.2719	
living quarters	29	3.1374	0.36711	3.1200	1.10820
outside	3	2.9895	0.01676	2.9894	1.00562
Truck Tillerman	1	3.9041		3.9041	

Table 12. Descriptive statistics of area elemental carbon concentrations after control, by location at fire station 3. Nondetectable values replaced by LOD. Costa Mesa Fire Department. (HETA 99-0266)

Location/Job	N=	Arithmetic Mean	Arithmetic Standard Deviation	Geometric Mean	Geometric Standard Deviation
bay	16	1.49980	0.42286	1.45554	1.27028
outside	4	1.27234	0.01038	1.27231	1.00822

Table 13. Descriptive statistics of area elemental carbon concentrations after control, by location at fire station 5. Nondetectable values replaced by LOD. Costa Mesa Fire Department. (HETA 99-0266)

Location/Job	N=	Arithmetic Mean	Arithmetic Standard Deviation	Geometric Mean	Geometric Standard Deviation
bay	16	1.43196	0.32426	1.40431	1.21359
outside	4	1.28243	0.03008	1.28217	1.02378

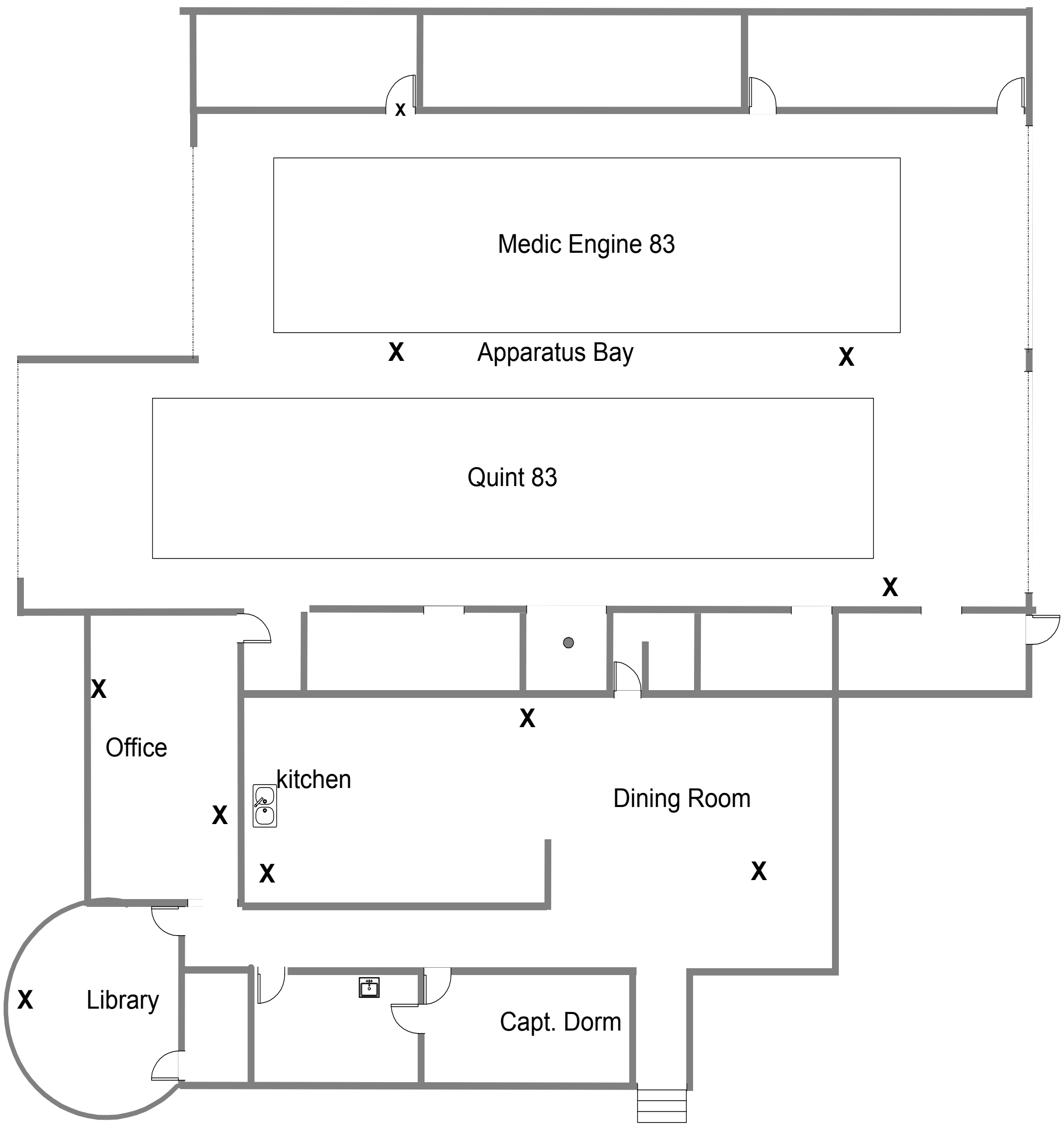

Figure 1. Ground floor of fire station 3. Pre-control elemental carbon sampling locations are indicated with an X.

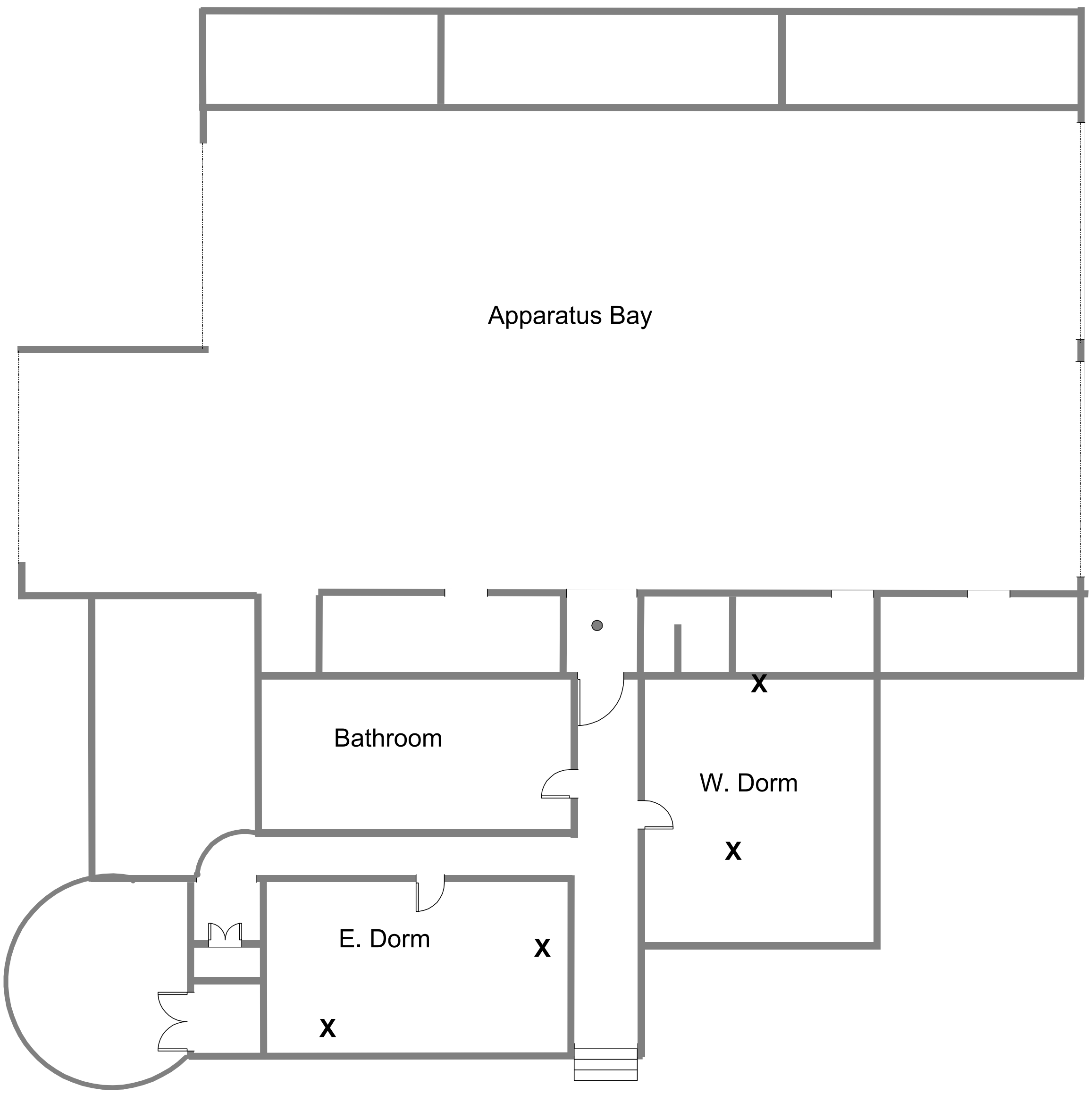

Figure 2. Second floor of fire station 3. Pre-control elemental carbon sampling locations are indicated with an X.

Figure 3. Ground floor of fire station 5. Pre-control elemental carbon sampling locations are indicated with an X.

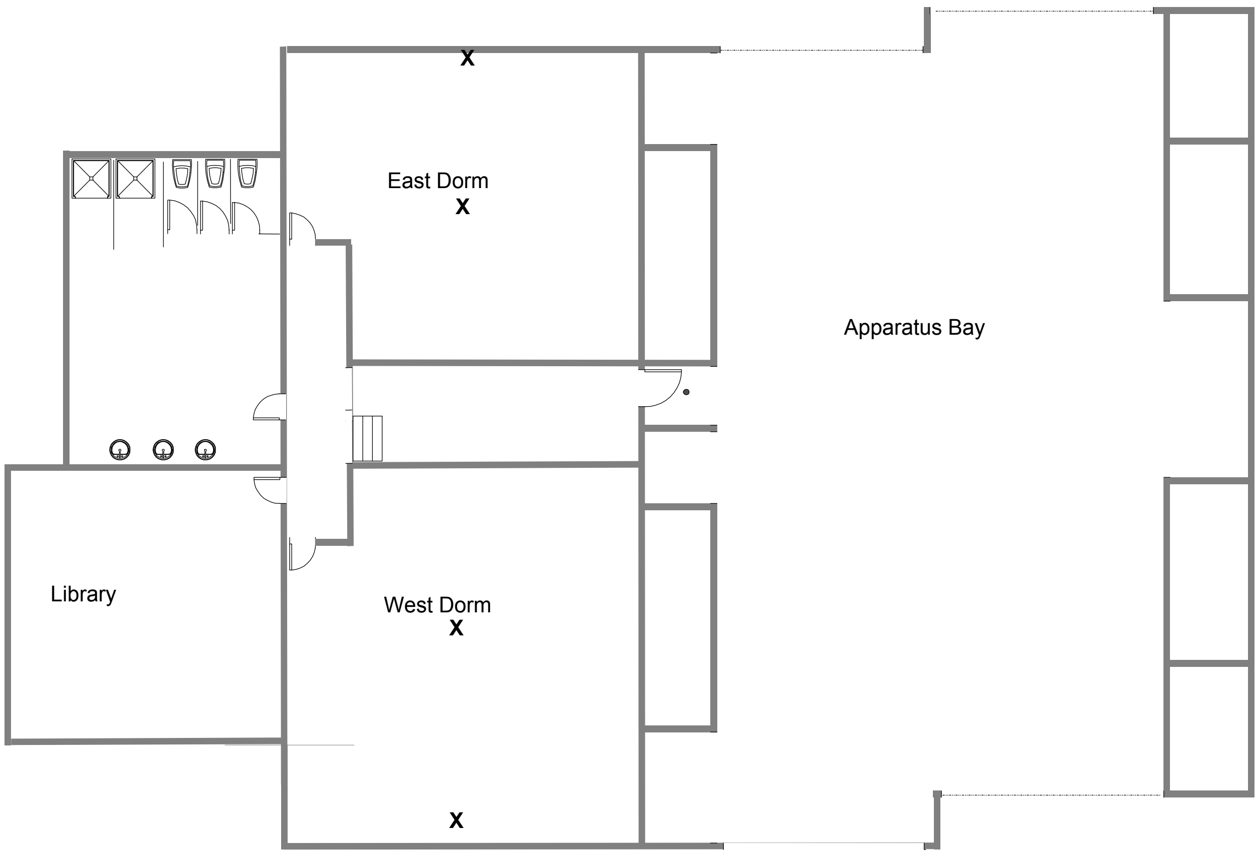

Figure 4. Second floor of fire station 5. Pre-control elemental carbon sampling locations are indicated with an X.

Plot of C_e concentrations measured in bay vs. number of calls.
Costa Mesa Fire Department. (HETA 99-0266)

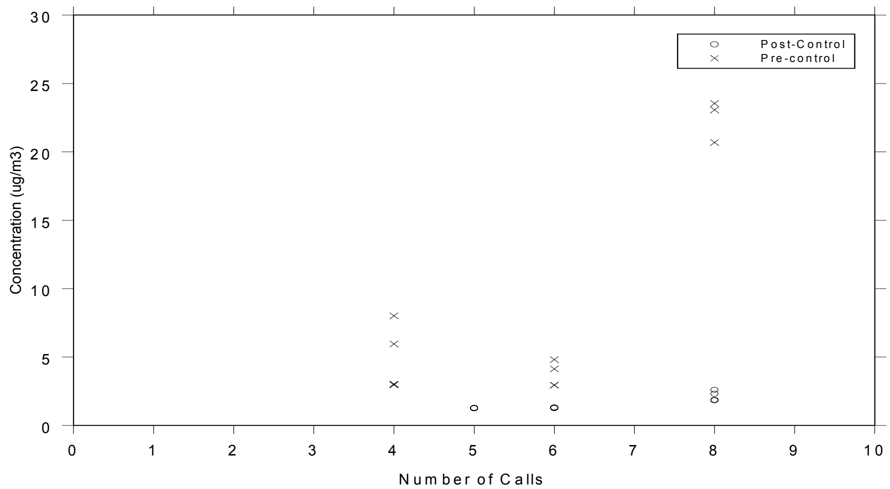

Figure 5. Comparison of pre- and post-control concentrations, fire station 3.

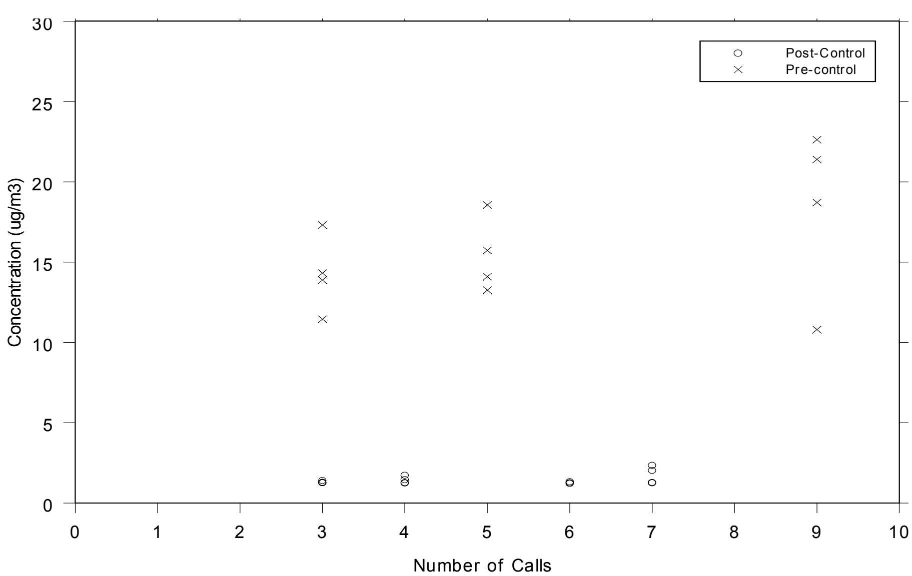

Figure 6. Comparison of pre- and post-control concentrations, fire station 5.

For Information on Other
Occupational Safety and Health Concerns

Call NIOSH at:
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