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Racine Fire Department
Racine, Wisconsin

Kevin C. Roegner, MPH
Alan Echt, MPH, CIH

PREFACE

The Hazard Evaluations and Technical Assistance Branch of 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 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 Roegner of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies and Alan Echt of the Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE). Field assistance was provided by Robert W. Kurimo, ECTB, DPSE. Desktop publishing was performed by Nichole Herbert. Review and preparation for printing was performed by Penny Arthur.

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Health Hazard Evaluation Report 97–0304–2695
Racine Fire Department
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Kevin C. Roegner, MPH
Alan Echt, MPH, CIH

SUMMARY

On September 5, 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request from fire fighters of the Racine Fire Department to conduct a health hazard evaluation (HHE) of diesel exhaust exposure at fire stations within the city of Racine, Wisconsin. Health concerns indicated on the request included headaches and concerns about the possible carcinogenic risk associated with exposure to diesel exhaust.

In response to the request, NIOSH investigators conducted an industrial hygiene evaluation at two fire stations on November 12 and 13, 1997. Environmental monitoring was conducted for components of diesel exhaust including nitrogen oxide (NO), nitrogen dioxide (NO_2), elemental carbon (EC), and miscellaneous hydrocarbons. Personal breathing zone (PBZ) and area air samples were collected for EC at each station. Area samples were collected in the kitchen, apparatus bay, and in the fire fighters' sleeping quarters. Additionally, one background EC sample was collected outside of each station as a comparative measure. Exhaust ventilation flow rates were also measured to estimate air changes per hour in apparatus bays.

Elemental carbon was not detected in any of the samples collected at station 5 on either night, indicating that the EC concentration for all area and PBZ samples (including background) was less than 4 $\mu g/m^3$ (micrograms per cubic meter). Five of 12 (42%) of the EC samples collected at station 8 were greater than background. These included two area samples collected in the apparatus bay and three PBZ samples. The highest EC concentration of 16 $\mu g/m^3$ was measured in the apparatus bay. Concentrations of NO_2 and NO in the stations were below exposure limits for these chemicals.

Only low levels of contaminants were detected at each station by qualitative organic vapor screening. Compounds detected included toluene, isooctane, benzene, C_6–C_{16} aliphatic hydrocarbons, methyl–t–butyl ether (MTBE), hexylene glycol, trimethylbenzenes, and naphthalenes. Based upon the standard spike analyzed with the air samples, concentrations on the thermal desorption tubes were estimated to be less than 0.5 micrograms (µg) for any single component (less than 0.07 parts per million [ppm], based on the minimum sample volume). Analyses of charcoal tubes for benzene, toluene, and xylenes identified trace (<0.07 ppm) quantities of xylenes on two samples, and did not detect benzene or toluene on any samples. The samples in which xylene was detected were collected during a 62–minute sampling period while the rescue unit left and returned to the station.

Exposure to individual constituents of diesel exhaust was below respective NIOSH recommended exposure limits (REL) at both stations, indicating that under the sampling conditions, these constituents should not pose a significant health hazard. Diesel exhaust in station 8 was confined to the apparatus bay.

Three factors could be credited for the low diesel exhaust concentrations at the time of the evaluation. First, the newer engines operate more efficiently and, consequently, generate cleaner exhaust than the older engines they replaced. Second, during the survey stations 5 and 8 may have responded to fewer than the typical number of calls. Third, the ventilation is effectively removing exhaust from the bays. Recommendations were made which could further reduce diesel exhaust exposure.

Keywords: SIC 9224 (Fire Protection), fire fighters, diesel, elemental carbon, nitrogen dioxide.

TABLE OF CONTENTS

INTRODUCTION

On September 5, 1997, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request from fire fighters of the Racine Fire Department to conduct a health hazard evaluation (HHE) of diesel exhaust exposure at fire stations 5 and 8 within the City of Racine Fire Department located in Racine, Wisconsin. Health concerns indicated on the request included headaches and concerns about the possible carcinogenic risk associated with exposure to diesel exhaust.

In response to the request, NIOSH investigators conducted an industrial hygiene evaluation at fire stations 5 and 8 on November 12 and 13, 1997. Following a meeting with city and fire fighter representatives to discuss the nature of the request, environmental monitoring was conducted for components of diesel exhaust including nitrogen oxide (NO), nitrogen dioxide (NO_2), elemental carbon (EC), and miscellaneous hydrocarbons.

BACKGROUND

At the time of the survey, the Racine Fire Department was comprised of 177 full–time uniformed employees working in seven fire stations, servicing approximately 85,000 people within the city of Racine, Wisconsin, and nearby contracted areas. Fire fighters typically work a 24–hour shift followed by 24–hours off duty then 24– hours on, 24 hours off, 24–hours on then 96–hours off. Station 5 was constructed in 1926 and consists of a ground floor and a basement. The apparatus bay, kitchen, dormitory, and sitting room are on the ground floor. Shower and storage areas are located in the basement. One fire engine and one rescue truck are housed in the apparatus bay; both are diesel–powered. Station 8, built in 1952, is a four level building with the apparatus bay, sitting room, kitchen, and an office at ground level; an additional sitting room is in the sub level; a two–bed dormitory is at the mezzanine level; and the main dormitory is on the top level, above the apparatus bay. Sliding poles extend through holes cut in the dormitory floor to the apparatus bay floor. The holes are partially sealed by spring–loaded doors which close around the poles. The apparatus bay houses one fire engine, one active rescue truck, and one reserve rescue truck; all are diesel–powered. Both stations are equipped with general exhaust ventilation systems designed to remove exhaust emissions from the apparatus bay. Replacement air is not mechanically supplied to the bay at either station.

METHODS

Elemental Carbon

Twenty–eight air samples for EC were collected and analyzed in accordance with NIOSH Method 5040.[1] The air samples were collected on 37–millimeter (mm) diameter quartz–fiber filters in open–faced cassettes connected via a length of Tygon® tubing to battery–powered air sampling pumps operating at a flow rate of 2 liters/minute (L/min). The limit of detection (LOD) and limit of quantification (LOQ) for this sample set was 3 micrograms (µg)/filter and 8 µg/filter, respectively.

Three personal breathing zone (PBZ) samples were collected each day at each station. Four area samples were collected each day at both stations: one in the kitchen, one in the apparatus bay, one in the fire fighters' sleeping quarters, and one background sample collected outside the station, away from sources of diesel exhaust. To evaluate only the exposure that occurred in the stations, rather than which occurred while riding the emergency vehicles, fire fighters were asked to turn off the sampling pumps when the vehicle, in which they were riding, left the station and turn the pumps back on when the vehicle began backing into the station upon their return. In this way, potential exposures were evaluated when the emergency vehicles' engines were started, and when the vehicles reentered the garage. NIOSH investigators permitted fire fighters to place the sampling devices near their bunks when the fire fighters went to sleep.

Oxides of Nitrogen

Area samples for oxides of nitrogen were collected and analyzed in accordance with NIOSH Method 6014.[1] 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 separated from NO, which is oxidized by the chromate oxidizer tube and collected on the second TEA sorbent tube (the tube closer to the sampling pump). Short–term samples to assess peak exposures during responses were collected in the apparatus bay of both stations at a flow rate of 0.2 L/min. Because no short–term exposure limits exist for NO, only NO_2 concentrations are reported for these short–term samples. Respective LOD and LOQ values for this sample set were 1μg/sample and 3μg/sample for NO_2. At station 5, one set of short–term samples was collected on November 12, and two sets of short–term samples were collected on November 13. At station 8, two sets of short–term samples were collected on both days. The front tube of an additional set of short term samples collected at station 8 on November 13 was lost in transit, and the back tube was not analyzed.

Samples intended to assess the time–weighted average (TWA) exposure to oxides of nitrogen were collected at a flow rate of 0.025 L/min. in the kitchen, dormitory, apparatus bay at station 8, and in the dormitory and apparatus bay at station 5. At station 5, four sets of long–term samples (approximately 4 hours per set) were collected each day. Three sets of long–term samples (ranging from approximately 5 to 9 hours per set) were collected at station 8 each day. As no TWA exposure criteria exists for NO_2, samples were only analyzed for NO. Respective LOD and LOQ values for this sample set were 0.6 μg/sample and 2μg/sample for NO.

Organic Vapors

Area samples were collected on thermal desorption tubes in accordance with NIOSH Method 2459 to screen for volatile organic compounds (VOCs). 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.[1] At station 5, one area sample was collected on November 12, and two were collected on November 13. The samples were collected in the apparatus bay, beginning when the response vehicles started in response to an emergency dispatch, and allowed to run for about two hours. A background sample was collected for about an hour on November 12 to assess the effects of humidity on the sampling media. At station 8, four samples were collected in the apparatus bay on November 12, and two were collected on November 13. The thermal desorption tubes were connected via Tygon tubing to battery–powered sampling pumps operating at a calibrated flow rate of 0.05 L/min. Samples were analyzed using an automatic thermal desorption (TD) system interfaced directly with a gas chromatograph (GC) and mass selective detector (MSD). Stock solutions of methanol containing known amounts of several compounds known to be present in vehicle exhaust were used to prepare spikes to estimate the concentrations of solvents collected on the air samples.

Area air samples on coconut–shell solid sorbent charcoal tubes were collected side by side with the TD tubes in order to quantify compounds identified during the analysis of those samples. The samples were collected on charcoal tubes in plastic holders connected via Tygon tubing to battery–powered sampling pumps operating at a flow rate of 0.2 L/min. Sample start–times matched those of the TD tubes. Based upon the results of the analysis of the TD tubes, the charcoal tubes were quantitatively analyzed for toluene, xylene, and benzene using NIOSH Method 1501. Respective per sample LODs and LOQs for these analyses were 0.4 µg and 1 µg for benzene, 0.4 µg and 3 µg for toluene, and 0.8 µg and 1 µg for xylenes.

Ventilation Measurements

Ventilation measurements were obtained using an Accubalance flow measuring hood, Model 8370 (TSI Incorporated, St. Paul, Minnesota). The flow hood was assembled at each station and placed flush against the grille in a manner which completely covered the grille. Three air flow measurements were obtained. The average of the three air flow values is reported.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre–existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criteria. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH recommended exposure limits (RELs)[2], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®)[3], and (3) the U.S. Department of Labor, OSHA (Occupational Safety and Health Administration) permissible exposure limits (PELs)[4]. NIOSH encourages employers to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criterion. The OSHA PELs reflect the feasibility of controlling exposures in various industries where the agents are used, whereas NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard.

A time–weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8– to 10–hour workday. Some substances have recommended short–term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short–term.

Diesel Exhaust

Diesel engines function by facilitating the combustion of 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, oxides of sulfur, and hydrocarbons (e.g., ethylene, formaldehyde, methane, benzene, phenol, 1,3–butadiene, acrolein, and polynuclear aromatic hydrocarbons).[5–8] 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).[9] Estimates indicate that as many as 18,000 different substances resulting from the combustion process may be adsorbed onto these particulates.[10] 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.[8,9,11]

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 emissions: (1) pulmonary irritation from oxides of nitrogen; (2) irritation of the eyes and mucous membranes from sulfur dioxide, phenol, sulfuric acid, sulfate aerosols, and acrolein; and (3) cancer in animals from polynuclear aromatic hydrocarbons.

Several recent studies confirm an association between exposure to whole diesel exhaust and cancer in rats and mice.[9] The lung has been identified as the primary site of carcinogenic or tumorigenic responses following inhalation exposure. Limited epidemiological evidence suggests an association between occupational exposure to diesel exhaust emissions and lung cancer.[12] The agreement of current toxicological and epidemiological evidence suggests that occupational exposure to diesel exhaust is a potential carcinogen.[9] Tumor induction is associated with diesel exhaust particulates, and limited evidence suggests that the gaseous fraction of diesel exhaust may be carcinogenic as well.[9]

NIOSH recommends that whole diesel exhaust be regarded as a "potential occupational carcinogen," as defined in the Cancer Policy of the OSHA ("Identification, Classification, and Regulation of Potential Occupational Carcinogens," 29 CFR 1990). This recommendation is based on findings of carcinogenic and tumorigenic responses in rats and mice exposed to whole diesel exhaust. The American Conference of Governmental Industrial Hygienists (ACGIH) has proposed, but not yet adopted, a TLV of 0.150 milligrams per cubic meter (mg/m^3) for diesel exhaust emissions.[4] Use of this proposed TLV is based upon either the collection and measurement (using a size–selective sampler and either a gravimetric measure or the thermo–optical measurement of EC) of the submicrometer fraction of the diesel exhaust particulate emissions, or the collection of a sample of respirable dust analyzed using the respirable combustible dust method.

Elemental Carbon

NIOSH researchers have selected EC as a surrogate measure of exposure to particulate diesel exhaust because it is more sensitive than the gravimetric approach.[13] Selection of EC as a marker for diesel exhaust exposure was based upon research which evaluated a number of species as indices of overall diesel exposure.[13] Included in that evaluation were CO_2, CO, NO, NO_2, total and fine particulate material (determined gravimetrically), volatilizable carbon (organic), and EC. Of these constituents of diesel exhaust emissions, EC was the most reliable measure of "diesel exhaust as an entity."[13] That is, it reflected exposures to the largest number of exhaust components studied.[13] EC constitutes a large portion of the diesel particulate mass, serves as a carrier of polycyclic aromatic compounds, can be quantified at low levels, and the diesel engine is its only significant source in many workplaces.[13]

Oxides of Nitrogen (NO and NO_2)

Nitric oxide (NO) is a colorless gas with a reported odor threshold in the range of 0.3 to 1 parts per million (ppm).[14] NO is converted spontaneously in air to NO_2; hence, some of the latter gas is invariably present whenever NO is found in the air.[15] Nitric oxide causes cyanosis (blue color of mucous membranes and skin) in animals, apparently from the formation of methemoglobin.[16] No effects in humans have been reported from NO alone.[16] However, intoxication of two patients from the use, as an anesthetic, of 75% nitrous oxide (N_2O) in oxygen that was contaminated with more than 1.5% NO resulted in both individuals suffering cyanosis and methemoglobinemia, as well as respiratory distress and pulmonary edema (fluid in the lungs) attributed to nitrogen dioxide (NO_2).[17] It is likely that the effects of concomitant exposure to NO_2 will become manifest before the methemoglobin effects due to NO can occur.[16] In 1968, experimental animal data indicated that NO is about one–fifth as toxic as NO_2.[15]

NO_2 is a reddish–brown gas; in high concentrations, it is partially associated to nitrogen tetroxide (N_2O_4).[17] The odor threshold is on the order of 0.12 ppm.[16] NO_2 is a respiratory irritant which can cause pulmonary edema.[16] Many deaths from pulmonary edema, induced by the inhalation of high concentrations of NO_2, have been reported.[17] Brief exposure of humans to concentrations of about 250 ppm causes cough, production of mucoid or frothy sputum, and increasing dyspnea (shortness of breath).[15,18] Within 1 to 2 hours, the person may develop pulmonary edema with tachypnea (rapid breathing), cyanosis, and tachycardia (rapid heart beat). The condition then may enter a second stage of abruptly increasing severity; fever and chills precede a relapse, with increasing dyspnea, cyanosis, and recurring pulmonary edema. Death may occur in either the initial or the second stage of the illness; a severe second stage may follow a relatively mild initial stage. The person who survives the second stage usually recovers over 2 to 3 weeks; however, some persons do not return to normal, but experience varying degrees of impaired pulmonary function.[16] Humans exposed to varying concentrations of NO_2 for 60 minutes can expect the following effects: 100 ppm, pulmonary edema and death; 50 ppm, pulmonary edema with possible residual lung damage; and 25 ppm, respiratory irritation and chest pain.[19] The incidence of chronic effects from long–term exposures is less well defined.[17]

On the basis of information from animal and human studies, the ACGIH has established a TLV for NO_2 of 3 ppm as a TWA and 5 ppm as a STEL. The NIOSH REL for NO_2 is 1 ppm as a STEL, while the OSHA PEL is a 5 ppm ceiling limit. The NIOSH REL, ACGIH TLV, and OSHA PEL for NO are all 25 ppm as a TWA.

OBSERVATIONS AND RESULTS

Station 5

No EC was detected in any of the samples collected at station 5 on either night. Based on the minimum sample volume of 854 L, these results indicate that the EC concentration for all area and PBZ samples (including background) was less than 4 µg/m^{3}.

Short–term area air samples were collected for NO_2 in the apparatus bay during the 15–minute period beginning when an engine was started in response to a call. A trace amount (a result between the LOD and the LOQ, with limited confidence in its accuracy) of NO_2 was detected in one sample collected from 5:18 to 5:35 p.m. on November 13, during which time engine 5 left the station and returned. This trace amount corresponds to a NO_2 concentration of less than 0.31 ppm, based on a sample volume of 12.2 L. Nitrogen dioxide was not detected (ND) in any other samples. Results for four area air samples collected for NO in the dormitory and apparatus bay ranged from ND in the dormitory to a trace in the apparatus bay on November 12, and from ND in the dormitory to 0.29 ppm in the apparatus bay, for a 487 min TWA on November 13. Based on the minimum sample volume of 10.5 L, the three were below the LOQ and had NO concentrations of less than 0.20 ppm.

Only low levels of any contaminants were detected on any of the TD tube samples collected at station 5. Compounds detected included toluene, isooctane, benzene, C_6–C_{16} aliphatic hydrocarbons, MTBE, hexylene glycol, trimethylbenzenes, and naphthalenes. Based upon the standard spike analyzed with the air samples, concentrations on the TD tubes were estimated to be less than 0.5µg for any single component (less than 0.07 ppm, based on the minimum sample volume of 1.8 L for this set of samples).

Three area samples were collected at station 5 and analyzed for benzene, toluene, and xylene. Analyses of these samples did not detect any benzene or toluene, corresponding to concentrations of less than 0.04 ppm, based on a minimum sample volume of 3.0L. One of the samples contained 3.5µg of xylene, a concentration of 0.03 ppm for this 24.8 L sample. This is well below the NIOSH REL for xylenes of 100 ppm, TWA, and 150 ppm, STEL.

The apparatus bay at station 5 is approximately 56 feet (ft) long by 25 ft wide by 11 ft high. The two vehicles housed there, rescue 5 and engine 5, are both diesel–powered. The vehicles enter and leave the station through a 10 ft high by 12 ft wide overhead door. Four other doors (to a sitting room, a hallway, the dormitory, and the kitchen) connect the apparatus bay with the rest of the building. There were noticeable gaps on all sides of the swinging door to the kitchen. A 23 inch (in) wide by 20 in high grille 20 in above the floor and 39 in from the outside wall in the southeast corner of the apparatus bay removes air from the apparatus bay at a flow rate of 1030 cubic feet/minute (cfm). This grille is connected via rectangular duct to a 1/4 horsepower Greenheck BSQ 9 – 4 inline EFI exhaust fan, rated at 780 cfm at 0.5 in static pressure. Smoke tube tests around doors showed that the apparatus bay is under negative pressure in relation to the remainder of the station, except when the vehicles are moving, when air entrained by their movement upsets this relationship. The station is heated by hot–water radiators supplied by a boiler in the basement. A “Modular Climate Changer,” installed in 1994–1995 provides ventilation and air conditioning to the station during the cooling season. This system is not equipped to heat the air, and was turned off at the time of this investigation. Three fire fighters are assigned to the station, and all three respond to any call. There was one engine response during our sampling period on November 12 (out at 7:41 p.m, in at 7:52 p.m.). There was one engine response (out at 5:18 p.m., in at 5:29 p.m.), and one rescue response (out at 10:21 p.m., in at 10:30 p.m.) during our sampling period on November 13. At the time of our site visit, engine 5 was equipped with a 1985, 568 in^3 Detroit Diesel engine, Model 8V71N, with scheduled oil and oil filter changes at 100–120 hours and a new crank case breather filter scheduled at 1 year intervals. This replaced a 1976, 426 in^3, 6–71N Detroit Diesel–powered rig. Rescue 5 is a 1991 model vehicle with a 444 in^3 diesel engine. Oil and oil filter changes are scheduled at 2000 miles, and the crank case breather air filter is replaced at 1 year intervals. Because Racine is an Environmental Protection Agency non–attainment area, low–sulfur diesel fuel is mandated.

Station 8

Only 1 of 12 air samples (6 samples each night) collected in station 8 detected EC above the LOQ. This sample was collected in the apparatus bay on November 13 and indicated an EC concentration of 16 $\mu g/m^3$. A trace amount of EC was detected in one area sample collected in the apparatus bay on November 12 and two personal air samples collected on November 13. Based on the LOQ and a minimum sample volume of 776 L, the EC concentration for these three samples was less than 10 $\mu g/m^3$. No EC was detected in the other samples, including background samples collected outdoors, indicating that the EC concentration in those sampling locations was less than 4ug/m^3.

Four air samples were collected in the apparatus bay to measure short–term air concentrations of NO_2 while the engine left or returned to the station. One 15–minute air sample, collected when the Quint 8 returned to the station at 9:28 p.m. on November 13, indicated a NO_2 concentration of 0.55 ppm. The amount of NO_2 in each of the other three samples was less then the LOQ. Based on the air volume of these samples the NO_2 concentration was less than 0.55 ppm.

A trace amount of NO was detected in each of three samples collected on November 12. Based on the volume of these samples and the LOQ of 2 µg/sample, concentrations of NO for each of these samples was less than 0.2 ppm. The highest NO concentration was detected in two samples collected in the apparatus bay on November 13. Both of these 435 minute samples indicated a NO concentration of 0.7 ppm. NO was ND in the main dormitory on the second night of sampling, indicating an average concentration of less than 0.10 ppm for this 311–minute sample.

Results of air samples collected for qualitative determination of VOCs were similar to those discussed above for station 5. Accordingly, samples collected on charcoal tubes were analyzed for benzene, toluene, and xylenes. These analyses identified trace quantities of xylene on two samples and did not detect benzene or toluene on any samples. The samples in which xylene was detected were collected during a 62–minute sampling period on November 12, during which time the rescue unit left and returned to the station. Based on the 3 µg/sample LOQ and 12.4L sample volumes, these samples detected xylene concentrations of less than 0.07 ppm. Based on the analytical LOD and sample volumes (ranging from7.2 to 20.4 liters) concentrations of benzene and toluene were less than 0.02 ppm.

The apparatus bay in station 8 is approximately 60 ft long by 32 ft wide by 14 ft high. Three diesel–powered vehicles Engine 8 , Rescue 8, and one reserve rescue truck, are housed in the apparatus bay. Vehicles enter and exit the station through a single large door located at the front of the apparatus bay. Other rooms adjacent to the apparatus bay include the kitchen via a short corridor, a sitting room on the main level, the Captain's office, and the main dormitory above the bay.

A 3/4 horsepower Dayton fan, Model #7C648, continuously exhausts air from the apparatus bay through a 32 in by 16 in grille 16 in above the floor at the rear of the apparatus bay. Air passes through the grille and to the top of the hose tower where the fan exhausts it to the outside. Two doors provide access to the hose tower, one from the apparatus bay and one from the outside. If not fully closed, air may be drawn into the hose tower from these sources as well as through the exhaust grille in the apparatus bay. Air flow of 430 cfm was measured passing through the grille while the doors were closed.

DISCUSSION AND CONCLUSIONS

Diesel exhaust exposure to fire fighters and emergency medical technicians (EMTs) was not greater than background concentrations in station 5, and was only slightly greater than background at station 8, based on EC monitoring results. The diesel exhaust in station 8 is confined to the apparatus bay. EC concentrations measured here are also significantly less than concentrations measured at other fire stations where no ventilation was provided.[20] EC concentrations in those stations ranged from 14 to 79 $\mu g/m^3$. Air concentrations of NO, NO_2, and VOCs were all well below respective RELs, indicating that these constituents should not pose a significant health hazard.

Three factors could be credited for the low diesel exhaust concentrations. First, the newer engines operate more efficiently and, consequently, generate cleaner exhaust than the older engines they replaced. Individuals working at the two stations indicated that the engines which were removed from service the week prior to the evaluation generated notably more diesel exhaust during routine operation than the new engines. This is not surprising given that the displaced engines were 1976 models. Second, stations 5 and 8 may have responded to fewer than the typical number of calls. Although it is difficult to determine, the level of activity during the survey seemed typical based on the stations' response logs from 1996. Third, the exhaust ventilation systems are effectively removing exhaust from the bays. Based on air flow measurements obtained during the survey, the exhaust ventilation in stations 5 and 8 provides four and one air changes per hour, respectively. The effectiveness of these air exchange rates in reducing airborne contaminants depends largely on how well air in the bay is mixed by turbulence. It should be noted, however, that the flow of air exhausted from station 8 is less than the Wisconsin Department of Industry, Labor, and Human Relations requirement of 0.5 cfm for every square foot of floor area. Based on the dimensions of the apparatus bay, air flow of 960 cfm or greater is required to meet this standard.[21]

RECOMMENDATIONS

Short– and long–term recommendations are provided based on the measurements and observations made during the evaluation. Short–term recommendations are those which may be readily implemented at little cost to minimize potential diesel exhaust exposures. Long–term recommendations are those which have been previously made by NIOSH or other authorities to reduce diesel exhaust exposures in fire stations. These are generalized approaches that typically require more capital investment than short–term recommendations. Large capital expenditures may not be warranted based on the findings of this study. The fire department should, however, consider implementing long–term recommendations if the number of responses increases, potentially increasing diesel exhaust exposures.[22]

Short–Term

1. The exhaust ventilation in the apparatus bay of station 8 is performing below design criteria and, consequently, is not meeting the Wisconsin Department of Industry, Labor, and Human Relations requirement of 0.5 cfm for every square foot of floor area. Determine why the air flow exhausted from the apparatus bay is less than design. It may be that air is leaking into the hose tower from the outside.

2. Weather stripping should be used to seal gaps on doors to rooms adjacent to the apparatus bay. The door between the apparatus bay and the kitchen in station 5 should be replaced with a door which better fits the frame. Weather stripping may not be effective on this door because the gaps span as much as an inch.

3. In general, doors between the apparatus bay and other work areas should remain closed. This does not seem to be a problem at these stations except for the door leading to the Captain's office in station 8. Better efforts should be made to keep this door closed.

4. Fire engine operations inside the garage need to be kept at an absolute minimum.

Long–term

1. Maintain a positive pressure differential between the living quarters and the apparatus bay at all times to confine diesel exhaust to the apparatus bay.[23] In station 5, this would require the addition of a heating system to the building's ventilation system, which does not run in the winter.

2. Engine Exhaust filters may be installed on diesel engines. 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 installed.[24]

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.[25] No documentation on the performance of the ceramic filter specifically for diesel–powered fire trucks was found in the literature; however, a number of local fire chiefs have written letters to the manufacturer of the filter system testifying to the good performance of the ceramic filter in reducing the diesel emissions from fire trucks.

3. Local tailpipe exhaust ventilation may be installed in the fire stations. A local exhaust ventilation control for diesel emissions from fire trucks while 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 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–sized 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 also removes gaseous emissions in the diesel exhaust such as oxides of nitrogen and sulfur. 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. An overhead duct system is available from some manufacturers which allows the vehicle's exhaust pipe to engage in an overhead exhaust duct when the vehicle enters the station. This type of system requires retrofitting the vehicle to equip it with an overhead exhaust stack rather than an under–vehicle tail pipe.

REFERENCES

1. NIOSH [1994]. Eller PM, ed. NIOSH manual of analytical methods. 4th rev. ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94–113.

2. NIOSH [1992]. NIOSH recommendations for occupational safety and health, compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control; National Institute for Occupational Safety and Health. DHHS (NIOSH) Publication No. 92–100.

3. ACGIH [1997]. Threshold limit values and biological exposure indices for 1997. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

4. OSHA [1989]. Air contaminants – permissible exposure limits (Title 29 Code of Federal Regulations Part 1910.1000). Washington, D.C.: U.S. Department of Labor, Occupational Safety and Health Administration. OSHA Publication No. 3112.

5. Linnell RH, Scott WE [1962]. Diesel exhaust composition and odor studies. J Air Pollut Control Assoc 12:510–545.

6. Environmental Health Associates [1978]. Health effects of diesel exhaust emissions. Berkeley, CA.

7. Schenker [1980]. Diesel exhaust—an occupational carcinogen? J Occup Med 22:41–46.

8. Travis CC, Munro NB [1983]. Potential health effects of light–duty diesel exhaust. Risk Analysis 3:147–155.

9. NIOSH [1988]. Current intelligence bulletin 50: Carcinogenic effects of exposure to diesel exhaust. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 88–116

10. Weisenberger [1984]. Health effects of diesel emissions—an update. J Soc Occup Med 34:90–92.

11. Cuddihy RG, Griffith WC, McClellan RO [1984]. Health risks from light–duty diesel vehicles. Environ Sci Technol 18:14A–21A.

12. Garshick E, Schenker MB, Munoz A, Segal M [1988]. A retrospective cohort study of lung cancer and diesel exposure in railroad workers. Am Rev Resp Dis 137:820–825.

13. NIOSH [1992]. NIOSH comments to DOL: comments from the National Institute for Occupational Safety and Health on the Mine Safety and Health Administration proposed rule on permissible exposure limit for diesel particulate. July 10, 1992. NIOSH policy statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

14. ACGIH [1991]. Documentation of the threshold limit values and biological exposure indices. 6th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienist, with supplements through 1994.

15. NIOSH [1976]. Criteria for a recommended standard: occupational exposure to oxides of nitrogen (nitrogen dioxide and nitric oxide). Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76–149.

16. Hathaway GJ, Proctor NH, Hughes JP, Fischman ML [1991]. Proctor and Hughes' chemical hazards of the workplace. 3rd ed. New York, NY: Van Nostrand Reinhold.

17. ACGIH [1991]. Documentation of the threshold limit values and biological exposure indices. 6th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists, with supplements through 1994.

18. Morgan WKC, Seaton A [1975]. Occupational lung diseases. Philadelphia, PA: WB Saunders, pp. 330–335, 344–345.

19. Anonymous [1964]. Emergency exposure limits: nitrogen dioxide. Am Ind Hyg Assoc J 25:580–582.

20.Echt A [1993]. Health Hazard Evaluation Report (HETA 92–0160–2360), Lancaster, Ohio. Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Safety and Health.

21. Wisconson Department of Industry, Labor, and Human Relations [1992]. Public Employee Safety and Health Inspection Order.

22. Froines JR, Hinds WC [1987]. Exposure of firefighters to diesel exhaust in fire stations. Am Ind Hyg Assoc J 48(3):202–207.

23. New Jersey Department of Health [1994]. Diesel exhaust in fire stations. Trenton, NJ: New Jersey Department of Health, Division of Epidemiology, Environmental and Occupational Health Services.

24. Ward Diesel Filter Systems, Inc. No smoke exhaust filtration. Elmira Heights, New York.

25. Baumgard KJ [1986]. Estimation of diesel particulate matter reductions in underground mines resulting from the use of a ceramic particle trap. Annals of the American Conference of Governmental Industrial Hygienists 14:257–263.