HETA 98–0152–2729
Wolfeboro Public Safety Building
Wolfeboro, New Hampshire

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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.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by David Sylvain, of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS), and Alan Echt of the Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE). Field assistance was provided by Teresa Ferrara of the Occupational Health and Safety Program, New Hampshire Division of Public Health Services. Analytical support was provided by DataChem Laboratories. Desktop publishing was performed by Pat Lovell. Review and preparation for printing was performed by Penny Arthur.

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Health Hazard Evaluation Report 98–0152–2729
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SUMMARY

On March 17, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation request (HHE) from the New Hampshire Department of Labor to conduct an evaluation of diesel exhaust exposure at the Wolfeboro Public Safety Building, in Wolfeboro, New Hampshire. The request indicated that Fire and Police personnel were exposed to diesel exhaust from fire apparatus. Asthmatic bronchitis was listed as a health problem resulting from this exposure.

On June 23, 1998, NIOSH conducted an industrial hygiene evaluation which included air sampling for elemental carbon ("EC," a component of diesel exhaust), and nitrogen dioxide (NO_2, also a component of diesel exhaust). With the exception of the 199–minute EC sample collected in the apparatus bay (0.009 milligrams per cubic meter [mg/m^3]), EC concentrations were below the minimum detectable concentration throughout the Wolfeboro Public Safety Building. An NO_2 concentration of 0.086 parts per million (ppm) was measured over a 189–minute period in the apparatus bay. Time–weighted average (TWA) NO_2 sampling in other areas of the building, revealed concentrations below the minimum quantifiable concentration. Direct–read ("grab") measurements, however, appear to indicate that higher NO_2 concentrations ("peak concentrations") *may* occur in the apparatus bays during *very* brief periods when vehicles are entering or returning.

It seems likely that the concentration of diesel exhaust and its constituent compounds in the Public Safety Building will vary, depending upon the operating conditions (e.g., engine temperature, tune–up condition, etc.), the type and size of engine, and the length of time that an engine runs in or near the building. Weather conditions may also affect indoor concentrations of diesel exhaust by changing the pressure differential between the apparatus bay and other parts of the building, thus driving contaminants into occupied indoor areas.

Although exposure to individual constituents of diesel exhaust was below respective NIOSH recommended exposure limits (RELs), complaints of diesel exhaust in the Public Safety Building are likely to reoccur as long as diesel–powered emergency vehicles are present, and fire and police staffs occupy adjacent offices and living areas. It appears that engineering controls may be needed to alleviate comfort and health concerns, especially among persons who are sensitive to the presence of diesel exhaust, such as asthmatics.

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

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INTRODUCTION

On March 17, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation request (HHE) from the New Hampshire Department of Labor to conduct an evaluation of diesel exhaust exposure at the Wolfeboro Public Safety Building, in Wolfeboro, New Hampshire. The request indicated that Fire and Police personnel were exposed to diesel exhaust from fire apparatus. Asthmatic bronchitis was listed as a health problem resulting from this exposure.

On June 23, 1998, NIOSH investigators, accompanied by an industrial hygienist from the New Hampshire Bureau of Health Risk Assessment, conducted an industrial hygiene evaluation at the Wolfeboro Public Safety Building. During the evaluation, fire and emergency vehicles were driven out, and then into the apparatus bays to simulate actual emergency responses. Sampling was conducted for elemental carbon ("EC," a component of diesel exhaust), and nitrogen dioxide (NO_2, also a component of diesel exhaust). In addition, direct reading instruments were used to measure peak concentrations of NO_2, and to obtain a count of airborne particulates.

BACKGROUND

The Public Safety Building is a 24–year–old two–story brick building, which houses the Wolfeboro Fire and Police Departments. During the daytime, the building is occupied by nine members of the police department, and three fire fighters. At night, the building is staffed by three members of the police department, and two from the fire department. The communications center and department offices are located on the first floor. The fire department dormitory, kitchen, and living area are on the second floor. Fire apparatus is housed in a single–story concrete block structure abutting the rear of the building. This structure contains 11 fire apparatus bays and two police vehicle bays. Five apparatus bays are occupied by fire and rescue vehicles, four of which are diesel–powered. The apparatus bays are not equipped with a mechanical ventilation system for removing exhaust emissions

During recent years, the Wolfeboro Fire Department has responded to approximately 750 emergency calls annually. Typically, one to two calls are received each day during the winter; seven to ten calls per day are received during the period running from July through September, when the summer population is at its peak. Approximately 400 of the 750 annual calls result in a response by one emergency vehicle; the other calls result in a response by two or more vehicles. At the time of the site visit, approximately 800 calls were anticipated for 1998.

The Fire Chief reported that exhaust remains in the building for approximately five minutes following a single vehicle response, and thirty minutes following larger responses. It was reported that the apparatus bays fill with white smoke when fire apparatus are started, and the exhaust spreads throughout the building, into the police and fire departments offices, as well as the second–floor dormitory. The diesels use #2 diesel fuel in the summer, with kerosene added for thinning in the winter months.

METHODS

During the evaluation at the Public Safety Building, 24 air samples (eight personal breathing zone (PBZ) and 16 area samples) were collected and analyzed for EC in accordance with NIOSH Method 5040.[1] Each PBZ sample was collected during one of three simulated emergency responses where fire personnel drove diesel–powered apparatus out of the building (into the parking lot), and returned the apparatus to the bay after approximately 17 minutes. Three different types of responses were simulated: (1) response by Engine 2, (2) nighttime response to a motor vehicle accident by Engine 1 and Rescue 1, and (3) box–alarm response typical of night or winter using Ladder 1, Engine 2, and Engine 4. All vehicles were diesel–powered except for Engine 4.

For this evaluation, EC was used as a surrogate for diesel particulate; thus, PBZ EC samples provided an estimate of firefighters' exposure to diesel exhaust at the times of departure from, and return to the station. The total sample times for PBZ samples were 34–35 minutes. Twelve short–term area samples were collected concurrently with the PBZ samples in the kitchen/dining area, dormitory, communications, and file room. Four area samples were collected over

188–199 minute periods (i.e., throughout the duration of the site visit) in the apparatus bay, kitchen, communications, and file room. In addition, one background (ambient) sample was collected outside the station, away from sources of diesel exhaust to assess the background concentration of EC. The PBZ and short–term area samples were collected on 37–millimeter (mm) diameter quartz–fiber filters in open–face cassettes connected by a length of Tygon® tubing to battery–powered air sampling pumps operating at a nominal flow rate of 4 liters/minute (L/min); 3–hour area samples were collected at 3 L/min.

Time–weighted average NO_2 concentrations were assessed at various locations within the building by collecting and analyzing area samples in accordance with NIOSH Method 6014.[1] NIOSH Method 6014 utilizes a triethanolamine (TEA)–treated molecular sieve sorbent tube attached by Tygon® tubing to a battery–powered sampling pump. These samples were collected for 189 to 198 minutes in the dormitory, as well as other locations where long–term EC samples were collected. A 215–minute ambient sample was collected outside the building. In addition to the TWA samples, short–term samples ("grab samples") to assess peak exposures to NO_2 during responses were collected using a Toxilog direct–reading gas detector equipped with an NO_2 sensor. NO_2 calibration gas was used to calibrate the Toxilog prior to sampling.

Because a major portion of diesel emissions are particulate, continuous particle counts were obtained in the apparatus bay using a factory calibrated Met One, Inc. Model 227B laser particle counter connected to a laptop computer. This unit is capable of monitoring two particle size ranges simultaneously, and was set to monitor all particles $\geq$0.3 micrometers in diameter (µmd) and those $\geq$1.0 µmd. (The Met One does not distinguish between particles generated by other sources (e.g., tobacco smoke) and those due to diesel emissions.) Particle counts were obtained during each simulated response, and during an actual response. A "background" particle count was obtained after the aparratus bay was allowed to air out for approximately 45 minutes after the units returned from the actual response. The particle counter was started when the response, background measurement, or simulation began, and counted particles continuously in 14 second cycles for the duration of each test. The sampling data was downloaded to the computer after each measurement. The unit was placed on the tongue of the trench rescue unit (TRU) trailer in the TRU bay, approximately 40 feet from the south door and 50 feet from the west wall.

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 criterion. 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, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[4] NIOSH encourages employers to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever is 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 exhaust is a complex mixture consisting of both gaseous and particulate fractions. The composition will vary greatly with fuel and engine type, maintenance, tuning, and exhaust gas treatment.[5,6] Gaseous constituents include carbon dioxide, carbon monoxide, nitrogen dioxide, oxides of sulfur and hydrocarbons. The particulate fraction (soot) of diesel exhaust consists of solid carbon cores produced during combustion and compounds deposited on the particle cores through sorption and condensation processes. More than 95% of diesel soot particles are less than 1 µmd. Up to 65% of the total particulate mass may be these adsorbed substances. The majority of the adsorbed material is unburned fuel and oil, but trace levels of compounds such as polynuclear aromatic hydrocarbons (PAHs) are also present, some of which are carcinogenic.[6] An estimated 18,000 substances from the combustion process can be adsorbed onto the particle cores.[6]

Studies of rats and mice exposed to diesel emissions, especially the particulate portion, confirmed an association with lung tumors.[6] Human epidemiology studies also suggest an association between occupational exposure to whole diesel exhaust and lung cancer.[6,7] In addition to the carcinogenic potential, many other components of diesel exhaust have known toxic effects. These effects include pulmonary irritation from nitrogen oxides, eye and mucous membrane irritation from sulfur dioxide and aldehyde compounds, and chemical asphyxiation from CO. Exposure criteria have been established for some of these compounds; however, the Occupational Safety and Health Administration has not established a permissible exposure limit for whole diesel exhaust emissions. The ACGIH has proposed a TWA TLV of 0.05 milligrams per cubic meter (mg/m^3) for diesel particulate.[8] The proposed TLV is stated in terms of sub–micrometer particulate mass.

Based on findings of carcinogenic responses in exposed rats and mice, NIOSH recommends that whole diesel exhaust be considered a potential occupational carcinogen and that exposures be reduced to the lowest feasible concentration.[6] In addition to the carcinogenic effects, eye irritation and reversible pulmonary function changes have been experienced by workers exposed to diesel exhaust.[6,9,10,11]

Assessing workers' exposures to diesel exhaust is difficult because of the complex makeup of the exhaust, uncertainty about which specific agent(s) may be responsible for the carcinogenic properties, and the presence of other fine aerosols (e.g., tobacco smoke particles) are also primarily < 1 µmd. Measurements of some commonly found components of diesel exhaust have generally shown concentrations to be well below established exposure criteria for the individual substances. Efforts have focused on evaluating the particulate portion because most animal studies have associated the carcinogenic potential of diesel exhaust with the particulate fraction of the exhaust. NIOSH is continuing to investigate the use of EC as a surrogate index of the particulate fraction. The use of EC holds promise as a selective measure of diesel particulate because the sampling and analytical method has a low limit of detection (background levels can be determined), and a high percentage of diesel particulate (80–90%) is carbon. Because tobacco smoke particulate is composed primarily of organic carbon, it does not interfere in the EC measurement.[12,13] Although neither NIOSH nor OSHA has established numerical exposure limits, sampling for EC to determine the relative diesel emission levels in different areas can provide baseline information for assessing the effectiveness of future control measures.

Nitrogen Dioxide (NO_2)

NO_2, a constituent of diesel exhaust, is a reddish–brown gas in high concentrations.[14] The odor threshold is on the order of 0.12 parts per million (ppm).[15] NO_2 is a respiratory irritant which can cause pulmonary edema (fluid in the lungs).[15] Many deaths from pulmonary edema, induced by the inhalation of high concentrations of NO_2, have been reported.[14] Brief exposure of humans to concentrations of about 250 ppm causes cough, production of mucoid or frothy sputum, and increasing dyspnea (shortness of breath).[16,17] Within one to two 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 two to three weeks; however, some persons do not return to normal, but experience varying degrees of impaired pulmonary function.[15] 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.[18] The incidence of chronic effects from long–term exposures is less well defined.[14]

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.

RESULTS

The minimum detectable concentration (MDC) for the 3–hour EC area samples was 0.007 mg/m^3; the minimum quantifiable concentration (MQC) was 0.03 mg/m^3. The MDC and MQC for all other EC samples were 0.03 mg/m^3 and 0.1 mg/m^3 respectively. With the exception of the 199–minute EC sample collected in the apparatus bay, EC concentrations were below the MDC throughout the Wolfeboro Public Safety Building. The *estimated* EC concentration in the apparatus bay was 0.009 mg/m^3. Since this concentration is below the MQC, it should be regarded as an approximation at best. The total carbon concentration (organic and elemental) was below the minimum level which is needed to obtain an estimate of the concentration of total diesel particulate matter (DPM) in the apparatus bay.[19]

An NO_2 concentration of 0.086 ppm was measured over a 189–minute period in the apparatus bay. TWA NO_2 sampling in other areas of the building, revealed concentrations below the MQC. (The MDC and MQC for the indoor samples were 0.01ppm and 0.04 ppm respectively.) The ambient (outdoor) sample indicated 0.02 ppm, which was below the MQC for this sample.

Although TWA samples revealed only low levels of NO_2, direct–read ("grab") measurements, obtained using the Toxilog, appear to indicate that higher NO_2 concentrations ("peak concentrations") *may* occur in the apparatus bays during *very* brief periods when vehicles are entering or returning. The highest Toxilog NO_2 reading was 50 ppm, which was measured as close as possible to the tailpipe of Rescue 1 as it backed into the building. A measurement taken one–minute later at PBZ–height, approximately eight feet behind the returning vehicles (Rescue 1 and Engine 1) indicated 0.2–0.3 ppm. Readings near the exhaust discharge of Engine 2 indicated 1.5–3 ppm. Another reading, taken between Engine 2 and the interior wall (where firefighters walk alongside Engine 2) revealed 2 ppm as Engine 2 "returned" from the simulated box alarm. Although these readings do not represent personal exposures, they do indicate the release of NO_2 into the apparatus bays, which may result in exposure to much higher short–term NO_2 concentrations than are indicated by TWA sampling. As noted in the discussion of evaluation criteria (above), concentrations of diesel exhaust constituents vary, depending on factors such as engine operating temperature, tuning of the engine, and fuel; thus, it appears possible that higher concentrations of NO_2 *could* be released from the diesel engines, depending upon the operating parameters at the time of release. The 2 ppm reading alongside Engine 2 (and the 50 ppm reading in the exhaust plume of Rescue 1) *may* indicate a potential for exposure to NO_2 which could exceed the NIOSH REL, and could approach, or exceed the OSHA ceiling limit of 5 ppm.

Particle counts for the actual response and simulations are provided in Figures 2 through 6. Figure 1 is the "background" count obtained to illustrate the increase in airborne particles in the apparatus bay above background levels during typical responses. However, the fact that the firefighters responded with Engine 1, Rescue 1, and the Chief's car prior to the background measurement probably resulted in this measurement being artificially elevated. The horizontal line in Figures 2 through 6 is the average of the background count in Figure 1, approximately 116,000 particles/sample. This line was placed in the figures for comparison. The results indicate that, on average, particle counts do increase during fire responses. During the summer simulation, Engine 2 alone was used. During the simulated motor vehicle accident, Engine 1 and Rescue 1 were used. Ladder 1, Engine 2, and Engine 4 (a gasoline–powered vehicle) were used for the simulated winter or night box response.

Note that exposure standards for particulates are based on mass per volume of air (e.g., mg/m^3), not particle counts over time, which was the measured parameter in this investigation. Size distributions of particles present in diesel exhaust vary with engine type and operating conditions. More than 95% of diesel particulates are less than 1 um in size.[6] However, some estimates indicate that average diesel particle diameters may be less than 0.3 µm.[20] Additionally, the regulatory standards for respirable nuisance, or otherwise unclassified dust are not comparable to diesel exhaust particulate. Therefore, the particle data should only be interpreted from the standpoint of assessing relative concentrations and clearance times, and should not be used for comparison with exposure criteria.

DISCUSSION

EC sampling revealed only low concentrations of diesel exhaust at the time of the sampling visit. Similarly, NO_2 monitoring indicated that personal exposures on this date were below exposure limits established by OSHA, ACGIH, and NIOSH; however, the potential for brief, episodic exposures to much higher NO_2 concentrations cannot be ruled out.

It seems likely that the concentration of diesel exhaust and its constituent compounds in the Public Safety Building will vary, depending upon the operating conditions (e.g., engine temperature, tune–up condition, etc.), the type and size of engine, and the length of time that an engine runs in or near the building. Weather conditions may also affect indoor concentrations of diesel exhaust by changing the pressure differential between the apparatus bay and other parts of the building, thus driving contaminants into occupied indoor areas; or by blowing diesel exhaust from the apparatus bay into other building areas when overhead doors are opened during windy conditions. During cold or inclement weather, overhead doors are likely to be closed shortly after departure or return of vehicles, thus trapping diesel exhaust in the building.

CONCLUSIONS

Occupant complaints are likely to reoccur as long as diesel–powered emergency vehicles are present in the building, and fire and police staffs occupy adjacent offices and living areas. Since diesel–powered vehicles are essential to the mission of the Wolfeboro Fire Department, it appears that engineering controls may be needed to alleviate comfort and health concerns, especially among persons who are sensitive to the presence of diesel exhaust, such as asthmatics. A well–designed, well–maintained tailpipe exhaust ventilation system could effectively remove diesel exhaust from the building. Such an exhaust system would allow vehicles to operate in the building for short periods without having to open the overhead doors. Opening the overhead doors to ventilate the apparatus bays is marginally effective at best, and may actually exacerbate indoor air quality problems elsewhere in the building.

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.

Short–Term

1. Minimize engine idling time inside apparatus bays.

2. Ensure that weather stripping on doors to rooms adjacent to the apparatus bay is intact and provides an effective barrier to diesel exhaust.

3. Keep doors closed between the apparatus bay and other work areas as much as possible.

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. This may require modification of the building heating/ventilation system.

2. Install a local tailpipe exhaust ventilation system (also called an exhaust extractor). Such a system utilizes a hose which attaches to the tailpipe of vehicles in the apparatus bays, 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 removes gaseous emissions in the diesel exhaust, such as oxides of nitrogen and sulfur, in addition to diesel particulate. The tailpipe exhaust hose captures the exhaust emissions when the vehicle exits the fire station and is manually reattached to the fire apparatus as it is backed into the building.

3. 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 three minutes, the electronic control vents the exhaust to the exhaust pipe, bypassing the ceramic filter. The timer should be set to allow enough time for the truck to exit the fire station. When the truck is shifted into reverse to back into the garage, the electronic control again routes the exhaust fumes through the filter. The ceramic filter weighs between 20 and 30 pounds and collects about 2 pounds of particulate before requiring servicing. The approximate cost for one filter system is $10,000 installed.[21]

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.[22] 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.

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Figure 1: Background Count of Particles >.3 and < 1 um

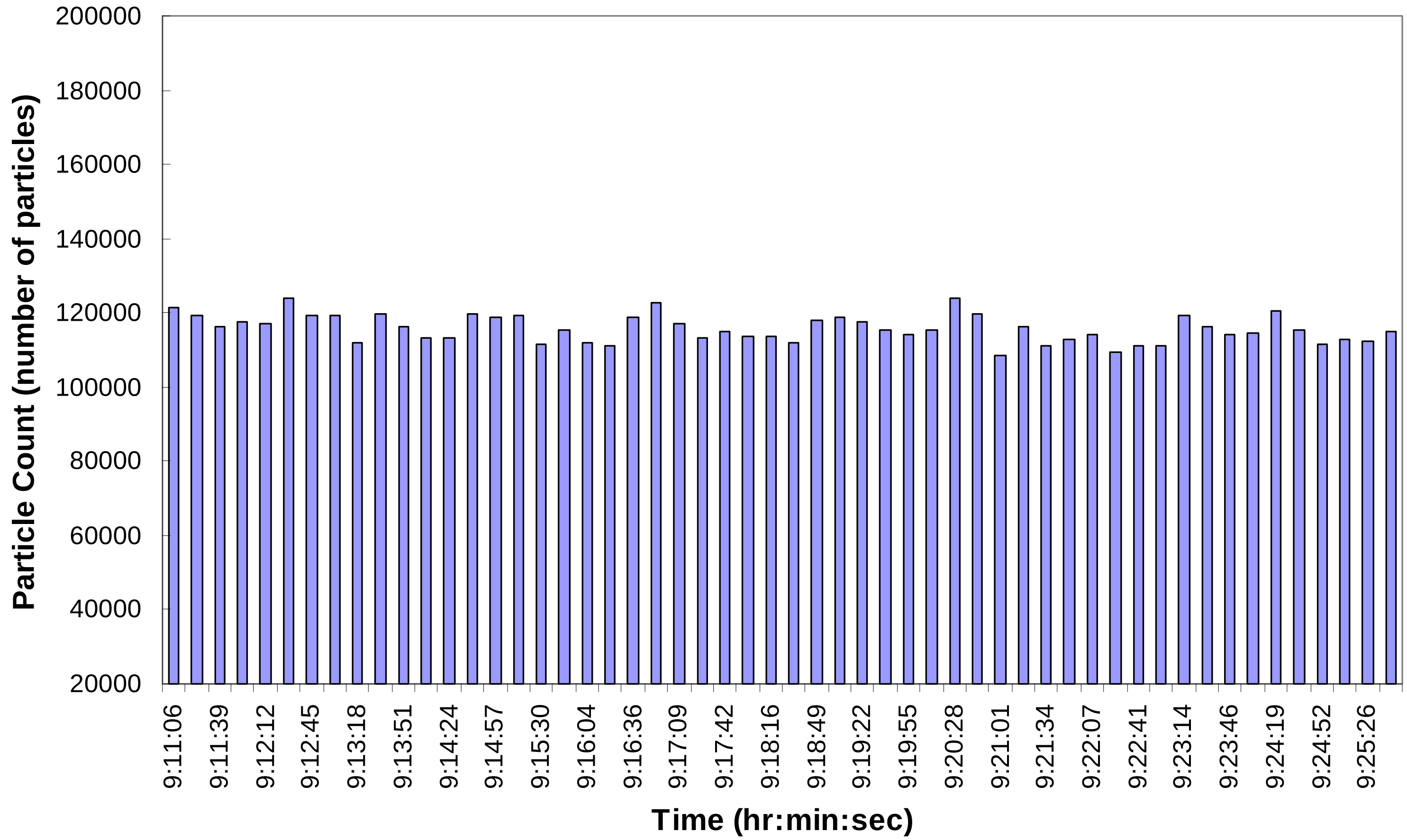


Figure 2: Dispatched Engine 1, Recue 1, Chief's Car
(Horizontal Line Indicates Average Background Particle Count)

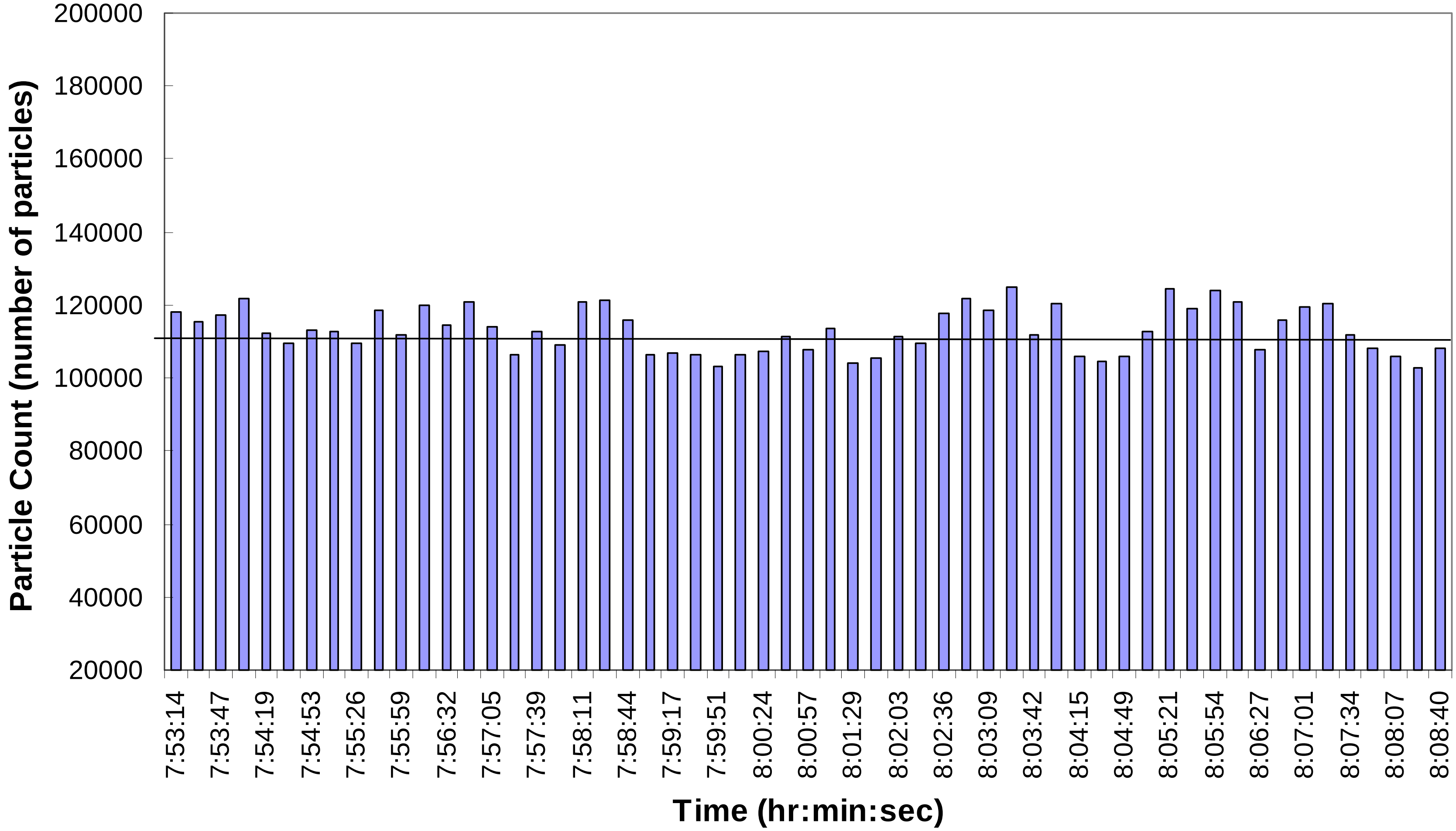


Figure 3: Summer Simulation, Engine 2 Depart
(Horizontal Line Indicates Average Background Particle Count)

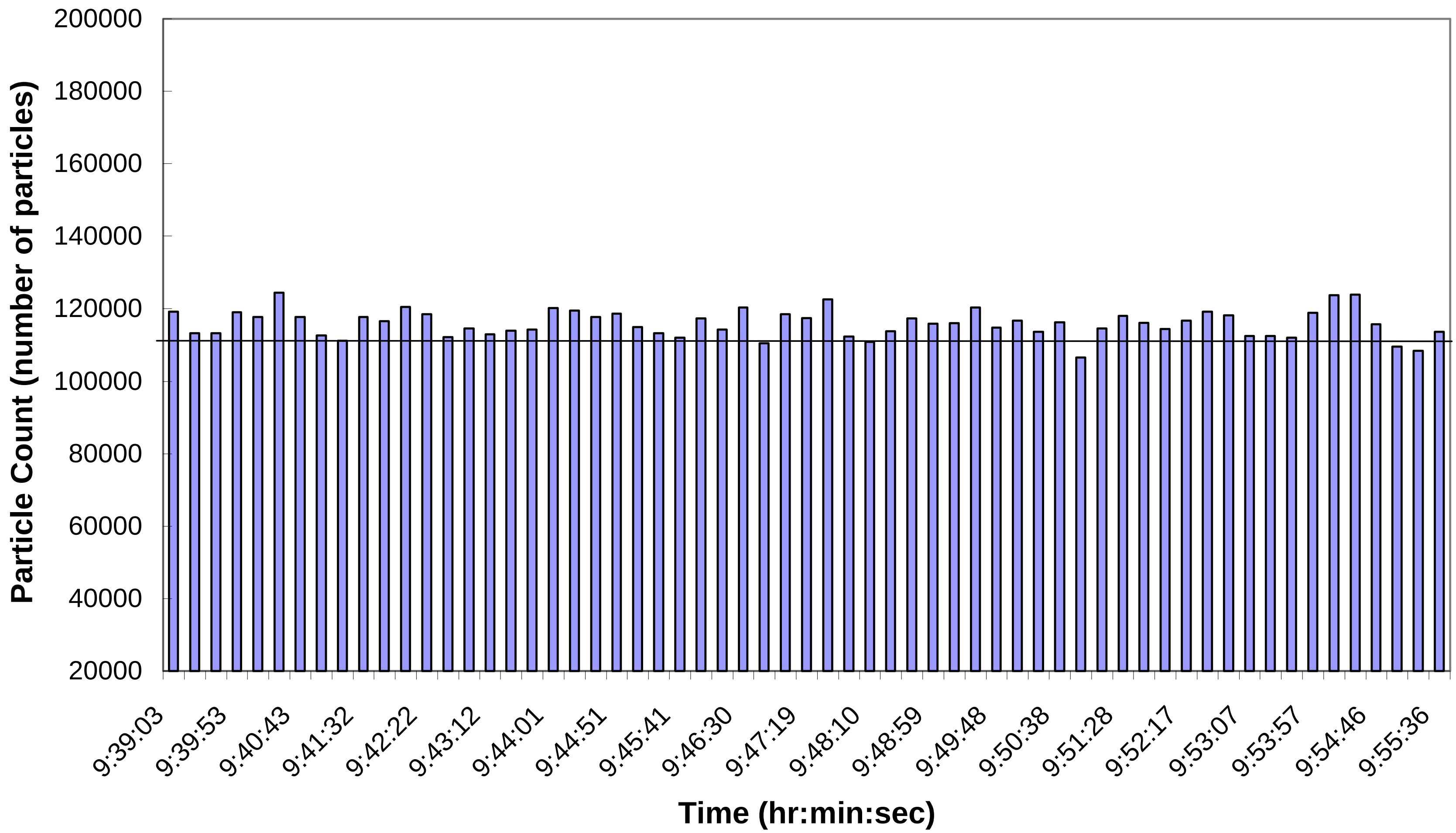


Figure 4: Summer Simulation - Engine 2 Return
(Horizontal Line Indicates Average Background Particle Count)

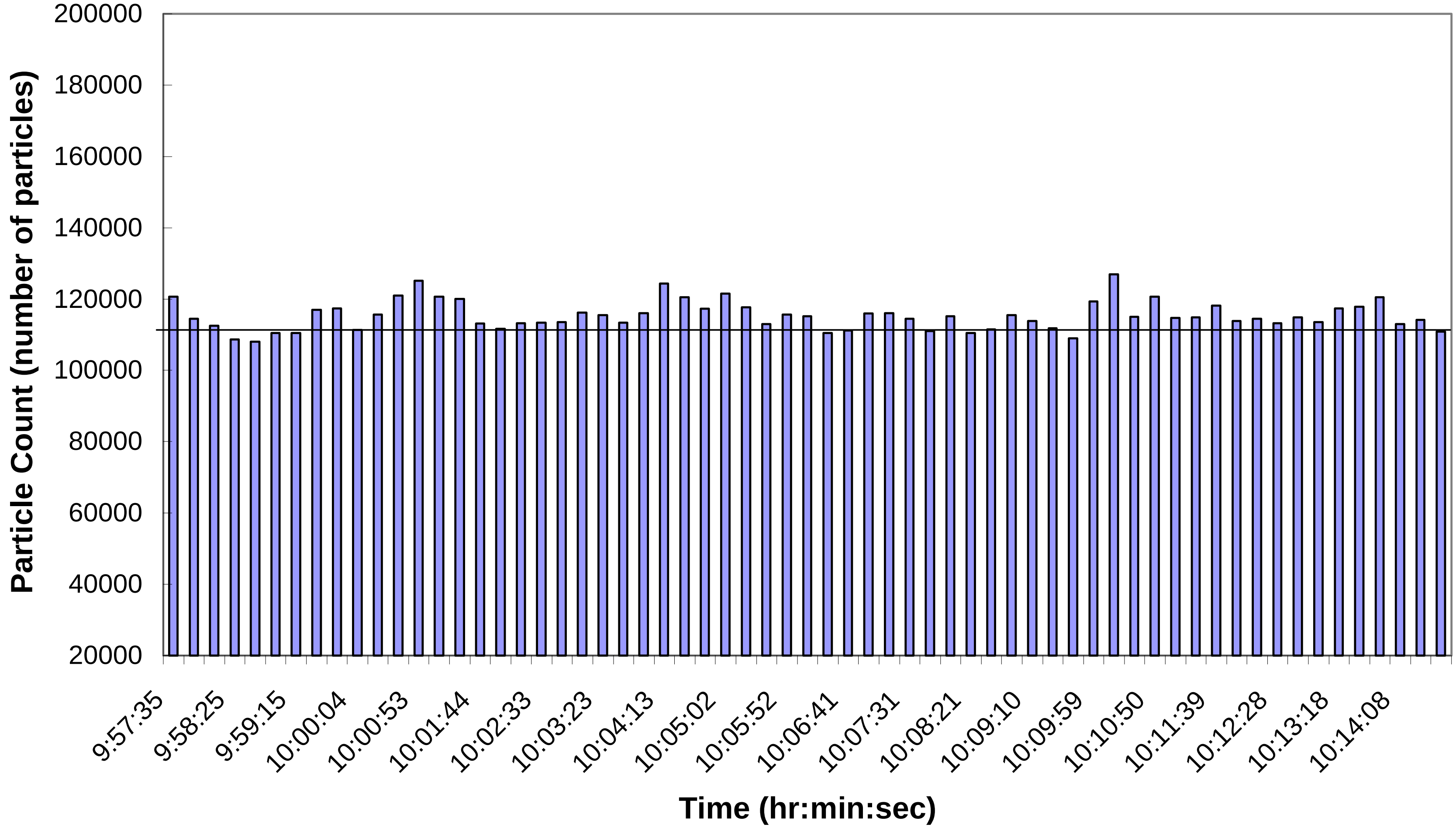


Figure 5: Simulated Motor Vehicle Accident Response
(Horizontal Line Indicates Average Background Particle Count)

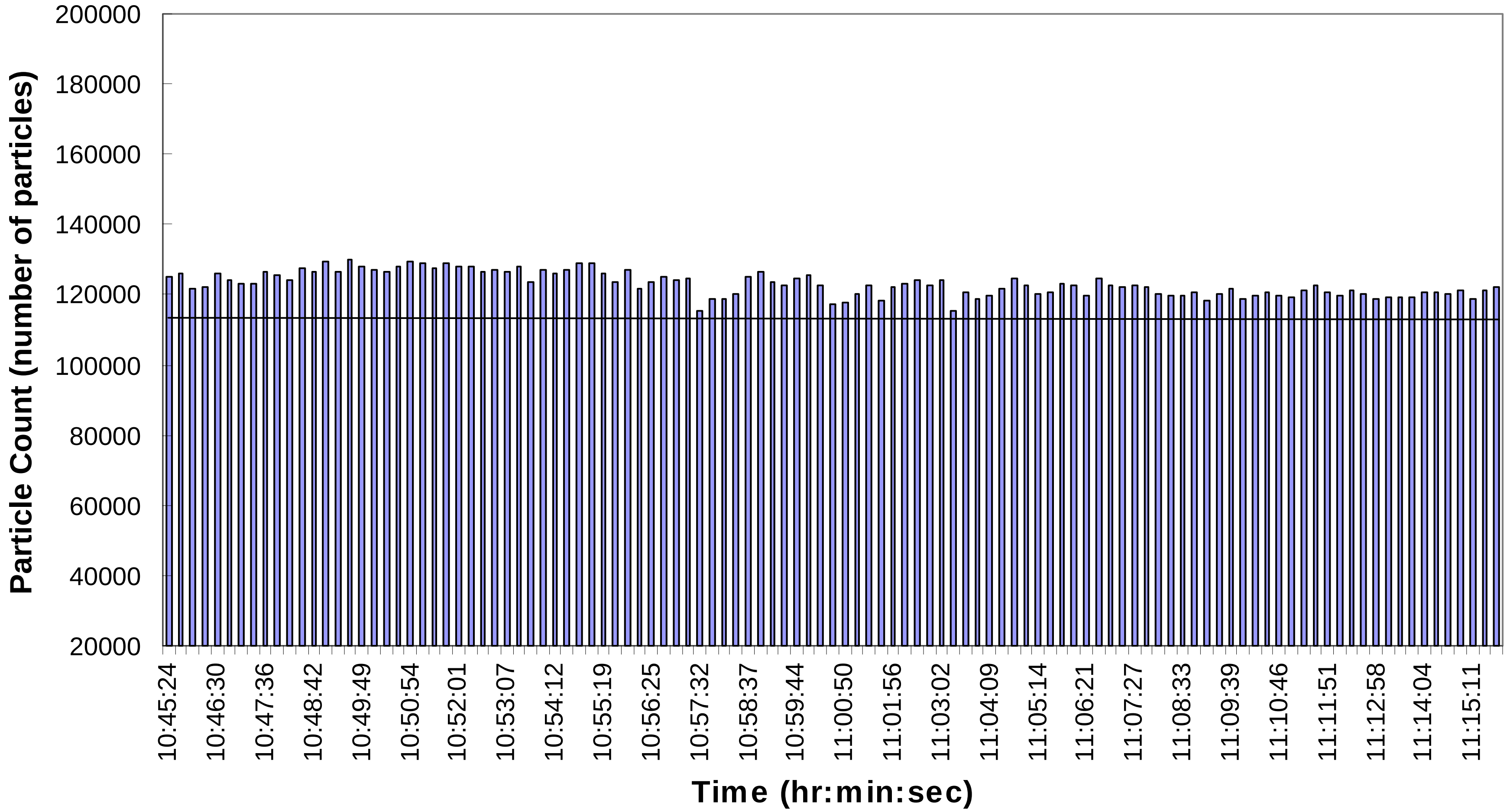
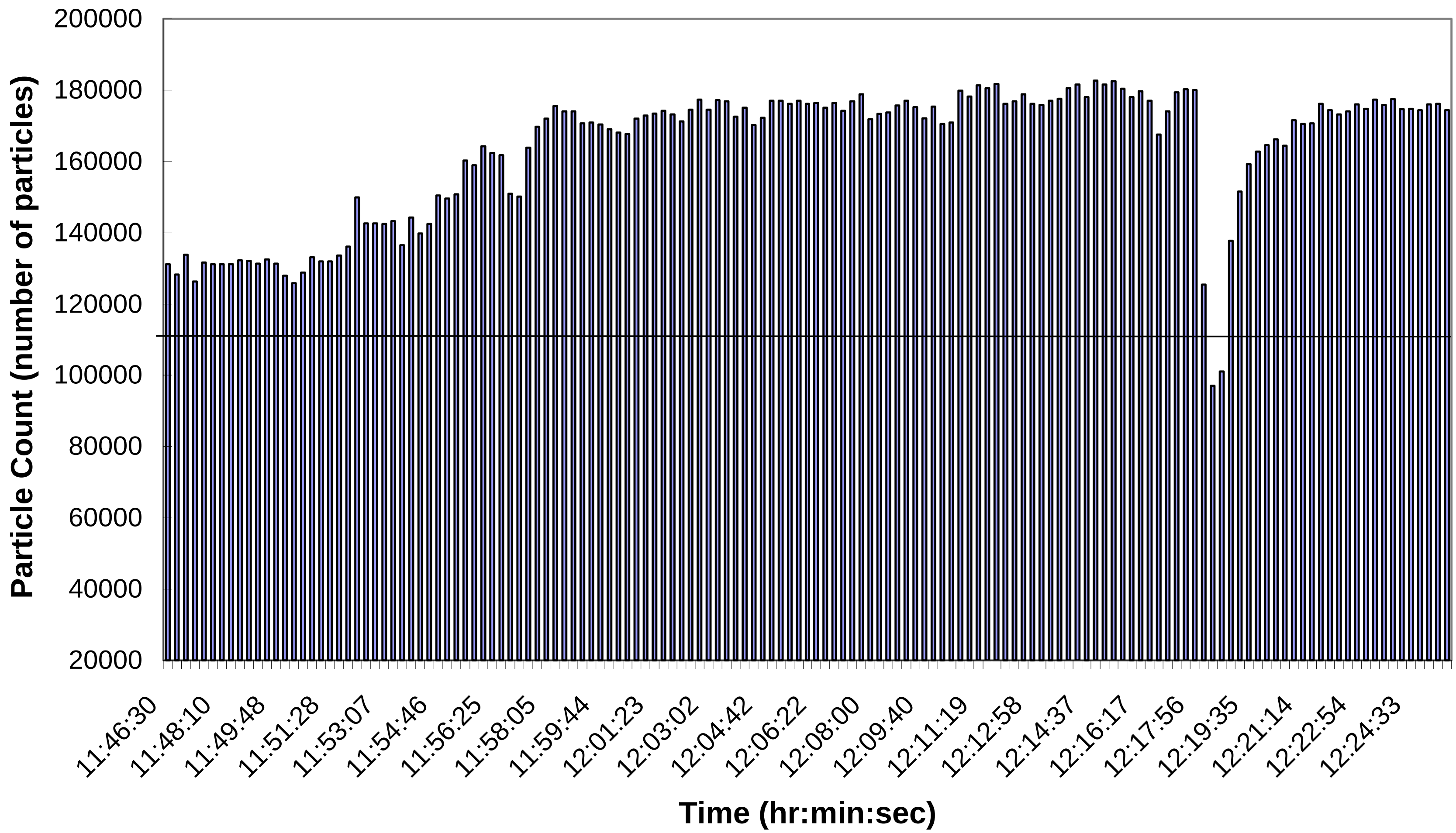


**Figure 6: Box Alarm Response, Winter or Night
(Horizontal Line Indicates Average Background Particle Count)**



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