HETA 98-0041-2741
San Francisco Municipal Railway, Flynn Facility
San Francisco, California

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PREFACE

The Hazard Evaluations and Technical Assistance Branch of 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 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

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Health Hazard Evaluation Report 98-0041-2741
San Francisco Municipal Railway, Flynn Facility
San Francisco, California
June 1999

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SUMMARY

The Director of Public Transportation for the City and County of San Francisco, California, requested that the National Institute for Occupational Safety and Health (NIOSH) conduct a health hazard evaluation (HHE) at the San Francisco Municipal Railway's Flynn Facility. The requester expressed concerns about the potential adverse effects of employees' exposures to diesel-engine exhaust emissions and the effectiveness of the ventilation systems. NIOSH investigators visited the facility in April 1998, and collected air samples for nitric oxide (NO), nitrogen dioxide (NO_2), and elemental and organic-based carbon (EC and OC). Ventilation effectiveness was assessed by using a flow-visualizing aerosol and by measuring particle concentrations.

The highest measured NO concentrations in air were about 1.5 parts per million (ppm), well below the relevant evaluation criterion of 25 ppm. Although some of the short-term, general-area concentrations of NO_2 in air exceeded the relevant evaluation criterion of 1 ppm for a 15-minute sample, most did not approach this criterion. One measured concentration of particulate-borne EC in air in the maintenance area was 150 micrograms of EC per cubic meter of air ($\mu g/m^3$), and far exceeded all other EC levels; the next highest EC concentration was 55 $\mu g/m^3$, measured in the personal breathing zone of an employee walking through the bus storage areas. No evaluation criteria exist for EC alone, although a recommended criterion of 150 $\mu g/m^3$ has been proposed for total diesel particulates. Most of the OC concentrations were unexpectedly much higher than the EC concentrations, leaving them difficult to interpret.

Based on both visual observations of air flow and the analysis of particle concentration data, the ventilation was determined to be inadequate for the amount of diesel exhaust generated. The diesel exhaust, which accumulated in the bus staging and service areas during peak periods of operation, was not adequately removed and replaced with outside air.

Since NIOSH recommends that whole diesel exhaust emissions be considered a potential occupational carcinogen, the NIOSH investigators have concluded that a potential health hazard exists at the Flynn Facility. Workers' exposures to diesel exhaust emissions should be reduced by using more effective control measures, such as a new ventilation-system design incorporating a "sweeping flow" ventilation configuration that would move air horizontally through the bus staging and service area. As an alternative, an individual-bus local exhaust ventilation system is recommended. For any ventilation system, air quality monitors and/or fan operation indicators should be installed. Finally, engine warm-up times in the bus staging and service area should be reduced to the minimums necessary.

Keywords: SIC Code No. 4111 (Local and suburban transit) Auxiliary Code No. 9 (Garages – maintenance); diesel-engine exhaust emissions; diesel-exhaust particulates; elemental carbon; organic-based carbon; oxides of nitrogen; nitrogen dioxide; nitric oxide; ventilation; dilution ventilation; local exhaust ventilation.

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INTRODUCTION

The Director of Public Transportation for the City and County of San Francisco, California, requested that the National Institute for Occupational Safety and Health (NIOSH) conduct a health hazard evaluation (HHE) at the San Francisco Municipal Railway's Flynn Facility. This facility serves as a base of operations for approximately 123 diesel-powered buses, leading to employee exposures to diesel-engine exhaust emissions in the workplace air. The requester, concerned about the potential adverse effects of these exposures on workers' health and about the apparent ineffectiveness of the facility's ventilation systems and other exposure-control measures, asked that NIOSH evaluate workplace exposures along with the ventilation system and other control measures and recommend appropriate improvements. NIOSH investigators conducted an initial site visit to the Flynn Facility on February 9 and 10, 1998. The initial visit was followed by a survey on April 6 through 8, 1998, during which NIOSH investigators conducted an in-depth evaluation which included extensive sampling for selected air contaminants and an evaluation of ventilation-system effectiveness.

BACKGROUND

The Flynn Facility, part of the San Francisco Municipal (MUNI) Railway, is located in the former U.S. Steel Warehouse at 1940 Harrison Street, southwest of San Francisco's Market Street commercial district. MUNI purchased the facility in 1983 as a base of operations for a fleet of diesel-powered "articulated" coaches; these are two-piece buses with the front and rear sections connected by a large hinge-like assembly which allows the vehicle to bend in the middle for easier maneuvering through the narrow quarters in some areas of the city. In addition to providing storage, fueling, cleaning, maintenance, and dispatch services for these buses, the Flynn Facility contains offices, lunchrooms, and areas devoted to other support services, and provides a base of operations for approximately 300 operators (drivers).

The Flynn Facility consists of a single, large building of an irregular but nearly square shape, which extends over 500 feet (ft) along each of its longer exterior walls and covers most of a city block. The building is primarily a tall ("high-bay") single-level structure with ceiling heights averaging about 40 ft, although the portions of the building containing the finished indoor spaces (e.g., offices, lunchrooms, etc.) on the ground level do have a partial second level which houses mechanical equipment. The office/mechanical equipment portion of the building occupies less than one quarter of the total area "under roof." The maintenance area occupies approximately 60,000 square feet (sq-ft) of floor area, accounting for nearly another quarter of the building. A very large, approximately 166,400 sq-ft space containing the bus storage, fueling and cleaning, and washing lanes occupies most of the remaining area. A figure showing the simplified plan view of the Flynn Facility is provided at the end of this report.

The bus operators work various shifts, with most starting between 5:00 and 7:00 a.m. Other drivers start at various times in the afternoon depending on the routes involved. There are 94 departures scheduled each weekday morning and 17 additional departures in the afternoon from the Flynn Facility. Approximately 33 maintenance mechanics are staggered among three shifts, seven days per week. On a typical weekday, approximately 12 mechanics work first shift (7:00 a.m. to 3:30 p.m.), 2 work second shift (3:00 to 11:30 p.m.), and 4 work third shift (11:00 p.m. to 7:30 a.m.). Approximately 25 "service workers" (maintenance technicians) are assigned to the facility, most of whom work at the fueling and cleaning lanes from 5:00 p.m. to approximately 1:30 a.m, with approximately 12 assigned to work a typical weeknight shift. A thorough cleaning of the coaches is performed periodically by approximately 4 "car cleaners" and 20 assistants who work from 5:00 a.m. to approximately 2:00 p.m. One supervisor works each shift for each of the above worker classifications, one dispatcher works each of two shifts (5:00 a.m. to 2:00 p.m. and 1:30 to 10:00 p.m.), and a small number of office employees and "stationary engineers" (for facilities operations) work daytime hours.

Routine operations such as daily vehicle start-up and inspection, vehicle cycling through the fueling, cleaning, and washing lanes, and general vehicular circulation within the facility lead to significant engine operation time inside the structure, particularly at idle speed. The resulting exhaust emissions are reported to accumulate during periods of peak operation, such as the morning start-up period between approximately 4:00 and 8:00 a.m., a mid-afternoon return period around 2:00 to 3:00 p.m. when some vehicles change operators and/or refuel, the evening return period from approximately 5:00 p.m. to midnight (peaking between approximately 6:00 and 9:00 p.m.), and a late night period between approximately midnight and 4:00 a.m. when vehicles are circulated for cleaning and maintenance purposes. Approximately 22 of the coaches in use at the time of the NIOSH visits were equipped with overhead engine-exhaust stacks, while the remaining, older buses exhaust below the chassis near the connection between the two coach sections.

Description of ventilation system

Ventilation was provided to each of the three major areas of the facility. A combination of natural and mechanical ventilation was used for the maintenance area and the bus staging and service area (the very large area housing the bus storage, fueling and cleaning, and washing lanes); mechanical ventilation only was used for the offices.

Outdoor air was supplied to the offices and the maintenance area by air-handling units located in the second-level mechanical-equipment area. Intake louvers were located on the front (east) wall of the building. Outdoor air was mixed with return air from the offices in each of the two air-handling units used to condition the air supplied to the office space. No air was returned from the maintenance area.

The maintenance area occupied a space approximately 150 ft wide and 400 ft long with an average ceiling height of 45 ft, giving it a volume of over 2,700,000 cubic feet (cu-ft). A design value of approximately 88,000 cubic feet per minute (cfm) of 100% outdoor air was supplied to the maintenance area by four mezzanine air handlers (Numbers 1 through 4). The calculated air change rate for this space is approximately two air changes per hour (ACH). Outdoor air could also enter the maintenance area through an overhead door on the southern portion of the east wall of the facility. Air could be exchanged with air in the bus staging and service area through a large opening at the southern end of the wall separating the two areas. Air could be exchanged with air in the main entrance/exit driveway through two openings at the north end of the maintenance area. Approximately 85,000 cfm (design value) of air was exhausted from the maintenance area by five exhaust fans (Nos. 17-21) located in the ceiling space of the maintenance area. The exhausted air was drawn from floor level by 39 10- x 14-inch open-end ducts and by the underground and overhead tailpipe exhaust system. Eight passive, roof-top ventilators were located in the maintenance area.

The bus staging and service area, approximately 320 ft wide and 520 ft long with an average ceiling height of approximately 38 ft, was ventilated by roof-top fans, passive roof-top ventilators, a ducted exhaust system, passive louvers around the outside wall perimeter, and the open entrance/exit driveway. Two roof-top supply fans supplied a total of 122,000 cfm of outdoor air to the area. Twelve roof-top exhaust fans exhausted approximately 569,000 cfm. A ducted exhaust system, consisting of 84 open-end ducts and exhaust openings on the underside of the sloped portion of the duct riser, exhausted approximately 245,000 cfm. The service area exhaust and an exhaust fan on the entrance/exit driveway side of the north wall of the maintenance area exhausted an additional 26,000 cfm. Taken together, the total exhaust air-flow rate from the bus staging and service area was 840,000 cfm. This space has a volume of approximately 6,300,000 cu-ft, so the air-exchange rate was approximately eight ACH.

A separate room, approximately 75 ft long and 25 ft wide with an average ceiling height of 42 ft, was located in the northwest corner of the maintenance area for steam cleaning. This area had overhead garage doors at each end, one open to the maintenance area, the other open to the main entrance/exit driveway. A roof-top exhaust fan exhausted approximately 38,000 cfm from the steam cleaning area. In this space with a volume of approximately 79,000 cu-ft, the air change rate was approximately 29 ACH. There was also a flue for the high-pressure washer.

The main entry/exit for buses was in the northeast corner of the building. This opening had an overhead door which was normally open. There was a secondary exit for buses in the southwest corner of the maintenance area. The overhead door at this location was normally open during the day, but closed at night. There also were two smaller, normally closed, overhead doors in this corner of the building for shipping and receiving. Around the building, there were a total of 11 pedestrian entry/exit doors – one for each of the four overhead doors, two on the front (east) side of the building for the office area, and five around the perimeter of the bus staging and service area (one on the south wall, three on the west wall and one on the north wall). These pedestrian doors were normally closed, and, except for the office-area door, seldom used. In the northwest corner of the bus staging and service area was a trash compactor/collector bin, accessible through an overhead door in the north wall to the outside of the building. This access door was normally closed.

METHODS

Flynn Facility employees' exposures to diesel-engine exhaust emissions, and the effectiveness of the facility's ventilation in controlling the exposures, were evaluated by using two primary techniques. Airborne contaminant concentrations were measured, during a 48-hour period on April 6 through 8, 1998, at selected stationary locations throughout the facility and in the breathing zones of selected employees. During that same time period, the movement of air within the facility was evaluated using a flow-visualizing, smoke-like aerosol.

Measurement of air-contaminant concentrations

The particulate fraction of diesel-engine exhaust emissions consists of elemental-carbon cores onto which thousands of different substances – mainly organic compounds, most of the mass of which is contributed by carbon atoms – are adsorbed. Therefore, concentrations in air of particulate-borne elemental carbon (EC) and organic-based carbon (OC) were measured using the following air sampling and analytical techniques, as specified in NIOSH Method 5040 (described in the NIOSH Manual of Analytical Methods [NMAM], Fourth Edition[1]). An air sample is collected using a battery-powered portable air-sampling pump to draw air at a measured rate (a nominal rate of 2.0 liters per minute [L/min] was employed for this field survey) through a 37-millimeter-diameter quartz-fiber filter in an open-faced plastic cassette for an entire work shift or some other relevant period of time. The filters are shipped to an analytical laboratory for evolved-gas analysis by thermal-optical analyzer to determine the masses of EC and OC collected on each filter.

Oxides of nitrogen are key members of the gaseous constituents of diesel exhaust emissions, and concentrations of nitrogen dioxide (NO_2) and nitric oxide (NO) in air were measured in accordance with NIOSH Method 6014 (described in the NMAM, Fourth Edition). Air samples are collected using battery-powered portable air-sampling pumps to draw air at measured rates through appropriate collection media. Long-term samples (usually several hours in duration) for both NO_2 and NO were collected; for these samples, an air-flow rate of

25 milliliters per minute (mL/min) and specialized sampling media arranged in series are utilized. Air first enters a 400-milligram (mg), triethanolamine (TEA)-treated molecular sieve in a glass tube, where NO_2 gas reacts with the TEA to form nitrite ion. Air then moves through a second glass tube containing 800 mg of chromate oxidizer, which converts NO gas to NO_2, and then through another TEA-containing tube identical to the first, where the NO_2 that was converted from NO also reacts to form nitrite ion. After shipment to an analytical laboratory, the TEA-treated molecular sieves from the two reagent tubes are separately subjected to extraction of the nitrite ion, and the extracts are reacted with a color-forming agent and subsequently analyzed with visible-absorption spectrophotometry, providing separate determination for NO_2 and NO. Additionally, short-term samples (of approximately 15 to 30 minutes in duration) for NO_2 only were collected; for these samples, an air-flow rate of 200 mL/min and a single TEA reagent tube for each sample are used. These tubes also were submitted to the analytical laboratory for NO_2 determination with the same analytical procedures.

In addition to the air samples for oxides of nitrogen collected in accordance with NIOSH Method 6014, "grab" samples (very-short-term air samples that take approximately one or two minutes to collect) for NO_2 and total oxides of nitrogen were collected and evaluated by drawing air through directly-read, colorimetric-reagent packed indicator tubes with a specially designed, hand-powered, air-sampling bellows pump. Specifically, Dräger® Nitrogen Dioxide 0.5/c and Nitrous Fumes 2/a ($NO+NO_2$) tubes and a Dräger® detector-tube pump were used.

Assessment of ventilation systems

The movement of air within the facility was evaluated by releasing a flow-visualizing aerosol, which looks like smoke, from a theatrical fog generator. The path of the "smoke" was then observed and recorded on video tape. The theatrical smoke was similar to the diesel-exhaust emissions in at least three characteristics. First, the smoke was an aerosol of very small particles, mostly in the same size range as the particulates in diesel-exhaust emissions. Second, the smoke from the fog generator was hotter than the surrounding air. Third, the smoke was discharged from the fog generator with an exit velocity that would carry it many feet from the release point, regardless of the velocity of the air into which it was released. Thus, the movement of the smoke would show the approximate path of the diesel-exhaust emissions.

The variability of air movement was evaluated by measuring airborne particle concentrations, with Grimm series 105 and series 106 optical particle counters, at selected points. These particle concentrations were recorded as one-minute averages. Three types of variability could be estimated: the fluctuation of particle concentrations from one moment to the next at a fixed location, the difference in the concentration profile and magnitude in the same time period from day to day, and the variation in the concentrations at the same time from one location to another.

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 adverse health effects even if the occupational exposures are controlled at the levels set by the criteria. Most evaluation criteria do not specifically account for the possible effects of such combined exposures. Furthermore, some hazardous substances are absorbed by direct contact with the skin and mucous membranes, potentially increasing workers' overall exposures above those from inhalation alone that are suggested by the substances' concentrations in the workplace air. This may produce adverse health effects even if the workers' breathing-zone exposures to the substances are controlled at air concentrations set by the criteria. 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 are the more protective criteria. 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-engine exhaust emissions

The exhaust emissions from diesel engines are complex mixtures that consist of both gaseous and particulate fractions. The composition of these emissions will vary depending on fuel and engine type, maintenance, tuning, and exhaust-stream treatment.[5,6] The major gaseous constituents include carbon dioxide, carbon monoxide, oxides of nitrogen, oxides of sulfur, and hydrocarbons. The particulate fraction (soot) of diesel exhaust is comprised of microscopic cores of solid carbon (in its pure, or elemental, state) and onto which are adsorbed thousands of different substances.[5] The elemental carbon contributes 35% to 85% of the total particulate mass, while the adsorbed material contributes the remaining 15% to 65% of the mass. The adsorbed material primarily consists of organic compounds — most of the mass of which is contributed by carbon atoms — such as polynuclear aromatic hydrocarbons (PAHs), some of which are carcinogenic.[5] Almost all of the particles are extremely small — more than 95% have "aerodynamic diameters" of less than 1 micron (or micrometer, μm) — and therefore can reach the deep regions of the human lung when inhaled. These "respirable" particles are considered more hazardous than larger particles, which are efficiently trapped in higher regions of the respiratory tract and removed.

Based on the results of laboratory-animal and human-epidemiology studies, NIOSH considers "whole" diesel exhaust emissions to be a potential occupational carcinogen.[5] (The term "whole" diesel exhaust emissions is used to differentiate the complete mixture from its individual components, some of which have been separately studied.) Human epidemiology studies *suggest* an association between occupational exposure to whole diesel exhaust emissions and lung cancer,[5,7] while studies of rats and mice exposed to whole diesel exhaust, and especially to the particulate portion, have *confirmed* an association with lung tumors.[5] In addition to the potential carcinogenic effects, eye irritation and reversible pulmonary function changes have been experienced by workers exposed to diesel exhaust emissions.[5,8,9,10] Several of these adverse health effects may be associated with individual constituents of diesel exhaust emissions, such as pulmonary irritation from oxides of nitrogen, eye and mucous membrane irritation from sulfur dioxide and aldehyde compounds, and chemical asphyxiation effects from carbon monoxide. Occupational exposure criteria have been established for some of these individual substances (such as those provided below for oxides of nitrogen). No exposure limits have been adopted that are directly applicable to whole diesel exhaust emissions. The ACGIH has provided notice of its intent to establish a TLV for diesel-exhaust *particulates* of 150 micrograms per cubic meter of air ($\mu g/m^3$) for an 8-hour TWA exposure, with that organization's "A2" (suspected human carcinogen) notation.[3]

Based on the information above, NIOSH recommends that whole diesel exhaust emissions be considered a potential occupational carcinogen. No safe level has been demonstrated for a carcinogen, and NIOSH has stated that "excess cancer risk for workers exposed to diesel exhaust has not yet been quantified, but the probability of developing cancer should be reduced by minimizing exposure." Therefore, NIOSH further recommends that workers' exposures to diesel exhaust emissions be reduced to the lowest feasible concentration.[5]

Exposure measurements may be most useful in evaluating control measures — by comparing exposures after controls are established or improved with baseline levels — rather than in establishing that a potential hazard exists. NIOSH investigators increasingly have utilized elemental carbon as an index of exposure to diesel-exhaust particulates. Measurements of particulate EC concentrations may provide a better indicator of whole diesel exhaust concentrations than measurements of total-mass particulate concentrations; since few other particulates contain the relatively high proportion (35% to 85%) of EC in the total particulate mass, particulates with high proportions of EC very likely consist mainly of diesel-exhaust emissions. For example, very little (only a few percent) of the mass of other combustion-product particulates, such as those in cigarette smoke and gasoline- and propane-powered engine exhausts, is EC. For these other combustion-product particulates, as with diesel-exhaust particulates, the remaining non-EC mass is primarily attributable to organic compounds, most of the mass of which is contributed by carbon atoms. This OC is conveniently measured with the same sampling and analytical technique used for EC, and the EC and OC levels may be compared to determine the likely source or sources of the particulates. Particulates with high EC/OC ratios very likely consist mainly of diesel-exhaust emissions.[11]

When evaluating exposures to diesel exhaust emissions by interpreting particulate EC concentrations in air, it may be desirable to estimate the total diesel-exhaust particulate concentrations as well (so that, for example, an approximate comparison with the proposed ACGIH TLV may be made). A low EC/OC ratio suggests the presence of particulate material other than diesel exhaust that contains OC but little or no EC, so the OC level should not be used in the estimate of the total diesel-exhaust particulate concentration. Instead, the total diesel-exhaust particulate concentration may be estimated at *no more than* 4 times the EC level, based on a conservatively low 25% EC mass composition of the diesel-exhaust particulate alone. (The total diesel-exhaust particulate concentration actually is more likely to be about two times the EC level, based on a 50% EC mass composition, which is near the middle of the 35% to 85% range cited above.) A high EC/OC ratio suggests that the particulate primarily contains diesel-exhaust emissions, and the particulate OC concentration may be used to estimate the mass concentration of the material adsorbed onto the EC particulate cores. The NIOSH investigators generally add, as a "rule-of-thumb," about 20% to the particulate OC mass concentration to account for the mass of the other elements compounded with carbon, such as hydrogen, oxygen, and nitrogen, to form the many and varied adsorbed organic compounds. The resulting estimated adsorbed-material mass concentration may be added to the particulate EC concentration to obtain an estimate of the total diesel-exhaust particulate concentration. The lesser of the above two estimates of the total diesel-exhaust particulate concentration (no more than four times the EC level, or the EC level plus the estimated adsorbed-material concentration) should be used.

Oxides of nitrogen

The primary adverse health effects of exposure to nitrogen dioxide, one of two oxides of nitrogen — the other is nitric oxide — that are prevalent among the many gaseous constituents of diesel-exhaust emissions, are respiratory-system effects such as irritation. At very high concentrations, inhalation of NO_2 may lead to pulmonary edema (fluid in the lungs), but at more modest levels of 10 to 20 parts per million parts of air (ppm), irritation of the eyes, nose and upper respiratory tract have been reported. One study has reported slight changes in lung "vital capacity" among workers exposed to NO_2 concentrations between 0.4 and 2.7 ppm. One animal study cited a possible decrease in the ability to clear viable bacteria from the lungs of mice continuously exposed to 0.5-ppm concentrations of this gas.[12]

The chief toxic effect of exposure to NO is the reaction between NO and hemoglobin in the blood to form nitrosylhemoglobin, which cannot transport oxygen as hemoglobin does. However, no effects in humans have been reported from exposure to NO alone. Experimental animal data has indicated that NO is about one-fifth as toxic as NO_2. NO slowly converts in air to the more-irritating NO_2.[12]

The OSHA PEL for NO_2 is a ceiling limit of 5 ppm, not to be exceeded at any time. The NIOSH REL is a STEL of 1 ppm for any 15-minute sampling period. The ACGIH TLVs are an 8-hour TWA limit of 3 ppm and a 15-minute STEL of 5 ppm.

The OSHA PEL, NIOSH REL, and ACGIH TLV for NO are each an 8-hour TWA of 25 ppm.

RESULTS

Measurements of air-contaminant concentrations

The results for the air samples collected and analyzed for elemental carbon and organic-based carbon are provided in Table 1. The results for the longer-term air samples for NO_2 and NO are provided in Table 2, while the shorter-term NO_2 results are provided in Table 3. The "grab" sampling results for NO_2 and total oxides of nitrogen are provided in Table 4.

Assessment of ventilation systems

During a visual inspection, air could be felt flowing in through the main entrance/exit passageway, into and across the bus staging and service area. The use of flow-visualizing smoke confirmed that outdoor air did indeed flow into the facility through the main entrance/exit passageway, and also through the louvers around the perimeter of the north, west, and south walls of the facility. The flow of outdoor air from the main entrance/exit passageway entered the northeast corner of the bus staging and service area and moved south and west.

A noticeable flow of outdoor air was also generated by two supply fans in the roof of the facility, in the southwest corner. This air was blown down to the floor of the bus staging and service area and then moved mostly north and east. When the overhead door in the southeast corner of the maintenance area was open, outdoor air also came into the facility and flowed into the bus staging and service area through the opening at the southern end of the wall separating the two areas.

Flow visualization showed that some smoke released near the exhaust openings on both sides of every column in the bus staging and service area was captured; however, most flowed past the area around the opening and dispersed. Visualizing air movement with smoke in many locations revealed a general upward flow. Some of the air that reached the ceiling level was exhausted from the building by the roof-top ventilator (exhaust) fans, and some of the ceiling space air was entrained into the airstream of the roof-top supply fans and blown down to the floor level.

With buses present, the upward flow of air was more pronounced. The hot exhaust gas injected into the space between the buses increased the movement of air up toward the ceiling. Only smoke that came within 12 inches from an exhaust opening was captured and exhausted. Most of the diesel exhaust first filled the lower portion of the bus staging and service area, then drifted up to the ceiling region where it was eventually exhausted by the roof-top ventilator fans or reintroduced to the floor-level space by a locally downward flow of air.

There were four major periods of diesel exhaust release in the bus staging and service area, each characterized by different durations and amount of exhaust release. The largest release of diesel emissions was the first of the day, starting around 4:00 in the morning. This period began with the buses being started and warmed-up, which elevated particle concentrations to more than twice the earlier "baseline" level in the space. Around 5:30 a.m., buses began leaving the facility, causing particle concentrations to more than double again. By 6:30 a.m., all buses had left the facility, and particle concentrations began to decrease, reaching the baseline level at approximately 7:30 a.m. A second, smaller increase to a little less than twice the baseline level followed later in the morning, from 8:15 until 9:30 a.m., when some buses returned at the end of the rush hour.

The other periods of elevated particle concentrations were in the evening: one with concentrations more than twice the baseline level from 6:30 till 8:00 p.m., and another increase to approximately twice the baseline level from 9:45 till 11:45 p.m.

Baseline particle concentrations were fairly uniform throughout the bus staging and servicing area; however, the elevated concentrations were from 10% to 100% higher in the western and southern portions than in the northeastern corner. The elevated concentrations during periods of bus activity were also greater at floor level than at the level of the ventilation fan catwalks.

The baseline level in the bus staging and service area increased suddenly to approximately twice the previous background level about 1:45 p.m. on Tuesday. The increases due to diesel emissions during periods of bus activity were less affected, some only about 30% greater than during the same periods on other days. This elevated baseline level returned to the previously observed value after the Wednesday morning departure period.

DISCUSSION

Air-contaminant concentrations

Diesel-exhaust particulates

Numerous air samples — mostly general-area and some personal breathing-zone — were collected and analyzed for elemental carbon, and the results for most of these reveal "trace" concentrations (between the minimum-detectable and minimum-quantifiable concentrations) or not-detectable concentrations (below the minimum-detectable concentration). For 17 samples, quantifiable TWA concentrations ranging from 10 to 150 $\mu g/m^3$ were measured. The only measured EC concentration considered unusually high based on the experience of the NIOSH investigators was the 150 $\mu g/m^3$ general-area concentration measured during a day shift at the fence along the service pit in the maintenance area. It is not known why this one result far exceeds all others including the 14 $\mu g/m^3$ measured at the same location during the next day shift. However, other TWA concentrations measured in the maintenance area — general-area levels as well as personal breathing-zone exposures (including those of day-shift maintenance mechanics) — do not suggest any potential for relatively high exposures to EC in this area on a consistent basis. Other than the one unusually high measured EC concentration in the maintenance area, the highest levels of EC were measured in the bus staging and service area (the very large area housing the bus storage, fueling and cleaning, and washing lanes). Specifically, general-area concentrations ranging up to 49 $\mu g/m^3$ were measured in the bus storage lanes during one morning-rush period, while the TWA personal breathing-zone exposure of the employee starting bus engines in that area during a 111-minute period that morning was 55 $\mu g/m^3$. Personal breathing-zone TWA exposures to EC of 15 and 30 $\mu g/m^3$ were measured for two service workers at the fueling and cleaning lanes one evening, while exposures of 11 and 20 $\mu g/m^3$ were measured for two drivers during morning shifts. Outdoor-background area concentrations were at "trace" or not-detectable levels.

The ratio of elemental carbon to organic-based carbon measured in most of the samples for these air contaminants was unusually low, suggesting (based on the previous discussion in the Evaluation Criteria section of this report) the presence of other airborne particulate material besides fresh diesel-engine exhaust emissions, and leaving most of the OC results difficult to interpret and of limited use. In a few cases, cigarette smoke may account for the additional particulate material. In most cases, other particulate sources must be considered, such as re-entrained dust containing adsorbed fuels and lubricants, ambient air pollution, or other unknown sources that contain much OC but little or no EC. Since relatively high proportions of the measured concentrations of OC apparently were present from sources other than the diesel-exhaust emissions, these concentrations should not, in most cases, be used in the estimation of total diesel-exhaust particulate concentrations; instead, a given total diesel-exhaust particulate concentration may be estimated as no more than four times the measured particulate EC concentration. Using this approach, most of the measured concentrations of EC at this facility did not exceed a total diesel-exhaust particulate level of 150 $\mu g/m^3$ (the proposed TLV). However, the estimated total diesel-exhaust particulate concentration from one general-area air sample (collected in the maintenance area along the service-pit fence), when adjusted following the methods described in the Evaluation Criteria section, was 330 $\mu g/m^3$.

The results for one air sample of particular interest, for which the concentration of EC was the highest measured at 150 $\mu g/m^3$ and the applicable OC value also was 150 $\mu g/m^3$, reveal a much higher EC/OC ratio. Using the alternate procedure for such cases described in the Evaluation Criteria section, the estimated total diesel-exhaust particulate concentration is 330 $\mu g/m^3$. This estimated general-area air concentration, measured in the maintenance area along the service-pit fence, does exceed the proposed TLV.

The air-contaminant concentration measurements may be most useful for comparing the exposure potential among the different areas and time periods and in evaluating changes in control measures — by comparing levels after controls are established or improved with "baseline" levels measured before such changes — rather than in establishing that a potential hazard exists.

Oxides of Nitrogen

Since all air samples for nitric oxide were general-area samples, the results cannot be directly compared with the exposure criteria because they do not represent actual worker exposures. However, they do suggest the potential for worker exposures in the measured ranges, and all concentrations of NO measured in the air at the Flynn Facility were well below the relevant evaluation criteria of 25 ppm for a full-shift TWA exposure. The highest long-term TWA level of NO measured was 0.56 ppm; the highest level of total oxides of nitrogen (which would include NO, nitrogen dioxide, and perhaps other, less common oxides of nitrogen) measured with a "grab" sample was 2 ppm, of which 0.5 ppm was simultaneously determined to be NO_2. These

NO levels were measured in the bus staging and service area during the morning rush period of two different days. Outside of the bus staging and service area, NO, when detectable at all, was detected only in "trace" concentrations. These results suggest that nitric oxide exposures *alone* are unlikely to represent a hazard to the health of employees at the Flynn Facility.

Most concentrations of NO_2 measured in air also were below all the relevant evaluation criteria, except for some which equaled or exceeded the NIOSH REL of 1 ppm for short-term air samples. Specifically, the measured concentration for one general-area "grab" sample collected in the bus staging and service area during the morning rush period of one day (April 8) was 1ppm. General-area concentrations of 1.4, 1.2, 1.1, and 1.0 ppm also were measured in that area with short-term air samples collected during that same morning (for the latter value) and the preceding morning (for the first three). These general-area levels cannot be directly compared with the exposure criteria because they do not represent actual worker exposures, but they do suggest the potential for worker exposures exceeding 1 ppm. However, two other short-term samples were collected from the personal breathing zones of bus operators while walking inside the facility and starting their buses during the morning rush period, and the exposure levels for these were below the 0.2-ppm minimum detectable concentration for these samples. The concentrations of NO_2 measured with the long-term air samples were well below the relevant criterion of 3 ppm (the TLV for full-shift TWA exposures). They also were below the short-term criteria, although these do not directly apply. Furthermore, all these long-term samples were general-area samples, so the results, while suggesting potential exposure ranges, cannot be directly compared with the exposure criteria. These results suggest at least the *potential* for intermittent employee exposures to NO_2 levels exceeding the NIOSH REL during the morning rush period in the bus staging and service area, and an associated potential risk for the irritative effects that may occur with NO_2 exposure. Outside of the bus staging and service area, NO_2, when detectable at all with any of the types of samples mentioned, was detected only in "trace" concentrations.

Ventilation system

The primary possibility for a potential problem seems to be ineffective ventilation for the amount of diesel exhaust generated. The diesel exhaust which builds up in the bus staging and servicing area is removed by approximately 800,000 cfm of exhaust. This volumetric flow rate, on an hourly basis, is over seven times the volume of the space in the bus staging and service area. If the air in the space were "perfectly mixed" (*the term, perfectly mixed, is a mathematical concept, not a realistic condition)*, mathematical theory predicts that the concentration of a contaminant would be halved in about 6 minutes. Particle concentrations, as measured during this survey, were halved in about 30 minutes. The longer time indicates that the air in the bus staging and service area was not well mixed, and the area around the sampling locations was poorly ventilated. Since the sampling locations were in the area around the buses, this means the air in the space occupied by workers was inadequately ventilated.

Particle concentrations at a particular location are reduced by the dispersion of the particles in the air inside the facility, in addition to the dilution of these particles in the relatively clean outdoor air entering the facility. Dispersion and mixing would be improved by more airflow in the area around the buses. The local exhaust ventilation in the island between the curbs was not effective, based on both visual observation of smoke and analysis of particle concentration data. A different ventilation system is needed, one which creates air movement around and above the buses.

Two possible alternatives for a redesigned ventilation configuration are an overhead local exhaust system and a longitudinal push/pull system. Each has advantages and disadvantages, which are discussed in the following paragraphs.

Overhead Local Exhaust Ventilation

The first alternative, an overhead local exhaust system, would consist of exhaust hoods above the location of the exhaust pipe of each parked bus. The hoods would be sized to give some leeway in the positioning of the buses, however, one concern is that if the exhaust discharge has a substantial horizontal velocity component, the exhaust may not be adequately captured and contained by the hood.

The main advantage of this local exhaust ventilation system is that the diesel exhaust is collected as close to the source as is possible without connecting a hose to the exhaust pipe of each bus. The disadvantages are that this system would only work for stationary buses with the top, rear discharge exhaust, not for the buses with the low, middle, side discharge exhaust, and the general ventilation effectiveness would not be improved. Thus, when the buses were moving, most of the exhaust would not be captured by the overhead hoods, and diesel exhaust which would not be immediately captured by the local exhaust hoods would be as poorly removed as with the current system.

With regard to design air flow rates for this local exhaust ventilation system, the buses with top/rear-exhaust, at idle, discharge approximately 500 cfm of air at an approximate temperature of 350°F. At maximum engine speed, the discharge flow rate is approximately 2500 cfm. Hemeon states that the exhaust flow rate of the hood should be greater than the hot air (diesel exhaust) flow rate by an amount sufficient to create a velocity of at least 100 ft/min through the area of the hood face not actively receiving the entering airstream.[13] For example, if the hood were sized to be 2 ft x 4 ft, the hood face area would be 8 sq-ft. Assuming the diesel exhaust airstream has an area of approximately 1 sq-ft, the hood exhaust flow rate should be at least 700 cfm greater than the exhaust discharge flow rate. For a bus at idle, 1,200 cfm would be adequate, as long as the surrounding air was relatively still and the bus exhaust airstream did not have a substantial horizontal velocity component. If either or both of those conditions would exist, higher hood exhaust flow rates would be required.

The existing catwalk-mounted fans could be used to provide exhaust for the new system; in this case, the existing terminal ductwork could be either reused to connect the new hoods to the existing fans, or removed to allow for the installation of new terminal ductwork. The current system has a total design flow rate of 245,000 cfm. This would equate to approximately 2,900 cfm through each of the 84 terminal branches, if the flows were uniformly distributed. The new individual-bus system would need at least 94 hoods to cover the current morning rush equipment demand, so approximately 2,500 cfm would be available for each hood. Based on the estimates in the previous paragraph, this would be more than adequate for buses at idle, but inadequate for buses at full throttle.

Cross-Flow Ventilation

The second alternative, a cross-flow, room-sweeping ventilation design, would consist of a row of fans along the north wall and a congregation of exhaust fans in the southwest corner of the bus staging and service area. The goal would be to create a flow of air across the bus staging and service area, from the north wall to the south wall, with adequate velocity to “sweep” the diesel exhaust to the south end of the facility to be exhausted by roof-top fans. Most of the existing ventilation, the catwalk-mounted fans and associated ductwork, the roof-top supply and four of the roof-top exhaust fans, would require removal. Three of the roof-top exhaust fans could be used in their present location, five fans would be relocated. The existing louvers around the north, west, and south perimeter and the remaining roof-top ventilators would be retained.

The main advantage of this cross-flow ventilation system is that the diesel exhaust generated from any location, even from moving buses, regardless of placement of the exhaust pipe, would be cleared from the space. The disadvantage is that more diesel exhaust would escape into the ambient air before being exhausted from the building, although the space would be cleared faster than with the current system, as will be discussed later.

A convenient mounting location would be in place of the row of windows approximately half-way up the wall. Estimating from the exterior elevation drawing, either a 54-in fan or a 60-in fan would fit the opening with appropriate space to attach the mounting plate. *(Note: A qualified engineer should be consulted to verify that the building structure can safely withstand the weight and force of the fans installed in the recommended locations.)*

To determine the number and design flow rate of the fans, 120 ft/min will be used as the average velocity of the main flow which will sweep through the large open area which the buses drive through and park. The cross-sectional area of this space, from the floor to the bottom-most portion of the roof, is approximately 10,000 sq-ft. A total of approximately 1,200,000 cfm would be required to develop and maintain this flow, about 50% more than the current total flow rate. To maintain a net negative pressure in the bus staging and service area, about 800,000 cfm would be supplied by the wall fans with the remaining 400,000 cfm drawn in through the entry/exit driveway and other openings.

Placing a supply wall fan in every other window space would split the flow between 24 fans. Each fan would have to move approximately 33,000 cfm, which is easily attained with a 54-in or 60-in fan. At this flow rate, either size fan would operate at a low (less than 800 rotations per minute [rpm]) rotational speed and require only a 3-HP motor. It may be more cost-effective to use a total of 16 fans, each moving approximately 50,000 cfm, although this application would require higher fan speeds and/or higher horsepower motors.

At the south end of the space, an exhaust fan would be positioned in each of the two roof-top ventilator spaces closest to the south wall (i.e. between truss rows 13 and 14 and between rows 16 and 17), exhausting a subtotal of 400,000 cfm. Twenty-four (or sixteen) exhaust wall fans would be mounted in existing window space in the south wall, similar to the installation in the north wall. Splitting the remaining 800,000 cfm between them, each fan would exhaust about 33,000 cfm, again similar to the supply fans in the north wall.

Theoretically, this “sweeping-flow” system would move diesel exhaust released into the air at the northern end of the facility to the south end to be exhausted in less than 5 minutes. The actual time may be longer due to inefficiencies, although the time to completely clear the room would be shorter than for the local exhaust ventilation system.

CONCLUSIONS

Since NIOSH recommends that whole diesel exhaust emissions be considered a potential occupational carcinogen, and no safe level has been demonstrated for a carcinogen, the NIOSH investigators have concluded that a potential health hazard exists at the Flynn Facility since workers are experiencing occupational exposures to diesel-engine exhaust emissions that plainly exceed ambient outdoor background levels. NIOSH has further stated that “excess cancer risk for workers exposed to diesel exhaust has not yet been quantified, but the probability of developing cancer should be reduced by minimizing exposure,” and therefore recommends that workers’ exposures to diesel exhaust emissions be reduced to the lowest feasible concentration. The NIOSH investigators have concluded that Flynn workers’ exposures could be reduced with more effective control measures, and therefore have recommended the adoption, whenever feasible, of the measures described below to reduce these exposures. The air-contaminant concentration measurements may be most useful for comparing the exposure potential among the different areas and time periods and in evaluating changes in control measures — by comparing levels after controls are established or improved with “baseline” levels measured before such changes — rather than in establishing that a potential hazard exists.

RECOMMENDATIONS

1. Strongly consider implementing the "sweeping flow" ventilation configuration. The advantage of more quickly clearing diesel exhaust generated from any location, even from moving buses, regardless of placement of the exhaust pipe, seems to outweigh the fact that more diesel exhaust would escape into the ambient air. The capacity of the building structure to safely withstand the weight and force of the fans installed in the recommended locations will have to be verified before this configuration can be undertaken.

2. If cost or structural considerations are not favorable to the "sweeping flow" configuration, consider the individual-bus local exhaust ventilation system. *(The capital cost comparison would involve, at a minimum, the acquisition and installation of many new fans and the relocation of some existing fans compared to the installation of new ductwork. The recurring cost comparison will involve the energy requirements for all the fans for each configuration.)* The disadvantage of not capturing exhaust from the older buses with side-discharge exhaust will be less a factor as the fleet is updated with new equipment with top/rear discharge exhaust.

3. Whichever system is chosen, operating the full ventilation system only when needed will reduce the recurring energy costs. Either system will need to be fully on to be effective, but during periods of inactivity, after the air has been cleared, acceptable air quality should be possible with a reduced ventilation rate. For example, for either system, operating only the roof-top exhaust fans might suffice.

4. For any ventilation system, air quality monitors and/or fan operation indicators should be installed. Air quality monitors would provide proof of system performance. Flow sensors would alert maintenance personnel when failed fans needed to be fixed. Each monitoring system would need to be periodically calibrated and maintained in accordance with the manufacturer's instructions, to assure proper operation.

5. A qualified, experienced ventilation design firm should be consulted for implementation of the specifics of the above recommendations.

6. Engine warmup times in the bus staging and service area should be reduced to the minimum time necessary. Improved ventilation effectiveness alone will never substantially reduce employees' exposures to diesel-exhaust emissions to the extent possible if lengthy warm-ups continue. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends a maximum warm-up time of 5 minutes.[14] To assure that buses' air-pressure systems are fully operational as quickly as possible, the Flynn Facility's existing air-supply system and hoses should be used.

REFERENCES

1. NIOSH [1994]. NIOSH Manual of Analytical Methods, Fourth Edition. 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]. 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 [1998]. 1998 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents. Cincinnati, OH: American

Conference of Governmental Industrial Hygienists.

4. Code of Federal Regulations [1997]. 29 CFR 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register.

5. 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.

6. ILO [1983]. Todradze C, Diesel engines, underground use of. In: Encyclopedia of Occupational Health and Safety. Vol I/a-k. Geneva: International Labour Office.

7. Garshick E, Schenker MB, Munoz A, Segal M, Smith TJ, Woskie SR, Hammond SK, Speizer FE [1987]. A case-control study of lung cancer and diesel exhaust exposure in railroad workers. Am Rev Respir Dis 135(6):1242-1248.

8. Gamble J, Jones, W, Mishall S [1987]. Epidemiological-environmental study of diesel bus garage workers: acute effects of NO_2 and respirable particulate on the respiratory system. Env Rsch 42(1):201-214.

9. Reger R, Hancock J [1980]. Coal miners exposed to diesel exhaust emissions. In: Rom, W, Archer, V, eds. Health implications of new energy technologies. Ann Arbor, MI: Ann Arbor Science Publishers, Inc, pp 212-231.

10. Ulfvarson U, Alexandersson R [1990]. Reduction in adverse effect on pulmonary function after exposure to filtered diesel exhaust. Am J Ind Med 17(3):341-347.

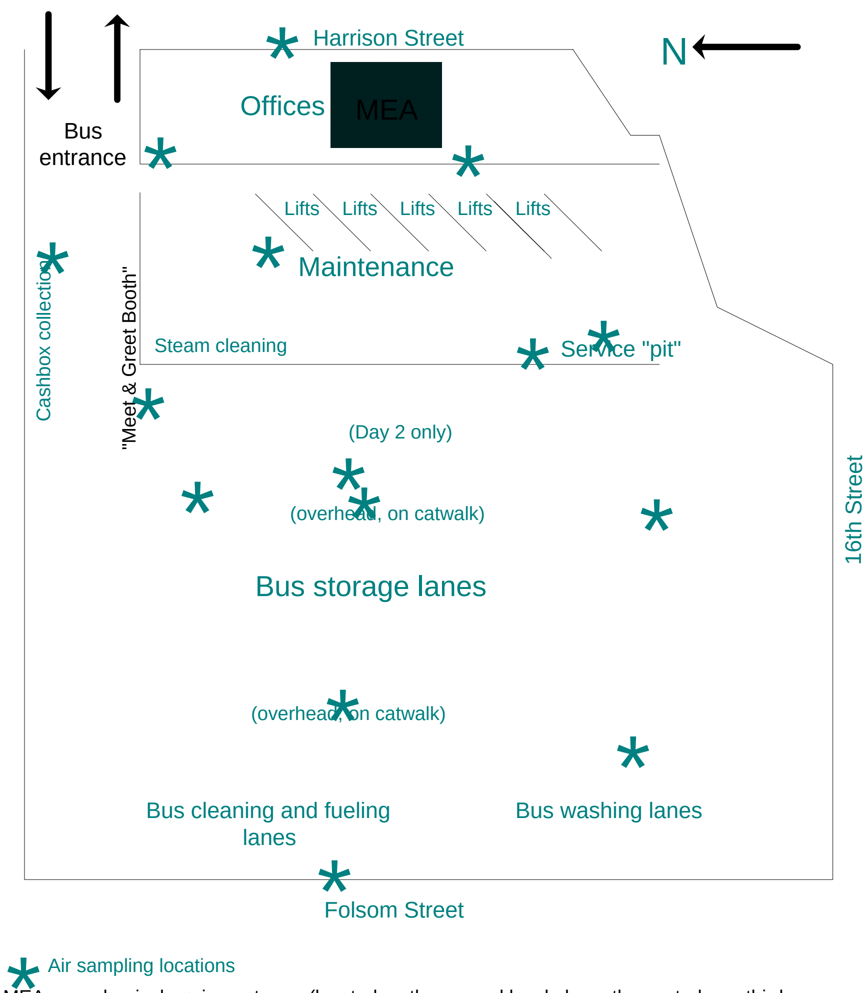
11. Zaebst D, Clapp D, Blade L, Marlow D, Steenland K, Hornung R, Scheutzle D, Butler J [1991]. Quantitative determination of trucking industry workers' exposure to diesel exhaust particles. Am Ind Hyg Assoc J 52(12):529-541.

12. ACGIH [1991-96]. Documentation of the threshold limit values and biological exposure indices. Sixth edition, with supplements through December 1996. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

13. Hemeon W C L [1962]. Plant and Process Ventilation, 2nd Edition. Industrial Press Inc., New York.

14. ASHRAE [1991]. Enclosed vehicular facilities. In: HVAC Applications, 1991 ASHRAE Handbook. Atlanta, GA: American Society of Heating, Refrigerating, and Air–Conditioning Engineers, Inc., p 13.13.

Figure.
San Francisco Municipal Railway, Flynn Facility Plan



MEA = mechanical equipment area (located on the second level above the central one-third protion of the "Offices" space).

Table 1
Results of air sampling for elemental carbon and organic-based carbon conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date of Sampling[@] and	Area	Location *OR* Job Title	Start	Stop	Concentrations in air ($\mu g/m^3$)†	
			(Using a 24-hour clock)		Elemental Carbon (EC)	Organic-based Carbon (OC)
Personal Breathing-Zone Samples						
April 6	Maintenance	Mechanic	17:05	22:57	Trace*	87.
April 6	Fuel and clean	Service worker	18:02	00:02	Trace	150
April 6	Fuel and clean	Service worker	18:03	00:05[#]	Trace[##]	82.[##]
April 7	On bus route	Bus Operator	04:45	00:51	Trace	40
April 7	On bus route	Bus Operator	05:49	13:49	Trace	54.
April 7	Maintenance	Mechanic	17:25	00:07	Trace	120
April 7	Fuel and clean	Service worker	18:52	00:12	15	130
April 7	Fuel and clean	Service worker	18:56	00:10	30	240
April 7	Maintenance	Maintenance worker	08:53	15:12	Trace	97.
April 7	Maintenance	Maintenance worker	08:56	15:12	Trace	79.
April 8	On bus route	Bus operator	05:55	10:24	20	130
April 8	On bus route	Bus operator	06:03	13:43	11	59.
General Area Air Samples						
April 6	Bus entrance	"Meet and greet" booth	17:10	01:48	ND**	Trace
April 6	Fuel and clean	Between lanes	17:21	00:47	Trace	46.
April 6	Bus storage	Southwest	17:28	02:20	Trace	16.
April 6	Bus storage	Northeast	17:33	02:21	Trace	14.
April 6	Maintenance	At service pit (on fence)	17:44	02:35	Trace	28.
April 6	Control room	Atop file cabinet	17:54	02:46	ND	25.
April 6	Ambient Outdoor	Above central front door	18:15	03:00	Trace	ND
April 6	Bus entrance	Outside Cash-box booth	18:22	00:33	ND	ND
April 6	Dispatch office	On desk	19:42	00:35	ND	41.
April 6	Maintenance	Between lifts 9 and 10	20:05	05:36	15.	70
April 6	Maintenance	On wall near service pit	20:15	05:44	Trace	13.
April 6	Bus storage	Southeast	20:24	02:15	Trace	Trace
April 6	Bus storage	Central	20:30	02:15	ND	22.

Table 1
Results of air sampling for elemental carbon and organic-based carbon conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date of Sampling@ and Area		Location OR Job Title	Start	Stop	Concentrations in air (µg/m³)†	
			(Using a 24-hour clock)		Elemental Carbon (EC)	Organic-based Carbon (OC)
April 7	Bus entrance	Outside cash-box booth	4:05	8:50	Trace	63.
	Bus storage	NE, on pillar	4:11	8:30	Trace	170
	Bus storage	End of row, between 5&6	4:20	8:10	Trace	130
	Bus storage	On electric box	4:22	8:14	Trace	260
	Ambient outdoor	Central front doors	03:00	08:11	ND	ND
	Maintenance	At service pit (on fence)	02:35	4:31	ND	ND
	Control room	On file cabinet	04:34	08:18	ND	Trace
	Fuel and clean	Between lanes	04:27	8:20	Trace	72.
	Maintenance	At service pit (on fence)	04:31	08:24	Trace	38.
	Maintenance	Behind service pit	5:45	9:20	Trace	Trace
	Maintenance	Between lifts 9&10	05:38	13:59	Trace	54.
	Facility engineer office	In office	06:20	14:45	Trace	22.
	Dispatch Office	On desk	06:28	15:00	ND	36.
	Fuel and clean	Between lanes	08:20	14:27	Trace	56.
	Bus storage area	Center, atop fire extinguisher	8:30	14:23	Trace	70.
	Ambient outdoor	Above central front door	08:13	17:39	ND	14.
	Control room	On top of computer	08:19	14:07	ND	23.
	Maintenance	At service pit (on fence)	08:25	14:02	150	150
	Car washing area	On electrical box	09:26	14:33	Trace	39.
	Maintenance	At service pit (on fence)	14:02	18:05	Trace	47.
	Control room	On computer	14:07	17:57	ND	Trace
	Bus storage	On center row	14:23	18:45	Trace	Trace

Table 1
Results of air sampling for elemental carbon and organic-based carbon conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date of Sampling[@] and	Area	Location *OR* Job Title	Start	Stop	Concentrations in air ($\mu g/m^3$)†	
			(Using a 24-hour clock)		Elemental Carbon (EC)	Organic-based Carbon (OC)
April 7	Fuel and clean	Between lanes	14:27	18:21	Trace	Trace
April 7	Bus storage	3rd row pillar	14:37	18:15	ND	55.
April 7	Dispatch office	On desk	17:20	00:50	ND	Trace
April 7	Bus entrance	"Meet & Greet" booth	17:32	23:18	Trace	Trace
April 7	Ambient outdoor	Above central front doors	17:45	01:40	ND	Trace
April 7	Bus entrance	Outside cash-box booth	17:53	23:17	ND	Trace
April 7	Control room	Atop file cabinet	17:59	00:46	ND	Trace
April 7	Maintenance	At service pit (on fence)	18:09	02:15	Trace	Trace
April 7	Bus storage	SW, atop electric panel	18:17	01:17	Trace	Trace
April 7	Fuel and clean	Between lanes	18:22	00:41	10	Trace
April 7	Bus storage	NE, atop electric panel	18:38	01:23	Trace	Trace
April 7	Bus storage	Center, atop fire extinguisher	18:46	01:21	10.	Trace
April 7	Bus storage	W-central	19:07	01:14	13.	Trace
April 7	Bus storage	NE, on catwalk	19:19	01:27	Trace	Trace
April 7	Bus storage	SE, atop electric panel	20:29	01:19	Trace	Trace
April 7	Maintenance	Behind service pit	20:35	02:16	Trace	Trace
April 7	Maintenance	Between lifts 9&10	20:39	02:18	Trace	Trace
April 8	Ambient outdoor	Above central front doors	01:56	08:16	Trace	Trace
April 8	Fuel and clean	Between lanes	04:10	08:26	Trace	Trace
April 8	Bus storage	SW, atop electric panel	04:00	7:57	45.	230
April 8	Bus storage	Center, atop fire exit	03:58	08:20	42.	190
April 8	Bus storage	NE, atop electric panel	03:45	7:57	36.	260
April 8	Bus storage	W-central on catwalk	04:03	7:57	49.	280
April 8	Bus storage	NE, on catwalk	03:49	7:57	32.	200
April 8	Bus entrance	Outside cash-box booth	03:40	8:25	Trace	Trace
April 8	Bus storage	SE, on electrical panel	03:55	7:57	18.	140

Table 1
Results of air sampling for elemental carbon and organic-based carbon conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date of Sampling@ and Area		Location *OR* Job Title	Start	Stop	Concentrations in air ($\mu g/m^3$)†	
			(Using a 24-hour clock)		Elemental Carbon (EC)	Organic-based Carbon (OC)
	Bus storage	Starter	05:20	7:11	55.	430
	Maintenance	On fence	03:59	08:30	Trace	Trace
	Maintenance	Behind service pit	04:01	07:57	Trace	Trace
	Maintenance	Between lifts 9&10	03:52	07:57	Trace	Trace
	Dispatch office	On desk	04:17	08:02	ND	Trace
	Car washing area	On electric box	08:22	14:13	Trace	Trace
	Ambient outdoor	Above central front door	08:11	15:44	Trace	Trace
	Bus storage	Middle row/center	08:20	14:06	NA‡	NA‡
	Fuel and clean	Between lanes	08:26	14:16	Trace	Trace
	Maintenance	At service pit (on fence)	08:30	14:20	14.	Trace
	Control room	On computer	09:49	14:23	ND	Trace
	Bus storage	Middle row/center	14:06	15:43	Trace	Trace
	Bus storage	Electric box/3rdpPillar	14:10	15:39	ND	Trace
	Fuel and clean	Between lanes	14:16	15:38	ND	Trace
	Maintenance	At service pit (on fence)	14:20	15:44	ND	Trace
	Control room	On top of computer	14:23	15:46	ND	Trace

@ = When sampling began (some went past midnight, into the next day.
† = concentration expressed in micrograms per cubic meter
* = "Trace" concentration: detectable, but not reliably quantifiable. Value lies between the minimum detectable and minimum quantifiable concentrations (MQCs). MQCs for samples in this set ranged from 4 to 37 $\mu g/m^3$ for EC and 10 to 200 $\mu g/m^3$ for OC.
ND** = not detectable. Concentration is less than the minimum detectable concentration (MDC). MDC for samples in this set ranged from 4 to 20 $\mu g/m^3$.
= Sampler stopped between 19:45 and 21:25, during worker's lunch break
= Damage to the filter inside the cassette was observed.
NA‡ = No analysis — defective collection device.

Table 2
Results of long-term, general-area air sampling for oxides of nitrogen conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date (sample started) and Area		Sample location	Start	Stop	Concentrations in air (ppm)	
			(24-hour clock)		Nitrogen dioxide (NO_2)	Nitric oxide (NO)
April 6	Bus storage	Northeast	17:38	22:29	Trace*	Trace
	Fuel and clean	Between lanes	17:40	22:05	Trace	0.32
	Ambient outdoor	Above central front door	18:43	23:15	Trace	Trace
	Maintenance	At service pit (on fence)	19:49	00:11	Trace	Trace
	Fuel and clean	Between lanes @ blower	22:17	00:42	Trace	Trace
	Bus storage	Northeast	22:38	04:15	Trace	Trace
	Ambient outdoor	Above central front door	23:28	04:08	Trace	ND**
April 7	Maintenance	At service pit (on fence)	00:20	08:23	Trace	Trace
	Ambient outdoor	Above central front door	08:10	17:39	Trace	Trace
	Ambient outdoor	Above central front door	04:09	08:09	Trace	Trace
	Storage	NE, on pillar	4:15	8:31	0.77	0.56
	Fuel and clean	Between lanes	4:20	8:17	Trace	Trace
	Fuel and clean	Between lanes	8:17	14:26	0.32	0.21
	Ambient Outdoor	Above main entrance	17:45	01:38	Trace	ND
	Maintenance	At service pit (on fence)	18:09	22:57	Trace	ND
	Fuel and clean	Between lanes	18:27	22:37	Trace	Trace
	Bus storage	NE, atop electrical panel	18:38	23:09	Trace	Trace
	Fuel and clean	Between lanes	22:37	00:39	Trace	ND
	Maintenance	At service pit (on fence)	22:57	03:50	Trace	ND
April 8	Ambient outdoor	Above control front doors	01:56	08:16	Trace	ND
	Maintenance	At service pit (on fence)	03:52	08:57	Trace	Trace
	Fuel and clean	Between lanes	04:09	08:27	Trace	Trace
	Bus Storage	1st row close to middle	04:05	08:57	0.66	0.51
	Ambient outdoor	Above control front doors	08:11	15:46	Trace	ND
	Bus storage	Middle row/center	09:25	14:07	Trace	Trace

Trace* = concentration lies between the minimum detectable** and minimum quantifiable concentrations (MQC). MQC for samples in this set ranged from 0.08 to 0.5 ppm for NO_2 and from 0.06 to 0.3 ppm for NO.

ND** = not detectable, concentration is less than the minimum detectable concentration (MDC). MDCs for NO samples in this set ranged from 0.03 to 0.1 ppm.

Table 3
Results of short-term air sampling for nitrogen dioxide (NO_2) in air conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Date and Area		Location OR Job Title	Start Time (24-hour clock)	Elapsed sampling time (minutes)	NO_2 concentrations (ppm)
April 7	Bus storage	Between lanes	04:54	17	1.4
	Bus storage	Bus operator (PBZ)	04:50	8	ND*
	Bus storage	East central	05:27	26	1.2
	Maintenance	At service pit (on fence)	06:07	18	Trace**
	Control room	Atop file cabinet	06:10	17	ND
	Bus storage	East central	11:26	18	Trace
	Maintenance	Between lifts 7 & 8	11:32	14	ND
	Bus storage	Central	14:40	36	Trace
	Fueling and cleaning	Between lanes, atop fuel control	22:14	31	0.52
	Bus Storage	SE/atop electrical panel	23:48	35	Trace
April 8	Bus Storage	Bus operator (PBZ)	05:46	8	ND
	Maintenance	Between lifts 9 & 10	05:15	20	ND
	Bus Storage	Middle row	06:47	19	1.1
	Bus Storage	Center, on fire extinguisher	04:45	17	ND
	Bus Storage	NE corner 3rd pillar	04:41	19	1.0
	Bus Storage	Center pillar on fire extinguisher	05:25	19	0.94
	Bus storage	Center pillar on fire extinguisher	06:37	27	0.81
	Bus storage	Middle row	10:30	29	ND
	Maintenance	Between lifts 9 & 10	10:27	32	ND
	Bus storage	3rd row/on elec. box near oil	14:10	24	ND

ND* = not detectable, concentration is less than the minimum detectable concentration (MDC). MDCs for samples in this set ranged from 0.07 to 0.2 ppm.
Trace** = concentration lies between the minimum detectable and minimum quantifiable concentrations (MQC). MQCs for samples in this set ranged from 0.08 to 0.4 ppm.
PBZ = Person breathing zone sample; all others are general area samples

Table 4
Results of "grab[‡]" area air sampling on April 6-8, 1998, for oxides of nitrogen conducted at the San Francisco Municipal Railway, Flynn Facility (HETA 98-0041)

Area	Sample location	Date and time of sample collection	Concentrations in air (ppm)	
			Nitrogen dioxide (NO_2)	Total oxides of nitrogen[†]
Bus storage	Northeast	4/6 @ 22:45	Trace*	NM**
Bus storage	Between lanes 5 & 6	4/7 @ 04:56	0.7	NM
Bus storage	Between lanes 10 & 11	4/7 @ 04:59	0.7	NM
Bus storage	Between lanes 7 & 8	4/7 @ 05:04	0.5	NM
Maintenance	Central	4/7 @ 05:13	ND[#]	NM
Fuel and clean	Between lanes	4/7 @ 07:32	Trace	Trace
Maintenance	Central	4/7 @ 07:42	Trace	Trace
Fuel and clean	Between lanes near fuel pump	4/7 @ 10:56	ND	ND
Bus storage	Central	4/7 @ 11:04	Trace	Trace
Maintenance	Between lifts 5 & 6	4/7 @ 11:12	ND	ND
Ambient Outdoor	Near central front door	4/7 @ 12:37	ND	ND
Fuel and clean	Between lanes	4/7 @ 22:22	Trace	Trace
Bus storage	SE	4/7 @ 23:47	ND	ND
Fuel and clean	Between lanes	4/8 @ 04:50	ND	ND
Bus storage	Middle	4/8 @ 04:59	ND	ND
Bus storage	East-central	4/8 @ 06:21	1	1.5
Bus storage	Middle row/center	4/8 @ 06:27	0.7	2
Bus storage	SW	4/8 @ 06:37	0.5	2
Fuel and clean	Between lanes	4/8 @ 11:49	ND	ND
Bus storage	Central	4/8 @ 11:52	ND	ND
Maintenance area	By fence at service pit	4/8 @ 11:56	ND	ND

† = Total oxides of nitrogen includes both nitrogen dioxide (NO_2) and nitric oxide (NO)
Trace* = concentration lies between the minimum detectable[#] and minimum quantifiable concentrations (MQC). MQCs are approximately 0.5 ppm of NO_2, 2 ppm total NO_x.
NM** = not measured. No sample collected for this air contaminant at this time and location.
ND# = not detectable. Concentration is less than the minimum detectable concentration (MDC). MDCs are approximately 0.1 ppm NO_2, and 0.5 ppm total NO_x.
‡ = "Grab" air samples are very short, about one or two minutes, in collection duration.

NIOSH evaluation of air quality and ventilation at San Francisco Municipal Railway's Flynn Facility

San Francisco's public transportation director asked NIOSH (the National Institute for Occupational Safety and Health) to evaluate the air quality and ventilation at the Flynn Facility. Employees were concerned about the possible harmful effects of their exposures to diesel-engine exhaust products.

What NIOSH Did

Took air samples and checked the ventilation over a 48-hour period in April 1998.

Checked diesel-exhaust particles by measuring for "elemental carbon" and "organic-based carbon" (EC and OC).

Measured levels of diesel-exhaust gases called "oxides of nitrogen."

Released a "smoke" to see air flows. We also used a continuous particle counter to help check the ventilation.

What NIOSH Found

Ventilation is not enough for the amount of diesel exhaust generated.

Diesel exhaust accumulates in the bus storage area during peak periods.

Since NIOSH considers diesel exhaust a "potential occupational carcinogen," a potential health hazard exists at the Flynn Facility.

Most EC levels were low and similar to other facilities.

Most OC levels could not be interpreted due to interferences.

While most oxides of nitrogen levels were low, some exceeded workplace limits.

What Flynn Facility Managers Can Do

If possible, install a new "sweeping flow" ventilation system (see full report for more details).

If this is not possible, install a new "local-exhaust" ventilation system (see full report for more details).

With either system, air-quality monitors should be installed.

Make sure that the facility's bus air-hose system is fully operational.

What Flynn Facility Employees Can Do

Bus engine idling during warmup should be as short as possible.

The bus air-hose system should be used to reduce engine idling times during warmup.

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513/841-4252 and ask for HETA Report # 98-0041-2741

NIOSH National Institute for Occupational Safety and Health

For Information on Other
Occupational Safety and Health Concerns

Call NIOSH at:
1–800–35–NIOSH (356–4674)
or visit the NIOSH Homepage at:
http://www.cdc.gov/niosh/homepage.html

National Institute for Occupational Safety and Health
NIOSH

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