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YELLOW FREIGHT SYSTEM, INC.
COLUMBUS, OHIO
MAYBROOK, NEW YORK

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## I. SUMMARY

On October 26, 1989, NIOSH received a request for technical assistance from Yellow Freight System, Inc., to evaluate the effectiveness of several techniques for controlling exposures of dockworkers to towmotor exhaust-system emissions. In this request, Yellow Freight System, Inc. agreed to provide forklift trucks (towmotors), exhaust after-treatment devices, and appropriate dock facilities for the study.

NIOSH investigators conducted the first survey in Columbus, Ohio over a three week period to measure relative exposures to several components of diesel exhaust during the use of three different vehicle types: 1) unfiltered diesel towmotors (used during the first week); 2) propane towmotors (used during the second week of the study); and 3) diesel towmotors fitted with exhaust filter units (used during the third week). During each week of the study, concentrations of air contaminants were measured, using both personal and area sampling devices, including submicrometer elemental carbon, submicrometer organic carbon, nitrogen dioxide, carbon monoxide (CO), benzene solubles, seventeen specific polynuclear aromatic hydrocarbons, respirable dust, formaldehyde, acetaldehyde, acrolein, sulfuric acid/sulfates, and the mutagenic activity of airborne particulate. Meteorological conditions, ventilation rates, forklift hour meters, and freight tonnage were also monitored as covariates. In addition, a self-administered symptomology questionnaire was distributed to all dockworkers during the three-week period of the study.

NIOSH investigators conducted the second survey in Maybrook, New York during March 13-15, 1990, to determine whether the use of overhead exhaust fans, located in the roof of the dock building, were effective in reducing diesel exhaust exposures in dock workers. Area and personal sampling were conducted over six shifts, during the normal use of diesel-powered towmotors. During three of the six shifts, the overhead fans were secured and, during the remaining three, operated. Meteorological conditions, forklift hour meters, and freight tonnage were again monitored as covariates.

<u>Columbus Dock:</u>

Analyses of covariance (ANCOVA) and a posteriori tests indicated that the geometric mean exposure to submicrometer elemental carbon during use of propane engines (0.9 $ug/m^3$) was significantly lower than during use of filtered-diesel engines (1.9 $ug/m^3$), and this was significantly lower than during use of unfiltered diesel engines (24 $ug/m^3$) ($p<0.001$ for both comparisons). For comparison, the geometric mean concentration in a light-industrial-zoned area about one mile from the dock was 1.6 $ug/m^3$. The geometric mean exposures during use of either filtered-diesel or propane forklifts were not significantly higher than the background mean concentration.

Concentrations of the other chemical components measured, and airborne mutagenicity, in two dock areas indicated no significant changes, or were extremely low or below the limit of detection during the three weeks of the study. This phenomenon was undoubtedly partly due to the ubiquitous presence of tobacco smoke, or because concentrations were near background levels. These results may have been partly due to

the fact that the dock was very well ventilated (by natural ventilation) during the survey.

Although the use of filtered diesel engines resulted in slightly higher elemental carbon exposures to the drivers than propane, peak carbon monoxide (CO) exposures were lower. In addition, the average CO concentration in the exhaust stream from the towmotors (measured inside the tailpipe prior to any engine adjustments) was substantially higher with propane engines (580 ppm) than with diesel engines (120 ppm).

Most workers' respiratory and other acute symptoms were significantly reduced when diesel-powered towmotors were substituted with either propane-powered towmotors, or with diesel-powered towmotors fitted with the exhaust filtration units. In the cases of the seven (out of a total of 11) symptoms found to be significantly different, unfiltered diesel engines produced significantly more complaints than either filtered diesel or propane engines. With six of these seven symptoms (except stopped-up nose), the rates of complaints from filtered diesel and propane engines did not differ significantly from each other. Based on the overall results of this study, either filtered-diesel or propane systems would be preferable to the use of unfiltered diesel engines. However, the long term performance of the filter systems with diesel engines will depend on strict maintenance of the units, as will control of CO from the propane engines.

Maybrook Dock:

At the Maybrook dock, the overhead fans had no significant effect on dockworkers' exposures to elemental or organic carbon, but did have a significant effect in reducing exposures to nitrogen dioxide. The actual reduction of $NO_2$ exposures seen, however, was very small (0.21 ppm with the fans off to 0.14 ppm with the fans on), and concentrations under either condition were substantially below the 3-ppm ACGIH TLV. Exposures to CO at the Maybrook dock were much higher than at the Columbus dock (ranging from 4 ppm to 11 ppm), but were well below the NIOSH/OSHA REL/PEL of 35 ppm. These exposures may have resulted from poorer natural ventilation at the Maybrook dock, a higher density of towmotors, and/or higher tailpipe emissions from the towmotors. Recommendations to reduce carbon monoxide emissions from vehicles used at the Maybrook facility were made.

Based on the overall results of the medical questionnaire and industrial hygiene evaluation at Yellow Freight System's Columbus dock, NIOSH investigators concluded that the substitution of diesel towmotors with either propane or filtered diesel towmotors significantly reduced particulate exposures and symptoms associated with exposure to diesel exhaust. The evaluation at the company's Maybrook, NY dock indicated that the 12 roof exhaust fans were not effective in reducing exposures to diesel exhaust. Recommendations were made to aid in controlling carbon monoxide exposures at the Maybrook facility.

KEYWORDS: SIC 4213 (Trucking, Except Local), diesel exhaust exposures, polynuclear aromatic hydrocarbons, elemental carbon, organic carbon, benzene-soluble particulate fraction, mutagenicity, forklift truck

## II. INTRODUCTION/BACKGROUND

On October 26, 1989, NIOSH received a request for technical assistance from Yellow Freight System, Inc., to evaluate the effectiveness of two techniques for controlling exposures of dockworkers to exhaust system emissions from diesel-powered forklift trucks (towmotors). These techniques were:

1) Retrofitting diesel towmotors with high-temperature exhaust filtration units. Because of logistical considerations, this evaluation was carried out by replacing the existing conventional diesel-powered towmotors with new ones which were identical, except for the addition of the filtration units to the exhaust system of each towmotor. According to the manufacturer, the filters are approximately 99% efficient at removing diesel particulate from the exhaust stream, but do not remove the gaseous or vapor components. Propane powered towmotors were also examined because they were potentially a useful alternative to diesel towmotors. Prior to about 1980, most towmotors used at truck docks were powered by propane engines.

2) The use of overhead exhaust fans located in the ceiling of the dock. Environmental tests were to be conducted both with the fans operating and with the fans secured. The tests were to be conducted at a facility in which such a ventilation system had been installed previously.

In this request, Yellow Freight System, Inc. agreed to provide towmotors, exhaust after-treatment devices, and appropriate dock facilities for the study. Subsequently, two industrial hygiene studies were conducted: the first at Yellow Freight System's Columbus, Ohio truck dock, and the second at the company's Maybrook, New York, truck dock. During the first survey in Columbus, questionnaires were also administered to dock workers to elicit worker symptoms. The questionnaire was used to determine whether changing the type of towmotor caused a significant change in the prevalence of these symptoms.

The Columbus, Ohio terminal is a large hub terminal consisting of a dock building, adjacent offices, and a separate building housing repair shops, inspection bays, and a truck wash. The function of the dock is to receive large, long-distance loads (inbound freight), and break them down into smaller loads (outbound) for distribution to regional or local destinations. The terminal is thus referred to as a "breakbulk" terminal. The dock is a 100' by 900' open-sided steel structure situated on an elevated concrete slab. Most of the wall space in the dock area (except for the office area at the southeast corner) consists of 163 open bay doors nearly the same size as the rear doors of truck trailers. "Switcher drivers" (not the truck drivers), using special switching vehicles, back truck trailers up to these doors to load and unload freight. Dockworkers use towmotors to move freight around on the dock, and into and out of truck trailers. The facility operates 24 hours per day on rotating 8-hour shifts. About 25 to 30 diesel-powered towmotors are normally used on the dock at a time, most of which are actively in use moving freight, and a few of which may be parked temporarily with the engine off. The existing diesel-powered towmotors were Toyota Model 5FGC25 vehicles fitted with 4 cylinder, 151 cubic inch diesel engines rated at 47hp and 1000 foot pounds torque at 2200 rpm, and catalytic converters. The filtered diesel engines were identical but were not fitted with catalytic converters. The propane-powered towmoters were Toyota Model 5FGC25 vehicles fitted with 4 cylinder OHV, 136 cubic inch gas engines rated at 52 hp and 115 ft. pounds torque at 1800 rpm, and were also fitted with catalytic converter.

Yellow Freight System's Maybrook, New York breakbulk dock is similar to the Columbus dock, but has about 280 open bay doors. The dock is 70' wide by 1,699' long, nearly twice as long as the Columbus dock. This dock also operates 24 hours per day on 8-hour rotating shifts, with 50 to 60 diesel powered towmotors on the dock, nearly twice as many as the Columbus facility.

At the Columbus and Maybrook docks, ventilation is mainly natural or passive dilution-type ventilation. Air from outdoors enters the building through open doors and openings between the truck and the door. Air also can enter through stationary gravity-type roof ventilators. In addition to natural ventilation at Maybrook, there are 12 roof exhaust fans, each rated at about 6,000 cubic feet per minute (cfm). During the six-shift survey at Maybrook, these fans were operated three shifts and secured for three shifts. Figure 1, Columbus, and Figure 2, Maybrook, show the docks, and list the number of truck doors, man-way doors, and roof ventilators at each facility. Figure 3 shows the typical spacing between the truck and the door when a truck is at the door.

NIOSH investigators conducted industrial hygiene and questionnaire surveys at the Columbus, Ohio dock during the period February 14 through March 2, 1990, and conducted an industrial hygiene survey at the company's Maybrook dock during the period March 13-15, 1990. Letters describing the environmental sampling results for both facilities, including tables and figures statistically summarizing the results, were sent to Yellow Freight System, Inc. and to the International Brotherhood of Teamsters (IBT) Health and Safety Office, on July 20 and October 4, 1990. The results of the questionnaire study were also sent to Yellow Freight System, Inc. and the IBT Health and Safety Office on September 12, 1990.

## III. EVALUATION DESIGN AND METHODS

### A. Environmental

The first survey was conducted at Yellow Freight's Columbus, Ohio dock over a three week period to compare relative exposures of dockworkers to several components of diesel exhaust during the use of three different vehicle types: 1) unfiltered diesel towmotors (used during the first week); 2) propane towmotors (used during the second week of the study); and 3) diesel towmotors fitted with high-temperature exhaust filtration units (used during the third week). The propane towmotors were included because they were available as a functional alternative to the filtered diesel units. The second survey was conducted at the same company's Maybrook, New York dock over six shifts on three consecutive days. The purpose of this survey was to evaluate the effectiveness of overhead mechanical exhaust fans in controlling diesel engine exhaust concentrations on the dock.

During each week of the Columbus dock study, concentrations of air contaminants were measured using both personal and area sampling devices. Personal sampling was conducted to evaluate exposures of dockworkers to submicrometer elemental carbon, submicrometer organic carbon, nitrogen dioxide, and carbon monoxide. Area sampling was conducted in two separate areas on the dock for the above contaminants, as well as benzene solubles, seventeen specific polynuclear aromatic hydrocarbons, respirable dust, formaldehyde, acetaldehyde, acrolein, and other aldehydes, sulfuric acid/sulfates, and the mutagenic activity of airborne particulate.

At Maybrook, the same personal sample strategy was followed, but area sampling was limited to elemental and organic carbon. In order to satisfy the research objective at this site, it was not considered necessary to evaluate airborne concentrations of a large number of chemical compounds. Determination of a surrogate of diesel exhaust contaminant concentrations (elemental carbon) was considered sufficient for the purpose, since the source or composition of the exhaust contaminants (unfiltered diesel engines) did not change during the survey.

Table I summarizes the general sampling strategy, including the type of sample obtained (personal or area), the analyte, method of analysis, the sampling parameters for each sampling train, the number of samples obtained per shift sampled, and the total number of samples of each type collected during the study at the two docks.

Concentrations of elemental carbon were used as the main marker of exposure to diesel exhaust in this study.[1,2] Particulate was collected using SKC Co. Universal sampling pumps at a flow rate of about 4 Lpm onto 37 mm Pallflex Corp. QAOT quartz fiber filters. Because almost all diesel particles (about 95%) are smaller than one micrometer (µM), only submicrometer particles (those smaller than 1 micrometer) were sampled. This technique also helped to exclude non-diesel particulate. This was accomplished by using modified "dichotomous" samplers (single stage, personal impactors) developed by researchers at NIOSH's Division of Respiratory Disease Studies.[3] The modifications to the DRDS design entailed resizing the inlet diameter to approximately 0.052" in order to accomodate a flow rate of 4 Lpm, and using quartz fiber filters (supported by stainless steel pads) instead of PVC filters. These samples were obtained for nearly a full shift, since the main problem is collecting enough carbon on the filter to analyze, not overloading. The limit of detection (LOD) is about 2 µg of either elemental or organic carbon per filter, which translates to a concentration limit of about 1 $\mu g/m^3$, assuming a 2 cubic meter air volume. Other personal sampling included nitrogen dioxide ($NO_2$), using Palmes tubes, and carbon monoxide (CO) using Draeger Model 190D personal CO data-logging monitors. These samplers were also worn by the dockworkers for a full shift.

On each of the nine day shifts (7:00 A.M. to 3:30 P.M.) at the Columbus dock (3 shifts x 3 weeks= 9 shifts sampled), eight personal samples were obtained for submicrometer carbon, carbon monoxide, and nitrogen dioxide. Whenever possible, samples were obtained on non-smoking dock workers (the elemental carbon measurement is only slightly affected by tobacco smoke, but the organic carbon, carbon monoxide, and $NO_2$ are affected). If no non-smoking dock workers were available, smokers were sampled, but the smoking status of that individual was recorded.

In addition, two area samples (were obtained per shift (one in each of the two dock areas monitored) of each of the sample types listed in Table I. These were obtained as replicates (i.e., over the same time period) so that statistical comparisons could be made between some of the methods.

Airborne particulate was collected for analysis of its mutagenic activity. Previous reports had indicated that exhaust after-treatment devices could actually increase the mutagenic activity of particulate emitted from diesel engines, particularly those which incorporated a fuel additive or catalyst, possibly by nitration of polynuclear aromatic hydrocarbons to, for example, 1-nitropyrene.[4,5]

Particulate for analysis of airborne mutagenic activity was obtained on 4" diameter Gelman Co. type AE glass fiber filters at a flowrate of about 20 cfm, using hi-volume pumps (General Metal Works) with a bypass rotameter. Airborne particulate on filters was extracted with 150 mL methylene chloride and then with 150 mL acetone + methanol. These two extracts were evaporated, added together, and concentrated to a final volume of 1.4 mL in dimethylsulfoxide. Mutagenic activity was tested with the Ames Salmonella microsome assay system.[6] The plate-incorporation test with and without S-9 activation of TA98 of Salmonella typhimurium was conducted. The liver homogenate of male CD rats pretreated with Aroclor-1254 (500 mg/kg body weight) was prepared according to Ames et al.[7] If at least one concentration gave a minimum of two times the number of spontaneous revertants with a dose-related response, it was considered a positive result.Background area samples were also obtained on each shift sampled for submicrometer elemental/organic carbon and airborne mutagenicity. These were obtained one to two miles away from the dock, for purposes of comparison to the samples obtained on the dock. These samples were very important since there are occupational health standards for exposure to only a few of the substances measured during this study.

B. Ventilation

From the ASHRAE Handbook, Chapter 22.6, Natural Ventilation,[8] natural or passive ventilation occurs because of wind and thermal pressures that produce a flow of outdoor air through openings into the building. Natural ventilation can be used effectively for both temperature and contaminant control. Factors affecting ventilation wind forces include average speed, prevailing direction, seasonal and daily variation in speed and direction, and local obstructions such as nearby buildings, hills, trees, and shrubbery. Usually, wind speeds are lower in the summer than in the winter. There are relatively few places where speed falls below half the average for more than a few hours a month.

To estimate the quantity of air forced through openings by wind, the following equation is used[8]:

$$Q = (Cf)C_vAv$$

where

Q = air flow, cfm
A = free area of inlet openings, $ft^2$
v = wind speed, mph
$C_v$ = effectiveness of openings (assumed to be 0.50 to 0.65 for perpendicular winds and 0.25 to 0.35 for diagonal winds)
Cf = conversion factor from mph to fpm, 88.0

No effort was made to determine air entering the building on the leeward side due to the complexity of air flow patterns. No effort was made to determine these patterns.

Wind speed inside the building was measured using a Kurz Analog Air Velocity Meter. At Columbus, measurements were taken at two-hour intervals at four locations along the length of the building each day of the survey. In Maybrook, measurements were taken at six locations, once a day on two different days. At the same time wind speeds were measured, the locations of open doors were recorded. Outside weather conditions were measured using an R.M. Young Wind Monitor No. 5305 recording weather station installed by Yellow Freight on the roof at each facility. The station recorded wind speed and wind direction at 15-minute intervals. In Columbus, it was oriented so that the 90-270 azimuth corresponded with the length of the building. In Maybrook, the 0-180 azimuth corresponded with the length of the building.

From the weather station data, average wind speeds and directions were determined for each eight-hour shift surveyed. The average inlet openings facing into the wind were estimated (open doors and open areas between the truck and the door) and used to determine the air flow entering the building. Average wind speeds inside the building were calculated from the air flow entering the building and compared with the measured wind speeds. Also, the existing ventilation rates were compared with the ventilation rates required to operate under existing conditions.

C. Covariates

It was determined a priori that several factors or conditions could affect the outcome of this study. Since the study was a field study, and not a laboratory study, it was anticipated that it would be more difficult to correct or control parameters such as environmental conditions or level of work activity. There was some risk, therefore, that the study results would be difficult to interpret. These difficult-to-control conditions might have resulted in incorrect decisions regarding the study parameters, either by not identifying a difference that exists, or by concluding that there is a difference when there is none. Conditions that artificially reduce the differences between the factors under study (towmotor type, presence/absence of mechanical ventilation systems) would cause the first error, and conditions that artificially increase these differences would cause the second error.

Covariates which were identified as potentially important prior to the study were wind conditions, the number of towmotors running on the dock, the aggregate length of time towmotors were running during a given shift, the quantity of freight moved per shift, and the relative condition of the engines. To control the potential effects of these factors, several additional procedures were followed. The number of towmotors running per shift was held constant during the three weeks of the study at the Columbus dock, and during the six shifts at the Maybrook facility. To detect high exhaust emitters, emission rates of CO and total particulate from each towmotor used during the study were measured at the beginning of each week. High exhaust emitters were adjusted in the repair shop and retested prior to their use. In addition, dilution ventilation rates, towmotor hour meters, and freight tonnages were monitored as covariates. Towmotor fuel usage was also monitored by fueling six of the towmotors at the beginning of each shift, and refueling the same towmotors at the end of the shift. The average amount of fuel used by these six vehicles was used as an indicator of relative fuel usage for all towmotors used on that shift.

D. Medical

A medical survey was designed which consisted of three identical self-administered questionnaires (Attachment 1) distributed on a voluntary basis to each dock and yard worker present at the Columbus dock during each of the three weeks of the study beginning February 12, 1990. The questionnaires asked the workers whether they felt certain symptoms were related to exposures from exhaust emissions. The most commonly reported health effects from previous studies on exposure to diesel exhaust consisted of respiratory tract and eye irritation, the production of black-colored phlegm, other respiratory difficulties, and headaches. Three "control" questions were also added to the questionnaire: 1) severe chest pain, 2) temporary blindness, and 3) pain on urination. These were symptoms that had not been previously reported as health outcomes from diesel exhaust and were designed to evaluate whether workers were truly reading the questionnaire and responding as honestly as possible. Workers were asked to determine whether they experienced the symptoms on the questionnaire, "never", "sometimes", or "often" during each week of the study.

E. Statistical Methods

Elemental and organic carbon air sampling data collected at the Columbus dock were grouped by type of towmotor and the type of sample (personal, dock area, background), and in Maybrook, by type of sample and exhaust fan status (on/off). The residuals in preliminary analyses were tested for normality. Results of these tests indicated that the residuals more closely followed a lognormal distribution. All subsequent analyses of the thermal-optical carbon analyses were therefore run using a natural log transformation of the concentrations of elemental or organic carbon. Descriptive statistics were calculated for each group, including the arithmetic and geometric means and standard deviations, and the 95% confidence limits.

Analyses of covariance were run on the elemental and organic carbon sampling data (and certain other compounds where data were adequate) from both the Columbus and Maybrook docks. In Columbus, the objective was to make unbiased comparisons of exposures to the carbon and other emissions of the three types of towmotors: unfiltered diesel, filtered diesel and propane. In Maybrook, the objective was to make unbiased comparisons of exposures to diesel exhaust emissions with and without mechanically assisted ventilation on the dock.

At both locations, the calculated ventilation rate (cfm), total freight moved (millions of pounds), and the total number of towmotor hours during each shift (related to the average duty cycle for all towmotors run during the shift, as well as the total number of towmotors operated) were used as covariates in the ANCOVA. These measured variables were used to correct for the uncontrolled temporal confounders (natural ventilation and level of work activity) identified prior to the field studies.

Cochran's test for related observations was used to statistically test the questionnaire results. This test allowed for comparisons of the three types of towmotors simultaneously, and evaluated significant differences in the prevalence of fourteen symptoms among workers from the use of the three types of towmotors. In this test, each worker acted as his own control during each of the three weeks of the study. If significant differences in symptoms from the use of the three types of towmotors were found, pair-wise comparisons were run using McNemar's test for 2 x 2 tables. All significant differences in the symptoms were noted by p-values. The p-values were viewed as probabilities indicating support for the null hypothesis of no difference in presence/absence or intensity of a single symptom during exposure over 5 days to each type of towmotor. Large p-values indicated no difference whereas small p-values (less than 0.05) indicated significant differences in symptoms.

## IV. EVALUATION CRITERIA

### A. Toxicological Effects of Diesel Exhaust Emissions

Three characteristics of diesel exhaust particles (DEP) are important in considering the toxicity of diesel exhaust. First, the particles are small and readily inhalable and therefore can reach the lower respiratory system, where they are retained.[9] Second, at least several thousand organic compounds can be adsorbed on the surface of the carbon particle aggregates, many of which are cytotoxic, carcinogenic or mutagenic.[10] These adsorbed compounds can include polynuclear aromatic hydrocarbons (PAHs), and nitro-substituted PAHs such as 1-nitropyrene and 2-nitrofluorene.[11] Third, diesel particles consist largely of carbonaceous material which is relatively stable in biological media. Thus, inhaled diesel particles tend to be retained for long periods in the lower respiratory tract and can accumulate, favoring induction of chronic pulmonary effects such as respiratory impairment and carcinogenesis.[11]

Whole diesel exhaust also includes a number of toxic gases or vapors (i.e., various oxides of nitrogen and sulfur, sulfuric acid and sulfates, aldehydes such as acrolein, etc.), which appear to play a major role in effects such as acute respiratory irritation. However, it is conceivable that these gases or the organic material adsorbed on deposited particles may play an additive or synergistic role in reducing ciliary clearance as well, perhaps through direct chemical cell toxicity.[11] Carbon monoxide and carbon dioxide are also produced in copious amounts by diesel engines. Carbon monoxide, in particular, is an acute toxin which, when inhaled, inhibits the ability of the blood to carry oxygen to the tissues, principally by preferentially combining with the hemoglobin in red blood cells. The carboxyhemoglobin formed is not able to combine with or transport oxygen, resulting in the typical symptoms of hypoxia, such as headaches, nausea, central nervous system depression, and in extreme cases, death.[12]

In a major chronic inhalation study conducted by the Lovelace Institute, rats exposed at a concentration of 350 $ug/m^3$ DEP for 7 hr/day, 5 days/wk for up to 2 years did not have clearance rates that were significantly different from controls.[13] However, rats similarly exposed at a concentration of 7000 $ug/m^3$ did show clear evidence of pulmonary accumulation of DEP after only 12 months, indicating impaired particle clearance. Rats exposed at concentrations of 3500 $ug/m^3$ did not demonstrate impaired clearance until after 18 months of exposure. These data suggest that (at least in rats) impairment of pulmonary clearance is a function of both concentration and duration of exposure, and that significant impairment of pulmonary clearance and subsequent accumulation of DEP begins somewhere between a concentration of 350 and 7000 $ug/m^3$ (0.35 and 7 mg/m3). However, substantial differences in lung clearance rates between test animals and humans make these data difficult to interpret in terms of human risk assessment.[9]

NIOSH recently published a current intelligence bulletin[14] which concluded that "...whole diesel exhaust be regarded as a potential occupational carcinogen in conformance with the OSHA Cancer Policy (29 CFR 1990)". This conclusion was based on the results of recent animal and human epidemiology studies. The studies in rats and mice confirmed the association between induction of lung tumors and exposure to whole diesel exhaust, and especially the particulate phase.[13,14,15,16,17,18] Several recent human epidemiology studies also consistently suggested an association between occupational exposure to whole diesel exhaust and lung cancer.[19,20,21,22,23]

The most recent and thorough epidemiological studies were done by Garshick, et al.[20,21] in railroad workers. In both of those case control studies, significant excesses of lung cancer were identified in certain age groups of exposed railroad workers, after controlling for tobacco smoking and asbestos exposures. Classification of the workers into exposed and unexposed groups was confirmed using adjusted respirable particulate (ARP) exposure measurements in 39 representative jobs from four U.S. railroads over a 3-year period. The measurements were adjusted by analyses for nicotine from composited filters obtained from each job group. Geometric mean exposures to ARP ranged from 17 $ug/m^3$ for clerks to 134 $ug/m^3$ for locomotive shop workers. Differences in climate, facilities, equipment, and work practices were found to affect exposures to diesel exhaust.[24]

B. <u>Environmental Criteria</u>

Permissible exposure limits (PELs) promulgated by the Occupational Safety and Health Administration (OSHA), Threshold Limit Values (TLVs) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), and NIOSH recommended exposure limits (RELs), exist for a number of gas/vapor species present in whole diesel exhaust (Table II). There are essentially no exposure limits (either promulgated as standards or recommended) directly applicable to evaluation of diesel aerosol (particulate phase) exposures. Both OSHA and MSHA have promulgated exposure limits for respirable nuisance (inert or non-toxic) dust for general occupational (5 mg/$m^3$) and coal-mine environments (2 mg/$m^3$). However, neither of these standards were intended to apply to diesel exhaust particulate. These standards are roughly comparable to the medium (3.5 mg/$m^3$) and high (7 mg/$m^3$) exposure concentrations used in the animal studies reported by Mauderly, et al.[13] Thus, it is unlikely that these concentrations represent reasonable exposure limits for human exposure to diesel aerosol. Other than those listed in Table II, there are also no existing exposure limits for specific PAHs or N-substituted PAHs. Similarly, the OSHA PEL for coal tar pitch volatiles (measured by benzene extraction of collected particulate) is not considered relevant to diesel emissions because of differences in origin and composition.[14] Measurements of the specific compounds mentioned above (and relating the results to published standards and recommendations) do not serve as adequate surrogates for diesel exhaust, nor do they allow an accurate assessment to be made of the effects of factors such as climate, facility design, work practices, and towmotor configuration, type, or age. The measurement of submicrometer elemental carbon, which was used in this survey, appears to be a more sensitive and specific surrogate for diesel exhaust than other previously used surrogates.[25] Currently there are no promulgated standards or recommended limits for exposure to submicrometer elemental carbon in whole diesel exhaust. Researchers in NIOSH's Division of Physical Sciences and Engineering are currently evaluating several potentially useful approaches for sampling and analysis of diesel exhaust, one of which is the thermal-optical method for elemental carbon. When an appropriate sampling and analytical method can be specified, work can continue on recommending an occupational permissible exposure limit for diesel exhaust.

C. Ventilation Criteria

Towmotors operated within a building require certain ventilation rates in order to protect the workers. Using the ACGIH Industrial Ventilation Manual, the basic design ventilation rates desirable to dilute carbon monoxide (CO) can be determined for large open areas in which several towmotors are being used.[26] The following are the basic design ventilation rates required:

> For each propane-fueled towmotor, 5,000 cfm of air is recommended by ACGIH. Since the concentration of CO measured in the exhaust pipe was less for diesel-powered towmotors (about 120 ppm for 26 diesel towmotors versus 580 ppm for 26 propane towmotors at the Columbus facility), a 5,000 cfm ventilation rate is also assumed as the basic design rate for the diesel lift trucks used at both facilities.

The conditions under which the basic design rate applies are:

1. A regular maintenance program incorporating final engine tuning through carbon monoxide analysis of exhaust gases must be provided. CO concentrations of exhaust gases should be limited to 1 percent for propane fueled towmotors. At

Columbus, the average measured exhaust CO concentration for both diesel and propane towmotors was below the 1% limit.

2. Actual operating time of lift trucks must be 50 percent or less of total exposure time. The towmotors at Columbus operated an average of 72% during the nine day survey and 64% at Maybrook over six shifts. Since operations were greater than 50%, a correction factor to the basic designed ventilation rate must be applied derived from the actual operating time divided by 50%. This results in correction factors of 72/50 = 1.44 for Columbus, and 64/50 = 1.28 for Maybrook.

3. A reasonably good distribution of air flow must be provided. This occurs at both facilities.

4. The volume of space must be 150,000 $ft^3$ per lift truck. If the volume is less, a correction factor must be applied to the basic designed ventilation rate. When the volume of space is 75,000 $ft^3$ per towmotor, the factor is 1.5 and for 30,000 $ft^3$, it is 2.0. At Columbus, the actual volume is 62,500 $ft^3$ (correction factor 1.64), and at Maybrook, it is 35,000 $ft^3$ (correction factor 1.94.)

## V. RESULTS

### A. Environmental

Tables A1 to A9 (Appendix A) contain the individual sample results from the Columbus survey. Tables A10 to A13 list the sample results from the Maybrook survey. Tables B1 through B7 (Appendix B) contain descriptive statistics by job or area for those contaminants which were consistently above the limits of detection of the sampling and analytical method (elemental and organic carbon, respirable dust, and nitrogen dioxide). Concentrations of other contaminants measured were not summarized statistically because the great majority of the analytical results for those compounds were below the limit of detection of the analytical method.

Sampling was conducted to collect airborne mutagenic particulate at the Maybrook facility, but due to an unusually high concentration of airborne sand dust (from the concrete pad surrounding the dock), the 4" diameter glass fiber filters overloaded after a short time and prevented the hi-volume pumps from operating properly. The results of these samples are not presented in this report due to the uncertainty about the volume of air these pumps collected. This problem, however, did not occur at Columbus, and those results are presented in this report.

#### Columbus Survey Results

Testing of towmotor tailpipe emissions (for CO and particulate emissions) was conducted prior to the main air sampling during each of the three weeks of the study. This testing indicated that a small number of towmotors (2 in the case of the unfiltered diesels, and six propane towmotors) required adjustment in the shop to reduce that vehicle's CO emissions. In the case of the diesel towmotors, the CO concentrations were 140 ppm and 151 ppm. After adjustment in the shop, these were reduced to 95 and 71 ppm, respectively. In the case of the six out-of-range propane towmotors, exhaust stream CO concentrations ranged from 564 to greater than 12,000 ppm (the highest possible reading from a high-range CO detector tube). After adjustment in the shop (fuel mixture screw adjusted to manufacturer's specifications), the CO concentrations dropped to below the average for all towmotors (about 580 ppm), ranging from 208 to 224 ppm. However, none of the the towmotors tested were found to have unusually high particulate emissions, and adjustment or removal for the purpose of eliminating high particulate emitters was not done during this study.

Elemental Carbon:

Tables A1-A2 (Appendix A) contain the individual sample results for elemental carbon and organic carbon, respectively, from all three weeks of the survey in Columbus. Tables B1 and B2 (Appendix B) present statistical summaries of these results by job or area, and towmotor type. Included are the number of samples (N), the range, arithmetic and geometric means, and the 95% lower and upper confidence limits surrounding each of the geometric means.

Analyses of covariance (ANCOVA) were run on the elemental and organic carbon data. The objective was to make unbiased comparisons of the elemental and organic carbon emissions of the three types of towmotors: unfiltered diesel, filtered diesel, and propane. Possible uncontrolled confounders in this study were identified as ventilation (CFM), total freight moved per shift (millions of pounds), and the total number of towmotor-hours during each shift.

The data analyses were done separately for personal and area samples, and in the case of the personal samples, separately for all personal samples (including smokers and non-smokers) and non-smokers. Two area samples were collected each shift with the exception of February 23 when one sample was voided due to pump failure. There were 72 personal samples (39 non-smokers and 33 smokers) and 17 area samples collected over nine different days. In preliminary analyses, the residuals more closely followed a lognormal distribution. Subsequent analyses were thus carried out using a natural log transformation of each of the sampling results.

An initial comparison of all personal elemental carbon means, unadjusted for covariates, showed a highly significant result ($F_{2,66} = 187.2$, $p < 0.001$), with geometric mean elemental carbon levels lower for propane than filtered diesel, and unfiltered diesel much higher than filtered diesel (Table III). After inclusion of the three covariates, it became obvious that only ventilation had a significant effect upon the elemental carbon concentration ($F = 7.1$, $p = 0.010$). The adjusted means and 95% confidence intervals are reported in Table III (background concentrations, however, obviously cannot be corrected for conditions on the dock). These corrections were very small and did not affect the significance tests previously conducted. A direct comparison of filtered diesel towmotors and propane towmotors was also made. The results indicated that propane towmotors produce significantly lower levels of elemental carbon than filtered diesel towmotors ($F = 1.5$, $P = 0.001$).

The overall relationships between the types of towmotors, and the results of samples measuring ambient "background" concentrations of elemental carbon, are shown in Figure 4. In this figure, the middle line of each box represents the median, the box represents the middle 50% of the data values (between the upper and lower quartiles) and the vertical lines extend out to the minimum and maximum values. The notches correspond to the width of the 95% confidence intervals for the median, and the width of the box is proportional to the square root of the sample size for each group. The notches allow visual, pairwise comparisons to be made at the 95% confidence level by examining whether the notches overlap. From Figure 4, it is obvious that neither propane (adjusted G.M. = 1.06 ug/m$^3$), nor filtered diesel towmotors (adjusted G.M. = 1.86 ug/m$^3$) result in dockworker exposures to elemental carbon significantly higher than background concentrations (G.M. = 1.55). Unfiltered diesel towmotors, however, result in substantially (and significantly) higher exposures in dock workers (adjusted G.M. = 23.2 ug/m$^3$). Although propane towmotors produce significantly less elemental carbon than filtered diesel towmotors, the absolute mean difference (1.86 - 1.06 = 0.80) is very small, and is only about 3.6% of the difference between propane and unfiltered diesel (23.2 - 1.06 = 22.14).

A similar analysis of covariance was carried out on non-smokers only, although almost all carbon (about 98% or greater) emitted with tobacco smoke is organic carbon,[25] and the elemental carbon concentrations should not have been affected by contamination with tobacco smoke. The adjusted means for this subset are also shown in Table III. Essentially, the result of this analysis was identical to that using all personal samples, and the geometric means differ only slightly. Results of a separate analysis of covariance of the elemental carbon concentrations, using only area samples, indicated that there was a significant difference among types of towmotors. Unlike the personal sample results, filtered diesel was not significantly different from propane (P = 0.336) but natural ventilation was significantly related to area elemental carbon levels. However, geometric mean exposures with both filtered diesel and propane towmotors were significantly lower than those during use of unfiltered diesel towmotors. Adjusted and unadjusted means and 95% confidence limits for the area samples are reported in Table IV.

Organic Carbon:

The unadjusted comparison of the geometric mean personal organic carbon concentrations (Table V) for the three towmotor types also showed a statistically significant overall difference ($F_{2,66} = 10.0$, $P < 0.001$). This data, however, shows relatively smaller differences among the mean concentrations of organic carbon (Figure 5). Propane towmotors were associated with significantly lower concentrations of organic carbon ($P < 0.001$), but filtered and unfiltered diesel means were essentially equal (47.9 vs 49.4 ug/m$^3$). In contrast to the elemental carbon analysis, ventilation did not have a significant effect upon organic carbon means (P = 0.33).

Since tobacco smoke contains mostly organic forms of carbon, a separate analysis of covariance was carried out using the subset of organic carbon concentrations from non-smoking employees (N = 39). In this analysis, only one covariate, weight of freight moved per shift in millions of pounds, had a statistically significant (but minor) effect on the means (P = 0.04). Again, ventilation was not a significant factor. The adjusted means for the non-smoking samples are shown in Table V. The overall result of the ANCOVA is similar to the analysis of the entire data set (propane significantly lower, $P < 0.001$, and filtered and unfiltered diesel much higher, but not different from each other). The geometric means in each case are somewhat lower, but the overall relationship between towmotor types is similar to that seen when all of the personal samples were included in the analysis.

The variability in the organic carbon area samples (geometric standard deviation (GSD)= 2.96) was considerably greater than that seen with the elemental carbon area samples (GSD = 1.68), and no significant differences were found among the three types of towmotors ($P = 0.102$). Ventilation was the only significant predictor of organic carbon concentrations from area samples ($P = 0.001$). Table VI reports adjusted means and 95% confidence limits. Although variability was relatively high in these data, the fact that no significant differences were seen is more than likely due to the fact that no true differences existed, and not due to high variability or small sample size.

Respirable Dust:

Tables A3 and B3 contain the results of sampling for respirable dust and summary statistics, respectively. Inspection of the substantially overlapping 95% confidence limits in Table B3 indicates that there were no significant differences between the three towmotor types, although the geometric mean of the measured respirable dust concentrations appeared to be substantially higher during the use of unfiltered towmotors, compared with those during use of filtered diesel or propane towmotors. An analysis of covariance, using ventilation rate, total towmotor hours, and weight of freight moved as covariates, also indicated no significant differences between towmotor types ($P = 0.091$). However, the sample sizes were necessarily small, and confidence limits were consequently very wide.

Nitrogen Dioxide:

Table A4 contains the individual $NO_2$ sampling results, and Table B4 a statistical summary of these samples by job, area, and towmotor type, respectively. The geometric means for the personal samples among the three towmotor types were essentially identical (0.16, 0.17, and 0.17 ppm). It does not appear from these data that towmotor type had any effect on exposures to $NO_2$. The highest single, 8-hr. TWA exposure was 0.32 ppm, nearly a factor of ten below the American Conference of Governmental Industrial Hygienist's TLV of 3 ppm.[27] Since these samples were taken over a full shift, these concentrations cannot be directly compared to the 1 ppm OSHA and NIOSH 15-minute STELs.

Other Chemical Contaminants:

Concentrations of aldehydes and sulfate were very low or not detectable. For example, concentrations of formaldehyde in samples placed in the two dock areas ranged from <0.01 to 0.01 ppm (Table A5). Acrolein and Acetaldehyde, also analyzed in these samples, were not found at detectable levels (about <0.02 ppm and <0.005 ppm, respectively). Concentrations of sulfuric acid/sulfate (expressed as weight of $SO_2$ per cubic meter of air) ranged from <9 to 19 ug/m$^3$ (Table A6). Concentrations of benzene soluble particulate (reported as mass of benzene extractable organic matter per volume of air) ranged from <36 ug/m$^3$ to 203 ug/m$^3$ (Table A7). With the exception of one sample collected during the use of filtered diesel towmotors (YFB-19: 22 ug/m$^3$), all of the detectable concentrations of benzene solubles were found during the use of propane towmotors during the second week of the survey. During this week, three of six samples indicated very high concentrations of benzene solubles ranging from 94 to 203 ug/$m^3$, while the remaining three indicated non-detectable concentrations (below 36 ug/$m^3$). Concentrations of benzene solubles during the use of unfiltered diesel towmotors, and during the use of filtered diesel engines, were very low or not detectable.

Trace amounts of naphthalene, acenaphthylene, and phenanthrene were found on three of the six backup sorbent tubes collected during the first week (during use of unfiltered diesel engines), and trace amounts of phenanthrene were found on two of the six sorbent tubes collected during the second week (propane). Only one sample, obtained during the use of unfiltered diesel towmotors, contained one of the PAHs (acenaphthylene) above the limit of quantitation of the method. This sample had a sample mass of 5 ug of acenaphthylene, and indicated a concentration of 5.0 ug/$m^3$. Otherwise, samples collected for analysis of polynuclear aromatic hydrocarbons (PAHs) did not contain detectable quantities of the 17 PAHs analyzed (Table VII), on either filters or sorbent tubes. These samples were obtained side-by-side (i.e., at the same times and locations) with the other area samples shown in Tables A3, A6-A8, and A10 (Appendix A).

Eight-hour time weighted average (8-hr. TWA) CO exposures in dock workers recorded by the Draeger Company Model 190D monitors were uniformly low, ranging from <1 ppm to 7 ppm (Table A8). Peak concentrations (representing the highest single one-minute average concentration during the work shift) ranged from <1 ppm to 475 ppm. Three peak concentrations exceeded the NIOSH recommended ceiling exposure limit and the OSHA permissible ceiling exposure limit of 200 ppm. All three of these occurred during the use of propane towmotors. However, all of the 8-hr. TWA exposures to CO were well below the NIOSH and OSHA exposure limits of 35 ppm.

Airborne Mutagenicity:

Table A9 contains the results of sampling for airborne mutagenic particles during the three weeks in Columbus, both on the dock and away from the dock (background). The a priori hypothesis was that the level of airborne mutagenicity (Revertants/$m^3$), or the particulate mutagenic activity (Revertants/mg) would change due to the changing composition of the exhaust emissions and the overall level of particulate emissions. Respirable dust concentrations measured in replicate (side-by-side) area samples are also reported in Table A9. The last two columns of Table A9, revertants/mg of airborne respirable particulate (not activated and S-9 activated), were calculated using the replicate respirable dust concentration reported for each sample location and time.

Analyses of covariance (correcting for the confounders of ventilation rate, pounds of freight moved, and lift hours) indicated no differences in concentrations of either revertants per cubic meter ($P = 0.15$), or revertants per milligram of particulate ($P = 0.19$) among the three towmotor types. The results with the S-9 activated assays were almost identical, indicating no differences between types of towmotors used. In addition, airborne concentrations of mutagenicity, measured in terms of revertants/$m^3$, were not significantly different than background levels during any of the three weeks. Background concentrations of revertants/mg of particulate could not be calculated since respirable dust concentrations were not measured at these locations.

Table VIII is a summary of overall results of the sampling for airborne mutagenic activity, and a summary of the sampling for respirable dust. The means and confidence limits shown have been adjusted for the covariates. Again, ANCOVA showed no statistically significant differences, among the towmotor types tested, in any of these measurements. This is very likely due to the small sample sizes and the large variability in the concentrations. However, the measured geometric mean respirable dust concentration was lowest during the use of filtered diesel towmotors (18 $ug/m^3$), higher during use of the propane towmotors (33 $ug/m^3$), and highest during use of the unfiltered diesel towmotors (74 $ug/m^3$). The highest mutagenic activity per volume of air was found during the use of propane towmotors (3.7 $ug/m^3$), and the lowest during use of the filtered diesel towmotors (2.5 $ug/m^3$). In addition, the least mutagenic airborne particulate was found during use of the unfiltered diesel towmotors (56 revertants/mg), and the most mutagenic particulate during use of the propane towmotors (214 revertants/mg). However, none of these means were significantly different from each other, nor were they significantly different than background concentrations.

<u>Maybrook Study Results</u>

The major hypothesis of the Maybrook, New York study was that the 12 roof exhaust fans would remove the diesel exhaust components from the dock area, and that the dock workers' exposures would therefore be reduced with the fans operating. In order to test this hypothesis, personal and area samples were collected over three shifts during which the fans were operated, and three additional shifts during which the fans were secured. The sequence of fans on/fans off (Table XII, which will be discussed later) was selected to minimize the chance that this factor would be confounded by any uncontrolled shift or day effects. As in the Columbus study, ventilation rate and the total number of towmotor hours were recorded and used to adjust the calculated means in an ANCOVA. However, it was not possible to obtain the weight of freight moved during each shift, since these were recorded by the dock personnel only for full 24 hour periods, and not by shift. Again, personal and area samples were analyzed separately, as were all personal samples, and samples obtained from non-smoking employees.

Elemental and Organic Carbon:

Table A10 presents the results of the individual elemental carbon samples collected at the Maybrook facility, and Table B5 statistically summarizes the unadjusted data by job and area. An ANCOVA was first calculated using all of the elemental carbon personal data (including smokers and non-smokers). Only ventilation rate (from natural sources) was found to be a significant factor in predicting elemental carbon concentrations in personal samples ($F = 5.8$, $P = 0.020$). The unadjusted and adjusted means are shown in Table IX. The main factor, fan operation, had no significant effect on elemental carbon exposures ($F = 0.99$, $P = 0.33$). Figure 6 visually depicts these results.

A separate analysis of elemental carbon results collected from non-smokers only indicated a very similar result, and fan operation was not found to affect elemental carbon exposures in dockworkers (P = 0.80), nor did it affect elemental carbon concentrations in area samples (P = 0.93). The adjusted means for non-smokers and area samples are also shown in Table IX. The geometric mean exposures to elemental carbon changed only slightly when comparing all personal samples with samples from non-smoking employees only (e.g., G.M. = 60.3 vs 54.5 when fans were not operating). This result is not surprising since diesel exhaust was the only known source of elemental carbon, other than very low ambient background concentrations.

Organic carbon sampling results are shown in Tables A11 and a summary of the unadjusted descriptive statistics are contained in Table B6. The ANCOVA also indicated no effect of fan operation, in either all personal samples (P = 0.37), non-smoking samples only (P = 0.37), or area samples (P = 0.92). Unadjusted and adjusted means are shown in Table X.

Carbon Monoxide:

Only a few samples were collected to measure exposures to CO at the Maybrook facility, since sampling for CO was not considered to be necessary to determine the effectiveness of the roof exhaust fans (which was the primary purpose of the Maybrook study), and since the survey at Columbus had indicated mostly non-detectable exposures to CO. Table A12 contains the individual 8-hr. TWA CO exposures measured on dock workers, and the results of three area samples. On the first day only, CO monitors were placed in the three widely separated area sampling stations (zones 4, 2, and 11) to determine the dock area ambient CO concentrations, with the expectation that they would be very low (based on the Columbus survey results). As indicated in Table A12, the 8-hr. TWA concentrations in these three area stations ranged from 33 to 45 ppm, approaching, or in excess of, the NIOSH REL and OSHA PEL of 35 ppm. In addition, peak concentrations approached or exceeded the NIOSH and OSHA 200 ppm ceiling limits.

Based on these surprisingly high results, additional personal monitoring for CO was conducted on the second and third day of the survey. As shown in Table A12, these results ranged from 4 to 11 ppm (with peak exposures ranging from 8 to 443 ppm) over the four shifts monitored. These exposures were well within the NIOSH and OSHA 35 ppm limits (although one peak exposure exceeded the 200 ppm limit), indicating that personal exposures (as contrasted with the area sampling results) were generally within control. However, these results were much higher than previously seen at the Columbus dock.

These results could be due to unusually high emissions of CO from the towmotors, to less than adequate ventilation on the dock, or to both factors. Testing of the exhaust stream from one of the towmotors used on the dock indicated a concentration of 450 ppm (which contrasted with a typical concentration of approximately 110-120 ppm in towmotors used at the Columbus dock). The higher emission rates may have been due to the age of the towmotors, or to less frequent maintenance, or both. Natural dilution ventilation appeared to be within acceptable guidelines (refer to section B in the text following) during the survey.

Nitrogen Dioxide:

Nitrogen dioxide sampling results are listed in Table A13, and are summarized in Table B7. The data in Table B7 suggest a consistent pattern of slightly higher exposures and area concentrations during shifts when the fans were not operating. An ANCOVA using all of the personal samples indicated that neither natural ventilation ($P = 0.83$) nor total towmotor hours ($P = 0.48$) influenced the geometric means. However, the main factor, fan operation, was highly significant ($P < 0.001$), indicating significantly higher concentrations of $NO_2$ when the fans were secured. Results of an ANCOVA using only data collected from non-smoking dock workers indicated essentially the same results.

Table XI contains the unadjusted means for both non-smokers and all personal samples, and Figure 7 visually compares the results for all personal samples. Although the geometric mean exposures to $NO_2$ were significantly higher when the roof exhaust fans were off (G.M. exposure = 0.21 ppm, vs G.M. = 0.14 ppm when fans were operated), all means and individual sample results were well below the ACGIH TLV of 3 ppm (8-hr. TWA). Short-term sampling for $NO_2$ was not conducted during this survey, and these data cannot be directly compared to the NIOSH and OSHA STELs of 1 ppm (averaged over any 15-minute period).

B. Ventilation

Table XII contains the measured average wind speeds and directions and the calculated air flows at the Columbus facility. During the three week survey, the average wind direction was from the south and averaged 750 fpm (8 to 9 miles per hour). It is estimated that approximately 683,000 cfm of air entered the building, resulting in a total air change every 2.9 minutes. The average measured and calculated wind speeds inside the building were similar, 89 fpm versus 113 fpm.

Table XIII shows the measured average wind speeds and directions and the calculated air flows at the Maybrook facility. During the one-week survey, the average wind direction was from the southwest and averaged 460 fpm (5 to 6 miles per hour). It is estimated that approximately 915,000 cfm of air entered the building, resulting in a total air change every 2.8 minutes. The average measured and calculated wind speeds inside the building were similar, 41 fpm versus 33 fpm. Table XIV lists the calculated ventilation rates required for each facility, based on control of carbon monoxide, and the estimated ventilation rates that existed during the survey. Based on these results, natural ventilation appears to be adequate to control carbon monoxide at both facilities during the time of the surveys.

C. Medical

The participants in the survey at the Columbus dock were all males. The ethnic composition of the group included 134 whites (non-hispanic), 5 blacks, 1 hispanic and 1 American Indian for a total of 141 participants (72% of the 197 total workers). The workers ranged in age from 22 to 58 years old with an average age of 40.6 years. Workers had been employed at the company an average of 4.0 years. There were 69 current smokers, 38 ex-smokers, and 34 never smokers among the cohort. Among the smokers and ex-smokers, the average number of cigarettes smoked per day was 20.1. There were 117 who classified themselves as dock workers, and 24 who classified themselves as yard workers.

Table XV lists the symptoms reported by workers as occurring during each of the three weeks when the three types of towmotors were in use. As shown in the Table, the symptoms most frequently reported by the 141 dock and yard workers during the three weeks were running nose, and stopped-up nose followed by eye irritation, headache, and sore/irritated throat. The three "control" questions, severe chest pain, temporary blindness, and pain on urination had the lowest frequencies of all symptoms reported.

Over the three-week time span of the study, significant changes ($p<0.05$) occurred in seven symptoms: 1) running nose, 2) stopped up nose, 3) sore/irritated throat, 4) hoarseness, 5) dry cough, 6) wheezing, and 7) shortness of breath (Table XVI). For those seven symptoms which were statistically significant, pairwise comparison tests were run to determine how those symptoms differed between the three types of towmotors.

The results of the comparison tests showed similar findings in all seven significant symptoms with one exception. For all seven significant symptoms, unfiltered diesel exhaust produced significantly more complaints than filtered diesel or propane exhaust. For six of the seven symptoms, complaints from filtered diesel and propane did not differ significantly from one another. In the case of stopped-up nose, however, filtered diesel also produced significantly more complaints than propane.

## VI. DISCUSSION

An important issue with many past environmental evaluations of exposures to diesel exhaust has been an inadequate characterization using relatively insensitive and non-specific methods; e.g., total or respirable dust measurements by gravimetry, or measurements of gases such as CO, carbon dioxide, nitrogen dioxide, or total oxides of nitrogen, benzene solubles, or specific polynuclear aromatic hydrocarbons. Many of these substances, such as benzene extractable matter from airborne particulate, specific PAHs or substituted PAHs, or the common combustion gases such as carbon monoxide, are also frequently present in the occupational environment from sources such as tobacco smoking and other workplace and non-workplace combustion sources; work with fuels, solvents, oils, greases; or suspension of soil or other particulates. In addition, as shown in previous NIOSH studies and in this study, most of these contaminants are present at relatively low levels in diesel exhaust, and are difficult to measure at the low levels typically found in the trucking industry. The results therefore can be seriously confounded by their presence in sources other than diesel exhaust. In this study, this problem was addressed by using the elemental carbon content of submicrometer particulate as the primary index of exposure to diesel exhaust. Since elemental carbon is present only at very low levels in general ambient particulate from sources such as tobacco smoke, sand, dirt, and fibers, it is much more likely that measured elemental carbon results from exposure to diesel exhaust. The thermal-optical method is also approximately 100 times as sensitive as methods based on gravimetry (e.g., respirable dust and benzene solubles), and thus is a much more reliable indicator at very low levels.

In the Columbus study, the two factors showing consistent association with both elemental and organic carbon concentrations were type of towmotor and natural ventilation rate in cfm. The largest differences among types of towmotors were found for elemental carbon using personal samples. Geometric mean elemental carbon exposures and area concentrations were greatly reduced (to essentially background levels) when the filtration units were used on diesel-powered towmotors, but were slightly (and significantly) lower yet when propane-powered towmotors were used. However, exposures during use of either filtered diesel or propane towmotors were not significantly higher than ambient background concentrations.

Organic carbon personal exposures were not reduced significantly using the exhaust filters, but were somewhat lower (from about 50 ug/$m^3$ to about 24 ug/$m^3$) during use of propane-powered towmotors. However, exposures to organic carbon were significantly higher than background concentrations during all three weeks of the study at the Columbus dock. In contrast with the elemental carbon personal sampling results, ventilation had no significant effect. The organic carbon area sampling data reversed this effect; i.e., ventilation was a significant factor but type of towmotor was not. It may be that a large proportion of the organic carbon found on the personal samples came from tobacco smoke, which was less affected by ventilation rate on the dock. This might be the case, for example, if more tobacco smoking occurred in the lunchroom, or inside truck trailers, than on the dock itself.

Separate analyses of the personal sampling results, using sample results from non-smoking employees only, indicated that tobacco smoking did not grossly affect either the elemental or organic carbon results; i.e., the conclusions were the same whether all personal samples were used, or samples from only non-smokers were used. However, during use of unfiltered diesel towmotors, comparison of the personal sample elemental to total carbon ratio in non-smokers ($C_e/[C_e + C_o] = 25.7/[25.7 + 38.5] = \underline{0.40}$) to the same ratio in area samples ($11.5/[11.5 + 1.89] = \underline{0.89}$) suggests that some non-diesel particulate (probably side-stream tobacco smoke) is being collected even on the personal samples collected from non-smokers. Typically, elemental carbon comprises 60-80% of the total carbon in diesel exhaust.[28,29,30]

Full-shift (8-hr. TWA) exposures to $NO_2$, and area concentrations of respirable dust and airborne mutagenicity (not activated and S-9 activated) indicated no observable differences among the three types of towmotors. Some peak exposures to CO during the use of propane towmotors exceeded the 200-ppm ceiling limits specified by NIOSH and OSHA, and one peak exposure exceeded the 400-ppm ACGIH ceiling limit. In contrast, peak exposures to CO were uniformly low during use of filtered diesel and unfiltered diesel engines at the Columbus, Ohio dock.

Eight-hour TWA area concentrations of the other contaminants measured (CO, 17 individual PAHs, benzene solubles, sulfuric acid/sulfates, and aldehydes) were very frequently below the limit of detection of the sampling and analytical method, and could not be adequately treated statistically. However, it is interesting to note that the lowest observed respirable dust concentrations were found in area samples during the use of filtered diesel engines (the highest were observed during use of unfiltered diesel, with propane falling about halfway in between), and the highest levels of airborne mutagenicity (both in terms of revertants/$m^3$ and revertants/mg) were found during the use of propane towmotors. In addition, the highest concentrations of benzene solubles (94, 166, and 203 ug/$m^3$ in three of six samples) were found during the use of propane towmotors. This is not consistent, however, with the pattern of organic carbon area concentrations measured in replicate samples by the thermal-optical method, where the highest concentrations were found during the use of filtered diesel engines. The results of these two methods should be roughly comparable.[31] However, these results cannot be considered to be more than merely suggestive, since the variability of the results of the gravimetric-based methods at these low levels (respirable dust and benzene solubles) is rather high.

It is possible that the testing and adjustment (if necessary) of the towmotors at the beginning of each week may have lead to smaller differences in contaminant exposures than if this intervention had not been done. CO exposures, in particular, might have been higher had the six propane towmotors with very high exhaust CO not been adjusted prior to their use on the dock.

In the Maybrook, New York study, the roof exhaust fans, exhausting a total of 72,000 cfm, did not affect the elemental or organic carbon sampling results, but did significantly reduce $NO_2$ exposures in dock workers. The actual reduction of $NO_2$ exposures seen, however, was very small, and concentrations under either condition were substantially below the 3-ppm ACGIH TLV.

Natural ventilation appeared to be adequate for control of carbon monoxide at both facilities during the respective surveys. At Columbus, natural ventilation may be adequate the entire year. This is the case since the ventilation rate was over twice that required for operating 26 propane or diesel towmotors. (There are relatively few places where the wind speed drops below half the average speed measured during the winter for more than a few days a month).[8] At the Maybrook facility, natural ventilation appeared to be adequate during the winter months. However, during the summer, natural ventilation may be inadequate, if average wind speed is much lower. The twelve exhaust fans, removing a total of 72,000 cfm of air, move only about 10% of the total air needed to meet the total requirements for operating 60 towmotors. If natural ventilation is half that measured in March, the combination of natural and mechanical ventilation would provide only about 70% of the air flow required. To meet the suggested ventilation rates would mean operating fewer towmotors, keeping more doors open (no trucks at the door), or additional exhaust fans.

The questionnaire study results suggest that the use of unfiltered diesel-powered towmotors on the dock increases respiratory symptoms over those found when propane powered or filtered diesel-powered towmotors are used. In this study, seven symptoms were significantly increased out of a possible total of eleven symptoms. However, with one exception, the data did not indicate a significant difference in symptoms during the use of propane as compared to diesel-powered towmotors when the exhaust filter was added. Only complaints of "stopped-up nose" were significantly more prevalent during the use of the filtered-diesel towmotors as compared to propane. The fact that many of the respiratory symptoms were more prevalent when the unfiltered diesel-powered towmotors were used supports the hypothesis that unfiltered diesel exhaust emissions can cause respiratory symptoms in humans.

Extremely low exposures to some of the known respiratory irritants (sulfuric acid/sulfates, aldehydes, $NO_2$) were measured during the Columbus study - usually an order of magnitude or more below any applicable evaluation criteria. Thus, there is no indication that these measured irritants likely would have caused any appreciable irritant effects in the employees. This typically has been the case in previous NIOSH studies.[32,33] Therefore, the exact cause of the acute effects from unfiltered diesel exhaust is uncertain. However, various possibilities have been discussed previously in other reports.[32,33] It may be the additive or synergistic effects among the various components of diesel exhaust, the presence of unrecognized component(s), and/or characteristics related to small particulate in diesel fume (e.g., irritation association with the size or shape of the particles, or the ability of the fine particulate to penetrate the lower regions of the lung, possibly more efficiently carrying certain absorbed components to these areas), or some other unrecognized factor(s) that are responsible for the health effects found. Unfiltered diesel exhaust is known to be characterized by levels of particulate that are 20-100 times higher than those found in gasoline exhaust, and 95% of diesel exhaust particles are submicron in size.[34,35,36,37]

In this study, most of the acute symptoms, and diesel exhaust particulate (as indicated by the elemental carbon concentrations) were simultaneously reduced with the addition of the exhaust filtration units to the diesel engines. These results suggest that the particulate phase (or possibly any irritants adsorbed onto the fine particulate) of diesel exhaust may be responsible for the acute, irritative symptoms in humans. This supposition, of course, would need to be confirmed by additional studies. In any case, at least in this study, it appears that the concentrations of the agent(s) responsible for the acute effects in the dock workers were reduced using the exhaust filtration units.

Cigarette smoking, uncontrolled in the questionnaire analysis, could explain some of the excess risk for respiratory disease since it is well known that cigarette smoking contributes to respiratory disease. However, in the Cochran test each person acts as his own control, and therefore, the smoking experience of each worker would not be expected to differ substantially during the three weeks of the survey. Cigarette smoking, then, would not likely explain the finding of excess respiratory symptoms.

The fact that workers were sensitized to the study could have had an effect on the way the questions were answered. Workers were aware that the experiment was taking place and were not "blinded" as to whether unfiltered diesel-powered, propane-powered or diesel-powered towmotors fitted with an exhaust filter were being used. Therefore, workers could have consciously or subconsciously answered questions the way they thought they wanted the outcome to appear. Furthermore, another phenomenon known as the "Hawthorne effect" could have been taking place. The "Hawthorne effect" is a term that covers the general finding that subjects often behave differently simply because they know they are the subjects of experimental investigation. In our survey, workers may have answered more positively (less affected) regarding symptoms during progressive weeks of the study simply because they knew they were being studied. The fact that responses to the three control questions did not change significantly over the three week study suggests that the workers answered the questions honestly, but does not preclude the possibility of subconscious bias in the workers responses.

Although workers in this study had used diesel-powered towmotors for various amounts of time (an average of 4 years), workers had only used the propane-powered and filtered diesel-powered towmotors for one week. This may have been an insufficient amount of time for workers to accurately evaluate their symptoms resulting from the use of these towmotors.

Finally, when a large number of statistical tests are run, it is more likely that statistical significance will be found by random chance. Fourteen tests were run to compare symptoms separately, with three follow-up tests done on the seven significant symptoms to compare each towmotor with the other two. This results in a total of 35 [14 + (3 x 7)] tests run. The possibility of one or two results being positive by chance alone at the alpha level of 0.05 is fairly good. However, the number and pattern of significant results would indicate a non-random set of outcomes.

## VII. CONCLUSIONS

Of the diesel exhaust contaminants measured during the survey at the Columbus facility, only elemental carbon (and to some extent, carbon monoxide) provided a clear basis for differentiation between towmotor configuration or type. Both filtered-diesel and propane towmotors provided a substantial and significant reduction in personal exposures to elemental carbon in dockworkers when compared to unfiltered diesel engines. However, personal exposures to elemental carbon were also significantly lower with propane towmotors than with filtered diesel engines, although by a very small absolute amount.

Although organic carbon exposures (by the thermal-optical method) were not reduced using filtered-diesel towmotors, it is likely that these results were substantially confounded by tobacco smoke in many personal samples, even in non-smokers (sidestream smoke). Evidence for this conclusion is based on the fact that the mean organic carbon concentration was far lower in area samples than in personal samples for all three towmotor configurations. In the case of the unfiltered diesel towmotors, the fraction of elemental carbon in the total carbon was also far higher in the area samples than in the personal samples (0.89 vs 0.40).
In addition, the remainder of the sampling results (both area and personal), provide little evidence to differentiate between types of towmotors. Results of sampling for respirable dust, $NO_2$, 17 specific polycyclic aromatic hydrocarbons, formaldehyde, acetaldehyde, acrolein, sulfuric acid/sulfates, benzene solubles, and airborne mutagenicity (both in terms of revertants/$m^3$ and revertants/mg of airborne particulate) did not provide any evidence, in this study, that any of the three types of towmotor configurations are differentiable in terms of measurable exposures, or are demonstrably more or less hazardous in terms of acute or chronic health effects. Sampling for CO, however, did indicate that excessive peak exposures (in comparison to the NIOSH and OSHA 200 ppm ceiling concentrations) to CO did occasionally occur during use of propane towmotors. These exposures were found despite the fact that all of the propane towmotors were new, had been tested for emissions of CO (as had the diesel and filtered diesel towmotors), and six of the 26 used on the dock had been adjusted to eliminate high CO emissions just prior to the study. In addition, CO emissions from propane towmotors were substantially higher (arithmetic mean = 580 ppm) than those from diesel towmotors (arithmetic means = 110 -120 ppm). If ventilation conditions had been poorer at the Columbus dock, CO exposures may have been substantially higher, particularly with the propane towmotors.

The medical portion of the survey conducted by NIOSH at the Yellow Freight Systems, Inc. dock in Columbus, Ohio was designed to help in determining whether switching from unfiltered diesel-powered towmotors to either propane or filtered diesel-powered towmotors significantly reduced workers' symptomatology. The results would appear to indicate that workers' symptoms were significantly reduced by using either propane or diesel-powered towmotors with the exhaust filters.

Either propane or diesel-powered towmotors would appear to provide a viable alternative, in terms of the potential exposures and acute health effects, to the unfiltered diesel towmotors currently used by many trucking companies. Although elemental carbon exposures were lower with propane engines, peak exposures to CO were higher. In addition, acute respiratory symptoms appeared to be substantially alleviated when substituting with either propane or filtered diesel engine configurations. The latter fact would appear to suggest that the particulate phase of diesel exhaust may be responsible for the acute, irritative effects observed with unfiltered diesel exhaust. If this were true, it is logical to assume that substantially reducing the particulate phase of diesel exhaust would simultaneously reduce the acute symptoms associated with diesel exhaust.

The twelve roof exhaust fans at the Maybrook dock were not adequate to significantly affect concentrations of diesel exhaust. The 72,000 cfm of exhaust volume provided only about 10% of the total required for the operation of 60 towmotors on the dock. In addition, geometric mean concentrations of elemental and organic carbon did not change significantly with fan operation status. Although concentrations of $NO_2$ were significantly reduced, the reduction was small relative to the 3 ppm OSHA PEL and ACGIH TLV.

Natural ventilation present on both docks appears to conform with ASHRAE guidelines for ventilation of indoor spaces where vehicles powered by internal combustion engines are used. However, at the Maybrook dock, the presence of surprisingly high CO concentrations (but well within the OSHA PEL, NIOSH REL, and ACGIH TLV of 35 ppm, averaged over 8-10 hours) is very likely due to the combination of higher emission rates of CO from the towmotors, a higher density of towmotors operating on the dock, and natural ventilation rates which were only marginally adequate (123% of the minimum required) during the survey.

## VIII. RECOMMENDATIONS

1. Based on the results of this study, it appears that substantial workplace improvement can be achieved by 1) substituting diesel-powered towmotors with propane-powered towmotors, or 2) by retrofitting existing diesel-powered towmotors with exhaust filtration units of the type tested in this study. Although slightly lower elemental carbon concentrations were found using propane towmotors as compared with filtered diesel-powered vehicles, both measures appear to be substantially effective in reducing particulate emissions and workers' acute symptoms associated with diesel exhaust. However, proper maintenance of either filtered-diesel or propane-powered vehicles is key to their safe use over a long period of time. In the case of the filtered-diesel towmotors, the filter systems (including the exhaust systems, filter housings, and filter elements, and necessary engine adjustments) require careful maintenance in order to assure their continued effectiveness in removing particulate from the exhaust stream. In the case of the propane vehicles, continued and frequent adjustment of engine intake and fuel mixture settings is important in controlling CO exposures.

2. In addition, based on the results of sampling for those agents suspected to be carcinogenic or to be associated with chronic health effects (e.g., diesel particulate as estimated by elemental carbon concentrations, benzene solubles, PAHs, and airborne mutagenicity, there is reason to be optimistic that filtered diesel engines will also be effective in reducing the potential for chronic health effects. Tumor

induction is associated with diesel exhaust particulates.[14] It is therefore logical to assume that a significant reduction in the exposures to diesel particulate will also reduce the potential for lung tumor induction in humans. However, the following caveats should be kept in mind:

a. Although the preponderance of animal data points to the particulate phase of diesel exhaust as the carcinogenic fraction,[14] at least one study (Heinrich et al.[15]) did find an excess of lung tumors in female NMRI mice, due primarily to a statistically significant excess of adenocarcinomas, when exposed to either filtered or unfiltered diesel exhaust. This finding led NIOSH, in its Current Intelligence Bulletin No. 50,[14] to conclude that "limited evidence indicates that the gaseous fraction of diesel exhaust may be carcinogenic as well", and to conclude that it is "whole diesel exhaust" which is suspect in causing cancer. However, there is currently a paucity of data regarding the potential carcinogenicity of emissions (gaseous or particulate) from propane engines.

b. These results represent only one study, at one site, under one set of conditions, and for a relatively short period of time. Because of the overall importance of assuring workers' health and safety, both in the short term and long term, it is recommended that this study be independently repeated, preferably under more severe conditions than were found during the study in Columbus. This would increase the likelihood that some of the suspected irritative and carcinogenic agents, or levels of airborne mutagenic particulate, would be consistently measurable, if they are present in diesel exhaust.

3. The results of this study should be verified further by conducting a follow up study one year or more after the changeover to propane and filtered diesel-powered towmotors, such that the potential effects discussed in Section VI of this report can be better addressed, and so that the continued effectiveness of the filter units over a longer period of time can be properly verified. Although the filter elements are replaced when they become inoperative (e.g., through wear and tear and regeneration processes), long-term effectiveness is dependent as well on the integrity of entire system in actual use. Proper maintenance and replacement of parts as necessary are key to the long-term effectiveness of the filter systems.

4. At the Maybrook dock, the overhead exhaust fans, configured as they are (number, location, and capacity, comprising only about 10% of the total ventilation at the Yellow Freight System's Maybrook, New York dock) were not effective in reducing exposures to diesel exhaust. In addition, it is not likely that it would be economically feasible to increase the fans' total capacity to substitute for inadequate natural ventilation. Measures such as increasing the number of open doors (on both sides of the dock), reducing the number of operating towmotors, shutting off towmotors when not in use, and a program of regular engine maintenance would be more effective in controlling exposures to airborne contaminants.

5. Carbon monoxide exposures were within acceptable limits during the survey at Maybrook, consistent with the overall results of the evaluation of natural ventilation at this site. However, relatively high exposures to carbon monoxide (4 to 11 ppm) were encountered during this study (compared to those at the Columbus dock). Management at this site should therefore create and adhere to a program of

regular testing of CO emissions and more thorough maintenance of towmotor engines. They should also consider keeping more of the doors open (not blocked by truck trailers) on both sides of the dock, and/or reducing the number of towmotors operating on the dock, particularly should natural ventilation drop significantly below that measured during the survey.

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5. NIOSH, Cincinnati Region, Boston Region

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

TABLE I

Sampling Strategy and Methods
Yellow Freight System Inc.
Columbus, Ohio and Maybrook, New York

HETA 90-088
February and March 1990

| Method | Sampling/Analytical Technique | Flow (Lpm) | No. per Shift | No. Total |
|---|---|---|---|---|
| COLUMBUS, OHIO | | | | |
| | Personal Samples (Dock workers): | | | |
| Elemental/Organic C | Dich/Quartz Filter/Thermal-optical | 4 | 8 | 72 |
| Nitrogen Dioxide | Palmes Tubes (NIOSH 6700) | ** | 8 | 72 |
| Carbon Monoxide | Draeger Co. Dosimeters | ** | 8 | 72 |
| | Area Samples (Placed in two areas on the dock): | | | |
| Nitrogen Dioxide | Palmes Tubes (NIOSH 6700) | ** | 2 | 18 |
| Carbon Monoxide | Draeger 190D CO Monitors | ** | 2 | 18 |
| Formaldehyde | Sorbent tube (NIOSH 2502) | 0.1 | 2 | 18 |
| Sulf acid/Sulfates | Sorbent Tube (NIOSH 7903) | 0.5 | 2 | 18 |
| Benzene Solubles | PFTE filter (NIOSH 5023) | 2.8 | 2 | 18 |
| PAHs (part./vapor) | PFTE/Orbo 43 (NIOSH 5506) | 2.0 | 2 | 18 |
| PAHs (particulate) | PFTE/extract/GC (NIOSH 5506) | 10-20 | 2 | 18 |
| Elemental/Organic C | Dich/Quartz Filt/Thermal-optical | 4.0 | 2 | 18 |
| Respirable Dust | PVC/cyclone (NIOSH 0600) | 1.7 | 2 | 18 |
| Mutagenicity | AE filt & sorb./extract/Ames | 20 CFM | 2 | 18 |
| | Exhaust Pipe Samples: | | | |
| Carbon Monoxide | Draeger 190D or CO Detector Tubes | -- | * | * |
| Particulate Emiss. | RAM real-time dust monitor | -- | * | * |
| | Background Samples: (Ce and Co): | | | |
| Elemental/Organic C | Dich/Quartz Filter/Thermal-optical | 4 | 1 | 9 |
| Mutagenicity | AE filt & sorb./extract/Ames | 20 CFM | 1 | 9 |

(Table I Continued Next Page)

TABLE I (Continued)

Sampling Strategy and Methods
Yellow Freight System Inc.
Columbus, Ohio and Maybrook, New York

HETA 90-088
February and March 1990

| Method | Sampling/Analytical Technique | Flow (Lpm) | No. per shift | No. Total |
|---|---|---|---|---|
| MAYBROOK, NEW YORK | | | | |
| | Personal Samples (Dock workers): | | | |
| Elemental/Organic C | Dich/Quartz Filter/Thermal-optical | 4 | 8 | 48 |
| Nitrogen Dioxide | Palmes Tubes (NIOSH 6700) | ** | 8 | 48 |
| | Area Samples (Placed in three areas on the dock): | | | |
| Elemental/Organic C | Dich/Quartz Filt/Thermal-optical | 4.0 | 3 | 18 |
| Mutagenicity | AE filt & sorb./extract/Ames | 20 cfm | 3 | 18 |
| | Exhaust Pipe Samples: | | | |
| Carbon Monoxide | Draeger 190D or CO Detector Tubes | -- | * | * |
| Particulate Emiss. | RAM real-time dust monitor | -- | * | * |
| | Background Samples (Ce and Co): | | | |
| Elemental/Organic C | Dich/Quartz Filter/Thermal-optical | 4 | 1 | 6 |
| Mutagenicity | AE filt & sorb./extract/Ames | 20 cfm | 1 | 6 |

* Number of samples depends on the number of towmotors used. Each truck operated during the survey will be evaluated at least once.

** Passive devices.

TABLE II

Evaluation Criteria
Yellow Freight Systems, Inc.
Columbus, Ohio and Maybrook, New York

HETA 90-088
February and March 1990

| Compound | ACGIH TLV 8-hr TWA[1] (ppm) | (ppm) | 15-min STEL[2] (ppm) | (ppm) | OSHA PEL 8-hr TWA | Ceiling | NIOSH REL 10-hr TWA (ppm) | 15-min Ceiling (ppm) |
|---|---|---|---|---|---|---|---|---|
| Carbon Dioxide | 5000 | | 30000 | 5000 | | - | 10000 | 30000[10] |
| Carbon Monoxide | 50 | | 400 | 35 | | 200[3] | 35 | 200[3] |
| Formaldehyde | 1[A2] | | 2[A2] | 1 | | 2[15] | 0.016[5,8] | 0.1[5] |
| Nitrogen Dioxide | 3 | | 5 | - | | 5 | - | 1 |
| Sulfur Dioxide | 5 | | 5 | 5 | | - | 0.5 | - |
| | ($mg/m^3$) | | ($mg/m^3$) | | ($mg/m^3$) | ($mg/m^3$) | ($mg/m^3$) | ($mg/m^3$) |
| Benzo[a]pyrene | [A2] | | - | - | | - | - | - |
| Chrysene | [A2] | | - | 0.2 | | - | [C] | - |
| Coal-Tar Pitch Volatiles (Benzene Solubles) | 0.2[A1a,4] | | - | 0.2[6] | | - | - | - |
| Respirable Dust | - | | - | 5 | | - | - | - |
| Sulfuric Acid | 1 | | - | 1 | | - | 1 | - |

1 Time-Weighted Average.
2 Short-Term Exposure Limit
3 Ceiling, no defined Time.
4 Also referred to as particulate polynuclear aromatic hydrocarbons (PPAHs) by ACGIH.
5 Designated as representing "the lowest feasible concentration that is reliably measurable" by NIOSH
6 OSHA specifically includes only anthracene, benzo[a]pyrene, phenanthrene, acridine, chrysene, and pyrene in the PEL.
8 8-hr TWA.
10 10-minute ceiling.
15 15-minute ceiling.
A1a Designated "human carcinogen" by ACGIH.
A2 Designated "suspected human carcinogen" by ACGIH.

C NIOSH recommends treating this material as a potential human carcinogen and controlling it as an occupational carcinogen.

TABLE III

Elemental Carbon Personal Sampling Summary
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | ALL PERSONAL SAMPLES (UNADJUSTED MEANS) | | |
| Unfiltered Diesel | 23.9 | 24 | 18.7 - 30.6 |
| Filtered Diesel | 2.03 | 24 | 1.59 - 2.60 |
| Propane | 0.94 | 24 | 0.74 - 1.20 |
| Background | 1.55 | 9 | 0.64 - 3.78 |
| | ALL PERSONAL SAMPLES (ADJUSTED MEANS) | | |
| Unfiltered Diesel | 23.2 | 24 | 18.6 - 29.1 |
| Filtered Diesel | 1.86 | 24 | 1.49 - 2.33 |
| Propane | 1.06 | 24 | 0.84 - 1.32 |
| | SAMPLES FROM NON-SMOKERS (ADJUSTED MEANS) | | |
| Unfiltered Diesel | 25.7 | 15 | 20.1 - 33.1 |
| Filtered Diesel | 1.89 | 15 | 1.49 - 2.46 |
| Propane | 0.90 | 12 | 0.67 - 2.46 |

TABLE IV

Elemental Carbon Area Sampling Summary
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | AREA SAMPLES (UNADJUSTED MEANS) | | |
| Unfiltered Diesel | 17.2 | 6 | 9.59 - 30.9 |
| Filtered Diesel | 2.27 | 6 | 1.26 - 4.07 |
| Propane | 1.18 | 5 | 0.62 - 2.24 |
| | AREA SAMPLES (ADJUSTED MEANS) | | |
| Unfiltered Diesel | 16.7 | 6 | 11.8 - 23.6 |
| Filtered Diesel | 1.94 | 6 | 1.37 - 2.75 |
| Propane | 1.48 | 5 | 1.01 - 2.16 |

TABLE V

Organic Carbon Personal Sampling Summary
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | ALL PERSONAL SAMPLES (UNADJUSTED MEANS) | | |
| Unfiltered Diesel | 49.4 | 24 | 37.9 - 64.3 |
| Filtered Diesel | 47.9 | 24 | 36.8 - 62.3 |
| Propane | 23.6 | 24 | 18.1 - 30.7 |
| Background | 2.06 | 9 | 0.48 - 5.46 |
| | SAMPLES FROM NON-SMOKERS (ADJUSTED MEANS) | | |
| Unfiltered Diesel | 38.5 | 12 | 30.0 - 48.9 |
| Filtered Diesel | 42.1 | 15 | 33.1 - 54.9 |
| Propane | 18.5 | 12 | 14.9 - 24.5 |

TABLE VI

Organic Carbon Area Sampling Summary
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | AREA SAMPLES (UNADJUSTED MEANS) | | |
| Unfiltered Diesel | 2.38 | 6 | 0.88 - 6.42 |
| Filtered Diesel | 6.17 | 6 | 2.27 - 16.8 |
| Propane | 1.65 | 5 | 0.55 - 4.92 |
| | AREA SAMPLES (ADJUSTED MEANS) | | |
| Unfiltered Diesel | 2.25 | 6 | 1.44 - 3.51 |
| Filtered Diesel | 4.60 | 6 | 2.94 - 7.20 |
| Propane | 2.50 | 5 | 1.53 - 4.09 |

TABLE VII

Limits of Detection: Polynuclear Aromatic Hydrocarbons
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Analyte | LOD[1] (ug/sample) | LOQ[2] (ug/sample) |
|---|---|---|
| Naphthalene | 1. | 3. |
| Acenaphthylene | 1. | 3. |
| Acenaphthene | 2. | - |
| Fluorene | 0.1 | - |
| Phenanthrene | 0.05 | 0.15 |
| Anthracene | 0.03 | - |
| Fluoranthene | 0.03 | 0.09 |
| Pyrene | 0.03 | 0.09 |
| Benz[a]anthracene | 0.03 | 0.09 |
| Chrysene | 0.03 | 0.09 |
| Benzo[b]fluoranthene | 0.03 | - |
| Benzo[k]fluoranthene | 0.03 | - |
| Benzo[e]pyrene | 0.05 | - |
| Benzo[a]pyrene | 0.03 | 0.09 |
| Indeno[1,2,3-cd]pyrene | 0.05 | - |
| Dibenz[a,h]anthracene | 0.03 | - |
| Benzo[ghi]perylene | 0.05 | - |

[1] Limit of Detection
[2] Limit of Quantitation

TABLE VIII

Airborne Mutagenicity Area Sampling Summary
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Towmotor Type | N | Geometric Means (95% CI) - ug/m$^3$ | | | Arithmetic Means (95% CI)-ug/m$^3$ | |
|---|---|---|---|---|---|---|
| | | Respirable Dust | Revertants/m$^3$ | S9 Activated Revertants/m$^3$ | Revertants/mg | S9 Activated Revertants/mg |
| Unfiltered Diesel | 6 | 74 (33 - 164) | 3.0 (2.0 - 4.5) | 4.5 (2.5 - 6.7) | 56 ( + , 220) | 75 ( + , 293) |
| Propane | 6 | 33 (15 - 74) | 3.7 (2.5 - 5.5) | 4.3 (1.8 - 5.0) | 214 (50, 378) | 263 (45, 481) |
| Filtered Diesel | 5 | 18 (8.2 - 45) | 2.5 (1.6 - 4.5) | 2.6 (1.3 - 4.1) | 143 ( + , 322) | 134 ( + ,372) |
| Background | 9 | ** (** - **) | 3.1 (2.2 - 4.3) | 2.7 (1.6 - 3.8) | ** ( **, **) | ** ( **, **) |

* Mutagenic Activity was tested with the Ames Salmonella microsome assay system (Maron and Ames, 1983); the plate incorporation test with and without S-9 Activation in TA98 of Salmonella typhimurium was conducted.

** Could not be calculated since no measurements of respirable dust were obtained at these locations.

*** Means (except for background samples) were adjusted by ANCOVA for the confounding variables ventilation rate, weight of freight moved per shift, and total towmotor hours.

+ The 95% lower confidence limit was calculated to be below zero.

TABLE IX

Elemental Carbon Personal and Area Sampling Summary
Yellow Freight Systems, Inc.
Maybrook, New York

HETA 90-088
March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | ALL PERSONAL SAMPLES (UNADJUSTED MEANS) | | |
| Fans off | 60.1 | 23 | 51.8 - 69.7 |
| Fans on | 54.7 | 24 | 44.3 - 67.4 |
| Background | 2.86 | 5 | 1.52 - 5.40 |
| | ALL PERSONAL SAMPLES (ADJUSTED MEANS) | | |
| Fans off | 60.3 | 23 | 50.4 - 71.5 |
| Fans on | 54.6 | 24 | 46.1 - 64.7 |
| | SAMPLES FROM NON-SMOKERS (ADJUSTED MEANS) | | |
| Fans off | 54.5 | 12 | 40.4 - 66.7 |
| Fans on | 60.3 | 14 | 44.7 - 73.7 |
| | AREA SAMPLES (ADJUSTED MEANS) | | |
| Fans off | 49.9 | 9 | 40.0 - 62.8 |
| Fans on | 47.9 | 9 | 38.5 - 60.3 |

TABLE X

Organic Carbon Personal and Area Sampling Summary
Yellow Freight Systems, Inc.
Maybrook, New York

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean ($ug/m^3$) | N | 95% Confidence Interval |
|---|---|---|---|
| | ALL PERSONAL SAMPLES (UNADJUSTED MEANS) | | |
| Fans off | 105 | 23 | 79.8 - 138 |
| Fans on | 138 | 24 | 87.9 - 217 |
| | ALL PERSONAL SAMPLES (ADJUSTED MEANS) | | |
| Fans off | 104 | 23 | 71.5 - 153 |
| Fans on | 138 | 24 | 95.6 - 200 |
| | SAMPLES FROM NON-SMOKERS (ADJUSTED MEANS) | | |
| Fans off | 110 | 12 | 73.7 - 164 |
| Fans on | 99.5 | 14 | 66.7 - 134 |
| | AREA SAMPLES (ADJUSTED MEANS) | | |
| Fans off | 26.6 | 9 | 17.5 - 40.9 |
| Fans on | 26.0 | 9 | 17.1 - 40.0 |

TABLE XI

Nitrogen Dioxide Personal Sampling Summary
Yellow Freight Systems, Inc.
Maybrook, New York

HETA 90-088
February and March 1990

| Sample/Towmotor Type | Geometric Mean (ppm) | N | 95% Confidence Interval |
|---|---|---|---|
| | ALL PERSONAL SAMPLES (UNADJUSTED MEANS) | | |
| Fans off | 0.21 | 23 | 0.17 - 0.26 |
| Fans on | 0.14 | 24 | 0.12 - 0.16 |
| Background | 0.10 | 2 | 0.00 - 20.2 |
| | SAMPLES FROM NON-SMOKERS (UNADJUSTED MEANS) | | |
| Fans off | 0.21 | 12 | 0.17 - 0.27 |
| Fans on | 0.14 | 14 | 0.11 - 0.16 |

TABLE XII

Summary of Natural Ventilation Characteristics
Yellow Freight Systems, Inc.
Columbus, Ohio

HETA 90-088
February and March 1990

| Date (1990) | Measured Wind Speed Inside (fpm) | Calc'd[1] Wind Speed Inside (fpm) | Measured Wind Speed Outside (fpm) | Calc'd[2] Air Flow Inside (cfm) | Wind[3] Bearing (Azm.) |
|---|---|---|---|---|---|
| Feb. 14 | 210 | 163 | 781 | 755,000 | 50 |
| Feb. 15 | 85 | 59 | 422 | 316,000 | 143 |
| Feb. 16 | 139 | 172 | 1179 | 890,000 | 228 |
| Feb. 21 | 63 | 59 | 408 | 308,000 | 143 |
| Feb. 22 | 87 | 131 | 925 | 1,182,000 | 162 |
| Feb. 23 | 78 | 156 | 1078 | 924,000 | 283 |
| Feb. 28 | 49 | 93 | 650 | 464,000 | 258 |
| March 1 | 24 | 56 | 391 | 514,000 | 214 |
| March 2 | 69 | 128 | 920 | 792,000 | 222 |
| Average | 89 | 113 | 750 | 683,000 | 189 |

[1] Based on open areas around doors and open doors facing the wind.
[2] These air flows result in total air changes inside this 1.6 million foot building every 1.4 to 5.3 minutes, averaging 2.9 minutes.
[3] The 90-270 azimuth axis is not true east - west but corresponds to the long axis of the building.

TABLE XIII

Summary of Natural Ventilation Characteristics
Yellow Freight Systems, Inc.
Maybrook, New York

HETA 90-088
March 1990

| Date (1990) | Fans[1] | Calc'd[2] Wind Speed Inside (fpm) | Measured Wind Speed Outside (fpm) | Calc'd[3] Air Flow Inside (cfm) | Wind[4] Direction (Azm.) |
|---|---|---|---|---|---|
| March 13 | ON | 49 | 553 | 1,509,000 | 276 |
| March 13 | ON | 28 | 339 | 852,000 | 238 |
| March 14 | OFF | 44 | 474 | 1,357,000 | 149 |
| March 14 | OFF | 22 | 484 | 668,000 | 170 |
| March 15 | ON | 21 | 534 | 652,000 | 188 |
| March 15 | OFF | 15 | 371 | 453,000 | 181 |
| Average | | 30 | 459 | 915,000 | 200 |

[1] Six fans exhausting a total of 72,000 cfm of air from the building.
[2] Based on open areas around doors and open doors facing the wind.
[3] These air volumes, which include fan volumes, result in total air changes inside this 2.1 million cubic foot building every 1.4 to 4.7 minutes, averaging 2.8 minutes.
[4] The 0 - 180 azimuth axis is not true north - south but corresponds to the long axis of the building.

TABLE XIV

Required Ventilation Rates
Yellow Freight System, Inc.
Columbus, Ohio and Maybrook, New York

HETA 90-088
February and March 1990

| | Columbus | Maybrook |
|---|---|---|
| 1. No. of towmotors | 26 | 60 |
| 2. Designed ventilation rate/truck (cfm) | 5000 | 5000 |
| 3. Measured % CO for propane towmotors | 0.058% | --- |
| 4. Measured % CO for Diesel towmotors | 0.012% | =0.012% |
| 5. Actual % operating time of towmotors | 72% | 64% |
| 6. Correction for operating over 50% | 1.44 | 1.28 |
| 7. Space Available for each towmotor (cu. ft.) | 62,500 | 35,000 |
| 8. Correction for space when less than 150,000 cu. ft. per towmotor | 1.64 | 1.94 |
| 9. Horsepower for propane towmotors | 52 | --- |
| 10. Horsepower for diesel towmotors | 47 | 47 |
| Calculated minimum ventilation rate (cfm)* | 307,000 | 745,000 |
| Actual Ventilation rate (cfm) | 683,000 | 915,000 |

* Calculations: (26)(5000)(1.44)(1.64) = 307,000 cfm
(60)(5000)(1.28)(1.94) = 745,000 cfm

Table XV

Analysis of Questionnaire-Response Results
Prevalence of Work-Related Symptoms During Three Weeks (Feb 12-Mar 2)
Comparing Three Types of Towmotors

Yellow Freight System, Inc.
Columbus, Ohio
HETA 90-088

| Symptoms | Unfiltered Diesel-Powered Towmotor *(141 Workers) | | | Propane-Powered Towmotor (141 Workers) | | | Filtered Diesel Powered Towmotor (141 Workers) | | |
|---|---|---|---|---|---|---|---|---|---|
| Headache | (64.5%) | 91 | (0) | (60.7%) | 82 | (6) | (57.8%) | 74 | (13) |
| Severe Chest Pain | (15.2%) | 21 | (3) | (14.1%) | 19 | (6) | (11.6%) | 15 | (12) |
| Eye Irritation | (64.7%) | 90 | (2) | (66.0%) | 75 | (7) | (55.0%) | 71 | (12) |
| Tearing of Eyes | (54.0%) | 74 | (4) | (49.3%) | 76 | (7) | (48.8%) | 63 | (12) |
| Temporary Blindness | ( 2.2%) | 3 | (5) | ( 5.9%) | 8 | (6) | ( 4.7%) | 6 | (12) |
| Running Nose | (88.7%) | 111 | (0) | (67.4%) | 91 | (6) | (65.9%) | 85 | (12) |
| Stopped-Up Nose | (74.8%) | 104 | (2) | (57.8%) | 78 | (6) | (64.8%) | 83 | (13) |
| Sore/Irritated Throat | (60.1%) | 83 | (3) | (47.4%) | 64 | (6) | (48.4%) | 62 | (13) |
| Hoarseness | (36.5%) | 50 | (4) | (23.0%) | 31 | (6) | (27.1%) | 35 | (12) |
| Pain on Urination | (11.1%) | 14 | (3) | ( 7.4%) | 10 | (6) | ( 6.3%) | 8 | (13) |
| Dry Cough | (51.1%) | 71 | (2) | (41.0%) | 55 | (7) | (39.5%) | 51 | (12) |
| Coughing up Phlegm | (53.6%) | 74 | (3) | (47.8%) | 64 | (7) | (45.7%) | 59 | (12) |
| Wheezing | (33.6%) | 46 | (4) | (24.6%) | 33 | (6) | (25.0%) | 32 | (13) |
| Shortness of Breath | (41.3%) | 57 | (3) | (24.6%) | 33 | (6) | (24.8%) | 32 | (12) |

* (Percent), number with symptoms, (Missing Values)

Table XVI

Analysis of Questionnaire-Response Results
Work-related Symptoms During Three Weeks (Feb 12-Mar 2)
Comparing the Three Types of Towmotors Simultaneously

Yellow Freight System, Inc.
Columbus, Ohio
HETA 90-088

| Symptoms | P-Value | *Significant Difference |
|---|---|---|
| Headache | 0.232 | no |
| Severe Chest Pain | 0.368 | no |
| Eye Irritation | 0.093 | no |
| Tearing of Eyes | 0.492 | no |
| Temporary Blindness | 0.264 | no |
| Running Nose | 0.005 | yes |
| Stopped-Up Nose | 0.001 | yes |
| Sore/Irritated Throat | 0.022 | yes |
| Hoarseness | 0.014 | yes |
| Pain on Urination | 0.145 | no |
| Dry Cough | 0.004 | yes |
| Coughing up Phlegm | 0.172 | no |
| Wheezing | 0.013 | yes |
| Shortness of Breath | 0.001 | yes |

*Significant difference in towmotors at alpha $<0.05$

Figure 1. Diagram of Columbus, Ohio Dock
Yellow Freight Systems, Inc.
HETA 90-088
February and March 1990

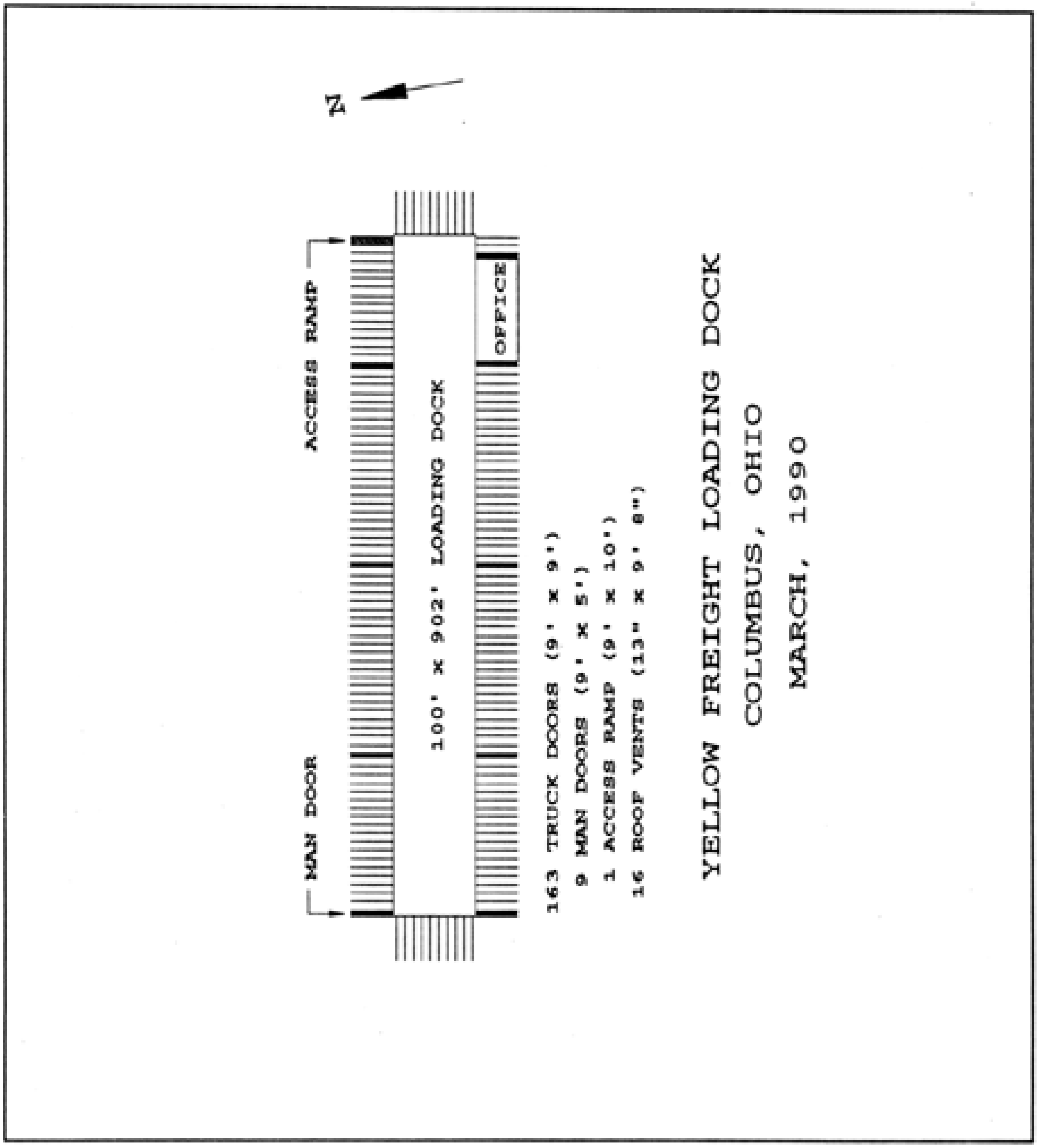


Figure 2. Diagram of Maybrook, New York Dock
Yellow Freight Systems, Inc.
HETA 90-088
February and March 1990

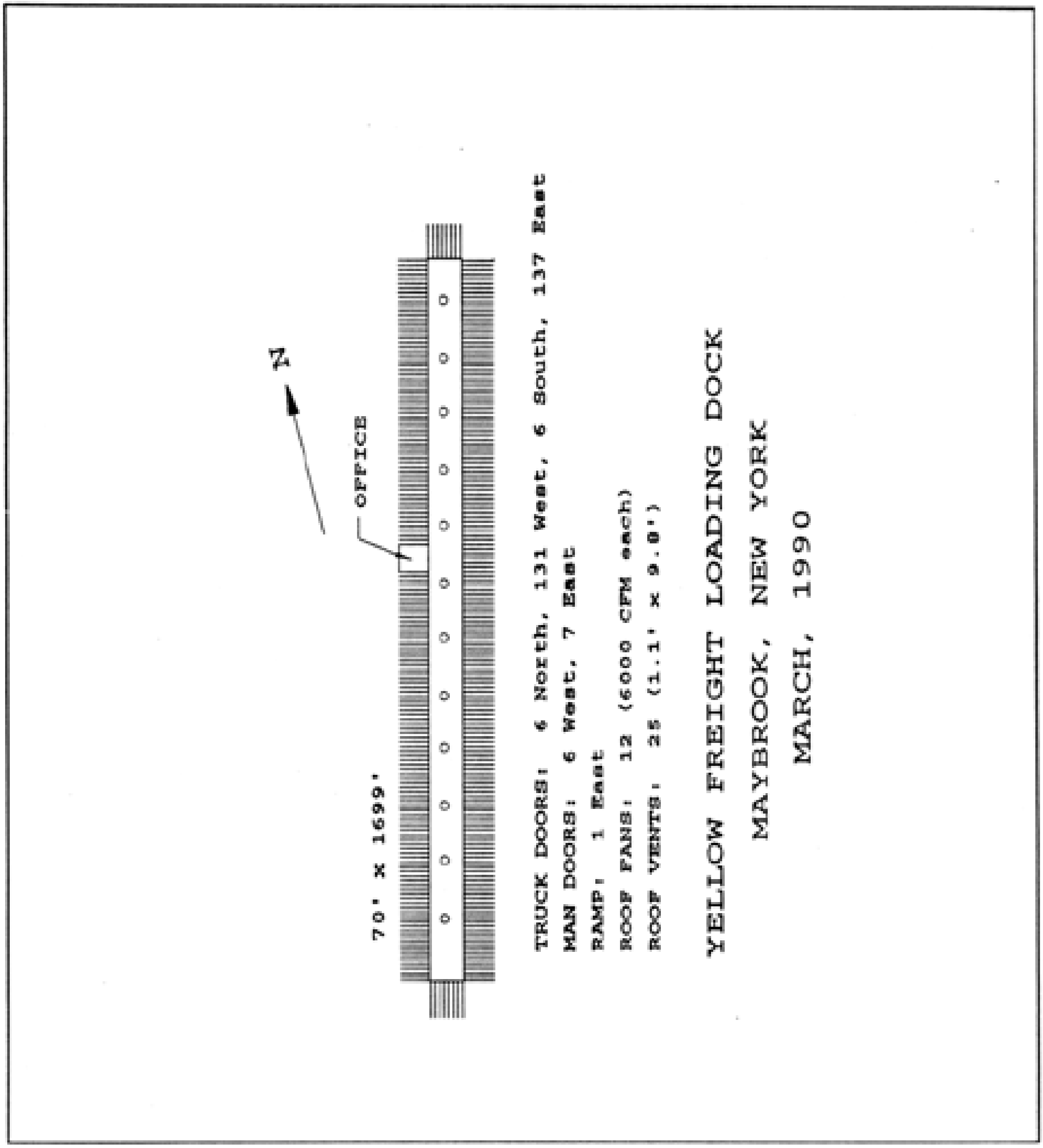


Figure 3. Diagram of Dock Door Openings
Yellow Freight Systems, Inc.
Columbus, Ohio and Maybrook, New York
HETA 90-088
February and March 1990

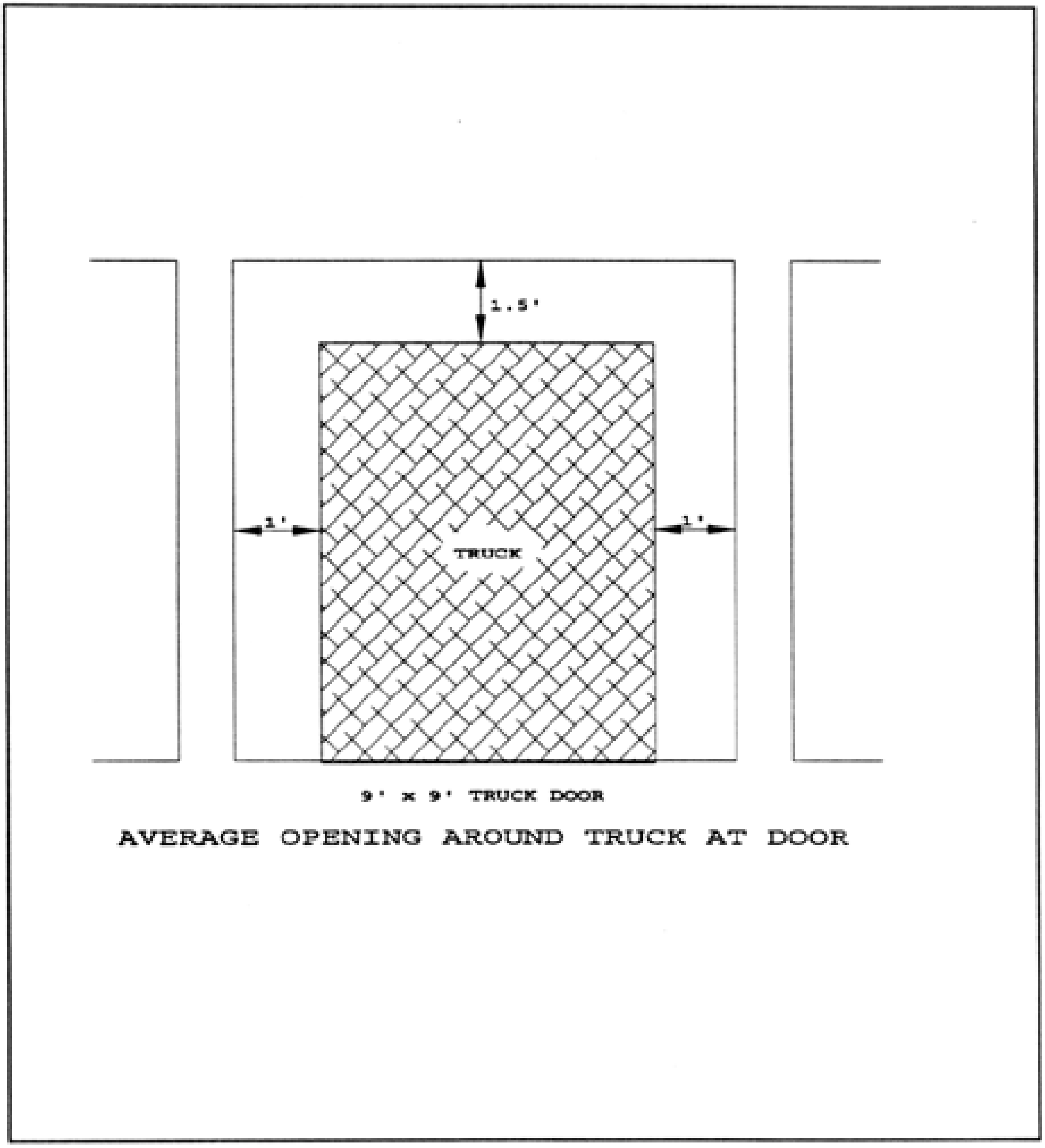


Figure 4. Yellow Freight Systems, Inc.
Columbus, Ohio
HETA 90-088
February and March 1990

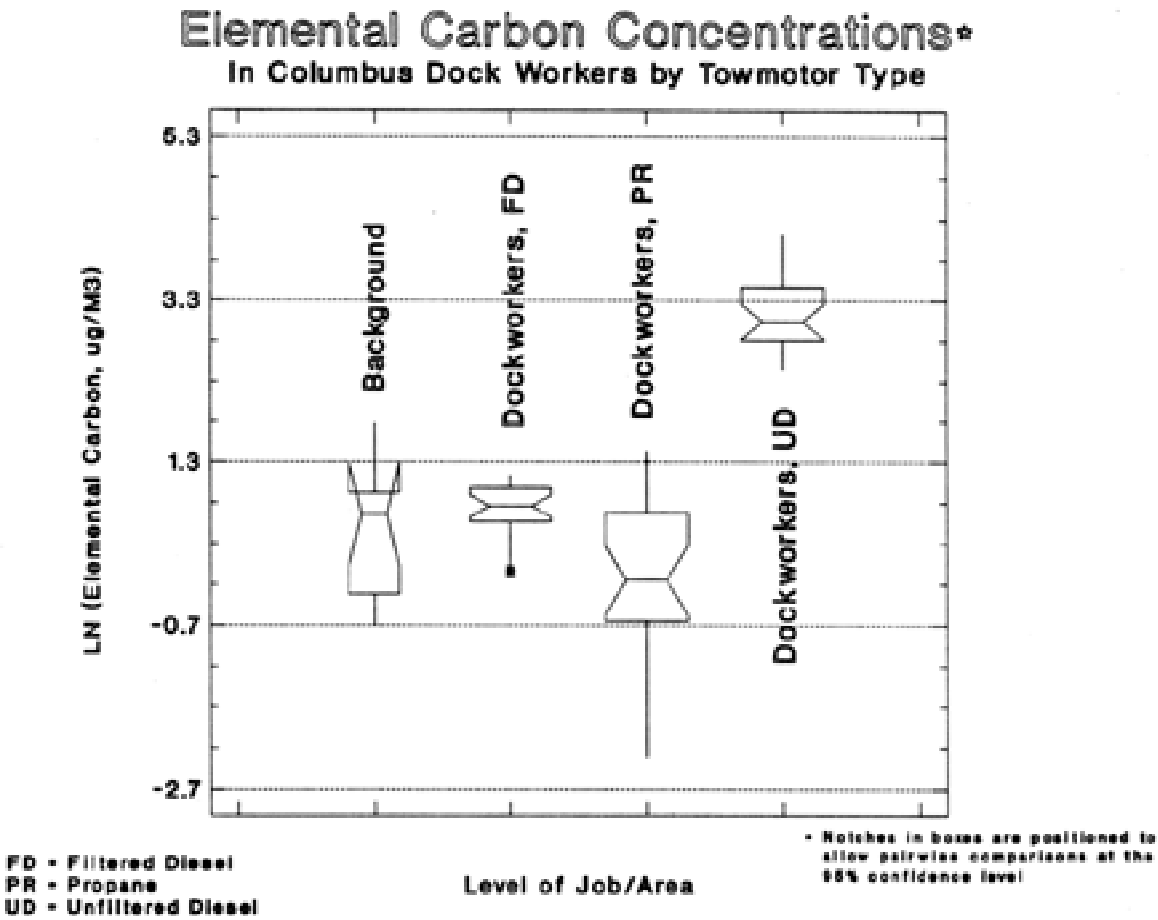


Figure 5. Yellow Freight Systems, Inc.
Columbus, Ohio
HETA 90-088
February and March 1990

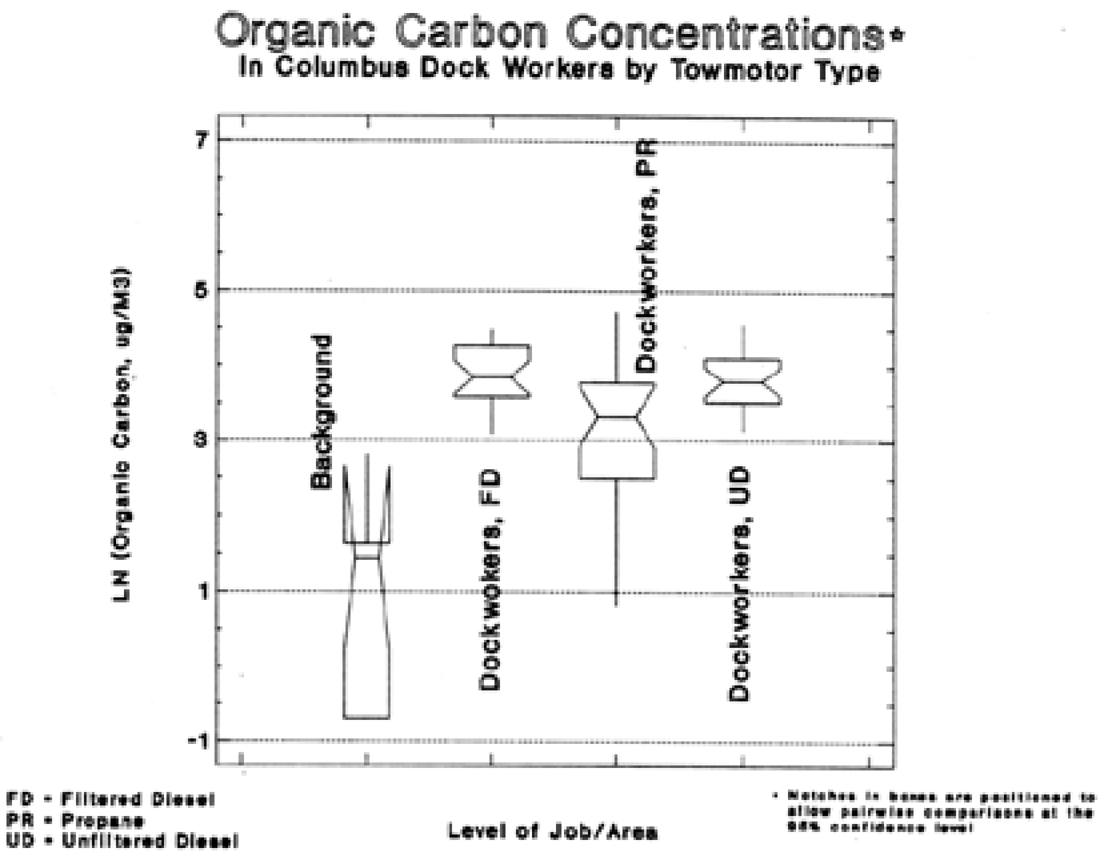


Figure 6. Yellow Freight Systems, Inc.
Maybrook, New York
HETA 90-088
March 1990

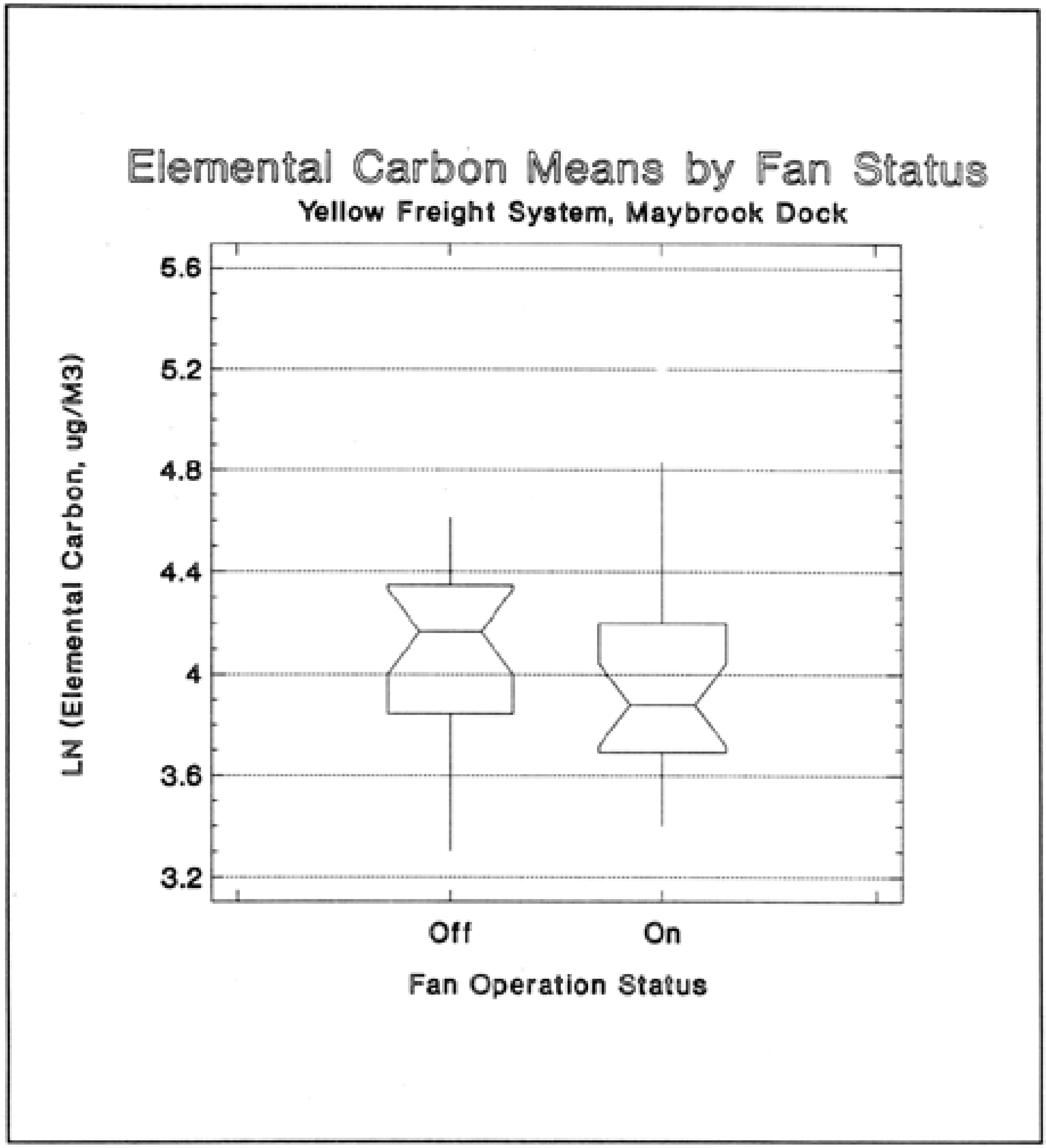
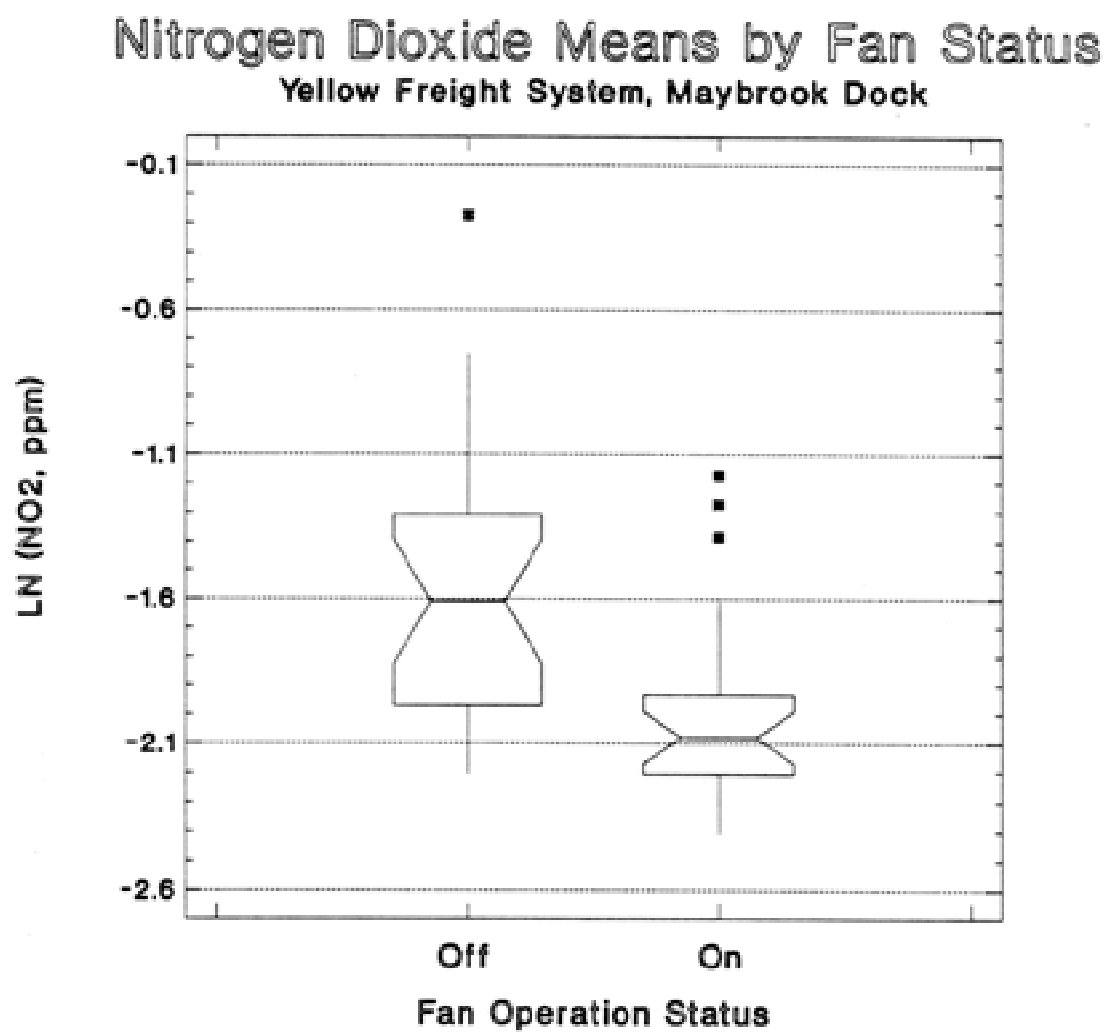


Figure 7. Yellow Freight Systems, Inc.
Maybrook, New York
HETA 90-088
March 1990



# Appendix A

# Table A1. Elemental Carbon Sample Results
# Yellow Freight System, Inc., Columbus, OH
# February and March 1990

| ate | Sample umber | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 02/14 | YFCe-10 | Background (UD*) | 4.0 | 0.0 | 480 | 1920 | <1.0 |
| 02/15 | YFCe-41 | Background (UD*) | 4.0 | 11.4 | 480 | 1920 | 5.9 |
| 02/16 | YFCe-32 | Background (UD*) | 4.0 | 3.7 | 371 | 1484 | 2.5 |
| 02/28 | YFCe-80 | Background, (FD***) | 4.0 | 0.0 | 439 | 1756 | <1.1 |
| 03/01 | YFCe-91 | Background, (FD***) | 4.0 | 3.8 | 480 | 1920 | 2.0 |
| 03/02 | YFCe-10 | Background, (FD***) | 4.0 | 3.6 | 472 | 1888 | 1.9 |
| 02/21 | YFCe-42 | Background, (PR**) | 4.0 | 5.0 | 480 | 1920 | 2.6 |
| 02/22 | YFCe-55 | Background, (PR**) | 4.0 | 1.4 | 480 | 1920 | 0.7 |
| 02/23 | YFCe-67 | Background, (PR**) | 4.0 | 2.8 | 405 | 1620 | 1.7 |
| 02/28 | YFCe-78 | Dock, Area 1; (FD***) | 4.0 | 4.4 | 480 | 1920 | 2.3 |
| 03/01 | YFCe-89 | Dock, Area 1; (FD***) | 4.0 | 5.6 | 480 | 1920 | 2.9 |
| 03/02 | YFCe-10 | Dock, Area 1; (FD***) | 4.0 | 5.4 | 480 | 1920 | 2.8 |
| 02/21 | YFCe-37 | Dock, Area 1; (PR**) | 4.0 | 7.0 | 480 | 1920 | 3.7 |
| 02/22 | YFCe-64 | Dock, Area 1; (PR**) | 4.0 | 0.7 | 480 | 1920 | 0.3 |
| 02/14 | YFCe-09 | Dock, Area 1; (UD*) | 4.0 | 13.9 | 482 | 1928 | 7.2 |
| 02/15 | YFCe-17 | Dock, Area 1; (UD*) | 4.0 | 58.1 | 480 | 1920 | 30.2 |
| 02/16 | YFCe-22 | Dock, Area 1; (UD*) | 4.0 | 19.3 | 475 | 1900 | 10.1 |
| 02/28 | YFCe-79 | Dock, Area 2; (FD***) | 4.0 | 2.6 | 480 | 1920 | 1.4 |
| 03/01 | YFCe-90 | Dock, Area 2; (FD***) | 4.0 | 4.8 | 480 | 1920 | 2.5 |
| 03/02 | YFCe-10 | Dock, Area 2; (FD***) | 4.0 | 4.1 | 480 | 1920 | 2.1 |
| 02/21 | YFCe-36 | Dock, Area 2; (PR**) | 4.0 | 7.6 | 480 | 1920 | 3.9 |
| 02/22 | YFCe-65 | Dock, Area 2; (PR**) | 4.0 | 0.8 | 480 | 1920 | 0.4 |
| 02/23 | YFCe-56 | Dock, Area 2; (PR**) | 4.0 | 2.1 | 480 | 1920 | 1.1 |
| 02/14 | YFCe-11 | Dock, Area 2; (UD*) | 4.0 | 31.6 | 470 | 1880 | 16.8 |
| 02/15 | YFCe-18 | Dock, Area 2; (UD*) | 4.0 | 65.1 | 480 | 1920 | 33.9 |
| 02/16 | YFCe-23 | Dock, Area 2; (UD*) | 4.0 | 39.6 | 480 | 1920 | 20.6 |
| 02/14 | YFCe-03 | Dockworker, (UD*) | 4.0 | 34.4 | 463 | 1852 | 18.6 |
| 02/14 | YFCe-04 | Dockworker, (UD*) | 4.0 | 33.9 | 460 | 1840 | 18.4 |
| 02/14 | YFCe-01 | Dockworker, (UD*) | 4.0 | 30.7 | 471 | 1884 | 16.3 |
| 02/14 | YFCe-02 | Dockworker, (UD*) | 4.0 | 32.0 | 463 | 1852 | 17.3 |
| 02/14 | YFCe-07 | Dockworker, (UD*) | 4.0 | 38.0 | 455 | 1820 | 20.9 |

# Table A1. Elemental Carbon Sample Results
## Yellow Freight System, Inc., Columbus, OH
## February and March 1990

| ate | Sample umber | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 02/14 | YFCe-08 | Dockworker, (UD*) | 4.0 | 30.2 | 450 | 1800 | 16.8 |
| 02/14 | YFCe-05 | Dockworker, (UD*) | 4.0 | 21.1 | 457 | 1828 | 11.6 |
| 02/14 | YFCe-06 | Dockworker, (UD*) | 4.0 | 37.9 | 455 | 1820 | 20.8 |
| 02/15 | YFCe-13 | Dockworker, (UD*) | 4.0 | 60.0 | 464 | 1856 | 32.3 |
| 02/15 | YFCe-12 | Dockworker, (UD*) | 4.0 | 80.0 | 468 | 1872 | 42.7 |
| 02/15 | YFCe-14 | Dockworker, (UD*) | 4.0 | 114.3 | 466 | 1864 | 61.3 |
| 02/15 | YFCe-15 | Dockworker, (UD*) | 4.0 | 44.0 | 475 | 1900 | 23.2 |
| 02/15 | YFCe-19 | Dockworker, (UD*) | 4.0 | 77.3 | 459 | 1836 | 42.1 |
| 02/15 | YFCe-16 | Dockworker, (UD*) | 4.0 | 58.6 | 461 | 1844 | 31.8 |
| 02/15 | YFCe-21 | Dockworker, (UD*) | 4.0 | 75.8 | 462 | 1848 | 41.0 |
| 02/15 | YFCe-20 | Dockworker, (UD*) | 4.0 | 89.5 | 458 | 1832 | 48.8 |
| 02/16 | YFCe-30 | Dockworker, (UD*) | 4.0 | 45.0 | 443 | 1772 | 25.4 |
| 02/16 | YFCe-31 | Dockworker, (UD*) | 4.0 | 28.2 | 435 | 1740 | 16.2 |
| 02/16 | YFCe-26 | Dockworker, (UD*) | 4.0 | 29.4 | 445 | 1780 | 16.5 |
| 02/16 | YFCe-25 | Dockworker, (UD*) | 4.0 | 56.5 | 444 | 1776 | 31.8 |
| 02/16 | YFCe-24 | Dockworker, (UD*) | 4.0 | 28.0 | 459 | 1836 | 15.2 |
| 02/16 | YFCe-29 | Dockworker, (UD*) | 4.0 | 29.2 | 443 | 1772 | 16.5 |
| 02/16 | YFCe-28 | Dockworker, (UD*) | 4.0 | 32.8 | 497 | 1988 | 16.5 |
| 02/16 | YFCe-27 | Dockworker, (UD*) | 4.0 | 56.0 | 440 | 1760 | 31.8 |
| 02/28 | YFCe-76 | Dockworker, (FD***) | 4.0 | 5.6 | 472 | 1888 | 3.0 |
| 02/28 | YFCe-77 | Dockworker, (FD***) | 4.0 | 3.3 | 459 | 1836 | 1.8 |
| 02/28 | YFCe-72 | Dockworker, (FD***) | 4.0 | 1.8 | 464 | 1856 | 1.0 |
| 02/28 | YFCe-71 | Dockworker, (FD***) | 4.0 | 3.9 | 476 | 1904 | 2.1 |
| 02/28 | YFCe-70 | Dockworker, (FD***) | 4.0 | 2.0 | 479 | 1916 | 1.0 |
| 02/28 | YFCe-75 | Dockworker, (FD***) | 4.0 | 4.1 | 471 | 1884 | 2.2 |
| 02/28 | YFCe-74 | Dockworker, (FD***) | 4.0 | 5.0 | 465 | 1860 | 2.7 |
| 02/28 | YFCe-73 | Dockworker, (FD***) | 4.0 | 3.6 | 469 | 1876 | 1.9 |
| 03/01 | YFCe-86 | Dockworker, (FD***) | 4.0 | 3.2 | 470 | 1880 | 1.7 |
| 03/01 | YFCe-87 | Dockworker, (FD***) | 4.0 | 4.1 | 472 | 1888 | 2.2 |
| 03/01 | YFCe-88 | Dockworker, (FD***) | 4.0 | 4.1 | 469 | 1876 | 2.2 |
| 03/01 | YFCe-85 | Dockworker, (FD***) | 4.0 | 4.1 | 468 | 1872 | 2.2 |

# Table A1. Elemental Carbon Sample Results
# Yellow Freight System, Inc., Columbus, OH
# February and March 1990

| ate | Sample umber | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 03/01 | YFCe-82 | Dockworker, (FD***) | 4.0 | 5.0 | 474 | 1896 | 2.7 |
| 03/01 | YFCe-81 | Dockworker, (FD***) | 4.0 | 3.4 | 476 | 1904 | 1.8 |
| 03/01 | YFCe-84 | Dockworker, (FD***) | 4.0 | 4.0 | 472 | 1888 | 2.1 |
| 03/01 | YFCe-83 | Dockworker, (FD***) | 4.0 | 2.8 | 468 | 1872 | 1.5 |
| 03/02 | YFCe-96 | Dockworker, (FD***) | 4.0 | 3.5 | 470 | 1880 | 1.8 |
| 03/02 | YFCe-95 | Dockworker, (FD***) | 4.0 | 2.6 | 460 | 1840 | 1.4 |
| 03/02 | YFCe-97 | Dockworker, (FD***) | 4.0 | 5.9 | 470 | 1880 | 3.1 |
| 03/02 | YFCe-99 | Dockworker, (FD***) | 4.0 | 3.9 | 459 | 1836 | 2.1 |
| 03/02 | YFCe-98 | Dockworker, (FD***) | 4.0 | 5.1 | 456 | 1824 | 2.8 |
| 03/02 | YFCe-92 | Dockworker, (FD***) | 4.0 | 3.8 | 466 | 1864 | 2.1 |
| 03/02 | YFCe-93 | Dockworker, (FD***) | 4.0 | 5.5 | 477 | 1908 | 2.9 |
| 03/02 | YFCe-94 | Dockworker, (FD***) | 4.0 | 5.0 | 469 | 1876 | 2.7 |
| 02/21 | YFCe-40 | Dockworker, (PR**) | 4.0 | 7.6 | 452 | 1808 | 4.2 |
| 02/21 | YFCe-39 | Dockworker, (PR**) | 4.0 | 5.0 | 459 | 1836 | 2.7 |
| 02/21 | YFCe-45 | Dockworker, (PR**) | 4.0 | 0.2 | 471 | 1884 | 0.1 |
| 02/21 | YFCe-44 | Dockworker, (PR**) | 4.0 | 0.8 | 275 | 1100 | 0.8 |
| 02/21 | YFCe-35 | Dockworker, (PR**) | 4.0 | 6.1 | 461 | 1844 | 3.3 |
| 02/21 | YFCe-34 | Dockworker, (PR**) | 4.0 | 3.6 | 468 | 1872 | 1.9 |
| 02/21 | YFCe-38 | Dockworker, (PR**) | 4.0 | 3.8 | 463 | 1852 | 2.1 |
| 02/21 | YFCe-33 | Dockworker, (PR**) | 4.0 | 4.8 | 468 | 1872 | 2.5 |
| 02/22 | YFCe-51 | Dockworker, (PR**) | 4.0 | 0.0 | 468 | 1872 | <1.0 |
| 02/22 | YFCe-50 | Dockworker, (PR**) | 4.0 | 0.7 | 469 | 1876 | 0.4 |
| 02/22 | YFCe-53 | Dockworker, (PR**) | 4.0 | 1.9 | 457 | 1828 | 1.0 |
| 02/22 | YFCe-52 | Dockworker, (PR**) | 4.0 | 0.8 | 442 | 1768 | 0.5 |
| 02/22 | YFCe-47 | Dockworker, (PR**) | 4.0 | 0.0 | 442 | 1768 | <1.1 |
| 02/22 | YFCe-46 | Dockworker, (PR**) | 4.0 | 1.6 | 471 | 1884 | 0.8 |
| 02/22 | YFCe-49 | Dockworker, (PR**) | 4.0 | 2.6 | 470 | 1880 | 1.4 |
| 02/22 | YFCe-48 | Dockworker, (PR**) | 4.0 | 0.4 | 467 | 1868 | 0.2 |
| 02/23 | YFCe-59 | Dockworker, (PR**) | 4.0 | 1.1 | 479 | 1916 | 0.6 |
| 02/23 | YFCe-60 | Dockworker, (PR**) | 4.0 | 1.6 | 466 | 1864 | 0.9 |
| 02/23 | YFCe-57 | Dockworker, (PR**) | 4.0 | 4.3 | 473 | 1892 | 2.3 |

# Table A1. Elemental Carbon Sample Results
# Yellow Freight System, Inc., Columbus, OH
# February and March 1990

| ate | Sample umber | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 02/23 | YFCe-58 | Dockworker, (PR**) | 4.0 | 0.0 | 310 | 1240 | <1.5 |
| 02/23 | YFCe-63 | Dockworker, (PR**) | 4.0 | 2.0 | 461 | 1844 | 1.1 |
| 02/23 | YFCe-66 | Dockworker, (PR**) | 4.0 | 1.6 | 457 | 1828 | 0.9 |
| 02/23 | YFCe-61 | Dockworker, (PR**) | 4.0 | 0.8 | 471 | 1884 | 0.4 |
| 02/23 | YFCe-62 | Dockworker, (PR**) | 4.0 | 3.4 | 465 | 1860 | 1.8 |

* Unfiltered Diesel Towmotors

** Propane Towmotors

*** Filtered Diesel Towmotors

# Table A2. Organic Carbon Sample Results
## Yellow Freight System, Inc., Columbus, OH
## February 1990

| Date | Sample Number | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 02/14 | YFCe-10 | Background, (UD*) | 4.0 | 38.1 | 480 | 1920 | 5.1 |
| 02/15 | YFCe-41 | Background, (UD*) | 4.0 | 28.3 | 480 | 1920 | <1.0 |
| 02/16 | YFCe-32 | Background, (UD*) | 4.0 | 23.2 | 371 | 1484 | <1.3 |
| 02/28 | YFCe-80 | Background, (FD***) | 4.0 | 57.6 | 439 | 1756 | 16.6 |
| 03/01 | YFCe-91 | Background, (FD***) | 4.0 | 36.8 | 480 | 1920 | 4.4 |
| 03/02 | YFCe-10 | Background, (FD***) | 4.0 | 38.6 | 472 | 1888 | 5.4 |
| 02/21 | YFCe-42 | Background, (PR**) | 4.0 | 36.5 | 480 | 1920 | 4.2 |
| 02/22 | YFCe-55 | Background, (PR**) | 4.0 | 18.2 | 480 | 1920 | <1.0 |
| 02/23 | YFCe-67 | Background, (PR**) | 4.0 | 19.8 | 405 | 1620 | <1.2 |
| 02/28 | YFCe-78 | Dock, Area 1; (FD***) | 4.0 | 46.0 | 480 | 1920 | 9.2 |
| 03/01 | YFCe-89 | Dock, Area 1; (FD***) | 4.0 | 42.3 | 480 | 1920 | 7.2 |
| 03/02 | YFCe-10 | Dock, Area 1; (FD***) | 4.0 | 35.8 | 480 | 1920 | 3.9 |
| 02/21 | YFCe-37 | Dock, Area 1; (PR**) | 4.0 | 46.5 | 480 | 1920 | 9.4 |
| 02/22 | YFCe-64 | Dock, Area 1; (PR**) | 4.0 | 21.3 | 480 | 1920 | <1.0 |
| 02/14 | YFCe-09 | Dock, Area 1; (UD*) | 4.0 | 31.2 | 482 | 1928 | 1.5 |
| 02/15 | YFCe-17 | Dock, Area 1; (UD*) | 4.0 | 44.7 | 480 | 1920 | 8.5 |
| 02/16 | YFCe-22 | Dock, Area 1; (UD*) | 4.0 | 29.7 | 475 | 1900 | 0.7 |
| 02/28 | YFCe-79 | Dock, Area 2; (FD***) | 4.0 | 76.1 | 480 | 1920 | 24.9 |
| 03/01 | YFCe-90 | Dock, Area 2; (FD***) | 4.0 | 33.8 | 480 | 1920 | 2.8 |
| 03/02 | YFCe-10 | Dock, Area 2; (FD***) | 4.0 | 34.2 | 480 | 1920 | 3.0 |
| 02/21 | YFCe-36 | Dock, Area 2; (PR**) | 4.0 | 46.4 | 480 | 1920 | 9.4 |
| 02/22 | YFCe-65 | Dock, Area 2; (PR**) | 4.0 | 22.9 | 480 | 1920 | <1.0 |
| 02/23 | YFCe-56 | Dock, Area 2; (PR**) | 4.0 | 17.2 | 480 | 1920 | <1.0 |
| 02/14 | YFCe-11 | Dock, Area 2; (UD*) | 4.0 | 35.2 | 470 | 1880 | 3.7 |
| 02/15 | YFCe-18 | Dock, Area 2; (UD*) | 4.0 | 49.5 | 480 | 1920 | 11.0 |
| 02/16 | YFCe-23 | Dock, Area 2; (UD*) | 4.0 | 27.4 | 480 | 1920 | <1.0 |
| 02/14 | YFCe-03 | Dockworker, (UD*) | 4.0 | 161.6 | 463 | 1852 | 72.0 |
| 02/14 | YFCe-08 | Dockworker, (UD*) | 4.0 | 87.0 | 450 | 1800 | 32.6 |
| 02/14 | YFCe-01 | Dockworker, (UD*) | 4.0 | 91.1 | 471 | 1884 | 33.3 |
| 02/14 | YFCe-02 | Dockworker, (UD*) | 4.0 | 125.7 | 463 | 1852 | 52.6 |
| 02/14 | YFCe-04 | Dockworker, (UD*) | 4.0 | 122.3 | 460 | 1840 | 51.0 |
| 02/14 | YFCe-05 | Dockworker, (UD*) | 4.0 | 100.6 | 457 | 1828 | 39.5 |

# Table A2. Organic Carbon Sample Results
## Yellow Freight System, Inc., Columbus, OH
## February 1990

| Date | Sample Number | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 02/14 | YFCe-07 | Dockworker, (UD*) | 4.0 | 91.4 | 455 | 1820 | 34.6 |
| 02/14 | YFCe-06 | Dockworker, (UD*) | 4.0 | 69.9 | 455 | 1820 | 22.8 |
| 02/15 | YFCe-15 | Dockworker, (UD*) | 4.0 | 161.4 | 475 | 1900 | 70.0 |
| 02/15 | YFCe-16 | Dockworker, (UD*) | 4.0 | 108.3 | 461 | 1844 | 43.4 |
| 02/15 | YFCe-14 | Dockworker, (UD*) | 4.0 | 202.0 | 466 | 1864 | 93.2 |
| 02/15 | YFCe-19 | Dockworker, (UD*) | 4.0 | 112.3 | 459 | 1836 | 45.7 |
| 02/15 | YFCe-20 | Dockworker, (UD*) | 4.0 | 99.9 | 458 | 1832 | 39.1 |
| 02/15 | YFCe-21 | Dockworker, (UD*) | 4.0 | 96.6 | 462 | 1848 | 36.9 |
| 02/15 | YFCe-13 | Dockworker, (UD*) | 4.0 | 82.4 | 464 | 1856 | 29.1 |
| 02/15 | YFCe-12 | Dockworker, (UD*) | 4.0 | 85.5 | 468 | 1872 | 30.5 |
| 02/16 | YFCe-29 | Dockworker, (UD*) | 4.0 | 74.0 | 443 | 1772 | 25.8 |
| 02/16 | YFCe-28 | Dockworker, (UD*) | 4.0 | 221.3 | 497 | 1988 | 97.0 |
| 02/16 | YFCe-31 | Dockworker, (UD*) | 4.0 | 108.0 | 435 | 1740 | 45.7 |
| 02/16 | YFCe-30 | Dockworker, (UD*) | 4.0 | 367.8 | 443 | 1772 | 191.5 |
| 02/16 | YFCe-27 | Dockworker, (UD*) | 4.0 | 306.5 | 440 | 1760 | 158.0 |
| 02/16 | YFCe-26 | Dockworker, (UD*) | 4.0 | 120.8 | 445 | 1780 | 51.9 |
| 02/16 | YFCe-24 | Dockworker, (UD*) | 4.0 | 124.9 | 459 | 1836 | 52.6 |
| 02/16 | YFCe-25 | Dockworker, (UD*) | 4.0 | 105.2 | 444 | 1776 | 43.2 |
| 02/28 | YFCe-76 | Dockworker, (FD***) | 4.0 | 102.9 | 472 | 1888 | 39.5 |
| 02/28 | YFCe-77 | Dockworker, (FD***) | 4.0 | 107.5 | 459 | 1836 | 43.1 |
| 02/28 | YFCe-75 | Dockworker, (FD***) | 4.0 | 189.9 | 471 | 1884 | 85.7 |
| 02/28 | YFCe-71 | Dockworker, (FD***) | 4.0 | 73.0 | 476 | 1904 | 23.4 |
| 02/28 | YFCe-70 | Dockworker, (FD***) | 4.0 | 70.0 | 479 | 1916 | 21.7 |
| 02/28 | YFCe-72 | Dockworker, (FD***) | 4.0 | 75.7 | 464 | 1856 | 25.5 |
| 02/28 | YFCe-74 | Dockworker, (FD***) | 4.0 | 178.1 | 465 | 1860 | 80.5 |
| 02/28 | YFCe-73 | Dockworker, (FD***) | 4.0 | 98.9 | 469 | 1876 | 37.6 |
| 03/01 | YFCe-86 | Dockworker, (FD***) | 4.0 | 116.3 | 470 | 1880 | 46.8 |
| 03/01 | YFCe-85 | Dockworker, (FD***) | 4.0 | 125.6 | 468 | 1872 | 52.0 |
| 03/01 | YFCe-88 | Dockworker, (FD***) | 4.0 | 148.9 | 469 | 1876 | 64.3 |
| 03/01 | YFCe-87 | Dockworker, (FD***) | 4.0 | 109.3 | 472 | 1888 | 42.9 |
| 03/01 | YFCe-82 | Dockworker, (FD***) | 4.0 | 134.1 | 474 | 1896 | 55.8 |
| 03/01 | YFCe-81 | Dockworker, (FD***) | 4.0 | 125.0 | 476 | 1904 | 50.7 |

# Table A2. Organic Carbon Sample Results
# Yellow Freight System, Inc., Columbus, OH
# February 1990

| Date | Sample Number | Job/Area | Flow (L/min | Weight (ug) | Time (min) | Volume (L) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|
| 03/01 | YFCe-84 | Dockworker, (FD***) | 4.0 | 142.1 | 472 | 1888 | 60.2 |
| 03/01 | YFCe-83 | Dockworker, (FD***) | 4.0 | 85.3 | 468 | 1872 | 30.4 |
| 03/02 | YFCe-96 | Dockworker, (FD***) | 4.0 | 93.2 | 470 | 1880 | 34.5 |
| 03/02 | YFCe-95 | Dockworker, (FD***) | 4.0 | 89.1 | 460 | 1840 | 33.0 |
| 03/02 | YFCe-97 | Dockworker, (FD***) | 4.0 | 194.5 | 470 | 1880 | 88.4 |
| 03/02 | YFCe-99 | Dockworker, (FD***) | 4.0 | 98.2 | 459 | 1836 | 38.0 |
| 03/02 | YFCe-98 | Dockworker, (FD***) | 4.0 | 186.1 | 456 | 1824 | 86.5 |
| 03/02 | YFCe-94 | Dockworker, (FD***) | 4.0 | 175.0 | 469 | 1876 | 78.2 |
| 03/02 | YFCe-92 | Dockworker, (FD***) | 4.0 | 191.5 | 466 | 1864 | 87.5 |
| 03/02 | YFCe-93 | Dockworker, (FD***) | 4.0 | 117.5 | 477 | 1908 | 46.7 |
| 02/21 | YFCe-40 | Dockworker, (PR**) | 4.0 | 232.6 | 452 | 1808 | 112.9 |
| 02/21 | YFCe-39 | Dockworker, (PR**) | 4.0 | 81.5 | 459 | 1836 | 28.9 |
| 02/21 | YFCe-45 | Dockworker, (PR**) | 4.0 | 50.0 | 471 | 1884 | 11.5 |
| 02/21 | YFCe-44 | Dockworker, (PR**) | 4.0 | 56.3 | 275 | 1100 | 25.4 |
| 02/21 | YFCe-34 | Dockworker, (PR**) | 4.0 | 89.7 | 468 | 1872 | 32.8 |
| 02/21 | YFCe-33 | Dockworker, (PR**) | 4.0 | 83.7 | 468 | 1872 | 29.5 |
| 02/21 | YFCe-38 | Dockworker, (PR**) | 4.0 | 77.3 | 463 | 1852 | 26.4 |
| 02/21 | YFCe-35 | Dockworker, (PR**) | 4.0 | 145.5 | 461 | 1844 | 63.5 |
| 02/22 | YFCe-53 | Dockworker, (PR**) | 4.0 | 48.0 | 457 | 1828 | 10.8 |
| 02/22 | YFCe-50 | Dockworker, (PR**) | 4.0 | 75.4 | 469 | 1876 | 25.1 |
| 02/22 | YFCe-51 | Dockworker, (PR**) | 4.0 | 50.9 | 468 | 1872 | 12.0 |
| 02/22 | YFCe-52 | Dockworker, (PR**) | 4.0 | 50.1 | 442 | 1768 | 12.3 |
| 02/22 | YFCe-47 | Dockworker, (PR**) | 4.0 | 46.6 | 442 | 1768 | 10.3 |
| 02/22 | YFCe-46 | Dockworker, (PR**) | 4.0 | 61.5 | 471 | 1884 | 17.6 |
| 02/22 | YFCe-49 | Dockworker, (PR**) | 4.0 | 115.7 | 470 | 1880 | 46.5 |
| 02/22 | YFCe-48 | Dockworker, (PR**) | 4.0 | 36.8 | 467 | 1868 | 4.5 |
| 02/23 | YFCe-59 | Dockworker, (PR**) | 4.0 | 91.2 | 479 | 1916 | 32.8 |
| 02/23 | YFCe-60 | Dockworker, (PR**) | 4.0 | 112.2 | 466 | 1864 | 45.0 |
| 02/23 | YFCe-57 | Dockworker, (PR**) | 4.0 | 93.8 | 473 | 1892 | 34.6 |
| 02/23 | YFCe-58 | Dockworker, (PR**) | 4.0 | 80.5 | 310 | 1240 | 42.0 |
| 02/23 | YFCe-63 | Dockworker, (PR**) | 4.0 | 32.5 | 461 | 1844 | 2.3 |
| 02/23 | YFCe-66 | Dockworker, (PR**) | 4.0 | 126.2 | 457 | 1828 | 53.5 |

## Table A2. Organic Carbon Sample Results
## Yellow Freight System, Inc., Columbus, OH
## February 1990

| *Date* | *Sample Number* | *Job/Area* | *Flow (L/min* | *Weight (ug)* | *Time (min)* | *Volume (L)* | *Concentration (ug/m3)* |
|---|---|---|---|---|---|---|---|
| 02/23 | YFCe-61 | Dockworker, (PR**) | 4.0 | 63.8 | 471 | 1884 | 18.8 |
| 02/23 | YFCe-62 | Dockworker, (PR**) | 4.0 | 168.1 | 465 | 1860 | 75.1 |

* Unfiltered Diesel Towmotors
** Propane Towmotors
*** Filtered Diesel Towmotors

# Table A3. Concentrations of Respirable Dust
## Yellow Freight System, Inc., Columbus, OH
## February and March 1990

| Date | Sample Number | Job/Area | Time Start | | Time Stop | | Flow (L/min | Time (min) | Concentration (ug/m3) |
|---|---|---|---|---|---|---|---|---|---|
| 02/14 | OM-8253 | Dock, Area 1; (UD*) | 7 | 27 | 15 | 29 | 1.7 | 482 | 49 |
| 02/14 | OM-8256 | Dock, Area 2; (UD*) | 7 | 39 | 15 | 33 | 1.7 | 474 | 74 |
| 02/15 | OM-8250 | Dock, Area 1; (UD*) | 8 | 58 | 16 | 58 | 1.7 | 480 | 294 |
| 02/15 | OM-8260 | Dock, Area 2; (UD*) | 9 | 20 | 17 | 20 | 1.7 | 480 | 25 |
| 02/16 | OM-8241 | Dock, Area 1; (UD*) | 7 | 48 | 15 | 43 | 1.7 | 475 | 87 |
| 02/16 | OM-8262 | Dock, Area 2; (UD*) | 8 | 25 | 16 | 25 | 1.7 | 480 | 86 |
| 02/21 | OM-8263 | Dock, Area 1; (PR**) | 7 | 31 | 15 | 31 | 1.7 | 480 | <12 |
| 02/21 | OM-8259 | Dock, Area 2; (PR**) | 7 | 45 | 15 | 45 | 1.7 | 480 | 61 |
| 02/22 | OM-6333 | Dock, Area 1; (PR**) | 7 | 47 | 15 | 47 | 1.7 | 480 | 25 |
| 02/22 | OM-8251 | Dock, Area 2; (PR**) | 8 | 5 | 16 | 5 | 1.7 | 480 | 49 |
| 02/23 | OM-8238 | Dock, Area 1; (PR**) | 7 | 42 | 15 | 42 | 1.7 | 480 | 49 |
| 02/23 | OM-8246 | Dock, Area 2; (PR**) | 7 | 58 | 15 | 58 | 1.7 | 480 | 49 |
| 02/28 | OM-7255 | Dock, Area 1; (FD***) | 7 | 36 | 15 | 36 | 1.7 | 480 | <12 |
| 02/28 | OM-8249 | Dock, Area 2; (FD***) | 7 | 58 | 15 | 58 | 1.7 | 480 | 37 |
| 03/01 | OM-7266 | Dock, Area 1; (FD***) | 7 | 42 | 15 | 42 | 1.7 | 480 | 12 |
| 03/01 | OM-7280 | Dock, Area 2; (FD***) | 7 | 57 | 15 | 57 | 1.7 | 480 | 37 |
| 03/02 | OM-7265 | Dock, Area 1; (FD***) | 7 | 45 | 15 | 45 | 1.7 | 480 | 12 |
| 03/02 | OM-7267 | Dock, Area 2; (FD***) | 8 | 2 | 16 | 2 | 1.7 | 480 | 25 |

* Unfiltered Diesel Towmotors

** Propane Towmotors

*** Filtered Diesel Towmotors

# Table A4. Concentrations of Nitrogen Dioxide
## Yellow Freight System, Inc., Columbus, Ohio
## February and March 1990

| Date | Sample Number | Job/Area | Mass (ug NO2 | Time (hr) | Concentration (ppm) |
|---|---|---|---|---|---|
| 2/14 | YFNO2-1 | Dock Worker, (UD*) | 0.23 | 7.9 | 0.15 |
| 2/14 | YFNO2-2 | Dock Worker, (UD*) | 0.18 | 7.7 | 0.09 |
| 2/14 | YFNO2-3 | Dock Worker, (UD*) | 0.27 | 7.7 | 0.20 |
| 2/14 | YFNO2-5 | Dock Worker, (UD*) | 0.23 | 7.6 | 0.15 |
| 2/14 | YFNO2-6 | Dock Worker, (UD*) | 0.23 | 7.6 | 0.15 |
| 2/14 | YFNO2-7 | Dock Worker, (UD*) | 0.28 | 7.6 | 0.21 |
| 2/14 | YFNO2-8 | Dock Worker, (UD*) | 0.17 | 7.5 | 0.08 |
| 2/15 | YFNO2-14 | Dock Worker, (UD*) | 0.27 | 7.8 | 0.20 |
| 2/15 | YFNO2-15 | Dock Worker, (UD*) | 0.21 | 7.7 | 0.12 |
| 2/15 | YFNO2-16 | Dock Worker, (UD*) | 0.37 | 7.8 | 0.32 |
| 2/15 | YFNO2-17 | Dock Worker, (UD*) | 0.29 | 7.9 | 0.22 |
| 2/15 | YFNO2-18 | Dock Worker, (UD*) | 0.29 | 7.7 | 0.22 |
| 2/15 | YFNO2-19 | Dock Worker, (UD*) | 0.31 | 7.7 | 0.25 |
| 2/15 | YFNO2-20 | Dock Worker, (UD*) | 0.23 | 7.6 | 0.15 |
| 2/15 | YFNO2-21 | Dock Worker, (UD*) | 0.3 | 7.7 | 0.23 |
| 2/16 | YFNO2-25 | Dock Worker, (UD*) | 0.21 | 7.7 | 0.13 |
| 2/16 | YFNO2-26 | Dock Worker, (UD*) | 0.26 | 7.4 | 0.19 |
| 2/16 | YFNO2-27 | Dock Worker, (UD*) | 0.19 | 7.4 | 0.10 |
| 2/16 | YFNO2-28 | Dock Worker, (UD*) | <0.01 | 7.3 | <0.15 |
| 2/16 | YFNO2-29 | Dock Worker, (UD*) | 0.27 | 8.3 | 0.18 |
| 2/16 | YFNO2-30 | Dock Worker, (UD*) | 0.16 | 7.4 | 0.07 |
| 2/16 | YFNO2-31 | Dock Worker, (UD*) | 0.2 | 7.3 | 0.12 |
| 2/16 | YFNO2-32 | Dock Worker, (UD*) | 0.34 | 7.3 | 0.30 |
| 2/21 | YFNO2-35 | Dock Worker, (PR**) | 0.21 | 7.9 | 0.12 |
| 2/21 | YFNO2-36 | Dock Worker, (PR**) | 0.25 | 7.9 | 0.17 |
| 2/21 | YFNO2-37 | Dock Worker, (PR**) | 0.2 | 7.8 | 0.11 |
| 2/21 | YFNO2-40 | Dock Worker, (PR**) | 0.37 | 7.8 | 0.32 |
| 2/21 | YFNO2-41 | Dock Worker, (PR**) | 0.29 | 7.7 | 0.22 |
| 2/21 | YFNO2-42 | Dock Worker, (PR**) | 0.25 | 7.7 | 0.17 |
| 2/21 | YFNO2-43 | Dock Worker, (PR**) | 0.18 | 7.7 | 0.09 |
| 2/21 | YFNO2-44 | Dock Worker, (PR**) | 0.25 | 7.5 | 0.18 |
| 2/22 | YFNO2-51 | Dock Worker, (PR**) | 0.25 | 7.8 | 0.17 |

# Table A4. Concentrations of Nitrogen Dioxide Yellow Freight System, Inc., Columbus, Ohio February and March 1990

| Date | Sample Number | Job/Area | Mass (ug NO2 | Time (hr) | Concentration (ppm) |
|---|---|---|---|---|---|
| 2/22 | YFNO2-52 | Dock Worker, (PR**) | 0.25 | 7.8 | 0.17 |
| 2/22 | YFNO2-53 | Dock Worker, (PR**) | 0.27 | 7.4 | 0.21 |
| 2/22 | YFNO2-54 | Dock Worker, (PR**) | 0.27 | 7.6 | 0.20 |
| 2/22 | YFNO2-47 | Dock Worker, (PR**) | 0.19 | 7.9 | 0.10 |
| 2/22 | YFNO2-48 | Dock Worker, (PR**) | 0.28 | 7.4 | 0.22 |
| 2/22 | YFNO2-49 | Dock Worker, (PR**) | 0.21 | 7.8 | 0.12 |
| 2/22 | YFNO2-50 | Dock Worker, (PR**) | 0.25 | 7.8 | 0.17 |
| 2/23 | YFNO2-55 | Dock Worker, (PR**) | 0.26 | 7.9 | 0.18 |
| 2/23 | YFNO2-58 | Dock Worker, (PR**) | 0.25 | 7.9 | 0.17 |
| 2/23 | YFNO2-59 | Dock Worker, (PR**) | 0.26 | 7.9 | 0.18 |
| 2/23 | YFNO2-60 | Dock Worker, (PR**) | 0.2 | 7.9 | 0.11 |
| 2/23 | YFNO2-61 | Dock Worker, (PR**) | 0.25 | 7.8 | 0.17 |
| 2/23 | YFNO2-62 | Dock Worker, (PR**) | 0.22 | 7.8 | 0.14 |
| 2/23 | YFNO2-63 | Dock Worker, (PR**) | 0.33 | 7.7 | 0.27 |
| 2.23 | YFNO2-64 | Dock Worker, (PR**) | 0.26 | 7.6 | 0.19 |
| 2/28 | YFNO2-70 | Dock Worker, (FD***) | 0.28 | 7.9 | 0.21 |
| 2/28 | YFNO2-72 | Dock Worker, (FD***) | 0.24 | 8.0 | 0.16 |
| 2/28 | YFNO2-73 | Dock Worker, (FD***) | 0.24 | 7.9 | 0.16 |
| 2/28 | YFNO2-74 | Dock Worker, (FD***) | 0.25 | 7.9 | 0.17 |
| 2/28 | YFNO2-75 | Dock Worker, (FD***) | 0.29 | 7.8 | 0.22 |
| 2/28 | YFNO2-78 | Dock Worker, (FD***) | 0.24 | 7.8 | 0.16 |
| 2/28 | YFNO2-76 | Dock Worker, (FD***) | 0.22 | 7.7 | 0.14 |
| 03/01 | YFNO2-66 | Dock Worker, (FD***) | 0.3 | 7.8 | 0.23 |
| 3/01 | YFNO2-85 | Dock Worker, (FD***) | 0.3 | 7.9 | 0.23 |
| 3/01 | YFNO2-84 | Dock Worker, (FD***) | 0.25 | 7.8 | 0.17 |
| 3/01 | YFNO2-67 | Dock Worker, (FD***) | 0.29 | 7.8 | 0.22 |
| 3/01 | YFNO2-82 | Dock Worker, (FD***) | 0.27 | 7.9 | 0.19 |
| 3/01 | YFNO2-86 | Dock Worker, (FD***) | 0.32 | 7.9 | 0.25 |
| 3/01 | YFNO2-81 | Dock Worker, (FD***) | 0.24 | 7.8 | 0.16 |
| 3/01 | YFNO2-83 | Dock Worker, (FD***) | 0.23 | 7.9 | 0.14 |
| 3/02 | YFNO2-92 | Dock Worker, (FD***) | 0.21 | 7.7 | 0.13 |
| 3/02 | YFNO2-96 | Dock Worker, (FD***) | 0.26 | 7.7 | 0.19 |

# Table A4. Concentrations of Nitrogen Dioxide Yellow Freight System, Inc., Columbus, Ohio February and March 1990

| Date | Sample Number | Job/Area | Mass (ug NO2 | Time (hr) | Concentration (ppm) |
|---|---|---|---|---|---|
| 3/02 | YFNO2-90 | Dock Worker, (FD***) | 0.2 | 7.8 | 0.11 |
| 3/02 | YFNO2-93 | Dock Worker, (FD***) | 0.24 | 7.8 | 0.16 |
| 3/02 | YFNO2-91 | Dock Worker, (FD***) | 0.24 | 8.0 | 0.16 |
| 3/02 | YFNO2-89 | Dock Worker, (FD***) | 0.28 | 7.8 | 0.21 |
| 3/02 | YFNO2-97 | Dock Worker, (FD***) | 0.25 | 7.8 | 0.17 |
| 3/02 | YFNO2-88 | Dock Worker, (FD***) | 0.2 | 7.6 | 0.11 |
| 2/14 | YFNO2-10 | Area 1; (UD*) | 0.29 | 8.0 | 0.21 |
| 2/14 | YFNO2-9 | Area 2; (UD*) | 0.2 | 8.4 | 0.10 |
| 2/15 | YFNO2-11 | Area 1; (UD*) | 0.27 | 8.1 | 0.19 |
| 2/15 | YFNO2-12 | Area 2; (UD*) | 0.27 | 8.1 | 0.19 |
| 2/16 | YFNO2-22 | Area 1; (UD*) | 0.32 | 7.4 | 0.27 |
| 2/16 | YFNo2-33 | Area 2; (UD*) | 0.21 | 7.7 | 0.13 |
| 2/21 | YFNO2-39 | Area 1; (PR**) | 0.24 | 8.3 | 0.15 |
| 2/21 | YFNO2-38 | Area 2; (PR**) | 0.27 | 8.8 | 0.17 |
| 2/22 | YFNO2-45 | Area 1; (PR**) | 0.23 | 8.3 | 0.14 |
| 2/22 | YFNO2-46 | Area 2; (PR**) | 0.26 | 8.4 | 0.17 |
| 2/23 | YFNO2-56 | Area 1; (PR**) | 0.3 | 8.2 | 0.22 |
| 2/23 | YFNO2-57 | Area 2; (PR**) | 0.22 | 8.2 | 0.13 |
| 2/28 | YFNO2-68 | Area 1; (FD***) | 0.18 | 8.2 | 0.08 |
| 2/28 | YFNO2-69 | Area 2; (FD***) | 0.27 | 8.0 | 0.19 |
| 3/01 | YFNO2-80 | Area 1; (FD***) | 0.21 | 8.1 | 0.12 |
| 3/01 | YFNO2-79 | Area 2; (FD***) | 0.27 | 8.1 | 0.19 |
| 3/02 | YFNO2-77 | Area 1; (FD***) | 0.22 | 8.2 | 0.13 |
| 3/02 | YFNO2-87 | Area 2; (FD***) | 0.2 | 8.2 | 0.11 |

* Unfiltered Diesel Towmotors
** Propane Towmotors
*** Filtered Diesel Towmotors

# Table A5. Concentrations of Formaldehyde
# Yellow Freight System, Inc., Columbus, Ohio
# February and March 1990

| *Date* | *Sample Number* | *Job/Area* | *Flow (cc/Min)* | *Weight (ug)* | *Time (min)* | *Volume (L)* | *Concentration (ppm)* |
|---|---|---|---|---|---|---|---|
| 02/14 | YFF-02 | Dock, Area 1, (UD*) | 102 | <0.4 | 482 | 49 | <0.01 |
| 02/14 | YFF-01+ | Dock, Area 2, (UD*) | 99 | <0.4 | 474 | 47 | <0.01 |
| 02/15 | YFF-03 | Dock, Area 1, (UD*) | 102 | <0.4 | 482 | 49 | <0.01 |
| 02/15 | YFF-04 | Dock, Area 2, (UD*) | 99 | <0.4 | 489 | 48 | <0.01 |
| 02/16 | YFF-05 | Dock, Area 1, (UD*) | 102 | <0.4 | 483 | 49 | <0.01 |
| 02/16 | YFF-06 | Dock, Area 2, (UD*) | 99 | <0.4 | 489 | 48 | <0.01 |
| 02/21 | YFF-07 | Dock, Area 1, (PR**) | 102 | <0.4 | 494 | 50 | <0.01 |
| 02/21 | YFF-08+ | Dock, Area 2, (PR**) | 99 | 0.7 | 517 | 51 | 0.01 |
| 02/22 | YFF-09 | Dock, Area 1, (PR**) | 102 | <0.4 | 480 | 49 | <0.01 |
| 02/22 | YFF-10 | Dock, Area 2, (PR**) | 99 | <0.4 | 516 | 51 | <0.01 |
| 02/23 | YFF-11 | Dock, Area 1, (PR**) | 102 | <0.4 | 490 | 50 | <0.01 |
| 02/23 | YFF-12 | Dock, Area 2, (PR**) | 99 | <0.4 | 488 | 48 | <0.01 |
| 02/28 | YFF-15 | Dock, Area 1, (FD***) | 102 | <0.4 | 480 | 49 | <0.01 |
| 02/28 | YFF-16 | Dock, Area 2, (FD***) | 99 | <0.4 | 483 | 48 | <0.01 |
| 03/01 | YFF-17 | Dock, Area 1, (FD***) | 102 | <0.4 | 485 | 49 | <0.01 |
| 03/01 | YFF-18 | Dock, Area 2, (FD***) | 99 | <0.4 | 485 | 48 | <0.01 |
| 03/02 | YFF-19 | Dock, Area 1, (FD***) | 102 | <0.4 | 491 | 50 | <0.01 |
| 03/02 | YFF-20+ | Dock, Area 2, (FD***) | 99 | 0.5 | 492 | 49 | 0.01 |

* Unfiltered Diesel Towmotors

** Propane Towmotors

*** Filtered Diesel Towmotors

+ Acetaldehyde and Acrolein were also analyzed in these samples and were not detected. The limits of detection were 0.4 and 2 ug per sample for acetaldehyde and acrolein, respectively. These values translate to "less than" concentrations of <0.005 ppm, and <0.02 ppm, respectively.

# Table A6. Concentrations of Sulfuric Acid/Sulfate
## Yellow Freight System, Inc.; Columbus, OH
## February and March 1990

| *Date* | *Sample Number* | *Job/Area* | *Flow (cc/min)* | *Weight (ug)+* | *Time (min)* | *Volume (L)* | *Concentration (ug/m3)++* |
|---|---|---|---|---|---|---|---|
| 02/14 | YFS-01 | Dock, Area 1, (UD*) | 461 | 3 | 394 | 182 | 17 |
| 02/14 | YFS-02 | Dock, Area 2, (UD*) | 450 | 3 | 474 | 213 | 14 |
| 02/15 | YFS-03 | Dock, Area 1, (UD*) | 461 | 4 | 480 | 221 | 18 |
| 02/15 | YFS-04 | Dock, Area 2, (UD*) | 450 | 4 | 480 | 216 | 19 |
| 02/16 | YFS-05 | Dock, Area 1, (UD*) | 461 | <2 | 475 | 219 | <9 |
| 02/16 | YFS-06 | Dock, Area 2, (UD*) | 450 | 2 | 480 | 216 | 9 |
| 02/21 | YFS-07 | Dock, Area 1, (PR**) | 461 | 3 | 480 | 221 | 14 |
| 02/21 | YFS-08 | Dock, Area 2, (PR**) | 450 | 2 | 480 | 216 | 9 |
| 02/22 | YFS-09 | Dock, Area 1, (PR**) | 461 | 3 | 480 | 221 | 14 |
| 02/22 | YFS-10 | Dock, Area 2, (PR**) | 450 | 2 | 480 | 216 | 9 |
| 02/23 | YFS-11 | Dock, Area 1, (PR**) | 461 | 2 | 480 | 221 | 9 |
| 02/23 | YFS-12 | Dock, Area 2, (PR**) | 450 | 2 | 480 | 216 | 9 |
| 02/28 | YFS-15 | Dock, Area 1, (FD***) | 461 | 2 | 480 | 221 | 9 |
| 02/28 | YFS-16 | Dock, Area 2, (FD***) | 450 | <2 | 480 | 216 | <9 |
| 03/01 | YFS-17 | Dock, Area 1, (FD***) | 461 | 2 | 480 | 221 | 9 |
| 03/01 | YFS-18 | Dock, Area 2, (FD***) | 450 | 3 | 480 | 216 | 14 |
| 03/02 | YFS-19 | Dock, Area 1, (FD***) | 461 | 3 | 480 | 221 | 14 |
| 03/02 | YFS-20 | Dock, Area 2, (FD***) | 450 | <2 | 480 | 216 | <9 |

* Unfiltered Diesel Towmotors

** Propane Towmotors

*** Filtered Diesel Towmotors

\+ Reported as micrograms SO2

++ All sample weights were below the limit of quantitation (7 ug), and concentrations should be regarded as semi-quantitative only

# Table A7. Concentrations of Benzene Solubles
## Yellow Freight System, Inc.; Columbus, OH
## February and March 1990

| *Date* | *Sample Number* | *Job/Area* | *Flow (L/min* | *Weight (mg)+* | *Time (min)* | *Volume (L)* | *Concentration (ug/m3)++* |
|---|---|---|---|---|---|---|---|
| 02/14 | YFB-01 | Dock Area 1; (UD*) | 2.9 | <0.05 | 482 | 1388 | <36 |
| 02/14 | YFB-02 | Dock Area 2; (UD*) | 2.9 | 0.06 | 474 | 1360 | <37 |
| 02/15 | YFB-03 | Dock Area 1; (UD*) | 2.9 | <0.05 | 480 | 1382 | <36 |
| 02/15 | YFB-04 | Dock Area 2; (UD*) | 2.9 | <0.05 | 480 | 1378 | <36 |
| 02/16 | YFB-05 | Dock Area 1; (UD*) | 2.9 | <0.05 | 475 | 1368 | <37 |
| 02/16 | YFB-06 | Dock Area 2; (UD*) | 2.9 | 0.06 | 480 | 1378 | <36 |
| 02/21 | YFB-07 | Dock Area 1; (PR**) | 2.9 | 0.21 | 480 | 1378 | 94 |
| 02/21 | YFB-08 | Dock Area 2; (PR**) | 2.9 | 0.31 | 480 | 1382 | 166 |
| 02/22 | YFB-09 | Dock Area 1; (PR**) | 2.9 | <0.05 | 480 | 1378 | <36 |
| 02/22 | YFB-10 | Dock Area 2; (PR**) | 2.9 | <0.05 | 480 | 1382 | <36 |
| 02/23 | YFB-11 | Dock Area 1; (PR**) | 2.9 | <0.05 | 480 | 1378 | <36 |
| 02/23 | YFB-12 | Dock Area 2; (PR**) | 2.9 | 0.36 | 480 | 1382 | 203 |
| 02/28 | YFB-15 | Dock Area 1; (FD***) | 2.9 | <0.05 | 480 | 1378 | <36 |
| 02/28 | YFB-16 | Dock Area 2; (FD***) | 2.9 | <0.05 | 480 | 1382 | <36 |
| 03/01 | YFB-17 | Dock Area 1; (FD***) | 2.9 | <0.05 | 480 | 1378 | <36 |
| 03/01 | YFB-18 | Dock Area 2; (FD***) | 2.9 | <0.05 | 480 | 1382 | <36 |
| 03/02 | YFB-19 | Dock Area 1; (FD***) | 2.9 | 0.11 | 480 | 1378 | 22 |
| 03/02 | YFB-20 | Dock Area 2; (FD***) | 2.9 | <0.05 | 480 | 1382 | <36 |

* Unfiltered Diesel Towmotors

** Propane Towmotors

*** Filtered Diesel Towmotors

\+ Reported as mass of benzene extractable organic matter in milligrams

\+\+ Analytical weights equal to or below 0.08 mg (average of several blank samples) were treated as not detectable (<0.05 mg).

# Table A8. Carbon Monoxide Sample Results
# Yellow Freight System, Inc., Columbus, OH
# February and March 1990

| Sample Type | *Date* | *Job/Area* | 8-hr TWA *Concentration (ppm)* | Peak *Concentration* (ppm) |
|---|---|---|---|---|
| Area | 02/14 | Dock, Area 1; (UD*) | <1 | <1 |
| Area | 02/14 | Dock, Area 2; (UD*) | <1 | 1 |
| Area | 02/15 | Dock, Area 1; (UD*) | <1 | 2 |
| Area | 02/15 | Dock, Area 2; (UD*) | <1 | 3 |
| Area | 02/16 | Dock, Area 1; (UD*) | <1 | 1 |
| Area | 02/16 | Dock, Area 2; (UD*) | <1 | 4 |
| Area | 02/21 | Dock, Area 1; (PR**) | <1 | 1 |
| Area | 02/21 | Dock, Area 2; (PR**) | <1 | 3 |
| Area | 02/22 | Dock, Area 1; (PR**) | <1 | <1 |
| Area | 02/22 | Dock, Area 2; (PR**) | <1 | 1 |
| Area | 02/23 | Dock, Area 1; (PR**) | <1 | 1 |
| Area | 02/23 | Dock, Area 2; (PR**) | <1 | 2 |
| Area | 02/28 | Dock, Area 1; (FD***) | <1 | <1 |
| Area | 02/28 | Dock, Area 2; (FD***) | <1 | <1 |
| Area | 03/01 | Dock, Area 1; (FD***) | <1 | 1 |
| Area | 03/01 | Dock, Area 2; (FD***) | <1 | <1 |
| Area | 03/02 | Dock, Area 1; (FD***) | <1 | 1 |
| Area | 03/02 | Dock, Area 2; (FD***) | <1 | 1 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 8 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 5 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 2 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 4 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | <1 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 6 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 1 |
| Personal | 02/14 | Dockworker, (UD*) | <1 | 2 |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 3 |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 1 |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 4 |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 2 |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 10 |

## Table A8. Carbon Monoxide Sample Results
## Yellow Freight System, Inc., Columbus, OH
## February and March 1990

| Sample Type | *Date* | *Job/Area* | 8-hr TWA *Concentration (ppm)* | Peak *Concentration* (ppm) | |
|---|---|---|---|---|---|
| Personal | 02/15 | Dockworker, (UD*) | <1 | 3 | |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 3 | |
| Personal | 02/15 | Dockworker, (UD*) | <1 | 7 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 5 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 3 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 10 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 5 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 25 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 4 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 4 | |
| Personal | 02/16 | Dockworker, (UD*) | <1 | 6 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 20 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 12 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 4 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 4 | |
| Personal | 02/21 | Dockworker, (PR**) | 1 | 98 | ❑ |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 17 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 9 | |
| Personal | 02/21 | Dockworker, (PR**) | <1 | 13 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 3 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 18 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 8 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 6 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 1 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 22 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 7 | |
| Personal | 02/22 | Dockworker, (PR**) | <1 | 2 | |
| Personal | 02/23 | Dockworker, (PR**) | 2 | 298 | ❑ |
| Personal | 02/23 | Dockworker, (PR**) | <1 | 2 | |
| Personal | 02/23 | Dockworker, (PR**) | <1 | 9 | |
| Personal | 02/23 | Dockworker, (PR**) | 1 | 368 | ❑ |

# Table A8. Carbon Monoxide Sample Results
# Yellow Freight System, Inc., Columbus, OH
## February and March 1990

| Sample Type | *Date* | *Job/Area* | 8-hr TWA *Concentration (ppm)* | Peak *Concentration* (ppm) | |
|---|---|---|---|---|---|
| Personal | 02/23 | Dockworker, (PR**) | <1 | 2 | |
| Personal | 02/23 | Dockworker, (PR**) | <1 | 2 | |
| Personal | 02/23 | Dockworker, (PR**) | <1 | 105 | |
| Personal | 02/23 | Dockworker, (PR**) | 1 | 475 | ❑ |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 2 | |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 1 | |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 2 | |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 1 | |
| Personal | 02/28 | Dockworker, (FD***) | 1 | 20 | ❑ |
| Personal | 02/28 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 10 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 5 | |
| Personal | 03/01 | Dockworker, (FD***) | 1 | 10 | ❑ |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 5 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 5 | |
| Personal | 03/01 | Dockworker, (FD***) | <1 | 3 | |
| Personal | 03/02 | Dockworker, (FD***) | 7 | 78 | ❑ |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 12 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 6 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 2 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 15 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 161 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 4 | |
| Personal | 03/02 | Dockworker, (FD***) | <1 | 3 | |

* Unfiltered Diesel Towmotors
** Propane Towmotors
*** Filtered Diesel Towmotors

Table A9. Airborne Mutagenicity Sampling Results*
Yellow Freight System, Inc., Columbus, OH
February/March 1990

| Treatment | Respirable Dust (ug/M3) | Revertants per M3 | Revertants per M3 (S9 activated) | Revertants per mg | Revertants per mg (S9 activated |
|---|---|---|---|---|---|
| Unfiltered Diesel | 49 | 3.6 | 3.9 | 73.5 | 79.6 |
| Unfiltered Diesel | 74 | 3.0 | 2.5 | 41 | 34 |
| Unfiltered Diesel | 294 | 7.2 | 9.2 | 24 | 31 |
| Unfiltered Diesel | 25 | 3.9 | 6.1 | 156 | 244 |
| Unfiltered Diesel | 87 | 2.6 | 3.6 | 30 | 41 |
| Unfiltered Diesel | 86 | 1.0 | 1.7 | 12 | 20 |
| Propane | 6 | 5.4 | 7.2 | 885 | 1180 |
| Propane | 61 | 5.9 | 9.5 | 97 | 156 |
| Propane | 25 | 2.8 | 2.9 | 112 | 116 |
| Propane | 49 | 3.6 | 3.5 | 73 | 71 |
| Propane | 49 | 3.6 | 0.7 | 73 | 14 |
| Propane | 49 | 2.1 | 1.9 | 43 | 39 |
| Filtered Diesel | 6 | 1.4 | 1.1 | 230 | 180 |
| Filtered Diesel | 37 | 2.9 | 1.9 | 78 | 51 |
| Filtered Diesel | 12 | 1.8 | 1.8 | 150 | 150 |
| Filtered Diesel | 37 | 3.4 | 2.8 | 92 | 76 |
| Filtered Diesel | 25 | 4.1 | 5.3 | 164 | 212 |
| Background | -- | 2.3 | 2.0 | -- | -- |
| Background | -- | 6.3 | 4.1 | -- | -- |
| Background | -- | 3.3 | 1.7 | -- | -- |
| Background | -- | 3.6 | 3.2 | -- | -- |
| Background | -- | 3.2 | 2.5 | -- | -- |
| Background | -- | 1.9 | 1.5 | -- | -- |
| Background | -- | 2.3 | 2.0 | -- | -- |
| Background | -- | 3.2 | 2.9 | -- | -- |
| Background | -- | 3.5 | 3.5 | -- | -- |

* Mutagenic activity was tested with the Ames Salmonella microsome assay system (Maron and Ames, 1983); the plate incorporation test with and without S9 activation in TA98 of Salmonella typhimurium was conducted.

# Appendix B

Table B1. Elemental Carbon Summary Statistics
Yellow Freight System, Inc., Columbus, OH
February and March 1990
(ug/M3)

| *Job or Area* | *N* | *Minimum* | *Maximu* | *Arithmetic Mean* | *Standard Error* | *Geometric Mean* | *Geometri Std. Dev.* | *95% Confidence Limit Lower* | *Upper* |
|---|---|---|---|---|---|---|---|---|---|
| Dock, Area 1; (FD***) | 3 | 2.29 | 2.92 | 2.68 | 0.20 | *2.66* | 1.14 | 1.92 | 3.70 |
| Dock, Area 1; (PR**) | 2 | 0.34 | 3.65 | 2.00 | 1.66 | *1.12* | 5.35 | 0.00 | 3.9E+06 |
| Dock, Area 1; (UD*) | 3 | 7.22 | 30.2 | 15.9 | 7.23 | *13.0* | 2.11 | 2.03 | 83.6 |
| Dock, Area 2; (FD***) | 3 | 1.36 | 2.48 | 2.00 | 0.33 | *1.94* | 1.37 | 0.89 | 4.21 |
| Dock, Area 2; (PR**) | 3 | 0.44 | 3.94 | 1.82 | 1.08 | *1.23* | 3.02 | 0.08 | 19.1 |
| Dock, Area 2; (UD*) | 3 | 16.8 | 33.9 | 23.8 | 5.17 | *22.7* | 1.43 | 9.29 | 55.7 |
| Diesel - Background | 3 | 0.49 | 5.94 | 2.98 | 1.59 | *1.94* | 3.56 | 0.08 | 45.6 |
| Diesel - Dockworker | 24 | 11.6 | 61.3 | 26.4 | 2.62 | *23.9* | 1.56 | 19.8 | 28.8 |
| Filtered Diesel - Background | 3 | 0.53 | 2.00 | 1.49 | 0.48 | *1.27* | 2.12 | 0.20 | 8.26 |
| Filtered Diesel - Dockworker | 24 | 0.96 | 3.13 | 2.12 | 0.12 | *2.04* | 1.36 | 1.79 | 2.32 |
| Propane - Background | 3 | 0.73 | 2.63 | 1.70 | 0.55 | *1.49* | 1.92 | 0.29 | 7.56 |
| Propane - Dockworker | 24 | 0.10 | 4.19 | 1.32 | 0.22 | *0.94* | 2.46 | 0.64 | 1.37 |

* Unfiltered Diesel Towmotors ** Propane Towmotors *** Filtered Diesel Towmotors

# Table B2. Organic Carbon Summary Statistics
## Yellow Freight System, Inc., Columbus, OH
## February 1990
## (ug/M3)

| *Job or Area* | *N* | *Minimum* | *Maximu* | *Arithmetic Mean* | *Standard Error* | *Geometric Mean* | *Geometric Std. Dev.* | *95% Confidence Limit Lower* | *Upper* |
|---|---|---|---|---|---|---|---|---|---|
| Dock, Area 1; (FD***) | 3 | 3.87 | 9.18 | 6.76 | 1.55 | *6.36* | 1.56 | 2.10 | 19.2 |
| Dock, Area 1; (PR**) | 2 | 0.49 | 9.42 | 4.95 | 4.47 | *2.14* | 8.13 | 0.00 | 3.2E+08 |
| Dock, Area 1; (UD*) | 3 | 0.71 | 8.50 | 3.56 | 2.48 | *2.08* | 3.57 | 0.09 | 49.1 |
| Dock, Area 2; (FD***) | 3 | 2.85 | 24.9 | 10.2 | 7.30 | *6.00* | 3.43 | 0.28 | 128 |
| Dock, Area 2; (PR**) | 3 | 0.49 | 9.37 | 3.45 | 2.96 | *1.30* | 5.52 | 0.02 | 90.8 |
| Dock, Area 2; (UD*) | 3 | 0.49 | 11.0 | 5.04 | 3.11 | *2.69* | 4.86 | 0.05 | 137 |
| Diesel - Background | 3 | 0.49 | 5.09 | 2.07 | 1.51 | *1.16* | 3.62 | 0.05 | 28.4 |
| Diesel - Dockworker | 24 | 22.8 | 192 | 58.0 | 8.37 | *49.4* | 1.70 | 39.4 | 61.9 |
| Filtered Diesel - Background | 3 | 4.41 | 16.6 | 8.82 | 3.92 | *7.35* | 2.04 | 1.25 | 43.4 |
| Filtered Diesel -Dockworker | 24 | 21.7 | 88.4 | 52.2 | 4.46 | *47.9* | 1.54 | 39.9 | 57.4 |
| Propane - Background | 3 | 0.49 | 4.21 | 1.76 | 1.23 | *1.06* | 3.32 | 0.05 | 20.8 |
| Propane - Dockworker | 24 | 2.26 | 113 | 32.3 | 5.15 | *23.6* | 2.43 | 16.2 | 34.3 |

* Unfiltered Diesel Towmotors    ** Propane Towmotors    *** Filtered Diesel Towmotors

Table B3. Respirable Dust Summary Statistics
By Job or Specific Location
Yellow Freight System, Inc., Columbus, OH
February 1990

| Job or Area | N | Minimum | Maximum | Arithmetic Mean | Standard Error | Geometric Mean | Geometri Std. Dev. | 95% Confidence Limit Lower | 95% Confidence Limit Upper |
|---|---|---|---|---|---|---|---|---|---|
| Dock, Area 1; (FD***) | 3 | 6.13 | 12.3 | 10.2 | 2.04 | *9.73* | 1.49 | 3.60 | 26.3 |
| Dock, Area 1; (PR**) | 3 | 6.13 | 49.0 | 26.6 | 12.4 | *19.5* | 2.88 | 1.40 | 270 |
| Dock, Area 1; (UD*) | 3 | 48.8 | 294 | 143 | 76.2 | *108* | 2.50 | 11.0 | 1050 |
| Dock, Area 2; (FD***) | 3 | 24.5 | 36.8 | 32.7 | 4.08 | *32.1* | 1.26 | 18.0 | 57.5 |
| Dock, Area 2; (PR**) | 3 | 49.0 | 61.3 | 53.1 | 4.08 | *52.8* | 1.14 | 38.3 | 72.7 |
| Dock, Area 2; (UD*) | 3 | 24.5 | 85.8 | 61.6 | 18.8 | *53.9* | 1.99 | 9.80 | 296 |

* Unfiltered Diesel

** Propane Towmotors

*** Filtered Diesel Towmotors

## Table B4. Nitrogen Dioxide Summary Statistics
## Yellow Freight Systems, Inc., Columbus, OH
## February 1990
## (ppm)

| *Job or Area* | *N* | *Minimum* | *Maximu* | *Arithmetic Mean* | *Standard Error* | *Geometric Mean* | *Geometri Std. Dev.* | *95% Confidence Limit Lower* | *95% Confidence Limit Upper* |
|---|---|---|---|---|---|---|---|---|---|
| Dock Worker, (UD*) | 23 | 0.07 | 0.32 | 0.17 | 0.01 | *0.16* | 1.55 | 0.13 | 0.19 |
| Dock Worker, (PR**) | 24 | 0.09 | 0.32 | 0.17 | 0.01 | *0.17* | 1.36 | 0.15 | 0.19 |
| Dock Worker, (FD*** | 23 | 0.11 | 0.25 | 0.18 | 0.01 | *0.17* | 1.25 | 0.16 | 0.19 |
| Area 1; (UD*) | 3 | 0.19 | 0.27 | 0.22 | 0.02 | *0.22* | 1.20 | 0.14 | 0.35 |
| Area 2; (UD*) | 3 | 0.10 | 0.19 | 0.14 | 0.03 | *0.13* | 1.37 | 0.06 | 0.29 |
| Area 1; (PR**) | 3 | 0.14 | 0.22 | 0.17 | 0.03 | *0.17* | 1.29 | 0.09 | 0.31 |
| Area 2; (PR**) | 3 | 0.13 | 0.17 | 0.16 | 0.01 | *0.16* | 1.18 | 0.10 | 0.24 |
| Area 1; (FD***) | 3 | 0.08 | 0.13 | 0.11 | 0.01 | *0.11* | 1.27 | 0.06 | 0.20 |
| Area 2; (FD***) | 3 | 0.11 | 0.19 | 0.16 | 0.03 | *0.16* | 1.40 | 0.07 | 0.36 |

* Unfiltered Diesel Towmotors ** Propane Towmotors *** Filtered Diesel Towmotors

Table B5. Elemental Carbon Summary Statistics
Yellow Freight System, Inc., Maybrook, NY
March 1990
(ug/M3)

| *Job or Area* | *N* | *Minimum* | *Maximu* | *Arithmetic Mean* | *Standard Error* | *Geometric Mean* | *Geometri Std. Dev.* | *95% Confidence Limit Lower* | *Upper* |
|---|---|---|---|---|---|---|---|---|---|
| Background | 5 | 1.27 | 5.17 | 3.14 | 0.63 | 2.86 | 1.67 | 1.52 | 5.40 |
| Dockworker, Fans off | 23 | 27.2 | 101 | 63.3 | 4.05 | 60.1 | 1.41 | 51.8 | 69.7 |
| Dockworker, Fans on | 24 | 30.0 | 193 | 63.1 | 8.77 | 54.7 | 1.64 | 44.3 | 67.4 |
| Zone 11, Fans off | 3 | 44.1 | 78.2 | 56.0 | 11.1 | 54.0 | 1.38 | 24.3 | 120 |
| Zone 11, Fans on | 3 | 31.4 | 71.0 | 53.5 | 11.6 | 50.6 | 1.53 | 17.6 | 145 |
| Zone 2, Fans off | 3 | 35.3 | 65.7 | 51.4 | 8.8 | 49.8 | 1.37 | 22.7 | 109 |
| Zone 2, Fans on | 3 | 36.4 | 65.5 | 51.5 | 8.4 | 50.1 | 1.35 | 23.9 | 105 |
| Zone 4, Fans off | 3 | 29.0 | 62.7 | 49.3 | 10.3 | 46.8 | 1.52 | 16.6 | 132 |
| Zone 4, Fans on | 3 | 32.4 | 64.4 | 46.0 | 9.5 | 44.2 | 1.42 | 18.6 | 105 |

Table B6. Organic Carbon Summary Statistics
Yellow Freight System, Inc., Maybrook, NY
March 1990
(ug/M3)

| Job or Area | N | Minimum | Maximu | Arithmetic Mean | Standard Error | Geometric Mean | Geometri Std. Dev. | 95% Confidence Limit Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|
| Background | 5 | 1.68 | 8.38 | 4.45 | 1.15 | 3.86 | 1.85 | 1.80 | 8.26 |
| Dockworker, Fans off | 23 | 36.1 | 433 | 129 | 19.8 | 105 | 1.88 | 79.8 | 138 |
| Dockworker, Fans on | 24 | 34.4 | 2012 | 285 | 95.1 | 138 | 2.92 | 87.9 | 217 |
| Zone 11, Fans off | 3 | 15.4 | 52.1 | 28.9 | 11.6 | 24.9 | 1.91 | 4.97 | 125 |
| Zone 11, Fans on | 3 | 20.0 | 42.8 | 32.5 | 6.69 | 31.0 | 1.48 | 11.6 | 82.3 |
| Zone 2, Fans off | 3 | 16.9 | 121 | 56.7 | 32.5 | 40.3 | 2.73 | 3.32 | 489 |
| Zone 2, Fans on | 3 | 18.3 | 40.1 | 28.2 | 6.36 | 26.8 | 1.48 | 10.1 | 71.0 |
| Zone 4, Fans off | 3 | 11.3 | 28.4 | 20.3 | 4.96 | 18.9 | 1.60 | 5.88 | 60.9 |
| Zone 4, Fans on | 3 | 15.5 | 26.7 | 22.1 | 3.37 | 21.5 | 1.33 | 10.6 | 43.9 |

## Table B7. Nitrogen Dioxide Summary Statistics
## Yellow Freight System, Inc., Maybrook, NY
## March 1990
## (ppm)

| *Job or Area* | *N* | *Minimum* | *Maximum* | *Arithmetic Mean* | *Standard Error* | *Geometric Mean* | *Geometri Std. Dev.* | *95% Confidence Limit Lower* | *95% Confidence Limit Upper* |
|---|---|---|---|---|---|---|---|---|---|
| Background | 2 | 0.07 | 0.15 | 0.11 | 0.04 | 0.10 | 1.80 | 0.00 | 20.22 |
| Dockworker, Fans off | 23 | 0.11 | 0.76 | 0.24 | 0.03 | 0.21 | 1.63 | 0.17 | 0.26 |
| Dockworker, Fans on | 24 | 0.09 | 0.31 | 0.15 | 0.01 | 0.14 | 1.42 | 0.12 | 0.16 |
| Zone 11, Fans off | 3 | 0.11 | 0.20 | 0.14 | 0.03 | 0.13 | 1.42 | 0.06 | 0.32 |
| Zone 11, Fans on | 3 | 0.08 | 0.13 | 0.10 | 0.02 | 0.10 | 1.31 | 0.05 | 0.19 |
| Zone 2, Fans off | 3 | 0.07 | 0.23 | 0.17 | 0.05 | 0.15 | 1.92 | 0.03 | 0.76 |
| Zone 2, Fans on | 3 | 0.06 | 0.11 | 0.09 | 0.01 | 0.08 | 1.37 | 0.04 | 0.19 |
| Zone 4, Fans off | 3 | 0.06 | 0.36 | 0.21 | 0.09 | 0.16 | 2.52 | 0.02 | 1.62 |
| Zone 4, Fans on | 3 | 0.04 | 0.18 | 0.09 | 0.04 | 0.07 | 2.29 | 0.01 | 0.56 |

(ATTACHMENT 1)

YELLOW FREIGHT SYSTEMS, INC.
COLUMBUS, OHIO

QUESTIONNAIRE

SUBJECT IDENTIFICATION: |  |  |  | (1-3)

TODAY'S DATE: |  |  | - |  |  | - |  |  | (4-9)
(Month) (Day) (Year)

## I. DEMOGRAPHIC INFORMATION

1. NAME: |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | (10-25)
(Last)

|  |  |  |  |  |  |  |  |  |  |  | (26-35) |  | (36)
(First) (Middle Initial)

. RACE: White, not of Hispanic origin ___1 (37)
Black, not of Hispanic origin ___2
Hispanic ___3
American Indian or Alaskan native ___4
Asian or Pacific Islander ___5

. SEX: Male ___1 (38)
Female ___2

. BIRTHDATE |  |  | - |  |  | - |  |  | (39-44)
(Month) (Day) (Year)

## II. WORK HISTORY

5. WHEN DID YOU START WORKING AT YELLOW FREIGHT SYSTEMS? |__|__| - |__|__| (Month) (Year) (45-48)

6. WHAT IS YOUR JOB TITLE? ________________________________ |__|__| (49-50)

7. DO YOU FEEL YOUR JOB INVOLVES A HAZARD TO YOUR HEALTH?

   Yes___1 (Go to Question 8) (51)
   No ___2 (Go to Question 9)

8. PLEASE DESCRIBE ANY PART OF YOUR JOB THAT YOU FEEL MAY BE HAZARDOUS TO YOUR HEALTH.

   ________________________________________________

   ________________________________________________

   ________________________________________________

   ________________________________________________

## III. TOBACCO SMOKING

9. HAVE YOU EVER SMOKED CIGARETTES (more than 20 packs of cigarettes in your life)?

   Yes___1 (Go to Question 10) (52)
   No ___2 (Go to Question 14)

10. HOW OLD WERE YOU WHEN YOU STARTED SMOKING CIGARETTES? |__|__| (age) (53-54)

11. IF YOU ARE AN EX-SMOKER, HOW OLD WERE YOU WHEN YOU LAST SMOKED CIGARETTES? (If you currently smoke, please leave this answer blank). |__|__| (age) (55-56)

12. OVERALL, HOW LONG HAVE YOU SMOKED CIGARETTES REGULARLY? |__|__| (# yrs) or |__|__| (# mos) (57-60)

13. OVER THE ENTIRE TIME YOU SMOKED CIGARETTES REGULARLY, ON THE AVERAGE HOW MANY CIGARETTES DO/DID YOU SMOKE PER DAY? |__|__| (# cigarettes) (61-62)

CARD |0|1| (79-80)

SUBJECT IDENTIFICATION: |__|__|__| (1-3)

TODAY'S DATE: |__|__| - |__|__| - |__|__| (4-9)
(Month) (Day) (Year)

NAME: |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__| (10-25)
(Last)

|__|__|__|__|__|__|__|__|__|__| (26-35) |__| (36)
(First) (Middle Initial)

1. SINCE YOU BEGAN WORK THIS WEEK, HOW FREQUENTLY HAVE YOU NOTICED THE FOLLOWING SYMPTOMS AT WORK?

| | SYMPTOM | AT WORK: | | | |
|---|---|---|---|---|---|
| a. | HEADACHE | Never___1 | Sometimes___2 | Often___3 | (37) |
| b. | SEVERE CHEST PAIN | Never___1 | Sometimes___2 | Often___3 | (38) |
| c. | EYE IRRITATION | Never___1 | Sometimes___2 | Often___3 | (39) |
| d. | TEARING OF EYES | Never___1 | Sometimes___2 | Often___3 | (40) |
| e. | TEMPORARY BLINDNESS | Never___1 | Sometimes___2 | Often___3 | (41) |
| f. | RUNNY NOSE | Never___1 | Sometimes___2 | Often___3 | (42) |
| g. | STOPPED UP NOSE | Never___1 | Sometimes___2 | Often___3 | (43) |
| h. | SORE/IRRITATED THROAT | Never___1 | Sometimes___2 | Often___3 | (44) |
| i. | HOARSENESS | Never___1 | Sometimes___2 | Often___3 | (45) |
| j. | PAIN ON URINATION | Never___1 | Sometimes___2 | Often___3 | (46) |
| k. | DRY COUGH | Never___1 | Sometimes___2 | Often___3 | (47) |
| l. | COUGHING UP PHLEGM | Never___1 | Sometimes___2 | Often___3 | (48) |
| m. | WHEEZING | Never___1 | Sometimes___2 | Often___3 | (49) |
| n. | SHORTNESS OF BREATH | Never___1 | Sometimes___2 | Often___3 | (50) |

CARD |0|2| (79-80)

THANK YOU FOR PARTICIPATING IN THIS SURVEY.

SUBJECT IDENTIFICATION: |_|_|_| (1-3)

TODAY'S DATE: |_|_| - |_|_| - |_|_| (4-9)
(Month) (Day) (Year)

NAME: |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_| (10-25)
(Last)

|_|_|_|_|_|_|_|_|_|_| (26-35) |_| (36)
(First) (Middle Initial)

2. SINCE YOU BEGAN WORK THIS WEEK, HOW FREQUENTLY HAVE YOU NOTICED THE FOLLOWING SYMPTOMS AT WORK?

| SYMPTOM | AT WORK: | | | |
|---|---|---|---|---|
| a. HEADACHE | Never___1 | Sometimes___2 | Often___3 | (37) |
| b. SEVERE CHEST PAIN | Never___1 | Sometimes___2 | Often___3 | (38) |
| c. EYE IRRITATION | Never___1 | Sometimes___2 | Often___3 | (39) |
| d. TEARING OF EYES | Never___1 | Sometimes___2 | Often___3 | (40) |
| e. TEMPORARY BLINDNESS | Never___1 | Sometimes___2 | Often___3 | (41) |
| f. RUNNY NOSE | Never___1 | Sometimes___2 | Often___3 | (42) |
| g. STOPPED UP NOSE | Never___1 | Sometimes___2 | Often___3 | (43) |
| h. SORE/IRRITATED THROAT | Never___1 | Sometimes___2 | Often___3 | (44) |
| i. HOARSENESS | Never___1 | Sometimes___2 | Often___3 | (45) |
| j. PAIN ON URINATION | Never___1 | Sometimes___2 | Often___3 | (46) |
| k. DRY COUGH | Never___1 | Sometimes___2 | Often___3 | (47) |
| l. COUGHING UP PHLEGM | Never___1 | Sometimes___2 | Often___3 | (48) |
| m. WHEEZING | Never___1 | Sometimes___2 | Often___3 | (49) |
| n. SHORTNESS OF BREATH | Never___1 | Sometimes___2 | Often___3 | (50) |

CARD |0|3| (79-80)

THANK YOU FOR PARTICIPATING IN THIS SURVEY.

SUBJECT IDENTIFICATION: |__|__|__| (1-3)

TODAY'S DATE: |__|__| - |__|__| - |__|__| (4-9)
(Month) (Day) (Year)

NAME: |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__| (10-25)
(Last)

|__|__|__|__|__|__|__|__|__|__| (26-35) |__| (36)
(First) (Middle Initial)

3. SINCE YOU BEGAN WORK THIS WEEK, HOW FREQUENTLY HAVE YOU NOTICED THE FOLLOWING SYMPTOMS AT WORK?

| SYMPTOM | AT WORK: | | | |
|---|---|---|---|---|
| a. HEADACHE | Never__1 | Sometimes__2 | Often__3 | (37) |
| b. SEVERE CHEST PAIN | Never__1 | Sometimes__2 | Often__3 | (38) |
| c. EYE IRRITATION | Never__1 | Sometimes__2 | Often__3 | (39) |
| d. TEARING OF EYES | Never__1 | Sometimes__2 | Often__3 | (40) |
| e. TEMPORARY BLINDNESS | Never__1 | Sometimes__2 | Often__3 | (41) |
| f. RUNNY NOSE | Never__1 | Sometimes__2 | Often__3 | (42) |
| g. STOPPED UP NOSE | Never__1 | Sometimes__2 | Often__3 | (43) |
| h. SORE/IRRITATED THROAT | Never__1 | Sometimes__2 | Often__3 | (44) |
| i. HOARSENESS | Never__1 | Sometimes__2 | Often__3 | (45) |
| j. PAIN ON URINATION | Never__1 | Sometimes__2 | Often__3 | (46) |
| k. DRY COUGH | Never__1 | Sometimes__2 | Often__3 | (47) |
| l. COUGHING UP PHLEGM | Never__1 | Sometimes__2 | Often__3 | (48) |
| m. WHEEZING | Never__1 | Sometimes__2 | Often__3 | (49) |
| n. SHORTNESS OF BREATH | Never__1 | Sometimes__2 | Often__3 | (50) |

CARD |0|4| (79-80)

THANK YOU FOR PARTICIPATING IN THIS SURVEY.