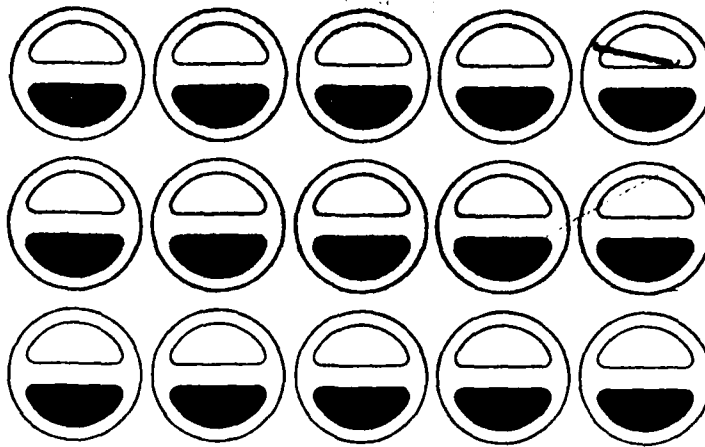
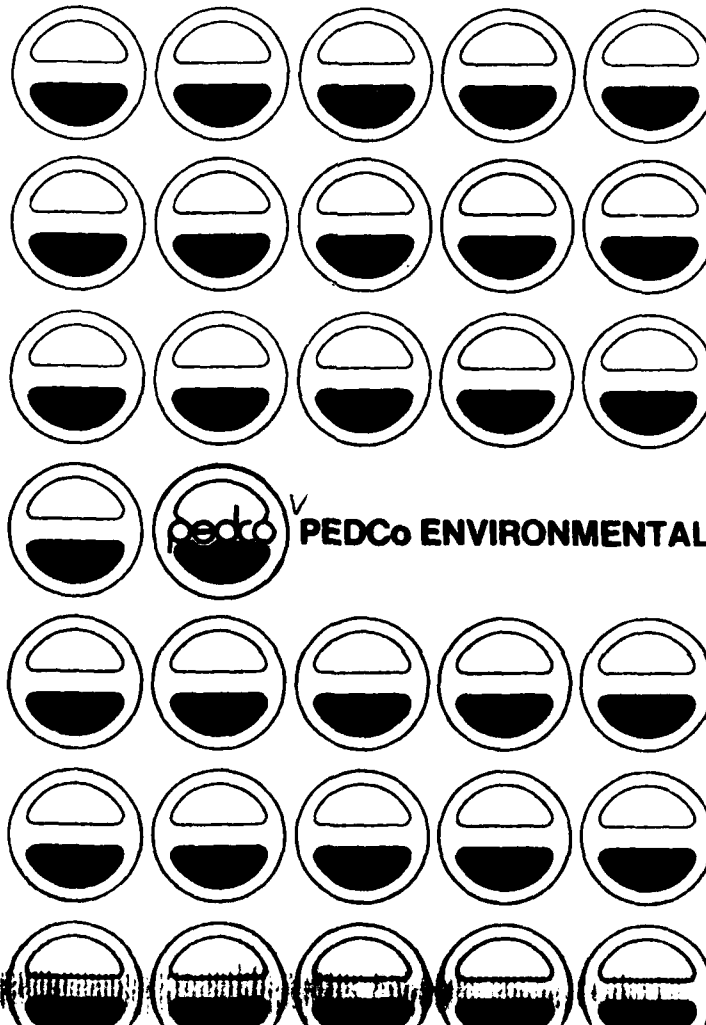


AD-A141 792



MEASUREMENT OF EXHAUST EMISSIONS  
FROM DIESEL-POWERED FORKLIFTS  
DURING OPERATIONS IN AMMUNITION  
STORAGE MAGAZINES

May 1984



**PEDCO ENVIRONMENTAL**

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## SUMMARY

Indoor air quality was monitored in Stradley-type ammunition magazines during the use of diesel-powered forklifts to determine worker exposures to exhaust components. The monitoring took place during storage and handling operations. The primary test vehicles used during this investigation were a Still forklift powered by a Deutz (F3L912W) diesel engine and a Hyster forklift powered by a Perkins (4.2000) diesel engine. Both breathing zone (personal) and continuous monitoring data were collected during the operation of the two vehicles. Ambient windspeed, ambient and magazine temperature, and magazine ventilation air velocity were also monitored and recorded during the tests.

The impact of diesel exhaust on breathing zone exposures and magazine air quality was monitored for two kinds of ammunition storage and handling operations: loading/unloading operations and warehousing operations. The following exhaust components were monitored: total suspended particulates, polycyclic aromatic hydrocarbons, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, and oxides of nitrogen, sulfuric acid as total sulfates, total hydrocarbons, and odorants.

The primary objectives of the investigation were 1) to determine the ability of the forklift operations to meet Federal Occupational Safety and Health Administration (OSHA) standards

and American Conference of Governmental Industrial Hygienist (ACGIH) exposure limits, and 2) to assess the relative "cleanliness" of the two diesel-powered test vehicles. In addition, the Army was interested in obtaining information to use as a data base for validation of a predictive model designed to estimate indoor air quality at Stradley and similarly designed ammunition magazines.

The test results indicated that the impact of diesel exhaust on workplace exposures and magazine air quality depends largely on the operations being performed. Of the two operations investigated, the warehousing operations presented the greater potential risk to the health and safety of Army personnel. A comparison of breathing zone exposures and continuous monitoring data with existing workplace standards indicates that nitrogen dioxide is the only exhaust component of those measured that presents a potentially serious health risk. Test results also indicated that the use of the Hyster/Perkins forklift during warehousing operations exposed Army personnel to nitrogen dioxide levels in excess of the ACGIH's threshold limit value (TLV) for this substance [the emission level was equal to approximately 64 percent of the OSHA permissible exposure limit (PEL)]. Although neither the PEL nor the more stringent TLV for nitrogen dioxide was exceeded during the use of the Still/Deutz forklift, the exhaust from this vehicle generated concentrations approaching the TLV.

A statistical test of the air quality data collected during warehousing operations when both low-sulfur (0.4 percent) and high-sulfur (1.02 percent) fuels were used indicated that the operation of the Still/Deutz vehicle is significantly cleaner than that of the Hyster/Perkins vehicle. The OSHA permissible exposure limits or ACGIH threshold limit values for the exhaust components measured were not exceeded during the operation of the Still/Deutz vehicle.

The severe weather conditions during the testing and their subsequent effect on engine operation and magazine ventilation prevented a final assessment of the vehicle's absolute safety.

Additional testing is proposed to arrive at better quantification of personnel exposure and magazine air quality during the use of the Still/Deutz vehicle. The main objective of the additional testing would be to monitor key exhaust components emitted from the Still/Deutz vehicle under opposite environmental conditions (i.e., lower ambient windspeeds and warmer temperatures) in an effort to complete the safety assessment of this vehicle. The additional testing would be limited to a shorter list of exhaust components (nitrogen dioxide, nitric oxide, carbon monoxide, sulfur dioxide, sulfuric acid, and possibly total suspended particulates and polycyclic aromatic hydrocarbons).

A tracer gas study designed for better characterization of magazine ventilation is also proposed.

## ACKNOWLEDGMENT

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Both the planning and execution of the indoor air monitoring effort required the cooperation of a number of individuals and government agencies. It would not be possible to give adequate credit to every person who has contributed to the investigation; however, we would like to identify a few individuals and agencies who were particularly helpful. We wish to thank Mr. Steve Edwards of the Occupational Safety and Health Administration (OSHA) Laboratory, Salt Lake City, Utah, and Ms. Dawn G. Tharr of the National Institute for Occupational Safety and Health (NIOSH), Cincinnati, Ohio, for providing assistance in obtaining certain pieces of equipment. We also wish to thank Messrs. Tim F. Lee, Steve Moyer, and Stephen F. Souk of Belvoir R&D Center for providing invaluable direction during the air quality testing of the diesel forklifts, and Messrs. John Sprague, Jerry Krohn, and Kevin White of the U.S. Army Defense Ammunition Center and School, whose patience and practical assistance assured a productive and timely completion of the onsite testing effort.

## I. INTRODUCTION

The U.S. Army currently uses gasoline- and electric-powered forklift trucks on a broad scale for ammunition handling operations in both the United States and Europe. Until a recent change in regulations, only electric-powered forklifts could be used inside ammunition storage magazines. Gasoline trucks have generally been used for all operations outside the magazines because of their speed and mobility advantages over electric trucks. The need to reduce or eliminate the problems associated with supporting electric forklift use at remote locations in Europe and the need to improve the Army's ability to move large quantities of supplies rapidly prompted an investigation to determine if electric forklifts could be replaced by diesel forklifts. As part of this investigation, a program was begun to evaluate the safety of exhaust emission levels inside ammunition magazines during the movement of large quantities of ammunition with diesel-powered forklifts.

### OBJECTIVES

The objectives of this investigation are to acquire sufficient indoor air monitoring data to assess the exhaust emission characteristics and health hazard potential of two "low emission" diesel-powered forklift trucks: a Still forklift powered by a Deutz (F3L912W) engine and a Hyster forklift powered by a

Perkins (4.2032) engine. Specifically, the investigation is designed to determine whether these vehicles can operate safely in a partially enclosed area for an amount of time compatible with both normal and military mission requirements. To meet these objectives, PEDCo Environmental, Inc., conducted a series of indoor air monitoring tests at the U.S. Army Defense Ammunition Center and School near Savanna, Illinois. These tests evaluated the impact of exhaust emissions from diesel-powered forklift trucks on indoor air quality in Stradley-type ammunition storage magazines. The data from these air monitoring tests are to be used: 1) to determine the ability of the forklift operations to meet Federal OSHA standards, 2) to assess the relative "cleanliness" of the two test vehicles, and 3) to provide a data base from which the Belvoir R&D Center could validate a predictive model designed to estimate indoor air quality at Stradley and similarly designed ammunition magazines.

#### SCOPE OF WORK

The scope of work for this investigation covers the following tasks:

- a) Become familiar with the use of a forklift truck during operations in ammunition storage magazines.
- b) Generate a list of exhaust components to be sampled and explain why each should be monitored.
- c) Develop a detailed test plan for measuring and analyzing each of the specified diesel exhaust components. Determine the type of test to be used; procedures and techniques for taking air samples; and the methodology, procedures, and equipment to be used for analysis and characterization of the samples taken.

- d) Conduct indoor air quality monitoring tests during simulated ammunition handling operations at two magazines at the U.S. Army Defense Ammunition Center and School near Savannah, Illinois.
- e) Analyze the indoor air quality data obtained during the test and, where applicable, compare it with Federal OSHA permissible exposure limits.
- f) Provide technical input that can enable the Army to determine whether a diesel-powered forklift truck, based on its emission output, is suitable for operations in ammunition storage magazines.

## 11. INVESTIGATION

### OPERATION OF FORKLIFT TRUCKS IN AMMUNITION STORAGE MAGAZINES

Two model scenarios are presented to characterize the operation and movement of forklift trucks in ammunition storage magazines. The first, which is described as a loading/unloading operation, is characterized by the movement of supplies in and out of a magazine. The second, which is described as a warehousing operation, involves the movement or rearranging of supplies within a magazine.

The loading/unloading operation is typified by the movement of supplies out of the magazine to waiting transport vehicles or into the magazine from the same vehicles. The activity of a forklift truck during loading/unloading operations can be classified into three modes: 1) movement while empty, 2) movement under loaded conditions, and 3) activities involving load transfer. During a loading/unloading operation the three modes are each performed once while the vehicle is inside the magazine; i.e., the vehicle enters the magazine in either a loaded or unloaded condition, transfers the load to or from storage inside the magazine, and leaves the magazine either loaded or empty, depending on its mission.

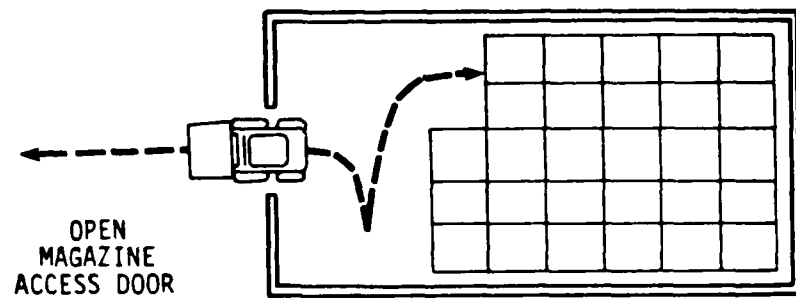


Warehousing operations involve the movement of ammunition, but only within the magazine. The activity of a forklift truck during warehousing operations is substantially different from that during loading/unloading operations. Although the warehousing operation can be divided into the same three activity modes, all three modes are performed within the magazine and load transfer is performed twice for each load being handled.

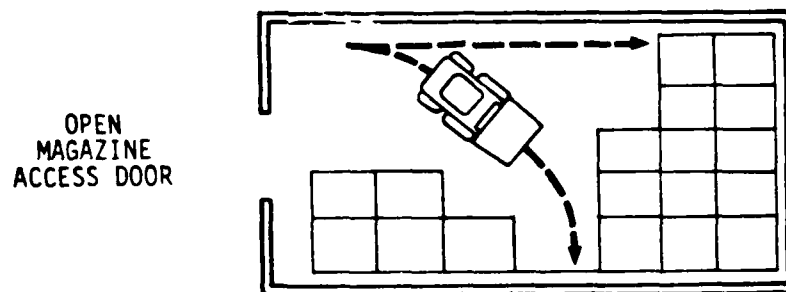
Although any given forklift operation can vary from the two model scenarios presented above, it is believed that these models present a reasonably accurate picture of what most operations are likely to involve. Figure 1 is a pictorial representation of the two model scenarios.

#### COMPONENTS OF DIESEL EXHAUST

Toxicological research programs are currently attempting to determine if diesel vehicle emissions have physical or chemical properties that would make them significantly more toxic than other combustion products associated with the use of fossil fuels. To date, however, no unique compounds have been identified in diesel emissions that present new concerns.<sup>1</sup> Despite the lack of conclusive research, some measurement of airborne contamination must be attempted to ensure that the diesel-powered equipment the Army plans to purchase will not adversely



LOADING/UNLOADING



WAREHOUSING

Figure 1. Two model scenarios for the operation and movement of forklift trucks in ammunition storage magazines.

affect the health of its personnel. A number of chemical substances can be considered prime candidates for testing. Candidate selection is based on a substance's capacity for producing a serious health hazard, having an irritant effect, or generating a noxious odor. Concern about a substance's toxic effects is obvious; the health and safety of Army personnel are important during both normal and combat service support operations. Irritant effects and noxious odors are important because their presence could hinder forklift operations during the execution of a military mission by adversely affecting morale. Final selection of exhaust components to be tested is also based on the availability of accurate and reliable methods of sampling and analysis.

Table 1 presents the diesel exhaust components tested during the forklift operation and their relevant health effects. These components include both airborne particulates and gaseous substances generated during the operation of diesel engines.

#### Particulate Component

The particulate components of diesel emissions include both soluble and insoluble fractions. Particulates were monitored as total suspended particulate (TSP) and polycyclic aromatic hydrocarbons (PAH). Total suspended particulates were considered during this investigation because this category of particulate is regulated by OSHA as nuisance or irritant dusts. Polycyclic aromatic hydrocarbons (PAH) are of particular interest because

TABLE 1. DIESEL EXHAUST COMPONENTS TESTED: THEIR RELEVANT HEALTH EFFECTS AND TARGET ORGANS<sup>a</sup>

Exhaust component tested	Relevant health effects	Target organs
<b>Particulates</b>		
Insoluble fraction		
Total suspended particulates (TSP)	Eye and mucous membrane irritation	Respiratory system, eyes, throat
Soluble fraction		
Polycyclic aromatic hydrocarbons (PAH)	Systemic toxicity and carcinogenicity	Respiratory system, liver
<b>Gases</b>		
Carbon monoxide (CO)	Vertigo, tachypnea, depression, angina, syncope, asphyxia	Respiratory, cardiovascular, and central nervous systems; blood
Carbon dioxide (CO <sub>2</sub> )	Vertigo, restlessness, paresthesia, dyspnea, asphyxia, coma	Respiratory and cardiovascular systems, skin
Nitrogen dioxide, as oxides of nitrogen (NO <sub>x</sub> )	Eye irritation, dyspnea, pulmonary edema, tachypnea, tachycardia	Respiratory and cardiovascular systems
Sulfur dioxide (SO <sub>2</sub> )	Mucous membrane and pulmonary irritation, bronchoconstriction	Respiratory system, skin, eyes
Sulfur acid, as sulfate (SO <sub>4</sub> <sup>+2</sup> )	Mucous membrane and pulmonary irritation, pulmonary edema, emphysema, dental erosion	Respiratory system, skin, teeth
<b>Other</b>		
Total hydrocarbons (THC)	Vertigo, eye and mucous membrane irritation, numbness	Respiratory system, skin, eyes
Odorants	Some irritation, psychosomatic effects	Olfactory senses

<sup>a</sup> Chemical Hazards, National Institute for Occupational Safety and Health and the Occupational Safety and Health Administration. DHEN (NIOSH) Publication No. 78-210, August 1981.

their presence can be an indication of the potential carcinogenicity of diesel exhaust. Although PAH are emitted from fossil fuel sources both as gaseous vapor and particulate, when released into the environment, the vapor portion will condense as, or on, fine particulates.<sup>2</sup> Because of the importance of PAH, the soluble fraction of each particulate sample was analyzed for this group of substances.

#### Gaseous Component

The gaseous emission components tested were carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and sulfuric acid aerosols as sulfates (SO<sub>4</sub><sup>+2</sup>).

Carbon monoxide was selected for sampling because it is potentially the most hazardous gaseous component. The cumulative effect of exposure to CO over a work period can cause central nervous system depression, blackouts, coma, and eventual death at the concentrations that could be reached in an enclosed work area. Due to the relatively hazardous nature of CO in the workplace, both the workers and general work area were monitored continuously for possible elevated levels.

Carbon dioxide, which is a simple asphyxiant, was monitored by both breathing zone (personal) and area samples. Due to the relatively high output of CO<sub>2</sub> from diesel engines, emphasis was placed on detecting the possible buildup of CO<sub>2</sub> in poorly ventilated areas of the magazine.

Oxides of nitrogen were monitored because of their relatively high volume of emissions from diesel engines and because

of their ability to produce odors and cause irritation, pulmonary edema, and tachycardia in humans.

Sulfur dioxide and sulfuric acid as sulfate ( $\text{SO}_4^{+2}$ ) cause severe irritation of the mucous membranes. Inhalation of sulfur dioxide may produce bronchoconstriction, uncontrolled coughing, and choking, particularly in individuals who already have asthmatic conditions. Sulfuric acid inhalation is also known to produce severe emphysema-type reactions.

#### Other Components

Other exhaust components tested included total hydrocarbons (THC) and odorants. The THC were analyzed with a continuous air monitor specifically for nonmethane hydrocarbons. Odor measurements were collected for the eventual determination of total intensity of the aroma.<sup>3</sup>

#### SAMPLING AND ANALYTICAL METHODS

A brief review of the sampling and analytical methods used during this investigation is presented here. A more detailed description of the methods used for breathing zone monitoring are presented in Appendix A.

#### Breathing Zone (Personal) Monitoring

Breathing zone monitoring was conducted on Army personnel involved in the ammunition handling operation. The objective of this monitoring effort was to determine time-weighted average (TWA) exposures to diesel exhaust components and compare these exposures with OSHA permissible exposure limits (PEL's).<sup>4</sup> The sampling and analytical methods used during the monitoring

effort are National Institute for Occupational Safety and Health (NIOSH)-approved techniques.<sup>5</sup> The monitoring apparatus consisted of real-time electronic dosimeters for CO; constant hi-flow pumps for TSP, PAH, and  $\text{SO}_4^{+2}$ ; and low-flow, constant-stroke pumps for  $\text{NO}_x$ ,  $\text{SO}_2$ , THC, and odorants. Carbon dioxide was monitored with passive dosimeters. The personal sampling methods and analytical procedures used for each exhaust component are summarized in Table 2.

The analysis of samples taken during the personal monitoring effort was conducted at PEDCo Environmental's analytical laboratory according to the prescribed reference analytical methods. This laboratory is accredited by the American Industrial Hygiene Association (AIHA) and participates in the NIOSH Proficiency Analytical Testing (PAT) program.

Because of the variety of collection methods required for the personal monitoring, directly equipping Army personnel with the necessary apparatus would have seriously interfered with normal working activities and may have affected the safe operation of the forklift vehicles. To avoid these problems, we mounted the sampling apparatus on the forklift trucks so that the point of collection for each apparatus was located in the breathing zone of the forklift operators (drivers). Sampling apparatus used to measure exposures for the other personnel (helpers) were located at stationary points, close to where these persons are likely to stand while observing and assisting the driver with load-transfer activities. It is worthwhile to note that the sampling apparatus used to measure a "helpers" exposures remained inside the magazine at all times during

TABLE 2. SAMPLING AND ANALYTICAL METHODS FOR DETERMINING WORKER EXPOSURES TO DIESEL EXHAUST COMPONENTS<sup>a</sup>

Exhaust component tested	Personal sampling method	Analytical method	Reference number <sup>b</sup>
<b>Particulates</b>			
Insoluble fraction			
Total suspended particulates (TSP) <sup>c</sup>	Filter	Gravimetric	329 (SDS)
Soluble fraction			
Polycyclic aromatic hydrocarbons (PAH)	Filter (Soxhlet extraction)	High-pressure liquid chromatography	-
<b>Gases</b>			
Carbon monoxide (CO) <sup>d</sup>	Passive dosimeter	Direct reading (dosimetry)	-
Carbon dioxide (CO <sub>2</sub> )	Continuous monitor	-	PCAM231
Nitrogen dioxide (as oxides of nitrogen, NO <sub>x</sub> ) <sup>c</sup>	Solid sorbent (triethanolamine extract)	Spectrophotometry	PCAM268
Sulfur dioxide (SO <sub>2</sub> ) <sup>c</sup>	Filter	Ion chromatography	SI74
Sulfur acid (as SO <sub>4</sub> <sup>+2</sup> )	Filter	Titration	
<b>Other</b>			
Total hydrocarbons (THC)	Continuous monitor	-	-
Odorants	Chromosorb 102	Liquid phase chromatography	e

<sup>a</sup> NIOSH Manual of Analytical Methods  
U.S. Department of Health and Human Services  
Public Health Service  
Center for Disease Control  
National Institute for Occupational Safety and Health, August 1981.

Schuetzle, D., and J. Perez. A CRC Cooperative Comparison of Extraction and HPLC Techniques for Diesel Particulate Emissions. APCA Paper 81-56.4. June 1981.

<sup>b</sup> Method identification number for NIOSH unless otherwise specified.

<sup>c</sup> Known human irritant.

<sup>d</sup> Carbon monoxide was monitored with portable, continuous, real-time electronic monitoring equipment.

<sup>e</sup> DOAS method.



the emission testing while the apparatus used to measure the "drivers" exposure was attached to the forklift trucks and moved in and out of the magazine with each loading/unloading effort.

#### Continuous Monitoring

A temperature-controlled mobile laboratory was positioned between the two ammunition magazines to be monitored and was used to house the data-acquisition computer and continuous-monitoring equipment. A continuous sampling system was used in conjunction with a programmable solenoid switching mechanism to collect air within the magazine. The air samples were collected for a period of 5 minutes three times an hour at four locations within the magazines (two sampling trains in each of two magazines). Air samples from each location were carried through heated Teflon sample lines to the programmable switching system located within the mobile lab. The continuous monitors drew air samples from a common manifold to analyze the air for concentrations of CO, CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and THC. Data were collected by a computerized data-acquisition system backed up by strip chart recorders.

The continuous monitoring system was comprised of three elements: a sequential sampling system, a bank of continuous monitors, and a computerized data-acquisition system. A schematic representation of the sequential sampling system is presented in Figure 2. Air samples from each of the four locations (two in each magazine) were carried through the heated 1/4-inch I.D. Teflon tubing at a rate of 10 liters/min. At the mobile

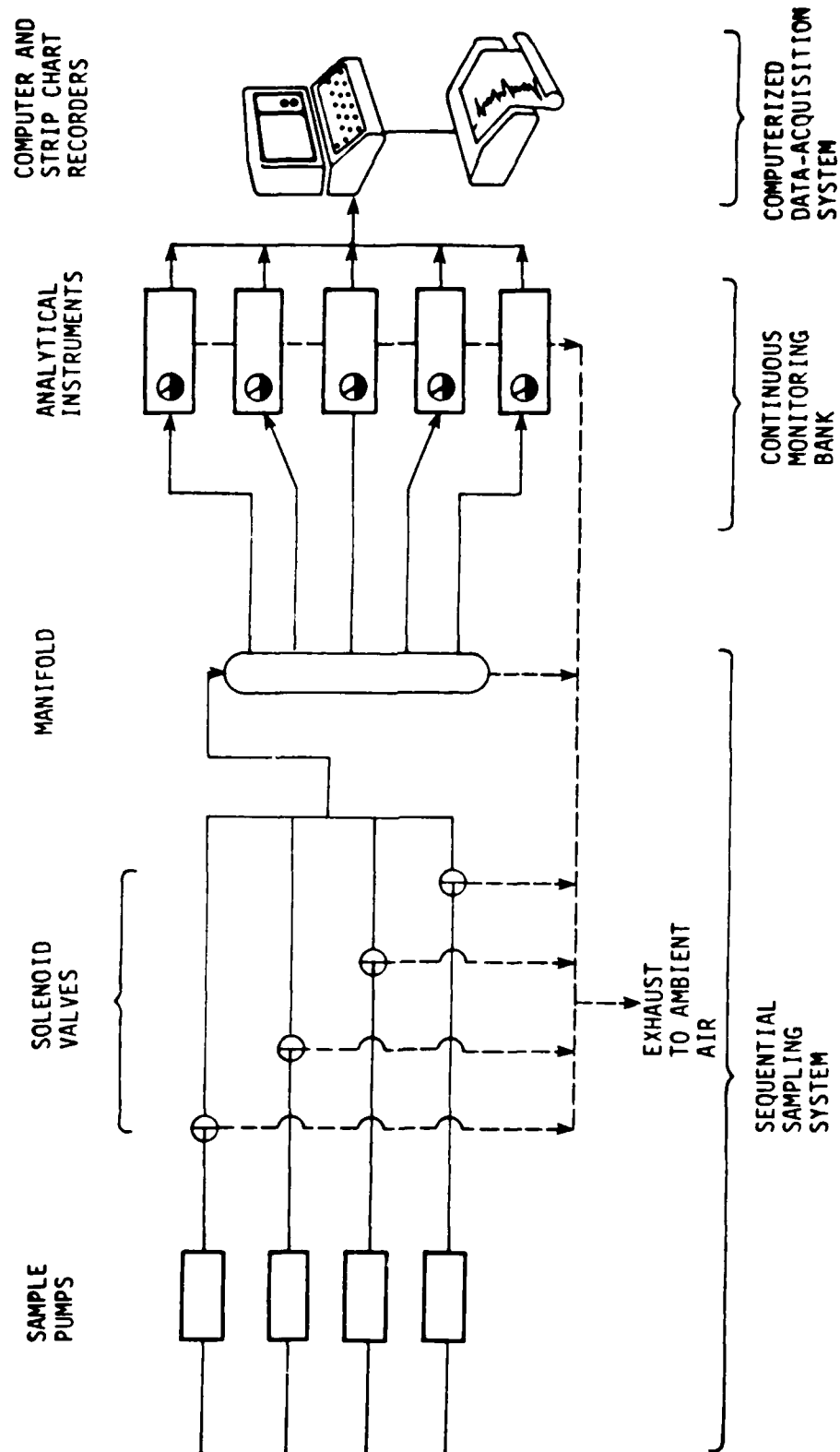


Figure 2. Sampling system for continuous monitors.

laboratory each sample line was connected to a two-way solenoid valve. The solenoid is open when in an unactivated condition and is then purging the sampling lines. Each valve setting is activated by the programmed data-acquisition system in a predetermined time sequence. Prior to activation, the valve to the manifold is closed and the valve to the exhaust is opened, thus allowing a constant flow of sample air through the sample lines. Upon activation, the valve to the exhaust is closed and the valve to the manifold is opened. Sample air is passed through the manifold at a rate of 10 liters/min. This system permits the air in the manifold to be changed at least once every 5 seconds. The analytical instruments then draw air from the manifold. After a 5-minute sampling period, the computer activates the valves on the next sampling line, while returning the first sample line to a purge condition. This process is repeated for the remaining sample locations, four in all, resulting in a sampling cycle time of 20 minutes. Thus, three 5-minute samples are obtained each hour for all gaseous pollutants at each of the locations.

In addition to the monitoring of magazine air, the data on the velocity through each magazine's ventilation duct were collected and stored by the computer system. Wind speed, wind direction, and temperature in and out of the magazines were recorded on strip charts.

A description of each continuous monitoring instrument and its limits of detection are presented in the following subsections.

#### Sulfur Dioxide--

A Beckman Model 953 fluorescent analyzer was used for the continuous monitoring of  $\text{SO}_2$ . The measurement principle of this instrument is based on the fluorescence of  $\text{SO}_2$  molecules when irradiated with ultraviolet light. Operating ranges of 0 to 1.0, 0 to 20.0, and 0 to 6.0 ppm  $\text{SO}_2$  were obtained with a minimum detection limit of 0.005, 0.010, and 0.030 ppm respectively. This instrument is certified by the U.S. Environmental Protection Agency (EPA) as a reference method for the measurement of sulfur dioxide.

#### Carbon Dioxide--

An Infrared Industries, Inc., Model 703-352 gas analyzer was used for the continuous monitoring of  $\text{CO}_2$ . The measurement principle of this instrument is based on absorption of infrared radiation by  $\text{CO}_2$ . Initially an operating range of 0 to 60,000 ppm or 0 to 6 percent  $\text{CO}_2$  was used during the testing (November 29 through December 2). Because only very low  $\text{CO}_2$  values were observed, however, the instrument was recalibrated on December 5 to a range of 0 to 42,000 ppm or 0 to 4.2 percent  $\text{CO}_2$ . The instrument has a minimum detection limit of 50 ppm.

#### Total Hydrocarbons--

A Meloy Model HC 500-2C analyzer was used for the continuous monitoring of THC. The measurement principle of this instrument is based on the ionization of hydrocarbon molecules in a hydrogen hyperventilated flame. An operating range of 0 to 1,000 ppm THC was used during the first two days of monitoring.

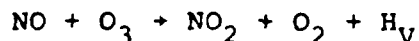
When only very low THC levels were observed, the instrument was recalibrated and run at a 0 to 50 ppm THC range (with a minimum detection limit of 0.1 ppm). The hydrocarbon analyzer was calibrated with propane gas concentrations and reported as parts per million total carbon (1 ppm propane is 3 ppm total carbon).

#### Carbon Monoxide--

A Bendix Model 8501-5CA analyzer was used for the continuous monitoring of CO. The measurement principle of this instrument is based on the absorption of infrared radiation by CO in a nondispersive photometer. An operating range of 0 to 50 ppm CO was achieved with a minimum detection limit of 0.5 ppm. This instrument is certified by the U.S. EPA as a reference method for the measurement of carbon monoxide.

#### Oxides of Nitrogen--

A Bendix 8101-B chemiluminescent analyzer was used for the continuous monitoring of NO and NO<sub>2</sub>. The measurement principle of this instrument is based on the chemiluminescent reaction between NO and ozone (O<sub>3</sub>) according to the reaction:



Light emissions result when the electronically excited NO<sub>2</sub> molecules revert to their ground state. A catalytic converter is used to convert NO<sub>2</sub> present in the air sample to NO before it enters the reaction chamber. The amount of NO<sub>2</sub> is then determined by subtracting the NO measurement from the NO<sub>x</sub> measurement. The analyzer provides automatic cycling through the NO

and NO<sub>x</sub> measurements, and the output difference (NO<sub>2</sub>) is updated after each cycle. The initial operating ranges used during the testing were 0 to 0.5, 1, and 2 ppm; with a minimum detection limit of 0.005 ppm. Because oxides of nitrogen concentrations above 2.0 ppm were observed, the instrument was adjusted to read concentrations up to 8.5 ppm during the second day of loading/unloading operations. During warehousing operations the instrument range was increased to 17.5 ppm full scale (December 13, 14, and 15). This instrument is certified by the EPA as a reference method for the measurement of oxides of nitrogen.

#### DATA COLLECTION

Continuous and breathing zone data were collected for both loading/unloading and warehousing operations in two ammunition storage magazines. The tests were conducted over a 16-day period starting on November 29, 1983, and ending on December 15, 1983. The continuous and breathing zone data were taken to characterize 9 days of loading/unloading operations and 3 days of warehousing operations.

The typical loading/unloading operation was accomplished by unloading a full magazine containing 404 pallets of 90mm ammunition with one forklift, transferring the load to a second forklift, and then loading an adjacent empty magazine. The mean time for accomplishing a loading/unloading operation was 8 hours and 5 minutes; the best time was 7 hours and 20 minutes, and the worst-case time was 9 hours and 35 minutes. The worst-case time occurred on the first day of testing and probably reflects some

confusion and unfamiliarity on the part of the forklift operators while adjusting to the demands of the investigation. The best time reflects the action of an experienced team of forklift operators.

The typical warehousing operation was accomplished by transferring supplies with a single forklift vehicle within a single magazine. The duration of a warehousing operation will vary greatly, depending on the purpose of the operation and the extent of reorganization that is needed. The warehousing tests performed during this investigation averaged 3 hours and 55 minutes in duration; the minimum time was 3 hours and 20 minutes, and the maximum time was 4 hours and 15 minutes.

### III. RESULTS

Two diesel-powered forklift trucks were the primary focus of the testing effort: a Still forklift powered by a Deutz (F3L912W) engine and a Hyster forklift powered by a Perkins (4.2032) engine. However, two other forklift trucks were also tested: a Baker forklift powered by a Deutz (F3L912W) diesel engine and a Hyster forklift powered by a Perkins (4.154) diesel engine. Funding constraints prevented the reduction and analysis of data from the secondary vehicles. The raw data from both the primary and secondary vehicles are presented in Appendix B at the end of the report.

During the loading/unloading operations and the first four warehousing tests (Tests 1 through 4), the vehicles fired a Phillips D-2 Diesel Fuel (Control Lot C-929) containing 0.4 percent sulfur. During the last warehousing test (Test 5), a high-sulfur fuel (MIL-F-46162B) containing 1.02 percent sulfur was substituted in each of the vehicles.

During this testing effort, only one loading or unloading operation could be conducted each day. This limitation made it impossible to run simultaneous loading and unloading activities with the two makes of forklifts. This constraint prevented the investigators from obtaining indoor air quality data under identical conditions of weather and magazine ventilation. To reduce the influence of changes in weather and ventilation, we have



selected only those test days with similar weather conditions (i.e., ambient wind speed) for discussion in this report. As a result of this screening process, only five days of test data were available for in-depth analysis. Two of the test days present the impact on indoor air quality during the operation of the Still/Deutz vehicle, whereas the other three days present the impact during operation of the Hyster/Perkins vehicle. Although the five days of data represent information collected under similar conditions, the conditions were not identical. Based on an analysis of variance, the variances in the daily air velocity measurements taken at magazine ventilation ducts were found to be significantly different ( $P < 0.05$ ). The importance of this difference is obscured by the fact that air flow through the magazines ventilation duct may be secondary to the effect of air exchanges at the magazine entrance.

The data obtained during the unloading activities are considered to be only suggestive of the relative performance of the two diesel-powered forklift trucks. The test results do provide information on the absolute performance of each vehicle under the given test conditions.

To determine the relative performance of these vehicles, we monitored magazine air quality during warehousing operations. The nature of the warehousing operations permitted the testing of both vehicles on the same day, in adjacent magazines, under identical weather and ventilation conditions. These test conditions allowed a direct comparison to be made of vehicle emissions and permitted the statistical treatment of the continuous monitoring data.

#### BREATHING ZONE SAMPLES

Breathing zone air samples representative of vehicle driver and helper exposures were taken during each of the loading/unloading operations. Only air samples representative of the drivers' exposures were taken during warehousing operations. From the results of these air samples, time-weighted averages were determined for comparison with OSHA permissible exposure limits.

Table 3 summarizes the exposure of drivers and helpers to diesel exhaust during five unloading activities. Only three of the exhaust components monitored are reported: particulates, sulfates, and nitrogen dioxide. Polycyclic aromatic hydrocarbons (PAH), CO, and SO<sub>2</sub> were not captured in sufficient amounts for detection by the sampling and analytical methods used. Carbon dioxide was not detected because of the failure of the direct-reading passive dosimeter to respond at the sub-zero temperatures experienced during the tests.

Table 4 summarizes the exposure of drivers to diesel exhaust during warehousing operations while operating forklifts using low-sulfur (0.4 percent) fuel. Again, only data on particulates, sulfates, and nitrogen dioxide were reported. The other exhaust components measured during the breathing zone monitoring were at levels below the detection limits of the sampling and analytical methods used.

Table 5 presents the TWA's for a single driver exposed to diesel exhaust during an entire warehousing operation while operating forklifts using high-sulfur (1.02 percent) fuel. Only

TABLE 3. BREATHING ZONE EXPOSURES DURING UNLOADING OPERATIONS

	Test date (1983)	Vehicle	Time-weighted average, <sup>a</sup>	
			Driver	Helper
Particulates	12/1 12/5	Still/Deutz Still/Deutz	(mg/m <sup>3</sup> )	
			0.05 0.12	<0.01 <0.01
	12/6 12/7 12/8	Hyster/Perkins Hyster/Perkins Hyster/Perkins	<0.01	0.10
			<0.01	0.15
			<0.01	<0.01
Total sulfates	12/1 12/5	Still/Deutz Still/Deutz	(μg/m <sup>3</sup> )	
			46 <10	<10 22
	12/6 12/7 12/8	Hyster/Perkins Hyster/Perkins Hyster/Perkins	<10	<10
			<10	18
			<10	18
Nitrogen dioxide	12/1 12/5	Still/Deutz Still/Deutz	(ppm)	
			<0.1 <0.1	0.6 0.1
	12/6 12/7 12/8	Hyster/Perkins Hyster/Perkins Hyster/Perkins	<0.1	0.2
			<0.1	<0.1
			<0.1	<0.1

<sup>a</sup> Time-weighted averages with "less than" signs indicate that the breathing zone samples collected were below the minimal detection of the method.

TABLE 4. BREATHING ZONE EXPOSURES DURING WAREHOUSING OPERATIONS  
USING LOW-SULFUR FUEL

	Test	Test date (1983)	Time-weighted average, <sup>a</sup>	
			Vehicle	Driver
Particulates	1	12/13	Still/Deutz Hyster/Perkins	(mg/m <sup>3</sup> ) <0.01 0.82
	2	12/13	Still/Deutz Hyster/Perkins	0.71 0.69
	3	12/14	Still/Deutz Hyster/Perkins	0.66 1.52
	4	12/14	Still/Deutz Hyster/Perkins	0.98 1.03
Total sulfates	1	12/13	Still/Deutz Hyster/Perkins	(ug/m <sup>3</sup> ) <10 <10
	2	12/13	Still/Deutz Hyster/Perkins	<10 30
	3	12/14	Still/Deutz Hyster/Perkins	<10 32
	4	12/14	Still/Deutz Hyster/Perkins	<10 <10
Nitrogen dioxide	1	12/13	Still/Deutz Hyster/Perkins	(ppm) 0.9 0.2
	2	12/13	Still/Deutz Hyster/Perkins	<0.1 0.6
	3	12/14	Still/Deutz Hyster/Perkins	0.9 3.2 <sup>b</sup>
	4	12/14	Still/Deutz Hyster/Perkins	1.8 0.3

<sup>a</sup> Time-weighted averages with "less than" signs indicate that the breathing zone samples collected were below the minimal detection limit of the method.

<sup>b</sup> Concentration is above the ACGIH threshold limit value (TLV) of 3 ppm for nitrogen dioxide.

TABLE 5. BREATHING ZONE EXPOSURES DURING WAREHOUSING OPERATIONS  
USING HIGH-SULFUR FUEL

	Test date (1983)	Vehicle	Time-weighted average <sup>a</sup>
			Driver
Particulates	12/15	Still/Deutz Hyster/Perkins	(mg/m <sup>3</sup> )
			0.95 1.33
Total sulfates	12/15	Still/Deutz Hyster/Perkins	(µg/m <sup>3</sup> )
			<10 24
Nitrogen dioxide	12/15	Still/Deutz Hyster/Perkins	(ppm)
			0.49 0.37

<sup>a</sup> Time-weighted averages with "less than" signs indicate that the breathing zone samples collected were below the minimal detection limit of the method.

levels of particulate, sulfates, and nitrogen dioxide were found above the detection limits of the methods used. These values may represent a worst-case scenario since it is likely that during real warehousing operations more than one driver would be involved in the operation of a single forklift truck during any given operation. During the test the Army utilized two drivers for each vehicle, resulting in each driver being exposed to diesel emission for a duration equal to approximately half the test period.

#### CONTINUOUS AIR MONITORING

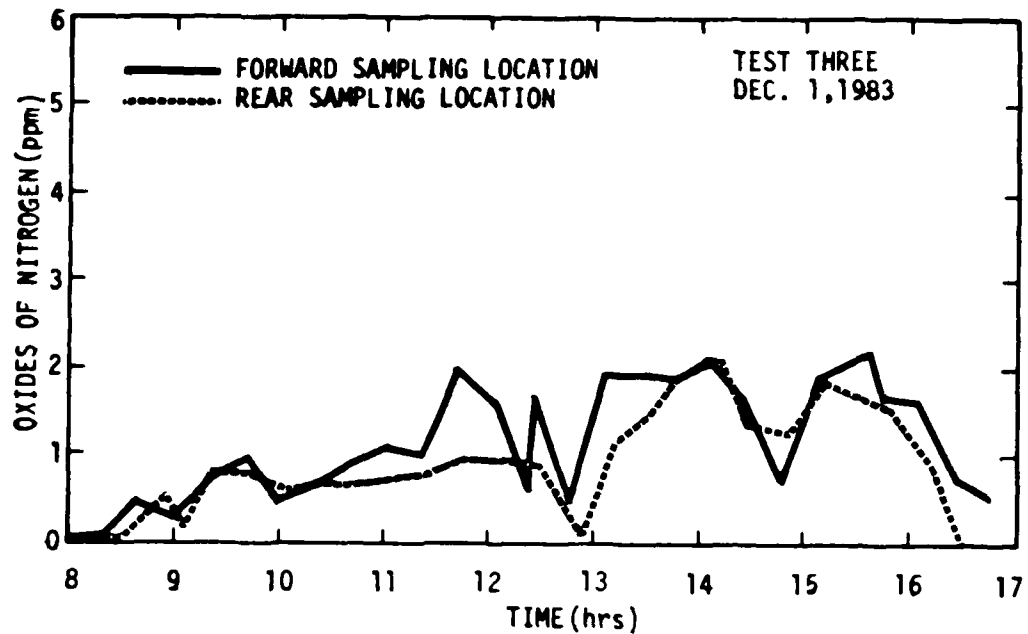
Continuous air monitoring was conducted during both the loading/unloading and warehousing operations. The results were compiled for both operations for each of the two vehicles tested. The data are presented in both graphic and tabular format. The graphic presentation consists of time-concentration profiles for each of the measured exhaust components during selected tests. The tabular format presents a summary of the mean and peak concentrations measured during the five unloading and five warehousing tests. Unloading operations are of greater interest than loading operations for two reasons 1) test data indicate that the unloading phase is likely to produce greater peak concentrations and 2) continuous unloading operations are more reflective of a real event likely to be required of vehicles and personnel during wartime. Warehousing operations are of interest because they appear to represent a worst-case scenario for using diesel-powered forklift trucks. The tables also present the results of

a statistical test for significant differences between the groups of air quality data measured during the operation of the two forklift vehicles.

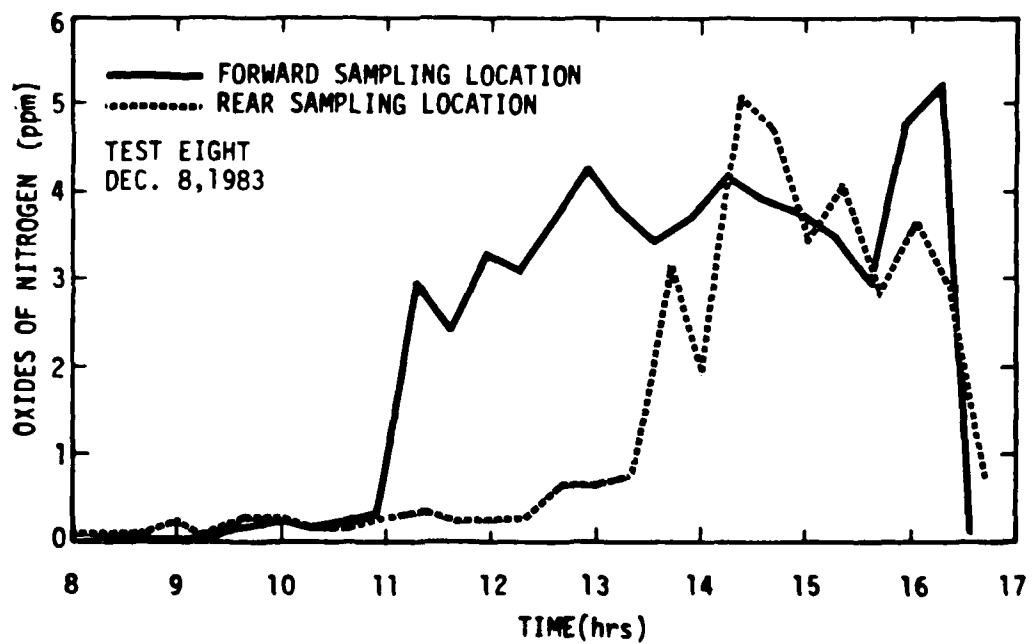
Figures 3 through 7 present example time-concentration profiles of unloading activities for the Still/Deutz and Hyster/Perkins vehicles. These figures summarize indoor air quality measured on the December 1 and December 8, test dates. In each figure, the duration of the loading activity (in military time) is presented along the abscissa of the profile, and the change in concentration (in ppm) of the exhaust component is presented along the ordinate.

The paired profiles presented in each figure summarize indoor air quality measured at each of the two locations within the magazine. One location (designated "forward") is situated approximately one-third the way into the magazine. The second location (designated "rear") is situated approximately two-thirds the way into the magazine. Both openings to the sample lines are located at approximately the centerline of the magazine, 2 feet below the magazine ceiling. Each time-concentration profile begins at the time of the test startup, just as the vehicles enter the ammunition magazines; the profiles end when unloading activity is completed.

Figures 8 through 12 present time-concentration profiles for a representative warehousing test. The profiles of both vehicles are presented for each exhaust component monitored during Warehousing Test 2, which was conducted on December 13. Only one



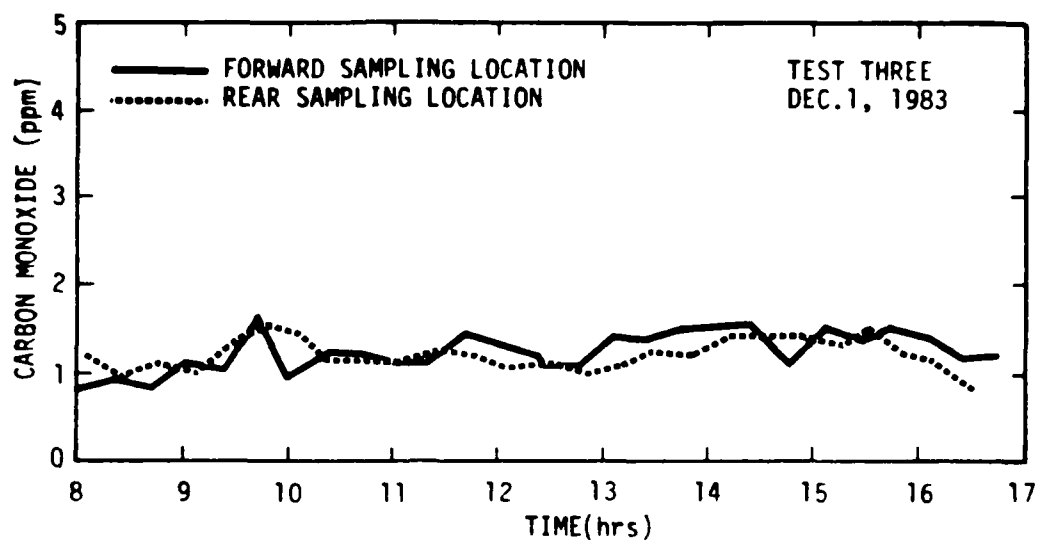
a. Still/Deutz forklift



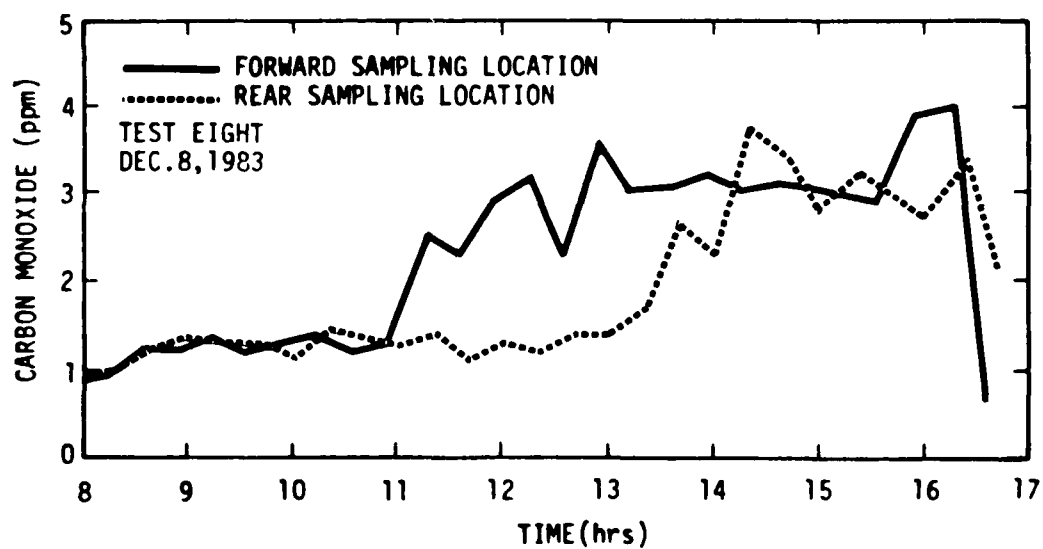
b. Hyster/Perkins forklift

Figure 3. Time-concentration profiles of oxides of nitrogen during magazine unloading activities.



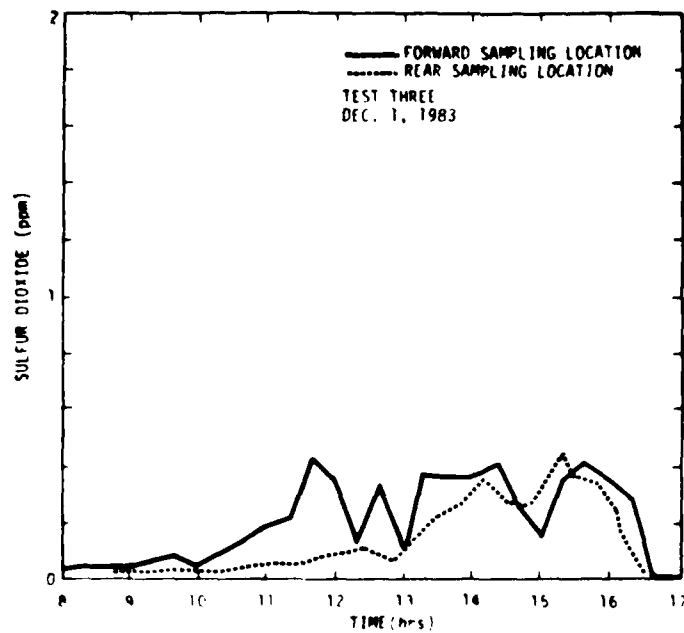


a. Still/Deutz forklift

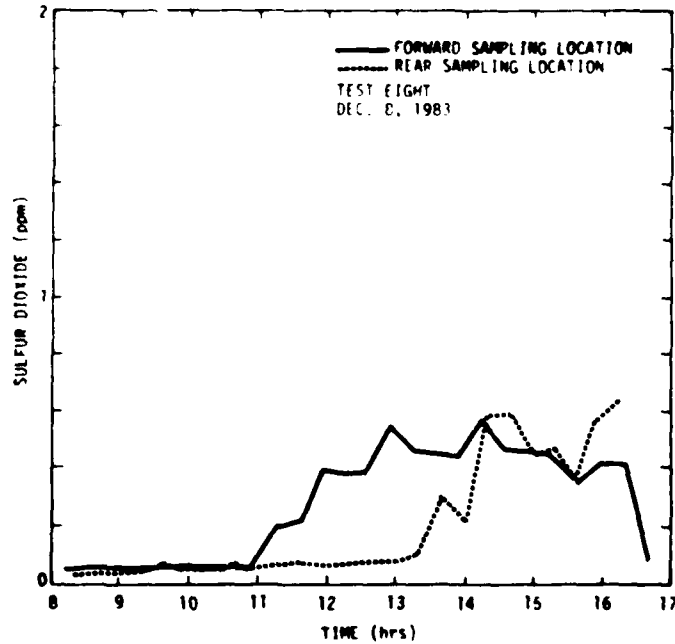


b. Hyster/Perkins forklift

Figure 4. Time-concentration profiles of carbon monoxide during magazine unloading activities.

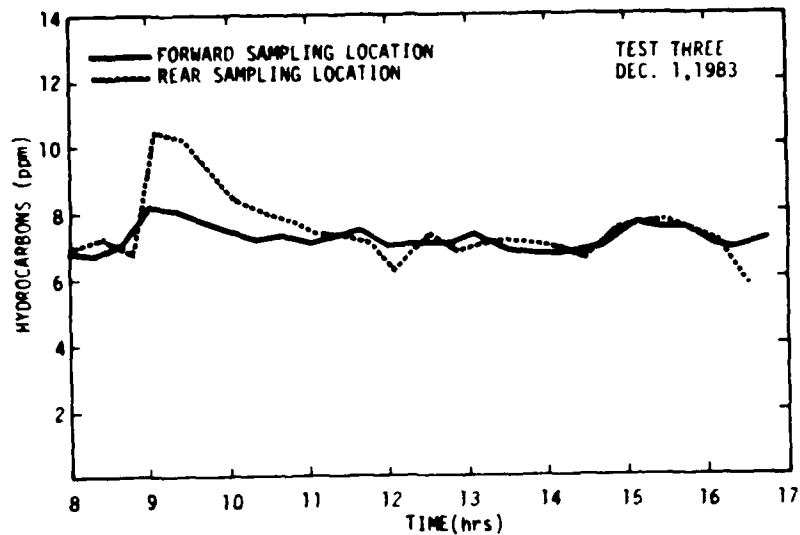


a. Still/Deutz forklift

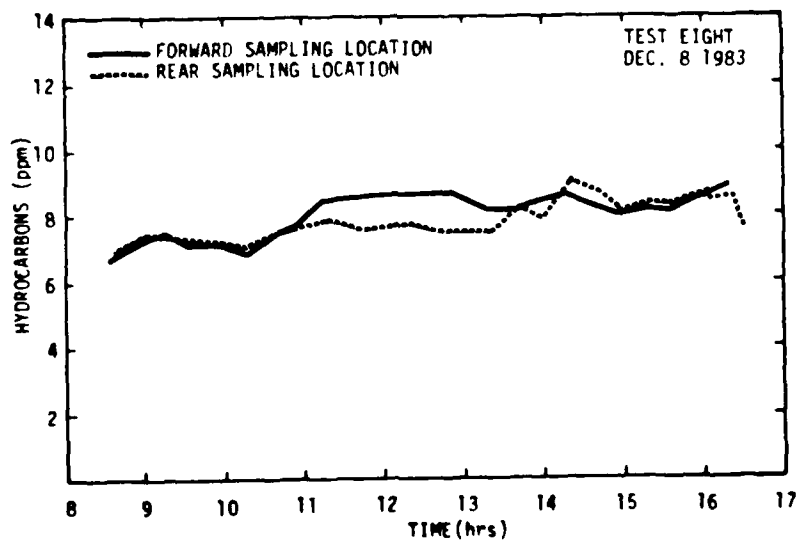


b. Hyster/Perkins forklift

Figure 5. Time-concentration profiles of sulfur dioxide during magazine unloading activities.

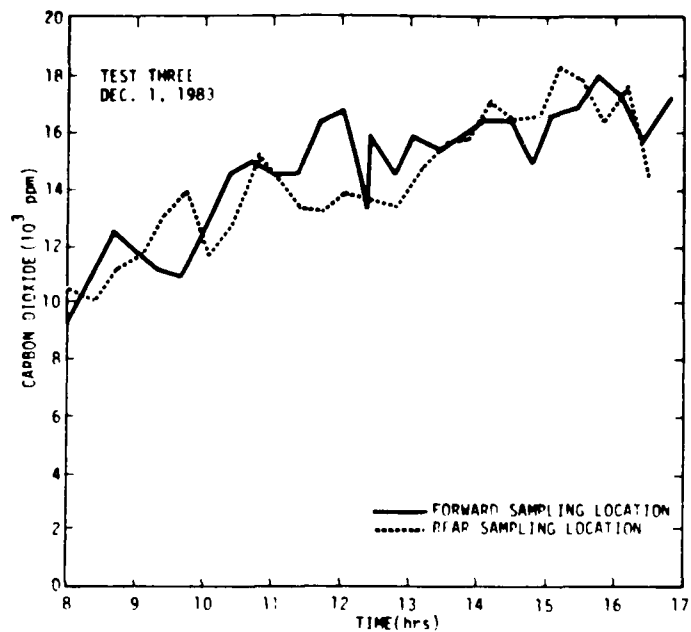


a. Still/Deutz forklift

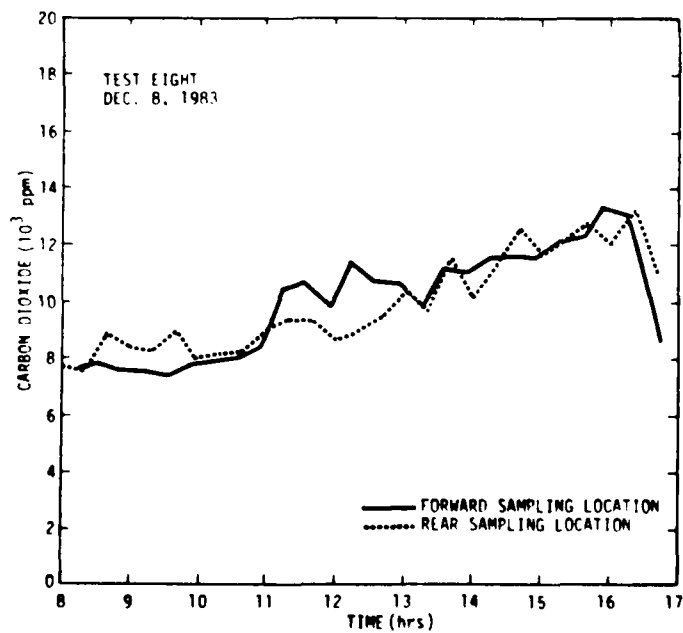


b. Hyster/Perkins forklift

Figure 6. Time concentration profiles of hydrocarbons during magazine unloading activities.

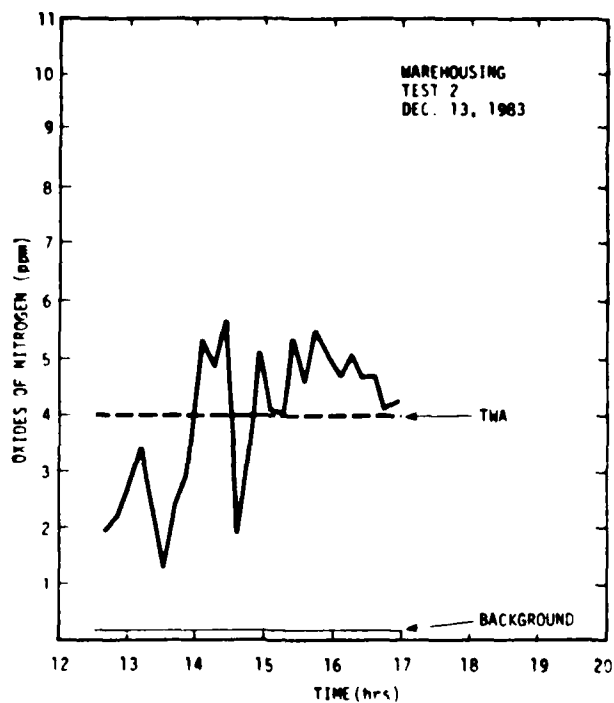


a. Still/Deutz forklift

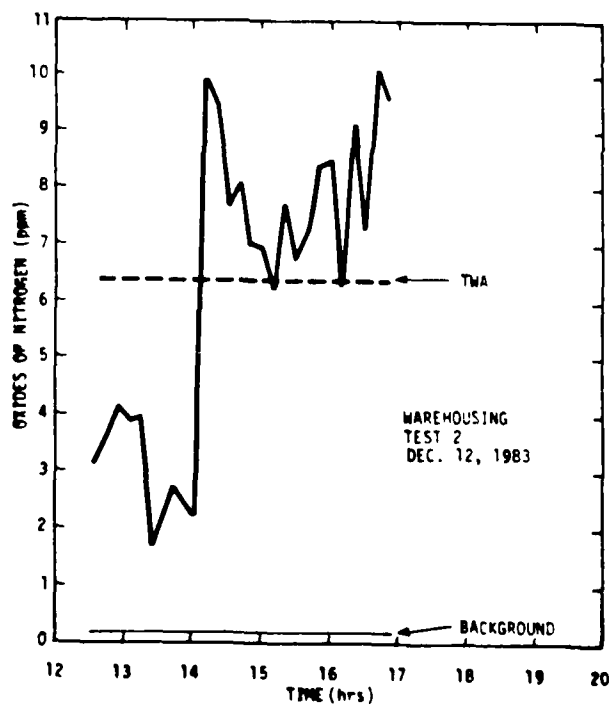


b. Hyster/Perkins forklift

Figure 7. Time concentration profiles of carbon dioxide during magazine unloading activities.

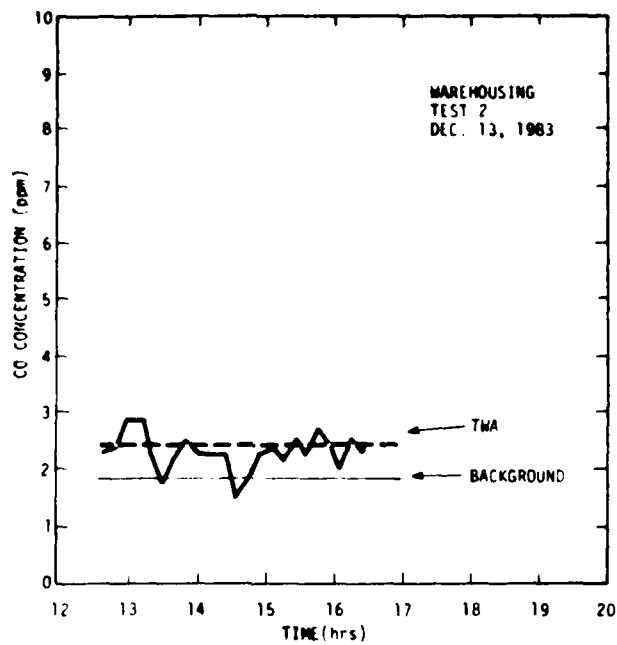


a. Still/Deutz forklift

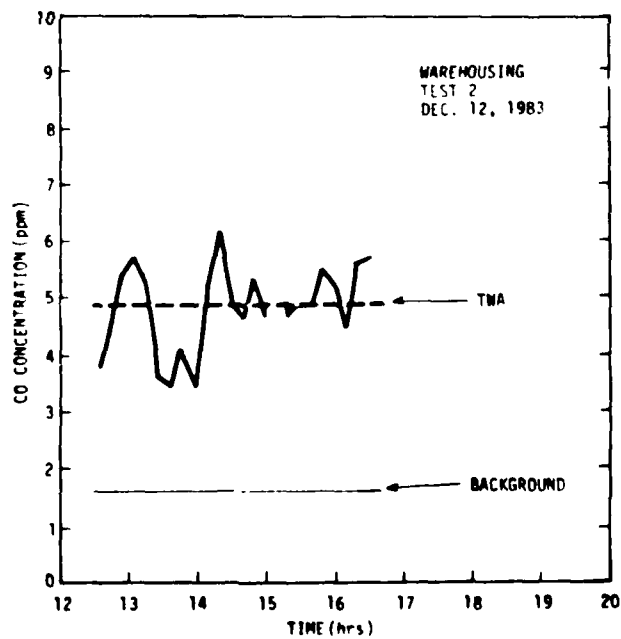


b. Hyster/Perkins forklift

Figure 8. Time-concentration profiles of oxides of nitrogen during magazine warehousing activities.

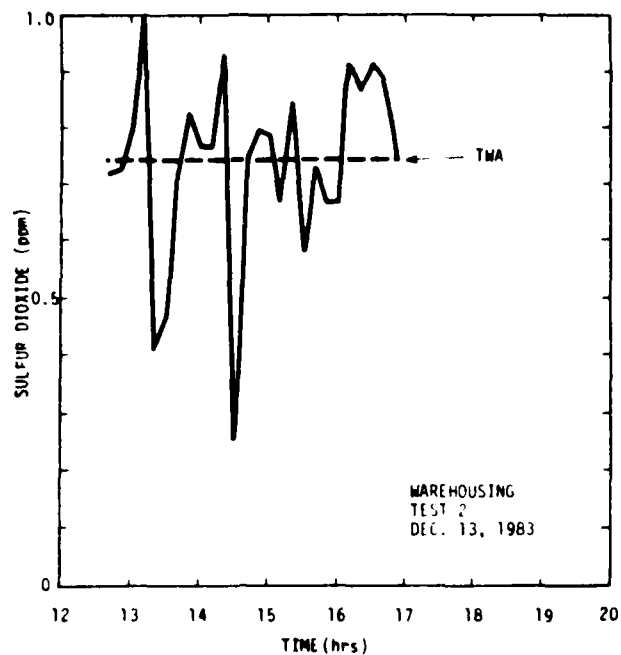


a. Still/Deutz forklift

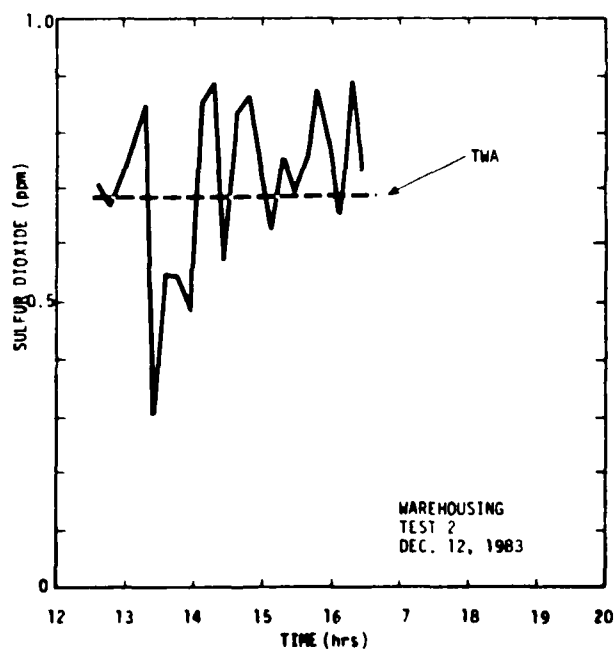


b. Hyster/Perkins forklift

Figure 9. Time-concentration profiles of carbon monoxide during magazine warehousing activities.

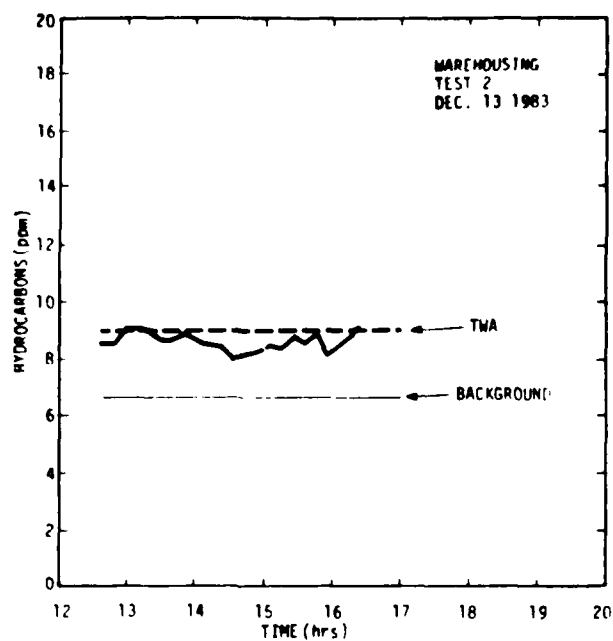


a. Still/Deutz forklift

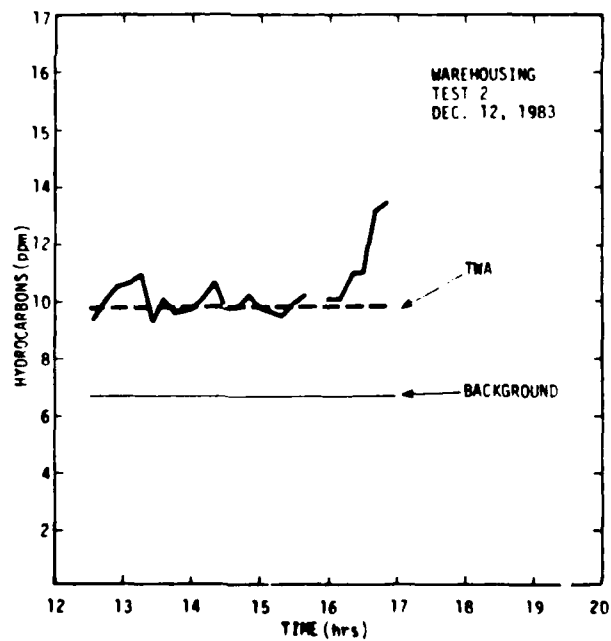


b. Hyster/Perkins forklift

Figure 10. Time-concentration profiles of sulfur dioxide during magazine warehousing activities.



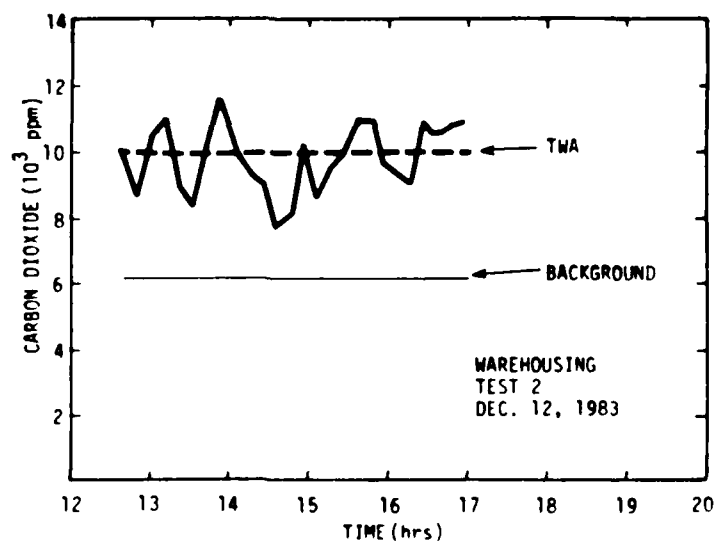
a. Still/Deutz forklift



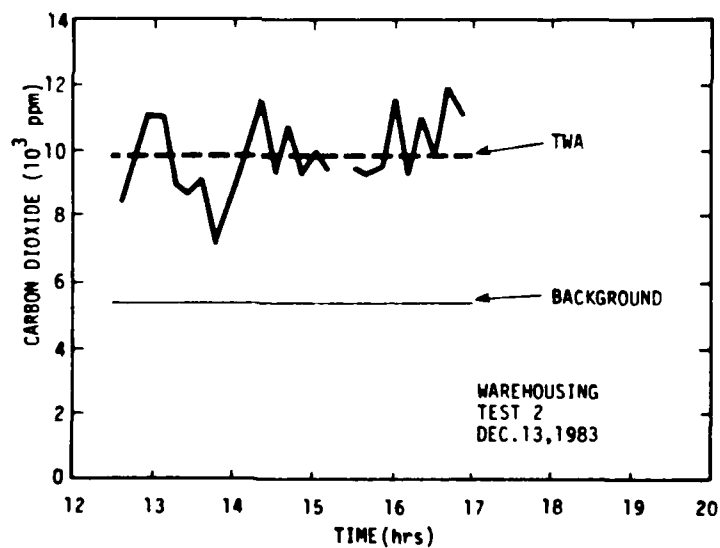
b. Hyster/Perkins forklift

Figure 11. Time-concentration profiles of hydrocarbons during magazine warehousing activities.





a. Still/Deutz forklift



b. Hyster/Deutz forklift

Figure 12. Time-concentration profiles of carbon dioxide during magazine warehousing activities.

profile (data from the "forward" location) is presented in each figure because the monitoring was limited to one sampling location during the warehousing tests. Because the warehousing activities had the greatest impact on air quality, the mean concentration (estimated TWA) is presented for each profile. The background concentration measured for each pollutant on the day before testing is also indicated on the time-concentration profile.

Tables 6 through 8 present summaries of the continuous monitoring data collected during the five tests of unloading activities and the five tests of warehousing operations. Results are presented for each exhaust component by test date and vehicle. The number of samples taken, the mean concentration during the test (estimated TWA), and the peak concentration observed during the test are reported. Also reported is the time to peak as calculated from the beginning of the test, i.e., 7:05 indicates that the peak occurred 7 hours and 5 minutes after the beginning of the test. Table 6 presents a summary of indoor air quality measured during the unloading activities. Table 7 presents a summary of the indoor air quality during warehousing operations conducted with forklifts using the lower-sulfur fuel. Table 8 presents the same activity with forklifts using high-sulfur fuel. Although two warehousing operations were performed during the test of high-sulfur fuels, only data from the second test are presented. The results of the first test are considered invalid because the vehicles were not supplied with fuel having an

TABLE 6. SUMMARY OF INDOOR AIR QUALITY DURING UNLOADING ACTIVITIES

	Test date (1983)	Vehicle	Concentration (ppm)			Time to peak (hour:min.)
			n	Mean	Peak	
Oxides of nitrogen	12/1	Still	49	1.132	2.155	7:05
	12/5	Still	43	1.726	2.910	4:00
	12/6	Hyster	46	2.506	6.070	5:40
	12/7	Hyster	49	2.646	8.861	5:00
	12/8	Hyster	49	2.018	5.379	7:40
Carbon monoxide	12/1	Still	49	1.2	1.6	0:80
	12/5	Still	43	1.6	2.2	3:00
	12/6	Hyster	46	1.9	3.3	3:20
	12/7	Hyster	49	3.3	21.4	4:40
	12/8	Hyster	49	2.2	4.0	7:40
Sulfur dioxide	12/1	Still	49	0.195	0.447	6:25
	12/5	Still	43	0.264	0.474	5:15
	12/6	Hyster	46	0.191	0.507	3:20
	12/7	Hyster	49	0.349	1.974	5:00
	12/8	Hyster	49	0.247	0.640	7:40
Hydrocarbons	12/1	Still	49	7.4	10.4	0:20
	12/5	Still	43	7.8	14.5	0:80
	12/6	Hyster	46	7.5	8.5	7:00
	12/7	Hyster	42	8.5	15.4	4:40
	12/8	Hyster	49	7.9	9.0	5:40
Carbon dioxide	12/1	Still	49	1474	1822	6:25
	12/5	Still	37	733	866	3:40
	12/6	Hyster	46	905	1097	3:40
	12/7	Hyster	49	801	1349	5:00
	12/8	Hyster	49	1010	1332	7:20

TABLE 7. SUMMARY OF INDOOR AIR QUALITY DURING WAREHOUSING OPERATIONS  
WITH FORKLIFTS USING LOW-SULFUR FUEL

	Test date (1983)	Test	Vehicle	n	Concentra- tion (ppm)		Time to peak (hour:min.)
					Mean	Peak	
Oxides of nitrogen	12/13	1	Still	13	3.583	5.086	0:30 <sup>a</sup>
			Hyster	15	5.096	8.567	1:00
		2	Still	26	3.925	5.661	1:45 <sup>a</sup>
			Hyster	26	6.327	10.066	4:15
	12/14	3	Still	26	4.792	6.759	4:00 <sup>a</sup>
			Hyster	26	8.025	11.122	1:30
		4	Still	24	5.624	7.843	1:30 <sup>a</sup>
			Hyster	24	7.167	11.015	0:40
Carbon monoxide	12/13	1	Still	14	2.0	2.7	0:50 <sup>a</sup>
			Hyster	15	3.8	5.3	0:60
		2	Still	25	2.4	4.5	3:45 <sup>a</sup>
			Hyster	24	4.8	6.2	1:55
	12/14	3	Still	26	2.6	3.1	0:50 <sup>a</sup>
			Hyster	26	5.4	7.1	3:15
		4	Still	24	3.6	4.4	1:30 <sup>a</sup>
			Hyster	24	5.2	6.8	0:40
Sulfur dioxide	12/13	1	Still	14	0.498	0.668	0:40
			Hyster	15	0.539	0.788	2:00
		2	Still	25	0.712	0.998	0:30
			Hyster	25	0.692	0.886	3:35
	12/14	3	Still	25	0.691	0.918	4:00
			Hyster	26	0.753	1.008	3:10
		4	Still	24	0.936	1.425	1:30
			Hyster	24	0.694	1.016	0:10 <sup>a</sup>
Hydrocarbons	12/13	1	Still	14	8.6	9.5	0:50 <sup>a</sup>
			Hyster	15	9.6	10.6	0:60
		2	Still	25	8.6	9.9	3:55 <sup>a</sup>
			Hyster	24	9.9	11.0	4:05
	12/14	3	Still	26	8.5	9.2	2:10 <sup>a</sup>
			Hyster	27	10.2	11.2	2:00
		4	Still	24	8.9	9.8	2:00 <sup>a</sup>
			Hyster	24	10.2	10.8	1:40
Carbon dioxide	12/13	1	Still	14	870	1067	0:10
			Hyster	15	830	977	1:00
		2	Still	26	989	1111	4:15
			Hyster	25	991	1189	4:05
	12/14	3	Still	26	1288	1539	0:50
			Hyster	26	1300	1507	1:30
		4	Still	24	1526	1761	3:30
			Hyster	24	1352	1523	0:10 <sup>a</sup>

<sup>a</sup> Air quality impact of this vehicle was found to be significantly lower than the other test vehicle ( $p < 0.05$ ).

TABLE 8. SUMMARY OF INDOOR AIR QUALITY DURING WAREHOUSING OPERATIONS  
WITH FORKLIFTS USING HIGH-SULFUR FUEL

	Test date (1983)	Vehicle	Concentra- tion (ppm)			Time to peak (hour:min.)
			n	Mean	Peak	
Oxides of nitrogen	12/15	Still	18	2.618	3.497	0:10 <sup>a</sup>
		Hyster	18	8.586	12.984	2:50
Carbon monoxide	12/15	Still	18	1.3	2.2	0:10 <sup>a</sup>
		Hyster	18	4.5	5.8	1:40
Sulfur dioxide	12/15	Still	18	1.246	1.643	1:10 <sup>a</sup>
		Hyster	18	1.829	2.863	2:50
Hydrocarbons	12/15	Still	18	8.7	9.3	1:50 <sup>a</sup>
		Hyster	18	10.7	11.9	1:40
Carbon dioxide	12/15	Still	18	1017	1215	0:10
		Hyster	18	1222	1501	1:40

<sup>a</sup> Air quality impact of this vehicle was found to be significantly lower than the other test vehicle ( $p < 0.05$ ).

idential sulfur content. Successful fueling of the vehicles prior to the second test was accomplished, and the data from this test are believed to reflect more equitable assessment of the diesel emission levels from the two test vehicles.

Tables 7 and 8 also present the results of a statistical analysis to test the significance of the difference between exhaust concentrations generated from the two test forklifts. The specific statistical tests used during this analysis are outlined in Appendix C.

#### LIMITATIONS OF THE DATA

A factor that may have confounded the indoor air quality data is the severe weather conditions experienced during the test period. Windspeeds outside the storage magazines were recorded at velocities ranging between 0 and 20 mph with gusts up to 30 mph. Ambient temperatures ranged between 12° and 40°F.

The weather conditions presented two problems in the interpretation and use of the test data. Windspeed directly affects the ventilation rate of the storage magazine by altering the volumetric flow of air through the magazine's passive system. The magnitude of the windspeed is believed to have influenced all test data to some degree because daily changes in the speeds frequently ranged between 5 and 15 mph. Increases in windspeed would significantly increase the ventilation of the magazines and retard the accumulation of diesel exhaust. The effect of elevated windspeed on the magazine ventilation certainly affected the

estimation of both mean indoor air quality and the TWA's and probably resulted in an underestimation of both the continuous monitoring and worker exposures.

The changes in windspeed were most detrimental to the utility of test data on the loading/unloading operations because the two forklift vehicles could not be tested while performing the same tasks on the same days. Because the nature of the warehousing operations allowed tests of both forklifts on the same day, the change in windspeed does not present a serious problem in the interpretation of the indoor air quality data taken during these operations.

The second problem associated with the weather related to the low temperatures experienced inside and outside of the magazines. Although it is not known what exact effect such extreme temperatures might have had on the vehicles, it is reasonable to assume that these conditions could have affected the performance of the test vehicles and therefore affected the indoor air quality of the magazines.

#### IV. CONCLUSIONS

The test results led to the following conclusions regarding the impact of diesel exhaust on magazine air quality:

- 1) The impact of diesel exhaust on breathing zone exposures and magazine air quality depends largely on the type of operation being performed. Of the two operating scenarios investigated (i.e., loading/unloading and warehousing), warehousing presents the greater potential risk to the health and safety of Army personnel.
- 2) Breathing zone exposures and magazine air quality data were compared with the OSHA permissible exposure levels and ACGIH threshold limit values. Under the operating conditions, ventilation, and temperature during the test, nitrogen dioxide is the only exhaust component of those measured that presents a potentially serious health risk to Army personnel.
- 3) The Still forklift powered by a Deutz (F3L912W) engine is clearly the cleaner of the two vehicles tested. Under the operating conditions, ventilation, and temperature during the tests, the Still/Deutz vehicle did not exceed any of the OSHA permissible exposure limits for the exhaust components measured.

#### CHARACTERIZATION OF DIESEL FORKLIFT IMPACT ON MAGAZINE AIR QUALITY

During the testing effort, the loading/unloading operation was broken down into separate activities. Indoor air quality was monitored during both loading and unloading activities with the Still/Deutz vehicle. The results indicated that although the time-concentration profiles of the two types of activity are separate and distinct, the average exhaust emission concentrations during these activities is not noticeably different. The data did indicate that the unloading phase of the operation was likely



to produce greater peak accumulations of exhaust emissions. The unloading phase presents the greatest concern because an all-out unloading effort is what is likely to occur when supporting a combat operation. A concentrated loading effort similar to the operation experienced during the tests is unlikely to occur.

Figure 13 presents hypothetical time-concentration profiles for each phase of the loading/unloading and warehousing operations. Although the profiles are highly idealized portrayals of the actual test data, they clearly illustrate the time-concentration characteristics of forklift operations. In the interest of focusing resources on those aspects of the testing most likely to yield useful results, an indepth analysis was performed only on data from the unloading phase.

A plot of the test data taken during the unloading phase of a loading/unloading operation is usually skewed to the right of the time-concentration profile because the forklift spends little time in the magazine during the movement of the first few ammunition pallets. As the unloading phase progresses, the forklift spends proportionately more of its operational time inside the magazine until, near the end of the phase, the truck has to travel the entire length of the magazine to get to the remaining pallets.

Conversely, the plot of test data taken during the loading phase is usually skewed to the left of the time-concentration profile because the forklift begins the loading phase by traversing the entire magazine with the first few pallets. As the

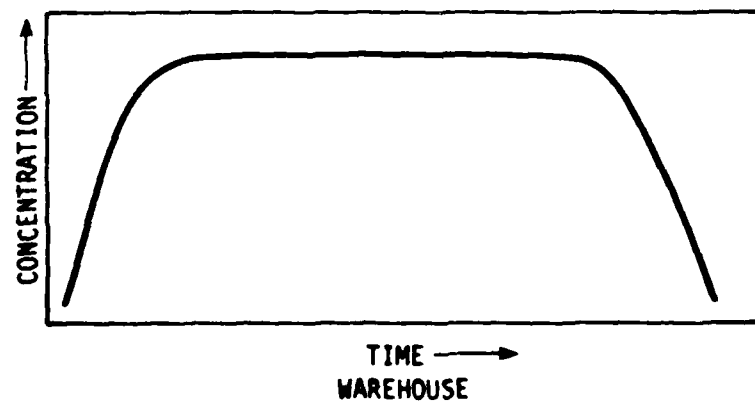
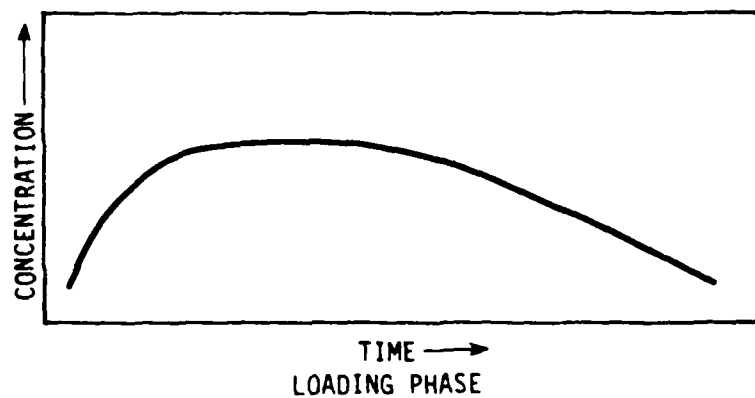
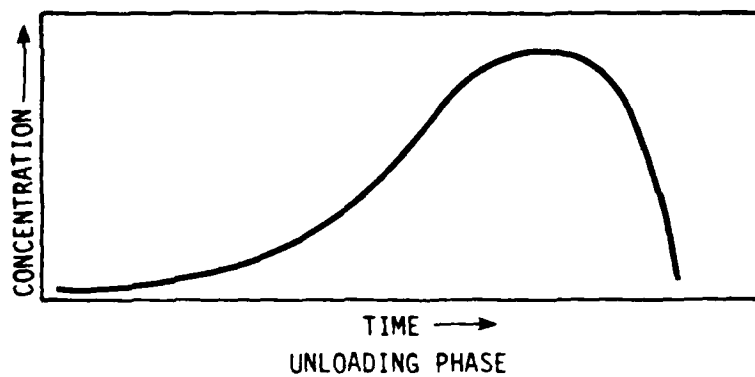


Figure 13. Hypothetical time-concentration profiles of loading, unloading, and warehousing operations.

loading phase progresses, the forklift spends less and less of its operating time inside the magazine.

Another important characteristic of these profiles is the similarity of the areas under the loading and unloading time-concentration curves; i.e., the mean air quality of each phase is approximately the same. The peak concentrations, although somewhat similar in magnitude, appear at different times. Peak concentrations during the unloading phase occur late in the operation, whereas peak concentrations in the loading phase are reached early in the operation.

Warehousing operations, which require the test vehicles to remain inside the magazine during the entire operation, have their own unique time-concentration profiles. Because the vehicles remain inside the magazine during the entire operation, the concentrations of exhaust emissions rise quickly and are sustained at higher levels than during the loading/unloading operations. Both the mean and peak concentrations that occur during warehousing operations are higher than those during loading/unloading operations of similar duration.

#### COMPARISON OF PERSONNEL EXPOSURES AND MAGAZINE AIR QUALITY WITH OSHA PERMISSIBLE EXPOSURE LIMITS

Two sources of information are available for use in judging the health risks associated with exposure to the diesel forklift exhausts: OSHA's permissible exposure limits (PEL's) and the ACGIH's threshold limit values (TLV's). Emphasis is placed on a comparison of the test results with the OSHA PEL's because these limits represent Federal health standards for the workplace. The

ACGIH TLV's are also of interest; although these limits are not binding regulations, they do represent what can be considered "good-practice" guidelines. The TLV's are exposure limits based upon the public health community's current knowledge of the effect of toxic substances on the workforce. The OSHA PEL's are different from the ACGIH TLV's in that, with a few exceptions, they represent the TLV's as interpreted in 1968. These 1968 TLV's were adopted by OSHA during the establishment of the Occupational Safety and Health Act of 1970. Table 9 summarizes the applicable exposure limits.

Based on the results of breathing zone monitoring conducted during the unloading activities and warehousing operations, the following conclusions can be drawn as to the health risks posed by each of the exhaust components monitored.

#### Particulates

The particulate exposures experienced by forklift drivers and helpers do not present a problem when interpreted as a nuisance dust. Under the worst conditions, the particulate exposures calculated as TWA's in Tables 3, 4, and 5 only begin to approach 10 percent of the OSHA standard and 15 percent of the TLV.

Exposures to the PAH's were below the detection limits of the sampling and analytical methods. Because the lack of data on exposure to PAH's is the result of a detection problem, we were unable to assess the health risk posed by these substances.

TABLE 9. EXPOSURE LIMITS FOR DIESEL EXHAUST COMPONENTS

Exhaust component	OSHA PEL <sup>a</sup> 8-h	ACGIH <sup>b</sup>	
		TWA 8-h	STEL 15-min
Particulate components			
Insoluble fraction			
Total nuisance dust	15 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>	-
Soluble fraction			
Polycyclic aromatic hydrocarbon (coal tar pitch volatiles)	0.2 mg/m <sup>3</sup>	0.2 mg/m <sup>3</sup>	-
Gaseous components			
Carbon monoxide	50 ppm	50 ppm	400 ppm
Carbon dioxide	5000 ppm	5000 ppm	15,000 ppm
Nitrogen dioxide	5 ppm	3 ppm	5 ppm
Sulfur dioxide	5 ppm	2 ppm	5 ppm
Sulfuric acid	1 mg/m <sup>3</sup>	1 mg/m <sup>3</sup>	-
Other components			
Total hydrocarbons	-		-
Odorants	-		-

<sup>a</sup> General Industry Safety and Health Standards - Toxic and Hazardous Substances. Code of Federal Regulations, Title 29, Chapter XVII, Part 1910, Subpart 2. 47 FR 51117. November 1982.

<sup>b</sup> TLV's - Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1983-84. ACGIH. Cincinnati, Ohio.

### Total Sulfates

The concentration of total sulfates was measured to obtain an estimate of the possible exposure of Army personnel to sulfuric acid. As in the case of TSP, exposure to sulfuric acid aerosols during the operation of diesel-powered forklifts should not present a health problem. Even if all the sulfates collected were assumed to represent airborne aerosols of sulfuric acid, the TWA exposures to this substance would be less than 5 percent of the OSHA standard and the TLV.

### Nitrogen Dioxide

Nitrogen dioxide appears to represent the only serious health risk to Army personnel involved in the types of ammunition handling operations tested. Detectable exposures to nitrogen dioxide ranged between 2 and 64 percent of the OSHA standard during unloading and warehousing activities. The largest TWA exposure occurred during a warehousing operation. Although this exposure level was only 64 percent of the OSHA standard, it exceeded the ACGIH threshold limit value for nitrogen dioxide.

Continuous monitoring for oxides of nitrogen indicates that the mean indoor air quality during unloading activities could reach levels equal to 53 percent of the OSHA standard for  $\text{NO}_2$ , with peak concentrations exceeding the ACGIH's short-term exposure limit (STEL). The oxides of nitrogen problem is more severe during warehousing operations; the mean concentration of these oxides was well in excess of the OSHA standard when interpreted as nitrogen dioxide (see Table 7). Although these test results indicate the potential for a serious health risk, the results of

the continuous monitoring for oxides of nitrogen cannot be compared directly with the OSHA PEL's or ACGIH TLV's for nitrogen dioxide because the continuous monitor reports data as total oxides of nitrogen (which include both NO and NO<sub>2</sub>). Although the NO<sub>2</sub> contribution to the total oxides of nitrogen (NO<sub>x</sub>) readings averaged about 10 to 20 percent, a review of the testing data (Appendix B) indicates that the contribution of NO<sub>2</sub> ranged from values as low as 1 percent to values as high as 50 percent of the NO<sub>x</sub> reading.

#### Carbon Monoxide

Carbon monoxide does not appear to present a serious health risk during these operations. Although initially of great concern, breathing zone measurements of carbon monoxide never exceeded any of the established standards or workplace limits. The breathing zone measurements taken were below the detection limit of the instrument. Continuous monitoring for CO during warehousing operations detected a few peak concentrations reaching values as high as 5 percent of the STEL.

#### Sulfur Dioxide

Sulfur dioxide levels were monitored by both breathing zone and continuous measurements. No breathing zone exposures were recorded because no levels were found above the detection limits of the sampling and analytical method.

The continuous monitoring data indicated that although the mean exposures to SO<sub>2</sub> were well below the OSHA standard and TLV, peak concentrations approach 30 percent of the STEL during warehousing operations when the forklifts burned low-sulfur fuel (see Table 7). Peaks approaching 60 percent of the STEL were detected

during similar operations when high-sulfur fuel was burned (see Table 8).

#### Carbon Dioxide

Carbon dioxide concentrations do not present a health risk to Army personnel during either unloading activities or warehousing operations. No carbon dioxide was found in amounts above the detection limit of the passive dosimeters used to determine breathing zone exposures.

The continuous monitoring instruments did detect CO<sub>2</sub>, but the levels were less than 30 percent of the OSHA standard and TLV.

#### Odorants

Samples of diesel exhaust were collected on Chromosorb 102 adsorbent for analysis using the Diesel Odor Analysis System (DOAS). However, due to delays in obtaining analytical standard reference solutions from the supplier, the analyses of the Chromosorb could not be performed within the time frame of the project. The chromosorb adsorbent has been archived in the PEDCo Environmental laboratory for future analysis.

It is unlikely that a future analysis of the Chromosorb will produce significant results since onsite subjective assessment of the odors levels by the testing team indicated that odors from unloading/loading and warehousing operations were slight or nondetectable.



## COMPARISON OF FORKLIFT EMISSION LEVELS

Comparison of emission levels from the two diesel-powered forklifts indicates that the Still forklift equipped with a Deutz (F3L912W) engine is the cleaner vehicle. Data collected during the warehousing activities and subjected to a statistical analysis (Appendix C) demonstrated that the impact on magazine air quality was significantly less when used with the Still/Deutz vehicle (see Tables 7 and 8).

The objective of the statistical analysis was to judge the relative "cleanliness" of the test forklifts by determining whether the difference in exhaust concentrations was significantly lower for one than for the other. Two sets of warehousing tests were analyzed; a set of four test runs in which both vehicles burned low-sulfur fuel and a single test run in which both vehicles burned high-sulfur fuel. The warehousing tests with low-sulfur fuel indicated the following:

- 1) The Still/Deutz vehicle was significantly cleaner than the Hyster/Perkins vehicle for oxides of nitrogen and carbon monoxide.
- 2) The Still/Deutz tested cleaner than the Hyster/Perkins in three of the four warehousing tests for total hydrocarbons. The remaining test for total hydrocarbons was inconclusive and showed no difference between the two vehicles.
- 3) The data on sulfur dioxide and carbon dioxide showed no significant difference between the two vehicles in three of the four tests. The last warehousing test indicated a significantly smaller contribution from the Hyster/Perkins vehicle.

The test results on warehousing operations with high-sulfur fuel were more conclusive:

- 1) The Still/Deutz operated significantly cleaner than the Hyster/Perkins vehicle with regard to emissions of oxides of nitrogen, carbon monoxide, sulfur dioxide, and hydrocarbons.
- 2) Only the test data on carbon monoxide indicated no significant difference between vehicle emissions.

## V. RECOMMENDATIONS

The current test results provide a data base from which to characterize the operation of diesel-powered forklifts during ammunition handling and storage activities in Stradley-type magazines. Also, the results have successfully characterized the relative performance of the two test vehicles and clearly identified the Still/Deutz (F32912W) diesel-powered forklift as the "cleaner-burning" vehicle. The absolute safety of the Still/Deutz vehicle, however, could not be firmly established from the test data.

Although no OSHA exposure limits were exceeded during the testing of the Still/Deutz vehicle, two facts associated with the test results prevent any final assessment: 1) levels of nitrogen dioxide and oxides of nitrogen, although not at concentrations in excess of the OSHA standard, were high enough to warrant concern; and 2) weather conditions were extreme enough to question the validity of using the test results to characterize more "normal" operating conditions. Specifically, test conditions during this investigation may have produced low estimates of indoor air quality. High windspeeds and low temperatures during the testing may have affected both magazine ventilation and engine performance in such a manner as to result in under estimation of the potential health risk involved.

To eliminate these areas of uncertainty associated with the operation of the Still/Deutz vehicle, PEDCo Environmental recommends that the Army consider an additional series of tests. These additional tests should be conducted with the objective of assessing the Still/Deutz forklift under the opposite weather conditions, i.e., low windspeed and high temperatures. At a minimum, breathing zone and continuous air monitoring data should be collected for nitrogen dioxide during the additional testing. In as much as the exact effects of windspeed and temperature on the other exhaust components cannot be determined with certainty, prudence would dictate that the more potent exhaust components (carbon monoxide, sulfur dioxide, and sulfuric acid) also be reassessed. Reassessment of particulates and polycyclic aromatic hydrocarbons, although not detected in any appreciable amounts during the initial test effort, should also be considered.

Carbon dioxide and total hydrocarbons can be dropped from future testing efforts. The current test results indicate that severe exposures to these substances are extremely unlikely.

A clear description of magazine ventilation could not be achieved during this investigation. Because ambient weather conditions (e.g., windspeed) can profoundly alter the ventilation of ammunition magazines, it would be useful to perform a detailed trace gas study of a Stradley-type magazine. Information obtained from such an investigation would be valuable in that it would allow the Army to extrapolate test results of indoor air quality in Stradley magazines to other magazine designs and other structures.

#### REFERENCES

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2. Lippman, M. and R. B. Schlensinger. Chemical Contamination in the Human Environment. Oxford University Press, New York. 1979.
3. Levins, P. L., et al. Chemical Analysis of Diesel Exhaust Odor Species. SAE Tech. Paper 740216, 1974.
4. General Industry Safety and Health Standards--Toxic and Hazardous Substances. Code of Federal Regulations, Title 29, Chapter XVII, Part 1910, Subpart 2, 47 FR 51117, November 1982.
5. U.S. Department of Health and Human Services. NIOSH Manual of Analytical Methods. DHHS (NIOSH) Publication No. 82-100, August 1981.

APPENDIX A  
SAMPLING PROCEDURES AND  
ANALYTICAL METHODS

## CONTENTS

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## Carbon Dioxide

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Analyte:	Carbon Dioxide	Method No.: S249
Matrix:	Air	Range: 2270-10000 ppm
OSHA Standard:	5000 ppm (9000 mg/cu m)	Precision ( $\overline{CV}_T$ ): 0.014
Procedure:	Collection in gas sampling bag, GC with thermal conductivity detector	Validation Date: 10/29/76

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### 1. Principle of the Method

- 1.1 A known volume of air is collected in a five-layer gas sampling bag by means of a low flow rate personal sampling pump capable of filling a bag.
- 1.2 The carbon dioxide content of the samples is determined by gas chromatography using a thermal conductivity detector.

### 2. Range and Sensitivity

- 2.1 This method was validated over the range of 2270-9990 ppm at an atmospheric temperature of 20.5°C and atmospheric pressure of 757 mm Hg using a 3.5 liter sample volume. The working range of the method is estimated to be 500-15000 ppm, under the experimental conditions cited.
- 2.2 The upper limit of the range of the method and the absolute sensitivity have not been established.

### 3. Interferences

- 3.1 When two or more compounds are known or suspected to be present in the air, such information, including their suspected identities, should be transmitted with the sample.
- 3.2 It must be emphasized that any compound which has the same retention time as the analyte at the operating conditions described in this method is an interference. Retention time data on a single column cannot be considered as proof of chemical identity.
- 3.3 If the possibility of interference exists, separation conditions (column packing, temperature, etc.) must be changed to circumvent the problem.



#### 4. Precision and Accuracy

- 4.1 The Coefficient of Variation ( $\overline{CV}_T$ ) for the total analytical and sampling method in the range of 2270-9990 ppm was 0.014. This value corresponds to a 69-ppm standard deviation at the OSHA standard level. Statistical information and details of the validation and experimental test procedures can be found in References 11.1 and 11.2.
- 4.2 On the average, the concentrations obtained at the OSHA standard level using the overall sampling and analytical method were 2.5% lower than the "true" concentrations for a limited number of laboratory experiments. Any difference between the "found" and "true" concentrations may not represent a bias in the sampling and analytical method, but rather a random variation from the experimentally determined "true" concentration. Therefore, no recovery correction should be applied to the final result.

#### 5. Advantages and Disadvantages of the Method

- 5.1 The sampling device is small, portable, and involves no liquids. Interferences are minimal, and most of those which do occur can be eliminated by altering chromatographic conditions. The samples in bags are analyzed by means of a quick instrumental method.
- 5.2. One disadvantage of the method is that the gas sampling bag is rather bulky and may be punctured during sampling and shipping.

#### 6. Apparatus

- 6.1 Personal Sampling Pump. A personal sampling pump capable of filling a bag at approximately 0.05 liter per minute is required. This pump should be calibrated to within  $\pm 5\%$ .
- 6.2 Gas Sampling Bag. 5-liter capacity; only the five-layer sampling bags manufactured by Calibrated Instruments, Inc. (731 Saw Mill Road, Ardsley, New York 10502) were found to be satisfactory for sample collection and storage for at least 7 days. The bag is fitted with a metal valve and hose bib. For the preparation of calibration standards in the laboratory, 5-liter Saran or Tedlar bags could be used.
- 6.3 Gas Chromatograph. The unit must be equipped with a thermal conductivity detector and a 5-milliliter gas sampling loop or equivalent. A portable unit with no column temperature control is adequate.
- 6.4 Column. (5-ft x 1/4-in stainless steel) packed with 80/100 mesh Porapak QS.
- 6.5 Area Integrator. An electronic integrator or some other suitable method for measuring peak areas.

6.6 Gas-tight syringes. 10-ml and other convenient sizes for making standards.

6.7 Calibrated Rotameters. convenient sizes for making standards.

7. Reagents

7.1 Carbon dioxide, 99% or higher purity.

7.2 Nitrogen, purified.

7.3 Helium, purified.

7.4 Air, filtered compressed.

8. Procedure

8.1 Cleaning of Sampling Bags and Checking for Leaks. The bags are cleaned by opening the closure mechanism and bleeding out the air sample. The use of a vacuum pump is recommended although this procedure can be carried out by manually flattening the bags. The bags are then flushed with carbon dioxide-free air and evacuated. This procedure is repeated at least twice.

Bags may be checked for leaks by filling the bag with air until taut, sealing and applying gentle pressure to the bag. Observe for any discernable leaks and any volume changes or slackening of the bag, preferably over at least a one-hour period.

8.2 Calibration of Personal Pumps. Each personal pump should be calibrated to minimize errors associated with uncertainties in the sample volume collected. Although sample volume is not actually used in this determination, the pump should be calibrated to avoid over filling the bags; i.e., a maximum sampling time can be determined based on flow rate and sample volume which is approximately equal to 80% volume of bag.

8.3 Collection and Shipping of Samples.

8.3.1 Immediately before sampling, attach a small piece of Tygon or plastic tubing to the hose bib of the five-layer gas sampling bag.

8.3.2 Unscrew the valve fitting and attach the tubing to the outlet of the sampling pump.

8.3.3 Air being sampled will pass through the pump and tubing before entering the sampling bag, since a "push" type pump is required.

8.3.4 A sample size of 3-4 liters is recommended. Sample at a flow rate of 0.05 liters per minute or less, but not less than 0.01 liters per minute. The flow rate should be known with an accuracy of at least  $\pm 5\%$ .

- 8.3.5 The temperature and pressure of the atmosphere being sampled should be recorded. If pressure reading is not available, record the elevation.
- 8.3.6 The gas sampling bag should be labeled appropriately and sealed tightly.
- 8.3.7 Gas sampling bags should be packed loosely and padded before they are shipped to minimize the danger of getting punctured during shipping.

#### 8.4 Analysis of Samples

- 8.4.1 GC Conditions. The typical operating conditions for the gas chromatograph are:

1. 100 ml/min (25 psig) helium carrier gas flow
2. Ambient injector temperature
3. 70°C manifold temperature (detector)
4. Ambient column temperature

A retention time of approximately 2 minutes is to be expected for the analyte under these conditions and at ambient temperatures of 20-25°C using the column recommended in Section 6.4. The carbon dioxide elutes after oxygen and nitrogen.

- 8.4.2 GC Analysis. The gas sampling bag is attached to the sample loop of the GC unit via a short piece of tubing. Open the closure valve of the gas sampling bag and fill the 5-ml sample loop by gently squeezing the sample bag. To allow the sample in the loop to attain atmospheric pressure, release the pressure applied to the sample bag just prior to turning the sample loop valve to inject the sample onto the column.

- 8.4.3 Measurement of area. The area of the sample peak is measured by an electronic integrator or some other suitable form of area measurement, and the results are read from a standard curve as discussed in Section 9.

#### 9. Calibration and Standards

- 9.1 Completely evacuate a 5-liter gas sampling bag, preferably with the aid of a vacuum pump. Introduce 1.0 liter of filtered air via a septum into the bag; this can be done using a calibrated rotameter. Then add a known volume of carbon dioxide gas through a septum and add more air to a total accurately known volume of

between 3-4 liters. It is necessary to know accurately the volume of carbon dioxide added and the total volume of air to determine concentration in ppm. The concentration in ppm is equal to the volume of carbon dioxide divided by the sum of the volume of carbon dioxide and the volume of air.

- 9.2 A series of standards, varying in concentration over the range of interest, is prepared as described above and analyzed under the same GC conditions and during the same time period as the unknown samples. Curves are established by plotting concentration in ppm versus peak area. Corrections for the unknown carbon dioxide concentration in the filtered air must be made if necessary. The carbon dioxide correction factor can be determined by filling an evacuated bag with 3-4 liters of the filtered air used for preparing the calibration standards. This "blank" air is analyzed under the same conditions as the calibration standards and the samples. The "blank" area thus determined is subtracted from the peak area of each calibration standard. A calibration curve is established by plotting concentration in ppm versus corrected peak area.

Note: Calibration standards should be analyzed at the same time the sample analysis is done. This will minimize the effect of variations in detector response.

#### 10. Calculations

- 10.1 Read the concentration in ppm, corresponding to each peak area from standard curve.
- 10.2 Another method of expressing concentration is mg/cu m (corrected to standard conditions of 25°C and 760 mm Hg).

$$\text{mg/cu m} = \text{ppm} \times \frac{\text{MW}}{24.45} \times \frac{760}{P} \times \frac{(T + 273)}{298}$$

where:

P = pressure (mm Hg) of air sampled  
T = temperature (°C) of air sampled  
24.45 = molar volume (liter/mole) at 25°C and 760 mm Hg  
MW = molecular weight  
760 = standard pressure (mm Hg)  
298 = standard temperature (°K)

#### 11. References

- 11.1 Memoranda, Kenneth A. Busch, Chief, Statistical Services, KLCD, to Deputy Director, DLCD, dated 1/16/75, 11/8/74, subject: "Statistical Protocol for Analysis of Data from Contract CDC-99-74-45."

11.2 Backup Data Report for Carbon Dioxide, prepared under NIOSH  
Contract No. 210-76-0123.

## NITROGEN DIOXIDE AND NITRIC OXIDE IN AIR

### Measurements Support Branch

#### Analytical Method

Analyte Nitrogen Dioxide  
and Nitric Oxide

Method No.: P&CAM 231

Matrix Air

Range 0.8 to 30 ppm of  $\text{NO}_2$   
or NO in a 1-liter sample

Procedure Solid sorbent  
collection, triethanol-  
amine extraction, spec-  
trophotometry

Precision(CVT)  $\text{NO}_2$ : 0.07 at  
0.5 to 5 ppm; NO: 0.06 at  
12.5 to 50 ppm

Classification D (Operational)

Date Issued 6/30/76

Date Revised

#### 1 Principle of the Method

Nitrogen dioxide ( $\text{NO}_2$ ) and nitric oxide (NO) are collected from air in a three-section sorbent tube. The  $\text{NO}_2$  is absorbed in the first section, which contains triethanolamine (TEA) impregnated on molecular sieve. The NO is converted to  $\text{NO}_2$  by a proprietary oxidizer in the second section. The  $\text{NO}_2$  thus formed from the NO is absorbed in the third section by another bed of TEA-impregnated molecular sieve. The first and third sections are desorbed with solutions of TEA in water and the nitrite in these solutions is determined spectrophotometrically by the Griess-Saltzman reaction. (Reference 11.1) The nitrite found in the first section is reported as  $\text{NO}_2$  and the nitrite in the third section is reported as NO.

#### 2 Range and Sensitivity

- 2.1 The linear range of the standard curve is from 0.5 to 18  $\mu\text{g}$  of nitrite in 10 mL of desorbing solution, which corresponds in this method to a range of 0.8 to 30 ppm of  $\text{NO}_2$  or NO in a 1-liter sample of air.
- 2.2 The sensitivity is 0.4  $\mu\text{g}/10\text{ mL}$  for an absorbance of 0.04.
- 2.3 The upper limit of the range can be extended by taking smaller aliquots for analysis, or by diluting intensely colored solutions with water.

#### 3 Interferences

- 3.1 Inorganic nitrites cause positive interference.

3.2 Nitric acid and nitrates do not interfere.

3.3 Ammonia does not interfere.

#### 4. Precision and Accuracy

4.1 The average recovery for 22 samples in the range 0.5 to 5 ppm of  $\text{NO}_2$  was greater than 96% and the coefficient of variation was 0.07.

4.2 For 18 samples the average recovery of NO varied with the amount of NO collected. The recovery was 100% at 12.5 ppm. At 25 ppm only 84% recovery was achieved, and at 50 ppm only 67%. However, the coefficient of variation over the range was only 0.06. The recovery may vary depending upon the sample flow rate and the properties of the particular lot of oxidizer used. Each laboratory should determine the efficiency of the sampling tubes employed.

4.3 The accuracy of the overall sampling and analytical method has not been determined.

#### 5 Advantages and Disadvantages of the Method

5.1 Both nitrogen dioxide and nitric oxide are collected simultaneously.

5.2 This method is simple and convenient for field sampling.

5.3 Samples can be stored at ambient temperature for at least 10 days without any effect on the results.

5.4 At 50 ppm of NO the collection efficiency is poor (about 67%) because the oxidizer is consumed.

5.5 If high humidity or water mist is present, the breakthrough volume can be severely reduced. If water condenses in the tube,  $\text{NO}_2$  and NO may not be collected quantitatively.

#### 6 Apparatus

##### 6.1 Sampling Equipment

6.1.1 Solid sorbent tubes are made in the following manner. Using a gas-oxygen torch, heat a section of 5-mm i.d., 7-mm o.d. Pyrex glass tubing and pull it

apart to form a tube approximately 15 cm long with a taper 2 cm long. Seal the tapered end of the tube in the flame. Allow it to cool, then insert a small plug of glass wool through the open end of the tube; push the glass wool through the open end of the tube with a thin wooden stick and pack gently. Weigh 400 mg of TEA sorbent and pour the material into the tube. (See Section 7.2) Gently tap the tube on the table top several times to ensure uniform packing. Insert another small plug of glass wool to keep the TEA sorbent in place. For the next section, pour 800 mg of oxidizer into the tube. (See Section 7.1.) Again tap the tube and insert a plug of glass wool, pack lightly. Insert another plug of glass wool, maintaining an air gap of 12 mm between these two plugs. Weigh 400 mg of TEA sorbent and pour the material into the tube. Carefully tap the tube and gently pack another glass wool plug without closing the 12-mm air gap. Seal the open end of the tube with the torch. See the figure on page 231-9.

- 6.1.2 A personal sampling pump that can provide a flow rate of 50 ml/min within 5% accuracy is required. The pump should be calibrated with a representative sorbent tube in the sampling line. A dry or wet test meter or glass rotameter that will determine the flow rate to within 5% may be used for the calibration.

6.2 Spectrophotometer capable of measurements at 540 nm.

6.3 Matched glass cells or cuvettes, 1-cm path length.

6.4 Assorted laboratory glassware: pipettes, glass-stoppered graduated cylinders, and volumetric flasks of appropriate sizes.

## 7. Reagents

7.1 Oxidizer. Proprietary material Number 1900277 from the Drägerwerk Company of West Germany, supplied through its U.S. distributor, National Mine Safety Company, or the equivalent.

7.2 TEA Sorbent. Place 25 g of triethanolamine in a 250-ml beaker; add 4 g of glycerol, 50 ml of acetone and sufficient distilled water to bring the volume up to 100 ml. To the mixture add about 50 ml of Type 13X, 30/40-mesh Molecular Sieve. Stir and let stand in a covered beaker for about 30 min. Decant the excess liquid, and transfer the molecular sieve to a porcelain pan. Place the pan under a heating lamp until most of the moisture has evaporated. Complete the drying in an oven at 110°C for 1 hr. The sorbent should be free flowing. Store it in a closed glass container.



- 7.3 **Desorbing Solution.** Dissolve 15.0 g of triethanolamine in approximately 500 mL of distilled water, add 0.5 mL of *n*-butanol, and dilute to 1 liter.
- 7.4 **Hydrogen Peroxide, 0.02%(v/v).** Dilute 0.2 mL of 30% hydrogen peroxide to 250 mL with distilled water.
- 7.5 **Sulfanilamide Solution.** Dissolve 10 g of sulfanilamide in 400 mL of distilled water. Add 25 mL of concentrated phosphoric acid, mix well, and dilute to 500 mL.
- 7.6 **NEDA Solution.** Dissolve 0.5 gm of N-(1-naphthyl)ethylenediamine dihydrochloride in 500 mL of distilled water.
- 7.7 **Nitrite Stock Standard Solution (100 µg/mL).** Dissolve 0.1500 g of reagent grade sodium nitrite in distilled water and dilute to 1 liter.

## 8. Procedure

- 8.1 **Cleaning of Equipment.** Wash all glassware with detergent solution, soak in nitric acid, rinse in tap water and distilled water, and then rinse thoroughly with double distilled water.
- 8.2 **Collection and Shipping of Samples**
- 8.2.1 Before sampling, break open the ends of the sorbent tube to provide an opening that is approximately one-half the internal diameter of the tube.
- 8.2.2 The air must flow through the 12-mm air space before it flows through the oxidizer. Therefore attach the end of the tube without the air gap between the oxidizer section and TEA sorbent section to the pump with a length of small diameter Tygon® tubing.
- 8.2.3 Mount the tube in a vertical position to avoid channeling
- 8.2.4 The air being sampled should not pass through any hose or tubing before it enters the sorbent tube.
- 8.2.5 Turn on the pump to begin sample collection. Sample at a flow rate of 50 mL/min or less to obtain a maximum sample volume of 1 liter. Measure the flow rate and time, or volume, as accurately as possible. If a low flow rate pump is used, set the rate to an approximate value and record the initial and final stroke counter readings. Obtain the sample volume by multiplying the number of strokes by the stroke volume.
- 8.2.6 Measure and record the temperature and pressure of the atmosphere being sampled.

- 8.2.7 Cap the sorbent tubes with 7-mm i.d. plastic caps immediately after sampling. (Masking tape can be substituted for the plastic caps.)
- 8.2.8 With each batch of samples, submit one blank sorbent tube. This tube is handled in the same manner as the other tubes (break, seal, and transport) except that no air is drawn through it. When more than ten samples are submitted, include an additional blank for every ten samples.
- 8.2.9 Pack the capped sorbent tubes tightly and pad them to minimize breakage during shipping

### 8.3 Analysis of Samples

- 8.3.1 With tweezers remove and discard the glass wool plugs from an exposed sorbent tube and transfer each TEA sorbent bed to separate, 25-ml glass-stoppered graduated cylinders. Label the graduated cylinder as to the location of the TEA sorbent with respect to the oxidizer section
- 8.3.2 To each graduated cylinder add enough of the desorbing solution to make the volume up to 20 ml, and shake the mixture vigorously for about 30 sec
- 8.3.3 Allow a few minutes for the solids to settle, and then transfer 10 ml to another 25-ml glass-stoppered graduated cylinder.
- 8.3.4 Develop the color of the solution for 10 min in the same manner as described for the preparation of the standard curve (Sections 9.4 to 9.6). From the standard curve determine the amount of nitrite in the 10-ml aliquot.

### 8.4 Determination of Collection and Desorption Efficiencies

- 8.4.1 Importance of Determination. The collection and desorption efficiencies of a given compound can vary from one laboratory to another and also from one batch of sorbent tubes to another. Thus, it is necessary to determine at least once the percentages of sample collected and then removed in the desorption process. Results indicate that the recovery of NO varies with the amount of NO collected, particularly at higher concentrations (for example, at 50 ppm).

8.4.2 **Procedure for Determining Collection and Desorption Efficiencies.** Sorbent tubes from the same batch as that used in obtaining samples are used in this determination. Known volumes of  $\text{NO}_2$  and  $\text{NO}$  are injected into a bag containing a known volume of air. The bag is made of Tedlar (or another material that will not absorb  $\text{NO}_2$  or  $\text{NO}$ ) and should have a gas sampling valve and a septum injection port. The concentrations of  $\text{NO}_2$  and  $\text{NO}$  in the bag may be calculated at room temperature and pressure. A measured volume is then sampled through a sorbent tube with a calibrated sampling pump. At least five tubes are prepared in this manner. These tubes are desorbed and analyzed in the same manner as the samples (Section 8.3).

8.4.3 **Calculation of Desorption Efficiency.** The desorption efficiency (D.E.) is the average concentration (corrected for the blank) of  $\text{NO}_2$  or  $\text{NO}$  found by analysis of the sorbent tubes divided by the concentration of  $\text{NO}_2$  or  $\text{NO}$  in the bag

## 9. Calibration and Standards

- 9.1 Dilute 2 mL of the nitrite stock standard (100  $\mu\text{g}/\text{mL}$ ) to 100 mL with the desorbing solution to prepare a solution with a nitrite concentration of 2  $\mu\text{g}/\text{mL}$ .
- 9.2 To a series of 25-mL glass-stoppered graduated cylinders add 1, 3, 5, 7, and 9 mL of the dilute standard solution
- 9.3 Add enough of the absorbing solution to bring the volume in each cylinder up to 10 mL to prepare working standards with nitrite concentrations of 2, 6, 10, 14, and 18  $\mu\text{g}/10\text{ mL}$
- 9.4 To each graduated cylinder, add 1 mL of the 0.02% hydrogen peroxide solution, 10 mL of the sulfanilamide solution, and 1.4 mL of the NEDA solution, with thorough mixing after the addition of each reagent
- 9.5 Allow 10 min for complete color development
- 9.6 Measure the absorbance of the solutions at 540 nm, using a reagent blank in the reference cell.
- 9.7 Prepare a standard curve by plotting absorbance versus weight of nitrite (in  $\mu\text{g}$ ) in 10 mL of the desorbing solution

## 10. Calculations

10.1 From the standard curve, read the weight of nitrite (in  $\mu\text{g}$ ) in 10 ml of the desorbing solution corresponding to the absorbance of the sample solution. Multiply this weight by 2 to determine the total amount (in  $\mu\text{g}$ ) of nitrite extracted with 20 ml of desorbing solution from the sorbent section being analyzed. The calibration procedure is based upon the empirical observation that 0.63 mole of sodium nitrite produces the same absorbance in the color-developed solution as 1 mole of  $\text{NO}_2$ . (See Reference 11.2.) Divide the amount of nitrite desorbed from the sorbent material by 0.63 to determine the apparent amount of  $\text{NO}_2$  collected in the sorbent section. These calculations are summarized in the following equation:

$$W = \frac{\mu\text{g NO}_2 \times 2}{0.63}$$

where  $W$  = weight (in  $\mu\text{g}$ ) of  $\text{NO}_2$  found

10.2 Correct the amount of  $\text{NO}_2$  calculated in Section 10.1 for the amount of  $\text{NO}_2$ , if any, found on the corresponding sorbent section of a blank tube to obtain the amount of  $\text{NO}_2$  in the sample, as follows

$$W_s = W - W_b$$

where  $W_s$  = corrected weight (in  $\mu\text{g}$ ) of  $\text{NO}_2$  in sample.

$W_b$  = weight (in  $\mu\text{g}$ ) of  $\text{NO}_2$  in the corresponding section of a blank tube

10.3 The concentration of  $\text{NO}_2$  in parts per million (ppm) by volume in the air sample is calculated as follows

$$\text{ppm} = \frac{W_s}{V} \times \frac{24.45}{\text{M.W.}} \times \frac{760}{P} \times \frac{T+273}{298}$$

where  $V$  = volume (liters) of air sampled

$\text{M.W.}$  = molecular weight.

24.45 = molar volume (liter/mole) at  $25^\circ\text{C}$  and 760 mmHg

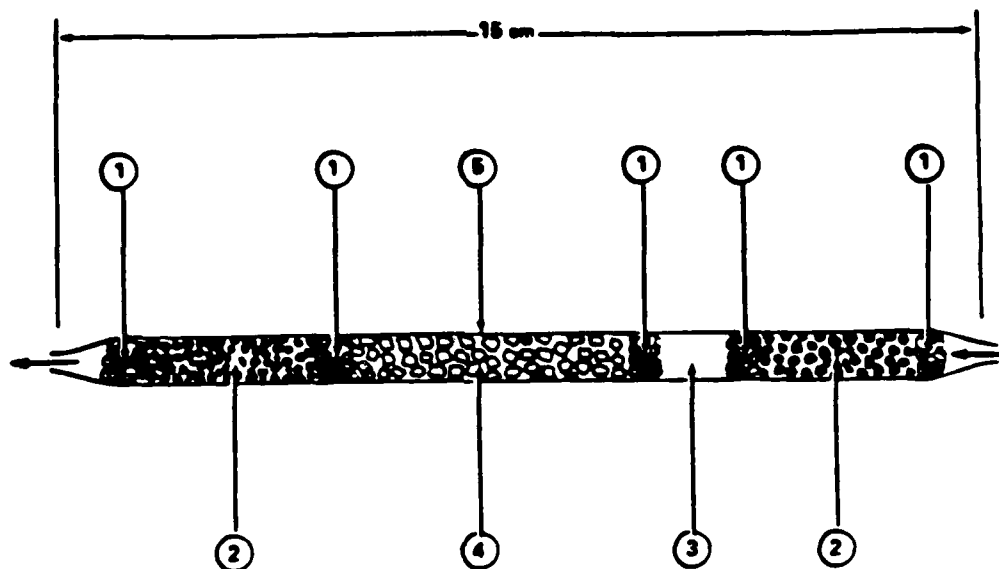
$P$  = pressure (mmHg) of air sampled

$T$  = temperature ( $^\circ\text{C}$ ) of air sampled

10.4 The ppm of  $\text{NO}_2$  found in the third section (downstream from the oxidizer) is reported as ppm of  $\text{NO}$

## **11. References**

- 11.1 Saltzman, B.E. "Colorimetric Microdetermination of Nitrogen Dioxide in the Atmosphere," Anal. Chem., 26, 1949 (1954).**
- 11.2 Blacker, J. H., "Triethanolamine for Collecting Nitrogen Dioxide in the TLV Range," Am. Ind. Hyg. Assoc. J., 34, 390 (1973).**
- 11.3 NIOSH Sampling Data Sheet No. 32.01, "NIOSH Manual of Sampling Data Sheets," Measurements Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, December 22, 1975.**
- 11.4 Willey, M.A., C. S. McCammon, Jr., and L. J. Doemeny, "A Solid Sorbent Personal Sampling Method for the Simultaneous Collection of Nitrogen Dioxide and Nitric Oxide in Air," presented at the American Industrial Hygiene Association Conference, Atlanta, Georgia, May 1976.**



- 1. GLASS WOOL PLUGS
- 2. TEA SORBENT, 400 mg
- 3. AIR GAP, 12 mm
- 4. OXIDIZER, 800 mg
- 5. GLASS TUBE, 5 mm i.d

SORBENT TUBE FOR  $\text{NO}_2$  and NO

## ODORANTS

To satisfy the need for an objective analytical technique for assessing diesel exhaust odorants as a group, the Diesel Odor Analysis System (DOAS) has been selected for use during this study.\* The sampling portion of the DOAS method is based on the collection of filtered exhaust emissions over Chromosorb 102 adsorbent. The analytical portion of DOAS is performed by elution of the adsorbent with cyclohexane, separation with methanol, and analysis using silica gel liquid chromatography with ultraviolet absorption detection. The method separates the total organic extract into paraffinic and aromatic, and polar (oxygenated) fractions. Because previous sensory studies have shown that smoky-burnt odors are the prime contributors to the total diesel exhaust odor and that the smoky-burnt odor is associated with the polar (oxygenated) fraction, this fraction best assesses the total intensity of the odor or aroma.

The total intensity of the aroma (TIA) scale has been generally accepted as a useful means to subjectively quantify odors when the risks to human judges are low. During potentially high risk exposures, the DOAS produces results that can be compared with the TIA scale. A number of studies have shown that the DOAS method gives good correlation with diesel odor intensity as measured on the TIA scale. Equation 1 is used to estimate the TIA from DOAS polar fraction (methanol extract) data.

$$TIA = 1.0 + 1.0 \log_{10}^f$$

Eq. 1

where:  $f$  = the polar fraction in  $\text{mg}/\text{m}^3$

With  $r^2 = 0.996$ , and  $26 = 0.32$ , the  $\pm 0.32$  TIA 95 percent confidence limits are better than normally observed (0.4) in odor observations.

\* Levins, P.L., et al. Chemical Analysis of Diesel Exhaust Odor Species. SAE Tech. Paper 740216, 1974.

**ORGANIC SOLVENTS IN AIR**  
**Physical and Chemical Analysis Branch**  
**Analytical Method**

<b>Analyte:</b>	<b>Organic Solvents</b> (See Table 1)	<b>Method No.:</b>	<b>P&amp;CAM 127</b>
<b>Matrix:</b>	<b>Air</b>	<b>Range:</b>	<b>For the specific compound, refer to Table 1</b>
<b>Procedure:</b>	<b>Adsorption on charcoal desorption with carbon disulfide, GC</b>		
<b>Date Issued:</b>	<b>9 15 72</b>	<b>Precision:</b>	<b>10.5% RSD</b>
<b>Date Revised:</b>	<b>2 15 77</b>	<b>Classification:</b>	<b>See Table 1</b>

**1. Principle of the Method**

- 1.1 A known volume of air is drawn through a charcoal tube to trap the organic vapors present.
- 1.2 The charcoal in the tube is transferred to a small, graduated test tube and desorbed with carbon disulfide.
- 1.3 An aliquot of the desorbed sample is injected into a gas chromatograph.
- 1.4 The area of the resulting peak is determined and compared with areas obtained from the injection of standards.

**2. Range and Sensitivity**

The lower limit in mg sample for the specific compound at  $16 \times 1$  attenuation on a gas chromatograph fitted with a 10:1 splitter is shown in Table 1. This value can be lowered by reducing the attenuation or by eliminating the 10:1 splitter.

**3. Interferences**

- 3.1 When the amount of water in the air is so great that condensation actually occurs in the tube, organic vapors will not be trapped. Preliminary experiments indicate that high humidity severely decreases the breakthrough volume.
- 3.2 When two or more solvents are known or suspected to be present in the air, such information (including their suspected identities), should be transmitted with the sample, since with differences in polarity, one may displace another from the charcoal.
- 3.3 It must be emphasized that any compound which has the same retention time as the specific compound under study at the operating conditions described in this method is an interference. Hence, retention time data on a single column, or even on a number of columns, cannot be considered as proof of chemical identity. For this reason it is important that a sample of the bulk solvent(s) be submitted at the same time so that identity(ies) can be established by other means.



- 3.4 If the possibility of interference exists, separation conditions (column packing, temperatures, etc.) must be changed to circumvent the problem.

#### 4. Precision and Accuracy

- 4.1 The mean relative standard deviation of the analytical method is 8% (11.4).
- 4.2 The mean relative standard deviation of the analytical method plus field sampling using an approved personal sampling pump is 10% (11.4). Part of the error associated with the method is related to uncertainties in the sample volume collected. If a more powerful vacuum pump with associated gas-volume integrating equipment is used, sampling precision can be improved.
- 4.3 The accuracy of the overall sampling and analytical method is 10% (NIOSH-unpublished data) when the personal sampling pump is calibrated with a charcoal tube in the line.

#### 5. Advantages and Disadvantages of the Method

- 5.1 The sampling device is small, portable, and involves no liquids. Interferences are minimal, and most of those which do occur can be eliminated by altering chromatographic conditions. The tubes are analyzed by means of a quick, instrumental method. The method can also be used for the simultaneous analysis of two or more solvents suspected to be present in the same sample by simply changing gas chromatographic conditions from isothermal to a temperature-programmed mode of operation.
- 5.2 One disadvantage of the method is that the amount of sample which can be taken is limited by the number of milligrams that the tube will hold before overloading. When the sample value obtained for the backup section of the charcoal tube exceeds 25% of that found on the front section, the possibility of sample loss exists. During sample storage, the more volatile compounds will migrate throughout the tube until equilibrium is reached (33% of the sample on the backup section).
- 5.3 Furthermore, the precision of the method is limited by the reproducibility of the pressure drop across the tubes. This drop will affect the flow rate and cause the volume to be imprecise, because the pump is usually calibrated for one tube only.

#### 6. Apparatus

- 6.1 An approved and calibrated personal sampling pump for personal samples. For an area sample, any vacuum pump whose flow can be determined accurately at 1 liter per minute or less.
- 6.2 Charcoal tubes: glass tube with both ends flame sealed, 7 cm long with a 6-mm O.D. and a 4-mm I.D., containing 2 sections of 20/40 mesh activated charcoal separated by a 2-mm portion of urethane foam. The activated charcoal is prepared from coconut shells and is fired at 600°C prior to packing. The absorbing section contains 100 mg of charcoal, the backup section 50 mg. A 3-mm portion of urethane foam is placed between the outlet end of the tube and the backup section. A plug of silylated glass wool is placed in front of the absorbing section. The pressure drop across the tube must be less than one inch of mercury at a flow rate of 1 lpm.
- 6.3 Gas chromatograph equipped with a flame ionization detector.
- 6.4 Column (20 ft × 1/8 in) with 10% FFAP stationary phase on 80/100 mesh, acid-washed DMCS Chromosorb W solid support. Other columns capable of performing the required separations may be used.

6.5 A mechanical or electronic integrator or a recorder and some method for determining peak area.

6.6 Microcentrifuge tubes, 2.5 ml, graduated.

6.7 Hamilton syringes: 10  $\mu$ l, and convenient sizes for making standards.

6.8 Pipets: 0.5-ml delivery pipets or 1.0-ml type graduated in 0.1-ml increments.

6.9 Volumetric flasks: 10 ml or convenient sizes for making standard solutions.

## 7. Reagents

7.1 Spectroquality carbon disulfide (Matheson Coleman and Bell).

7.2 Sample of the specific compound under study, preferably chromatography grade.

7.3 Bureau of Mines Grade A helium

7.4 Prepurified hydrogen

7.5 Filtered compressed air

## 8. Procedure

8.1 **Cleaning of Equipment:** All glassware used for the laboratory analysis should be detergent washed and thoroughly rinsed with tap water and distilled water.

8.2 **Calibration of Personal Pumps.** Each personal pump must be calibrated with a representative charcoal tube in the line. This will minimize errors associated with uncertainties in the sample volume collected.

### 8.3 Collection and Shipping of Samples

8.3.1 Immediately before sampling, the ends of the tube should be broken to provide an opening at least one-half the internal diameter of the tube (2 mm).

8.3.2 The small section of charcoal is used as a back-up and should be positioned nearest the sampling pump.

8.3.3 The charcoal tube should be vertical during sampling to reduce channeling through the charcoal.

8.3.4 Air being sampled should not be passed through any hose or tubing before entering the charcoal tube.

8.3.5 The flow, time, and or volume must be measured as accurately as possible. The sample should be taken at a flow rate of 1 lpm or less to attain the total sample volume required. The minimum and maximum sample volumes that should be collected for each solvent are shown in Table 1. The minimum volume quoted must be collected if the desired sensitivity is to be achieved.

8.3.6 The temperature and pressure of the atmosphere being sampled should be measured and recorded.

8.3.7 The charcoal tubes should be capped with the supplied plastic caps immediately after sampling. Under no circumstances should rubber caps be used.

8.3.8 One tube should be handled in the same manner as the sample tube (break, seal, and transport), except that no air is sampled through this tube. This tube should be labeled as a blank.

8.3.9 Capped tubes should be packed tightly before they are shipped to minimize tube breakage during shipping.

8.3.10 Samples of the suspected solvent(s) should be submitted to the laboratory for qualitative characterization. These liquid bulk samples should not be transported in the same container as the samples or blank tube. If possible, a bulk air sample (at least 50 l air drawn through tube) should be shipped for qualitative identification purposes.

#### 8.4 Analysis of Samples

8.4.1 Preparation of Samples. In preparation for analysis, each charcoal tube is scored with a file in front of the first section of charcoal and broken open. The glass wool is removed and discarded. The charcoal in the first (larger) section is transferred to a small stoppered test tube. The separating section of foam is removed and discarded; the second section is transferred to another test tube. These two sections are analyzed separately.

8.4.2 Desorption of Samples. Prior to analysis, one-half ml of carbon disulfide is pipetted into each test tube. (All work with carbon disulfide should be performed in a hood because of its high toxicity.) Tests indicate that desorption is complete in 30 minutes if the sample is stirred occasionally during this period.

8.4.3 GC Conditions. The typical operating conditions for the gas chromatograph are:

1. 85 cc/min. (70 psig) helium carrier gas flow.
2. 65 cc/min. (24 psig) hydrogen gas flow to detector.
3. 500 cc/min. (50 psig) air flow to detector.
4. 200°C injector temperature.
5. 200°C manifold temperature (detector).
6. Isothermal oven or column temperature — refer to Table 1 for specific compounds.

8.4.4 Injection. The first step in the analysis is the injection of the sample into the gas chromatograph. To eliminate difficulties arising from blowback or distillation within the syringe needle, one should employ the solvent flush injection technique. The 10  $\mu$ l syringe is first flushed with solvent several times to wet the barrel and plunger. Three microliters of solvent are drawn into the syringe to increase the accuracy and reproducibility of the injected sample volume. The needle is removed from the solvent, and the plunger is pulled back about 0.2  $\mu$ l to separate the solvent flush from the sample with a pocket of air to be used as a marker. The needle is then immersed in the sample, and a 5- $\mu$ l aliquot is withdrawn, taking into consideration the volume of the needle, since the sample in the needle will be completely injected. After the needle is removed from the sample and prior to injection, the plunger is pulled back a short distance to minimize evaporation of the sample from the tip of the needle. Duplicate injections of each sample and standard should be made. No more than a 3% difference in area is to be expected.

8.4.5 Measurement of area. The area of the sample peak is measured by an electronic integrator or some other suitable form of area measurement, and preliminary results are read from a standard curve prepared as discussed below.

#### 8.5 Determination of Desorption Efficiency

8.5.1 Importance of determination. The desorption efficiency of a particular compound can vary from one laboratory to another and also from one batch of charcoal to another. Thus, it is necessary to determine at least once the percentage of the specific compound that is removed in the desorption process for a given compound, provided the same batch of charcoal is used. NIOSH has found that the desorption efficiencies for the compounds in Table 1 are between 81% and 100% and vary with each batch of charcoal.

8.5.2 Procedure for determining desorption efficiency. Activated charcoal equivalent to the amount in the first section of the sampling tube (100 mg) is measured into a 5-cm, 4-mm I.D. glass tube, flame-sealed at one end (similar to commercially available culture tubes). This charcoal must be from the same batch as that used in obtaining the samples and can be obtained from unused charcoal tubes. The open end is capped with Parafilm. A known amount of the compound is injected directly into the activated charcoal with a microliter syringe, and the tube is capped with more Parafilm. The amount injected is usually equivalent to that present in a 10-liter sample at a concentration equal to the federal standard.

At least five tubes are prepared in this manner and allowed to stand for at least overnight to assure complete absorption of the specific compound onto the charcoal. These five tubes are referred to as the samples. A parallel blank tube should be treated in the same manner except that no sample is added to it. The sample and blank tubes are desorbed and analyzed in exactly the same manner as the sampling tube described in Section 8.4.

Two or three standards are prepared by injecting the same volume of compound into 0.5 ml of CS<sub>2</sub> with the same syringe used in the preparation of the sample. These are analyzed with the samples.

The desorption efficiency equals the difference between the average peak area of the samples and the peak area of the blank divided by the average peak area of the standards, or

$$\text{desorption efficiency} = \frac{\text{Area sample} - \text{Area blank}}{\text{Area standard}}$$

## 9. Calibration and Standards

It is convenient to express concentration of standards in terms of mg/0.5 ml CS<sub>2</sub> because samples are desorbed in this amount of CS<sub>2</sub>. To minimize error due to the volatility of carbon disulfide, one can inject 20 times the weight into 10 ml of CS<sub>2</sub>. For example, to prepare a 0.3 mg/0.5 ml standard, one would inject 6.0 mg into exactly 10 ml of CS<sub>2</sub> in a glass-stoppered flask. The density of the specific compound is used to convert 6.0 mg into microliters for easy measurement with a microliter syringe. A series of standards, varying in concentration over the range of interest, is prepared and analyzed under the same GC conditions and during the same time period as the unknown samples. Curves are established by plotting concentration in mg/0.5 ml versus peak area.

NOTE: Since no internal standard is used in the method, standard solutions must be analyzed at the same time that the sample analysis is done. This will minimize the effect of known day-to-day variations and variations during the same day of the FID response.

## 10. Calculations

10.1 The weight, in mg, corresponding to each peak area is read from the standard curve for the particular compound. No volume corrections are needed, because the standard curve is based on mg/0.5 ml CS<sub>2</sub>, and the volume of sample injected is identical to the volume of the standards injected.

10.2 Corrections for the blank must be made for each sample.

$$\text{Correct mg} = \text{mg}_s - \text{mg}_b$$

where:

$mg_s$  = mg found in front section of sample tube

$mg_b$  = mg found in front section of blank tube

A similar procedure is followed for the backup sections.

10.3 The corrected amounts present in the front and backup sections of the same sample tube are added to determine the total measured amount in the sample.

10.4 This total weight is divided by the determined desorption efficiency to obtain the corrected mg per sample.

10.5 The concentration of the analyte in the air sampled can be expressed in mg per  $m^3$ .

$$mg\ m^{-3} = \frac{\text{Corrected mg (Section 10.4)} \times 1000\ (\text{liters}/m^3)}{\text{Air volume sampled (liters)}}$$

10.6 Another method of expressing concentration is ppm (corrected to standard conditions of 25°C and 760 mm Hg)

$$ppm = mg\ m^{-3} \times \frac{24.45}{MW} \times \frac{760}{P} \times \frac{(T + 273)}{298}$$

where

P = pressure (mm Hg) of air sampled

T = temperature (°C) of air sampled

24.45 = molar volume (liter/mole) at 25°C and 760 mm Hg

MW = molecular weight

760 = standard pressure (mm Hg)

298 = standard temperature (°K)

## 11. References

- 11.1 White, L. D., D. G. Taylor, P. A. Mauer, and R. E. Kupel, "A Convenient Optimized Method for the Analysis of Selected Solvent Vapors in the Industrial Atmosphere", Am Ind Hyg Assoc J 31:225, 1970.
- 11.2 Young, D. M. and A. D. Crowell. Physical Adsorption of Gases, pp. 137-146, Butterworths, London, 1962.
- 11.3 Federal Register, 37:202-22139-22142, October 18, 1972.
- 11.4 NIOSH Contract HSM-99-72-98, Scott Research Laboratories, Inc., "Collaborative Testing of Activated Charcoal Sampling Tubes for Seven Organic Solvents", pp. 4-22, 4-27, 1973.

**TABLE 1**  
**Parameters Associated With P&CAB Analytical Method No. 127**

Organic Solvent	Method Classification	Detection Limit (mg/sample)	Sample Volume (liters)		GC Column Temp.(°C)	Molecular Weight
			Minimum <sup>(a)</sup>	Maximum <sup>(b)</sup>		
Acetone	D	—	0.5	7.7	60	58.1
Benzene	A	0.01	0.5	55	90	78.1
Carbon tetrachloride	A	0.20	10	60	60	154.0
Chloroform	A	0.10	0.5	13	80	119
Dichloromethane	D	0.05	0.5	3.8	85	84.9
p-Dioxane	A	0.05	1	18	100	88.1
Ethylene dichloride	D	0.05	1	12	90	99.0
Methyl ethyl ketone	B	0.05	0.5	13	80	72.1
Styrene	D	0.10	1.5	34	150	104
Tetrachloroethylene	B	0.06	1	25	130	166
1,1,2-trichloroethane	B	0.05	10	97	150	133
1,1,1-trichloroethane (methyl chloroform)	B	0.05	0.5	13	150	133
Trichloroethylene	A	0.05	1	17	90	131
Toluene	B	0.01	0.5	22	120	92.1
Xylene	A	0.02	0.5	31	100	106

(a) Minimum volume, in liters, required to measure 0.1 times the OSHA standard

(b) These are breakthrough volumes calculated with data derived from a potential plot (11.2) for activated coconut charcoal. Concentrations of vapor in air at 5 times the OSHA standard (11.3) or 500 ppm, whichever is lower, 25°C, and 760 torr were assumed. These values will be as much as 50% lower for atmospheres of high humidity. The effects of multiple contaminants have not been investigated, but it is suspected that less volatile compounds may displace more volatile compounds (Sec 3.1 and 3.2).

## PARTICULATES

### Substance :

Inert or Nuisance Dust

### Standard :

8-hour time-weighted average for respirable dust:  $5 \text{ mg/m}^3$

8-hour time-weighted average for total dust:  $15 \text{ mg/m}^3$

Reference: 29 CFR 1910.93

### Analytical Method:

The amount of material on a filter is determined by filter weight gain. Before sampling, the filter is pre-weighed to the nearest 0.01 mg. After sampling, the filter is reweighed. The difference in the filter's weight is assumed to be the mass of material collected.

### Sampling Equipment:

**Pump:** A calibrated personal sampling pump whose flow can be determined to an accuracy of  $\pm 5\%$ . The pump must have been calibrated with a representative filter and filter holder in line. If the respirable dust concentration is being measured, the pump must have a pulsation dampener and be certified under 30 CFR 74.

**Filter Holder:** 2 or 3-piece, 37-mm filter holder held together by tape or shrinking band.

**Filter:** 37-mm diameter, 5.0 micrometer pore size polyvinyl chloride filter or equivalent that has been pre-weighed to the nearest 0.01 mg. These filters must be hydrophobic. The filter should be supported with a back-up pad.

**Cyclone:** 10-mm nylon cyclone. When the respirable dust concentration is measured, it is used with a 2-piece filter holder.

**Sampling Head Assembly:** This assembly must hold the filter holder, cyclone, and coupler together rigidly so that air enters only at the cyclone inlet.

### Sample Size :

A minimum sampling period of 60 minutes is recommended and longer periods up to eight hours are preferable. If the respirable dust concentration is being measured, a flow rate of 1.7 liters per minute must be used. To determine total dust concentration, use a flow rate of 1.5 liters per minute.

#### Sampling Procedure:

1. Assemble the filter and three-piece filter cassette and close firmly to insure that the center ring seals the edge of the filter. Examine the holder for a good filter seal. If the cassette will not seal tightly, it should be discarded. If respirable dust is being measured, the center ring is not included in the filter holder. The filter cassette should be held together by a shrinking band or tape.
2. If total nuisance dust is being sampled, remove the filter holder plugs. Attach the filter holder to the sampling pump with a 1/4 inch diameter, 3-foot piece of tubing and an adaptor. The adaptor is used to provide a tight connection between the filter holder and tubing.
3. If the respirable dust is being sampled, assemble the two-piece filter holder, coupler, cyclone, and sampling head. The sampling head rigidly holds together the cyclone and filter holder. The outlet of the sampling head is connected to the pump by a 3-foot piece of 1/4 inch flexible tubing.
4. Clip the cassette or cyclone assembly to the worker's lapel.
5. Turn the pump on and begin sample collection. The pump flow rate should be checked periodically and readjusted if necessary.
6. Terminate sampling after the predetermined time and note sample flow rate, collection time, and ambient temperature and pressure. If a pressure reading is unavailable, record the elevation.
7. Collected sample cassette should be firmly sealed with the plugs in both the inlet and outlet.
8. With each batch of samples, submit one filter subjected to exactly the same handling as for the samples except that no air is drawn through it. Label these as blanks.

#### Special Considerations:

1. Filter holders molded from cellulose-acetate-butyrate, which is commonly known as Tenite plastic, have been shown to cause blank filter weight gains and must not be used.
2. The alignment of the filter holder and cyclone in the sampling head must be checked. If these parts are not aligned properly, leakage can result.
3. Before use, the cyclones grit cap or vortex finder should be removed and the interior of the cyclone should be inspected. If the inside of the cyclone is visibly scored, this cyclone should be discarded since the dust separation characteristics of the cyclone might be altered. If it is dirty, the interior of the cyclone should be cleaned before use. This will prevent the reentrainment of this dirt.



Shipping :

After sampling, the samples and the blank should be shipped in a suitable container designed to prevent damage in transit.

Reference:

"Sampling and Evaluating Respirable Coal Mine Dust", US Bureau of Mines, Pittsburgh, Pa. Information Circular 8503, February, 1971, p. 47.

# SULFATES, SULFITES AND SULFUR DIOXIDE

## Measurements Research Branch

### Analytical Method

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Analyte:	Sulfates, Sulfites and Sulfur Dioxide	Method No.:	P&CAM 268
Matrix:	Air	Range:	Sulfates: 0.1-10 mg/m <sup>3</sup> Sulfites: 0.1-10 mg/m <sup>3</sup> SO <sub>2</sub> : 0.04-4 ppm (200-L air sample)
Procedure:	Particulate sulfates and sulfites collected on filter; SO <sub>2</sub> on treated filter; analysis by ion chromatography	Precision:	5% (Analytical)
Date Issued:	7/2/79		
Date Revised:		Classification:	E (Proposed)

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#### 1. Synopsis

A known volume of air is drawn through a filter train consisting of a cellulose ester membrane filter followed by an impregnated cellulose filter containing potassium hydroxide. Particulate matter, including sulfates and sulfites, is collected on the first filter, while sulfur dioxide passes through the first filter and is collected on the second filter.

The filters are extracted with deionized water and the extracts are analyzed by anion-exchange chromatography. The following quantities are obtained:

SO<sub>2</sub> concentration: calculated from the sulfite peak on the impregnated cellulose filter chromatogram.

Total sulfates concentration (sulfuric acid plus soluble metal sulfates): from the sulfate peak on the untreated cellulose ester membrane filter chromatogram.

Particulate sulfites concentration: from the sulfite peak on the untreated cellulose ester membrane filter chromatogram.

## 2. Working Range, Sensitivity, and Detection Limit

- 2.1 The working range for a 200-L air sample is 0.1-10 mg  $\text{SO}_4^{2-}$  or  $\text{SO}_3^{2-}/\text{m}^3$ , and 0.04-4 ppm  $\text{SO}_2$  (0.1-10 mg  $\text{SO}_2/\text{m}^3$ ). This corresponds to 20-2000  $\mu\text{g}$  of sulfate, sulfite or sulfur dioxide per sample.
- 2.2 The sensitivity at 30  $\mu\text{mho}$  full scale is 5  $\mu\text{g}$  sulfate, sulfite, or sulfur dioxide per sample per mm chart deflection. The sensitivity may be improved by using scale expansion on the readout and by using a smaller volume than 10 mL to desorb the sample.
- 2.3 The detection limit is approximately 0.5  $\mu\text{g}$   $\text{SO}_4^{2-}$  or  $\text{SO}_3^{2-}/\text{mL}$  in the solution injected, corresponding to 5  $\mu\text{g}$  sulfate, sulfite, or sulfur dioxide per sample.

## 3. Interferences

- 3.1 Oxidation of particulate sulfite on the sample filters results in a positive bias for sulfates and a negative bias for particulate sulfites.
- 3.2 Sulfur trioxide gas, if present in dry atmospheres, gives a positive bias in the sulfur dioxide determination.
- 3.3 Nitrate or phosphate ions may give similar retention times to sulfite. Identity of the sulfite peak may be established by spiking the samples with known amounts of sulfite and analyzing with at least two different eluents (e.g., the eluent in Section 7.14 and 0.003 M  $\text{NaCO}_3$ /0.001 M  $\text{NaHCO}_3$ ).
- 3.4 Insoluble sulfates collected on the first filter will not be measured unless special care is taken to dissolve them.

## 4. Precision and Accuracy

- 4.1 The relative standard deviation of the analytical method is 5% or less in the range 50-1000  $\mu\text{g}$   $\text{SO}_3^{2-}$  or  $\text{SO}_4^{2-}$  per sample, corresponding to 0.25-5 mg/m<sup>3</sup>  $\text{SO}_2$ , sulfites, or sulfates.
- 4.2 A major factor affecting accuracy is the tendency of particulate sulfites and absorbed sulfur dioxide to oxidize. Because of this, a negative bias which has not been thoroughly investigated occurs.

## 5. Advantages and Disadvantages

- 5.1 The sampling device uses only filters and involves no liquids.
- 5.2 Oxidation of a significant fraction of the particulate sulfites and sulfur dioxide in the sample is unavoidable.
- 5.3 Because identification is based on retention time, interferences may not be easily identified (see Section 3.3).

## 6. Apparatus

6.1 The apparatus for the collection of personal air samples consists of:

- 6.1.1 Filter holder, 3-piece cassette, polystyrene, 37-mm diameter.
  - 6.1.2 Shrinkable cellulose band.
  - 6.1.3 Mixed cellulose ester membrane filter, 0.8 micrometer pore size, 37-mm diameter, supported by a cellulose backup pad.
  - 6.1.4 Cellulose filter, Whatman-40 or equivalent, impregnated with potassium hydroxide-glycerine solution, supported by a cellulose backup pad. To prepare the filter, saturate it with filter impregnating solution on a clean glass plate or watch glass and dry at 100°C for 20-30 minutes.
  - 6.1.5 Personal sampling pump whose flow can be calibrated in line with a representative loaded filter holder to an accuracy of +5% at the recommended flow rate.
  - 6.1.6 Thermometer
  - 6.1.7 Manometer
  - 6.1.8 Stopwatch
  - 6.1.9 Screw cap, glass bottles, such as scintillation vials.
  - 6.1.10 Tweezers
- 6.2 Ion-exchange chromatograph, equipped with electrical conductivity detector and recorder or integrator.
- 6.3 10-mL pipette
- 6.4 10-mL plastic syringe with male Luer fitting
- 6.5 In-line filter with Luer fitting, 25 mm diam (0.8  $\mu$ m membrane filter).
- 6.6 Volumetric flask, 100 mL

## 7. Reagents

All reagents used should be ACS Reagent Grade or better.

- 7.1 Deionized, filtered water. Conductivity-grade deionized water with a specific conductance of 10  $\mu$ mho/cm or less is needed for preparation of eluents and other solutions which will be used on the ion chromatograph. The water should be filtered through a membrane filter (0.45-0.8  $\mu$ m pore size) before use to avoid plugging valves on the chromatograph.

AD-A141 792

MEASUREMENT OF EXHAUST EMISSIONS FROM DIESEL-POWERED  
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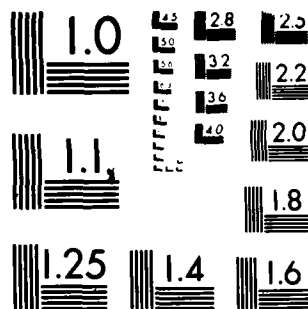
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963-A

- 7.2 Potassium hydroxide, KOH (pellets)
- 7.3 Glycerol
- 7.4 Sodium carbonate,  $\text{Na}_2\text{CO}_3$
- 7.5 Sodium bicarbonate,  $\text{NaHCO}_3$
- 7.6 Sodium sulfite,  $\text{Na}_2\text{SO}_3$
- 7.7 Sodium sulfate,  $\text{Na}_2\text{SO}_4$
- 7.8 Nitrogen gas
- 7.9 Filter impregnating solution. Dissolve 20 g KOH in about 50 ml deionized water, add 10 ml glycerol and dilute with deionized water to 100 ml.
- 7.10 Sulfite stock standard (1000 ppm  $\text{SO}_3^{=}$ ). Add 5 ml glycerol to a 100 ml volumetric flask and dissolve in approximately 75 ml deionized water which has been heated to 100°C and cooled under nitrogen to remove dissolved oxygen. Add 0.1575 g  $\text{Na}_2\text{SO}_3$  and dilute to 100 ml with deionized water. This standard should be prepared fresh weekly.
- 7.11 Sulfite working standard (100 ppm  $\text{SO}_3^{=}$ ). Pipette 10.0 ml of 1000 ppm sulfite stock standard into a 100 ml<sup>3</sup> volumetric flask and dilute to 100 ml with a solution containing 2% (v/v) glycerol. Prepare fresh daily.
- 7.12 Sulfate stock standard (1000 ppm  $\text{SO}_4^{=}$ ). Dissolve 1.4792 g  $\text{Na}_2\text{SO}_4$  in deionized water and dilute to 1 liter.
- 7.13 Sulfate working standard (100 ppm  $\text{SO}_4^{=}$ ). Dilute 10.0 ml of the sulfate stock standard to 100 ml with deionized water.
- 7.14 Eluent (0.003 M  $\text{CO}_3^{=}$ /0.003 M  $\text{HCO}_3^{-}$ ). Dissolve 1.27 g  $\text{Na}_2\text{CO}_3$  and 1.01 g  $\text{NaHCO}_3$  in 4<sup>3</sup> liters of deionized, filtered water.

## 8. Procedure

- 8.1 Cleaning of Equipment. Glassware, including screw cap bottles, should be washed in detergent and rinsed in dilute (1-5%) nitric acid, followed by thorough rinsing with distilled or deionized water.
- 8.2 Collection and Shipping of Samples
  - 8.2.1 Each personal sampling pump must be calibrated with a representative filter cassette in line to assure accurately known sample volumes.

- 8.2.2 Assemble the filter cassette as follows: First, place a backup pad in place in the rear section of the cassette. On top of this place a treated cellulose filter (Sec. 6.1.4) and then put the center retaining ring of the cassette in place. Next, put another backup pad on top of the retaining ring, place a mixed cellulose ester membrane filter (Sec. 6.1.3) on top of the backup pad, and put the front section of the cassette in place. A shrinkable band should be used to seal the cassette.
- 8.2.3 Collect the sample at 1.5 liters per minute. The air being sampled should not pass through any hose or tubing before entering the cassette. A sample size of 200 liters is recommended.
- 8.2.4 If significant amounts of sulfuric acid are suspected in the sample, the cellulose ester membrane filter must be transferred to a clean, glass bottle within 4 hours of sampling to avoid low recovery of sulfate. Handle the filter with tweezers to avoid contamination. Reclose the cassette containing the treated cellulose filter.
- 8.2.5 Carefully record the sample identity and all pertinent sampling data. With each batch of up to 10 samples submit appropriate blank filters for analysis.

### 8.3 Analysis of Samples

- 8.3.1 Put the two filters from the cassette into two separate, clean, screw-top glass bottles. Add 10.0 mL eluent (Sec. 7.14) to each bottle and let stand, with occasional vigorous shaking, for 30 minutes.
- 8.3.2 Pour the contents of the bottle into a syringe fitted with an in-line filter and collect the filtrate in a second syringe.
- 8.3.3 Inject the filtered sample onto the chromatograph and record the sample identity and instrumental conditions. Typical operating conditions are:
- sensitivity: 30  $\mu$ mho full scale (for 5-100 ppm sulfate and sulfite)
  - eluent: 0.0030 M  $\text{Na}_2\text{CO}_3$ , 0.0030 M  $\text{NaHCO}_3$
  - flow rate: 138 mL/hr
  - separator column: 3 mm I.D. x 500 mm (anion exchanger), preceded by a precolumn
  - suppressor column: 6 mm I.D. x 250 mm (cation exchanger)



- $\text{SO}_3^-$  retention time: 6-7.5 min (depending on eluent)
- $\text{SO}_4^-$  retention time: 9-10.5 min (depending on eluent)

8.3.4 Measure and record the peak height or peak area of each sulfite and sulfate peak. If interfering substances (e.g., nitrate or phosphate) are present, establish positive identity of sulfite and sulfate peaks by adding known amounts of standard solutions and by changing eluent concentration for better separation, if necessary.

## 9. Calibration and Standardization

- 9.1 From the 100 ppm working standards, prepare 5, 10, 15, 20, 30, 50, and 80 ppm sulfate and sulfite standards by diluting, respectively, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, and 8.0 mL to 10 mL with deionized water. These standard solutions should be prepared fresh daily.
- 9.2 With each set of samples analyzed, a complete calibration curve should be constructed, using the standards prepared in 9.1 or additional standards as needed. Plot peak height or peak area vs. concentration for both sulfite and sulfate. A sulfite standard with nominal concentration  $C_n$  (ppm) will give two peaks: a sulfite peak,  $C$ , and a sulfate peak,  $C_s$  (ppm). The relationship between these is  $C = C_n - C_s \times 0.8334$ .

## 10. Calculations

- 10.1 From the calibration curves obtained in Sec. 9.2, read the concentrations of sulfite and sulfate ions in each sample in ppm. Designate whether the ions originated on the cellulose ester membrane filter or the treated cellulose filter. Thus, four concentrations will be obtained.

$C_1$  = concentration, ppm, of sulfite from cellulose ester membrane filter

$C_2$  = concentration, ppm, of sulfate from cellulose ester membrane filter

$C_3$  = concentration, ppm, of sulfite from treated cellulose filter

$C_4$  = concentration, ppm, of sulfate from treated cellulose filter

10.2 Calculate the concentrations in the air sample using the formulae:

$$\text{Total particulate sulfite (mg/m}^3\text{)} = \frac{C_1 \times 10}{V}$$

$$\text{Total particulate sulfate (mg/m}^3\text{)} = \frac{C_2 \times 10}{V}$$

$$\text{Sulfur dioxide (mg/m}^3\text{)} = \frac{(C_3 \times 10 \times 0.08002) + (C_4 \times 10 \times 0.6669)}{V}$$

$$\text{Sulfur dioxide (ppm)} = 0.3817 \times \text{sulfur dioxide (mg/m}^3\text{)} \times \frac{760 \times T}{298 \times P}$$

where V is the volume (liters) of air sampled.

T is the absolute temperature (°K = °C + 273) at which the sample was taken.

P is the pressure (mm Hg) at which the sample was taken.

## 11. References

- 11.1 Mulik, J.D., R. Puckett, D. Williams, and E. Sawicki: Analysis of Nitrate and Sulfate in Ambient Aerosols. Anal. Lett. 9: 653(1976)
- 11.2 Pate, J.B., Lodge, and M.P. Neary: The Use of Impregnated Filters to Collect Traces of Gases in the Atmosphere. Anal. Chim. Acta 28: 341 (1963)

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Inorganic Methods Development  
Section

## TOTAL PARTICULATE AROMATIC HYDROCARBONS (TpAH) IN AIR

### Physical and Chemical Analysis Branch

#### Analytical Method

Analyte:	TpAH	Method No.:	P&CAM 206
Matrix:	Air	Range:	Lower limit, 3 nanograms benzo(a)pyrene
Procedure:	Sampling with glass fiber filter, extract ultrasonically, enrich and measure with HPLC	Precision:	$\pm 1.33\%$ RSD (Analytical)
Date Issued:	1/1/75	Classification:	E (Proposed)
Date Revised:			

#### 1. Principle of the Method

Airborne particles collected from polluted atmospheres on glass fiber filters are extracted ultrasonically in the presence of silica powder (11.1-3). The TpAH in the filtered extract are separated by high speed liquid chromatography on a column of Corasil H with a non-polar solvent, and the absorbance is measured by a UV detector at 254 nm. Compounds responding to the detector are shown in Tables 1, 2, 3, and 4. The extract is suitable also for the analysis of the aliphatic hydrocarbons (11.4).

#### 2. Range and Sensitivity

- 2.1 Minimum reproducible level of standard benzo(a)pyrene at 254 nm is approximately 3 nanograms.
- 2.2 The minimum detectable TpAH (in terms of benzo(a)pyrene) for particulates collected on one glass fiber filter of approximately 452 cm<sup>2</sup> is approximately 5 micrograms, or 3.3 nanograms/m<sup>3</sup> of air if 1500 m<sup>3</sup> of air are sampled in the ambient atmosphere.
- 2.3 The upper range of TpAH concentrations can be increased by dilution of the extract and/or analyzing smaller samples. Sensitivity for low concentrations can be increased by injecting larger samples into the chromatograph. Thus, very high levels of TpAH can be measured.

#### 3. Interferences

- 3.1 Any compound which is not retained on the silica column and absorbs light at 254 nm is measured in this procedure.  
Fluorene and some of its analogues and derivatives listed in Table 2, and polychloro derivatives of some di- and tricyclic hydrocarbons in Table 3 are examples of such compounds.
- 3.2 Amino, carbonyl, hydroxy and nitro compounds elute after the PAH, so do not interfere. See Table 2.
- 3.3 Carbazoles and aldehydes are either retained or have retention times larger than the PAH, except N-alkyl substituted derivatives, which elute with the PAH. See Table 4.

- 3.4 Oxygenated compounds, some phenols and aza and imino-heterocyclics (except some members of the indole series) are retained. Examples are benzoquinone, o-ethylphenol, acridine, and quinoline.
- 3.5 Most interfering compounds have quite low peak area/ $\mu\text{g}$  values, which decreases their significance, as shown in Tables 2, 3, and 4.

TABLE 1  
Elution of PAH<sup>a</sup>

Compound	% Eluted Through Column	PA <sup>b</sup> / $\mu\text{g}$ $\times 10^{-2}$
<b>Mono-, dicyclics</b>		
Benzene	99	0.4
N-Hexylbenzene	100	0.5
N-Heptylbenzene	100	0.7
Naphthalene	101	0.7
Azulene	93	3.0
<b>Tricyclics</b>		
Anthracene	100	36.0
9-Methylanthracene	99	15.0
Xanthene	102	1.3
Phenoxathiin	92	0.2
Phenanthrene	100	10.0
<b>Tetracyclics</b>		
Naphthacene	95	4.7
Chrysene	105	4.5
Pyrene	96	3.6
4-Methylpyrene	100	1.7
1,3-Dimethylpyrene	96	0.9
Triphenylene	100	9.0
Benz(a)anthracene	96	4.3
7,12-Dimethylbenz(a)anthracene	102	3.3
<b>Pentacyclics</b>		
Dibenz(a,h)anthracene	96	0.6
Benzo(a)pyrene	100	5.3
Benzo(e)pyrene	92	2.2
Picene	99	5.0
Perylene	96	5.8
<b>Hexacyclics</b>		
Benzo(ghi)perylene	99	1.8
Anthanthrene	93	2.6
Dibenzo(fg, op)naphthacene	93	0.6
Coronene	91	0.5
Dibenzo(g,p)chrysene	96	1.0
Naphtho(2,1,8-qr)anthracene <sup>b</sup>	100	0.7

<sup>a</sup>Retention time is approximately 2 minutes. <sup>b</sup>Or naphtho(2,3-a)pyrene. PA = Peak Area.

#### 4. Precision and Accuracy

- 4.1 Homogeneous glass fiber samples containing air particulates were analyzed by Soxhlet and ultrasonic extraction. See Table 5. The relative standard deviation for 6 ultrasonic extracts was  $\pm 1.33\%$  and for 4 Soxhlet extracts  $\pm 26.1\%$ . The ratio of ultrasonic to Soxhlet recovery was 1.14.
- 4.2 Recovery of PAH added to glass fiber filter blanks and extracted ultrasonically was 95% for anthracene; 97.5% for phenanthrene; and 98.2% for benzo(a)pyrene (Table 6).

### 5. Advantages and Disadvantages of the Method

- 5.1 The extraction is done at room temperature. Complete extraction of the TPAH is assured by the fine shredding of the glass fibers and the breaking up of clumps of particulates.
- 5.2 Only a relatively small sample of air particulates is required. Complete analysis time is well under an hour, most of which is waiting time.
- 5.3 Most of the polar constituents are removed by adsorption in the homogenizing vessel. The remainder are removed by the fast simple chromatographic analysis.
- 5.4 The method can accommodate a wide range of hydrocarbon pollution concentrations, since sample extract volumes ranging from 0.1 to 2 ml can be chromatographed.
- 5.5 Time and work are saved by not weighing the particulates or soluble organics.

TABLE 2

#### Elution of Fluorene, Analogues and Derivatives

Compound	t, Min.	% Eluted Through Column	PA/ $\mu\text{g} \times 10^{-3}$
Fluorene	2.0	100	2.9
Dibenzothiophene	2.0	96	1.8
Dibenzofuran	2.0	98	0.3
Fluoranthene	2.0	95	2.5
Benzo(k)fluoranthene	1.8	97	1.4
Benzo(b)fluoranthene	1.0	99	1.6
2-Ethylfluorene	1.0	95	1.6
11H-Benzo(b)fluorene	1.0	110	5.6
2-Nitrofluorene	4.8	104	0.2
2,5-Dinitrofluorene	7.0	71	0.3
9-Fluorenoi	8.5	14	0.2
3,6-Dinitrodibenzoselenophene	18.2	38	0.2
3-Aminofluorene	18.2	68	0.4
4-Fluorenicarboxylic acid		Retained on column	
2-Hydroxyfluorene		Retained on column	
2-Nitro-7-hydroxyfluorene		Retained on column	
Fluorenone		Retained on column	

TABLE 3

#### Elution of Polychloro Derivatives of Di- and Tricyclic Hydrocarbons\*

Compound	% Eluted Through Column	PA/ $\mu\text{g} \times 10^{-3}$
1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane (p,p'DDD)	94	0.02
1,1-Dichloro-2,2-bis(p-chlorophenyl)ethylene (DDE)	97	0.50
1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane (p,p'DDT)	85	0.02
Aroclor 1260 (chlorinated biphenyls, 60% chlorine)	100	0.13
Aroclor 5432 (chlorinated triphenyls, 32% chlorine)	104	0.61
Halowax 1099 (mixture of tri- and tetrachloro naphthalenes, 52% chlorine)	101	0.25
1,2,3,4,5,6,7,8-Octachloronaphthalene	97	0.64
2,3,4,5,6,2',3',4',5',6'-Decachlorobiphenyl	95	0.19
1,2,3,4,5,6,7,8-Octachlorodibenzofuran	93	0.33
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	98	0.85
Tetradecachloro-p-terphenyl	95	0.22

\*Retention times from 1 to 2 min.

5.6 A disadvantage is that a blank correction must be made for the fiber glass filter. Also, care must be taken to avoid evaporation of the extract to dryness.

5.7 A further disadvantage is that the ultrasonic extraction must be done in a sonobox to reduce the unacceptably high noise level.

#### 6. Apparatus

- 6.1 Sonifier Cell Disruptor, 20 kHz power ultrasonic generator capable of dialing 70 watts accurately, with a 1.27-cm (1/2-inch) horn disruptor and Sonobox.
- 6.2 Liquid Chromatograph, with stainless steel column 2.6 × 300 mm, UV Detector with 254 nm filter and loop injector with a capacity ranging from 0.1 to 2 ml.
- 6.3 Strip Chart Recorder with Disc Integrator.
- 6.4 An approved and calibrated personal sampling pump for collection of particulate matter. Any vacuum pump whose flow can be determined accurately to within 1 lpm or less.

**TABLE 4**  
Elution of Some Indoles, Carbazoles and Aromatic Aldehydes

Compound	t <sub>R</sub> Min.	% Eluted Through Column	PA <sup>a</sup> /μg × 10 <sup>-3</sup>
Indole	5.3	82	1.1
Carbazole	11.8	67	0.7
4-H-Benzo(def)carbazole	8.0	98	2.0
11-H-Benzo(a)carbazole	14.5	55	3.0
7-H-Dibenzo(c,g)carbazole	18.0	92	2.1
N-Phenylcarbazole	2.3	74	1.8
N-Ethylcarbazole	2.5	98	0.5
5-Methyl-5, 10-dihydroindeno(1,2-b) indole	2.8	103	1.9
2,3-Dimethylindole	5.3	90	5.5
2-Methylcarbazole	6.8	100	0.8
2-Hydroxycarbazole		Retained on column	
		Retained on column	
N-Ethyl-3-aminocarbazole			
Benzaldehyde	12.8	56	1.1
2-Naphthaldehyde	8.2	78	0.3

<sup>a</sup>Peak Area

**TABLE 5**  
Comparison of Ultrasonic and Soxhlet Extractions

Sample No.	Ultrasonic		Soxhlet	
	PA/ $\mu$ S	% Eluted*	PA/ $\mu$ S	% Eluted
1	0.575	51	0.449	28
2	0.562	53	0.509	—
3	0.567	50	0.500	—
4	0.579	48	0.545	31
5	0.560	44	—	—
6	0.573	44	—	—
Average	0.569	49	0.509	30
Rel. Std. Dev.	$\pm 1.33\%$		$\pm 26.1\%$	
Ultrasonic/Soxhlet Recovery = 1.14				

<sup>a</sup>Refers to % of TPAH in the extracted material.

**TABLE 6**  
**Recovery of Added PAH**

Compound	Sample, $\mu\text{g}$	Peak Area		% Recovery
		Sonified Filter + Std.	Standard Solution	
Anthracene	0.035	1005	1055	95.0
Phenanthrene	0.147	1155	1185	97.5
Benzo(a)pyrene	0.355	1846	1880	98.2

6.5 Column Bypass.

6.6 Fisher Filtrator and medium sintered glass filter.

6.7 U.S. Standard Sieve Series No. 120, with 125-micron openings.

#### 7. Reagents

7.1 Cyclohexane, ACS spectroanalyzed, distilled once from glass.

7.2 Polynuclear aromatic hydrocarbons.

7.3 Glass powder, spherical, non-wettable, 38-53 microns in diameter.

7.4 Corasil II.

#### 8. Procedure

##### 8.1 Extraction

8.1.1 The 1.27-cm horn of the sonifier cell disruptor is supported in a sonabox to reduce noise. The sonifying vessel is a beaker 3.8 cm I.D.  $\times$  10 cm tall. The end of the horn is set about 0.6 cm above the bottom of the beaker to insure adequate "stirring" of the mixture and equal exposure to areas of intense cavitation. Approximately 16 square cm of the exposed glass fiber filter and blank are cut into roughly 1.3-cm squares to facilitate shredding. The sonifying vessel is surrounded by an ice water bath up to the level of the solvent mixture.

8.1.2 Homogeneous replicate samples of approximately 16 square cm of exposed and blank glass fiber filters are prepared and adjusted to exactly 100 mg. This weight necessarily includes both the particulates and the glass fiber. These samples were used to maximize parameters and for comparison of ultrasonic and Soxhlet extractions, shown in Table 5.

8.1.3 Samples for routine analysis are not weighed. Only the areas of the sample (16 square cm) and the whole filter, the volume of air sampled and the volume of extract injected need to be determined. Sample at rate of at least 2 lpm for 1 hr or more.

8.1.4 Extraction Procedure. The sample, 60 ml cyclohexane, and 5 ml silica powder are placed in the sonifying vessel, and sonified for 8 min at 70 watts. The supernatant is decanted into the sintered glass filter supported on a Fisher Filtrator. Cyclohexane is added to the sonifying vessel to the level of the original mixture (usually about 50 ml). Sonification is carried on for an additional 4 minutes. The contents are filtered and combined with the first fraction, and rinsed with 50 ml cyclohexane. The filtrates and rinsings are collected in an Erlenmeyer flask and evaporated to about 5 ml, transferred quantitatively to a 10-ml volumetric flask and made to the mark.

8.1.5 Sample and blank filters (8.1.2) are extracted by Soxhlet with 80 ml cyclohexane for 6-8 hr, for comparison with the ultrasonic extraction. See Table 5. After filtering, the extracts are evaporated in the same manner as the ultrasonic extracts.

8.1.6 The glass fiber filters used for air sampling should be as free as possible of soluble compounds which absorb at 254 nm. It may be necessary to flash fire or extract them and care should be taken to avoid contaminating them.

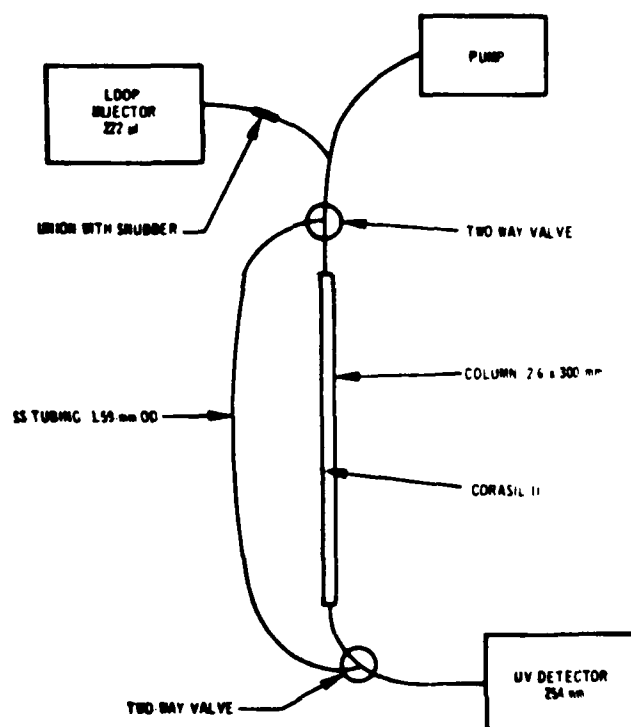


FIGURE 1. Schematic of Chromatographic System



8.2.2 To test the performance of the column, the percent of PAH which elutes is calculated from the peak areas through the column and the column bypass. Typical chromatograms from column and tubing are shown in Figure 2. Recovery of benzo(ghi)perylene was 99%. The percent of other hydrocarbons which eluted through the column ranged from 91 to 105, Table 1.

### 8.3 Analysis Procedure

8.3.1 An appropriate volume of extract is injected through the loop injector. A flow rate of 1.6 ml/min gives a pressure drop of less than 800 PSI. The peak area is measured with a disk integrator, driven by 0 to 10 servo strip chart recorder with a 0.5 in/min chart speed. The PAH elute in 3 to 5 min. Benzo(a)pyrene is used as the standard. Polar compounds are retained on the column. Samples can be chromatographed every 5 to 10 minutes.

8.3.2 The column bypass is also used to determine the percent of PAH in the organic material of the extract. Chromatograms of sample extracts made on the column and column bypass are shown in Figure 3. On the basis of absorbance measurements 254 nm, approximately 50% of the organic material in the unchromatographed extract is PAH. This procedure is not necessary for routine analyses, but is helpful in elucidating the analytical situation in research samples.

### 8.4 Effects of Storage

8.4.1 Urban particulates on glass fiber filters stored in the dark in an envelope for one year lost 32% of their benzo(a)pyrene. Losses of some other PAH ranged from 1-88% (11.5).

8.4.2 Benzene-soluble extracts evaporated to dryness and stored in closed bottles in a refrigerator were stable (in terms of benzo(a)pyrene concentrations) for 4 years (11.6).

8.4.3 The ultrasonic extract is stable in the dark at room temperature for several days, longer in the refrigerator. However, losses usually occur after about two weeks.

## 9. Calibration and Standards

The benzo(a)pyrene (BaP) standard is made in cyclohexane and is chromatographed when the samples are run, and repeated whenever a parameter such as solvent lot is changed. Both standard and samples are run at concentrations which do not overload the detector and give reproducible results when diluted. For example, 0.4  $\mu$ g BaP gave a peak area of about 2000 and fulfilled the above criteria.

The standard is expressed in terms of peak area per microgram (PA/ $\mu$ g). The unit of measurement for the samples is corrected peak area per cubic meter of air (PA/ $m^3$ ). The BaP equivalent of the TpAH is calculated from these data (10.2). The standard is kept in the dark and is stable for more than 30 days when refrigerated nights and weekends.

## 10. Calculations

10.1 The peak area of the TpAH in a cubic meter of air is given by the equation

$$PA/m^3 = \frac{PA \times A \times B}{V \times a \times b}$$

where:

PA = Peak area, corrected for the blank

V = Volume of air sampled in  $m^3$ , corrected to 25°C and 760 Torr

A = Area of whole glass fiber filter in  $cm^2$

- B = Volume of extract in ml  
 a = Area of glass fiber filter sample in cm<sup>2</sup>  
 b = Volume of extract injected in ml

10.2 The concentration of the TpAH may be expressed in terms of their equivalent in benzo(a)-pyrene.

$$\text{TpAH}(\mu\text{g})/\text{m}^3 \text{ air} = \frac{\text{PA}/\text{m}^3 \text{ air (See Table 7)}}{\text{PA}/\mu\text{g benzo(a)pyrene (See Table 1)}}$$

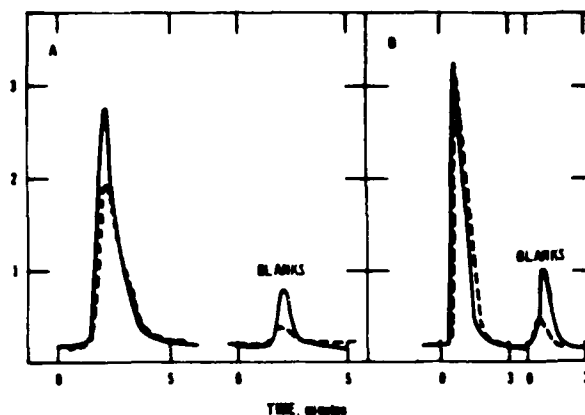


FIGURE 3. Chromatograms of ultrasonic and Soxhlet extracts of composited sample No. 1, Table 6 and blanks, through the column (A) and through the column bypass (B). Stationary phase, Corasil II; eluent, cyclohexane; flow rate, 1.6 ml/min. Solid lines are ultrasonic extracts; broken lines are Soxhlet extracts. Extracts were diluted x 3.3 for column bypass.

TABLE 7  
 Analysis of Particulate Samples

Description	Corrected Peak Area	m <sup>3</sup> Air Sampled	PA/m <sup>3</sup> Air <sup>a</sup>	TpAH <sup>b</sup> (μg)/m <sup>3</sup> Air
Urban I	1200	1500	1120	0.211
Urban II	620	1500	580	0.109
Urban III	545	1500	509	0.096
Mt. Storm	0	1673	0	0.000

<sup>a</sup>See Calculations—Section 10.1. <sup>b</sup>See Calculations—Section 10.2.

#### 11. References

- 11.1 Brown, B. and J. E. Goodman, High Intensity Ultrasonics, Industrial Applications, Chapter 2, pp. 30-55, Van Nostrand Company, Princeton, New Jersey, 1965.
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APPENDIX B  
CONTINUOUS AIR MONITORING DATA

## NOTES ON CONTINUOUS AIR MONITORING DATA

### FIELD DATA REDUCTION

During the testing, the Apple computer took about 45 readings per minute from each of the eight instruments ( $\text{SO}_2$ , CO,  $\text{CO}_2$ , THC,  $\text{NO}_x$ , and two air channels). Approximately 5 million individual readings were taken during the period from November 29 through December 15, 1983:

- ° 2 days of background data
- ° 9 forklift tests
- ° 6 warehousing tests
- ° 1 stationary forklift test
- ° 9 overnight periods following tests

The sampling covered approximately 110 hours of tests and 130 hours of background and overnight readings.

At the end of each minute of sampling, an arithmetic average was calculated of the readings for each channel. At the end of each sampling period (5 or 15 minutes), these averages were written as a subfile onto the data disk.

A single sequential text file was created for each hour's data at each sampling location. Therefore, a single-hour file might contain as many as 12 individual sampling period subfiles (in the case of a 5-minute cycle and only one location) or as few as 1 sampling period subfile (in the case of a 15-minute cycle with four locations). Each subfile begins with the first minute of the sampling period (e.g., 5, 10, 15, etc.). This is followed by an 8 x SP matrix containing the 1-minute averages (where SP is the length of the sampling period). A 15-minute sampling period therefore contains 120 entries after the starting minute figure. An entry of -999 was used whenever an instrument was off line.

### CALCULATION OF AVERAGE READINGS

The field sampling sequence operated on either a 5-minute cycle (during tests) or a 15-minute cycle (during overnight runs). At the end of each

cycle, the sampling location was switched to the next location in the sequence. Although individual 1-minute readings were stored on the data disks to simplify the data analysis, it was desirable to calculate averages for the entire sampling period of each instrument. Because of the slow response time of some instruments, the first few minutes of data recorded after a switch in location could not always be considered valid. The following 1-minute readings were therefore averaged to come up with the overall average for the two types of sampling periods:

<u>Channel</u>	<u>Minutes averaged</u>	
	<u>5-minute cycle</u>	<u>15-minute cycle</u>
SO <sub>2</sub>	4-5	4-15
CO	2-5	2-15
CO <sub>2</sub>	2-5	2-15
THC	2-5	2-15
NO	3-5	3-15
NO <sub>x</sub>	3-5	3-15
Air 1	1-5	1-15
Air 2	1-5	1-15

#### ZERO-DRIFT CORRECTIONS

During operation, continuous monitors experience a slight drift in their zero response. This drift is detected from the output of each instrument's backup strip-chart recorder. The zero drift experienced during the tests was negligible (less than 5 percent of the average reading) for all instruments except the one used to detect sulfur dioxide. The sulfur dioxide data presented in this Appendix represent the raw uncorrected data. The information presented in the body of text (i.e., the tabular or graphic results) has been corrected for zero drift.

#### DATA TABLE DESCRIPTION

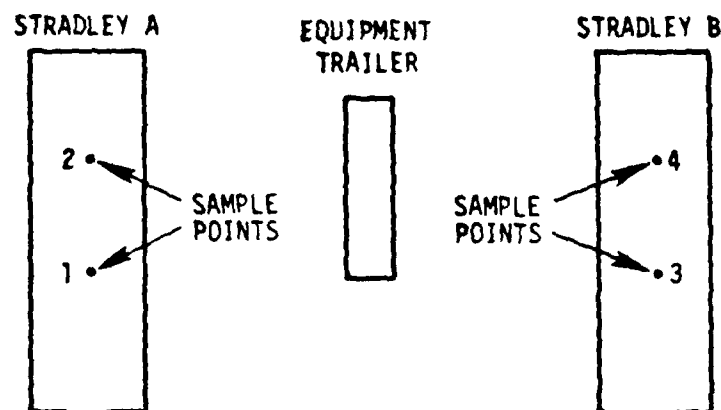
The continuous monitoring data are presented for each vehicle test (by sampling location) for sulfur dioxide, carbon monoxide, carbon dioxide, total hydrocarbons, nitric oxide, and oxides of nitrogen. The recorded air velocities detected at each ventilation duct are also presented.

Figure B-1 is useful for comparison of the results in the appendix tables with summaries in the body of the text. The schedule of the test operations is presented in Table B-1.

TABLE B-1. SCHEDULE OF TEST OPERATIONS

Test Date	Operation/Truck	Magazine
11/29/83 Day 1	Unload with Truck No. 1 (Still/Deutz F3L912W)	A
	Load with Truck No. 3 (Baker/Deutz F3L912W)	B
11/30/83 Day 2	Unload with Truck No. 3	B
	Load with Truck No. 1	A
12/1/83 Day 3	Unload with Truck No. 1	A
	Load with Truck No. 3	B
12/2/83 Day 4	Unload with Truck No. 3	B
	Load with Truck No. 1	A
12/5/83 Day 5	Unload with Truck No. 1	A
	Load with Truck No. 3 (Using high sulfur fuel)	B
12/6/83 Day 6	Unload with Truck No. 2 (Hyster/Perkins 4.2032)	B
	Load with Truck No. 4 (Hyster/Perkins 4.154)	A
12/7/83 Day 7	Unload with Truck No. 2	A
	Load with Truck No. 4	B
12/8/83 Day 8	Unload with Truck No. 2	B
	Load with Truck No. 4 (Using high sulfur fuel)	A
12/9/83 Day 9	Unload with Truck No. 3 (Using high sulfur fuel)	A
	Load with Truck No. 1	B
12/13/83 Day 10	Warehousing with Truck No. 1	2 hrs B
	Warehousing with Truck No. 2	4 hrs B
12/14/83 Day 11	Warehousing with Truck No. 1	4 hrs B
	Warehousing with Truck No. 2	4 hrs A
12/15/83 Day 12	Warehousing with Truck No. 1	3 hrs A
	Warehousing with Truck No. 2 (Both trucks using high sulfur fuel)	3 hrs B

NOTE: The primary diesel fuel used is Phillips D-2 Diesel Control Fuel Lot C-929 (.4% sulfur). The high sulfur diesel fuel used is a referee grade diesel fuel conforming to MIL-F-46162B (1.02% sulfur). Warehousing tests were conducted with each magazine half full of storage. The trucks moved the load continuously in the front half of the magazine.



DESCRIPTION	SAMPLING LOCATIONS
FORWARD SAMPLING POINT IN MAGAZINE A	1
REAR SAMPLING POINT IN MAGAZINE A	2
FOREWARD SAMPLING POINT IN MAGAZINE B	3
REAR SAMPLING POINT IN MAGAZINE B	4
VENTILATION DUCT IN MAGAZINE A	AIR 1 (IN LINEAR FEET PER MINUTE)
VENTILATION DUCT IN MAGAZINE B	AIR 2 (IN LINEAR FEET PER MINUTE)

Figure B-1 Location of sampling points, magazines, and equipment trailer.

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST ONE  
Date: NOVEMBER 29, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	TNC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
9:10	20	23	2.4	559.9	5.8	15	19	852	682
9:25	35	31	1.5	862.7	8.8	388	600	1027	628
9:45	55	31	3.3	702.7	5.3	313	353	1082	684
10:05	75	26	2.2	856.0	7.3	59	80	1471	748
10:25	95	23	2.3	732.4	6.8	8	9	1760	824
10:45	115	33	2.6	852.1	5.7	238	278	1242	786
11:05	135	35	2.2	889.8	6.7	315	342	1293	843
11:25	155	38	2.2	723.4	5.2	154	201	1302	818
11:45	175	56	2.5	841.5	7.2	439	515	1280	780
12:05	195	63	1.7	723.2	7.7	600	682	1099	619
12:25	215	83	1.7	789.7	7.1	505	561	1172	706
12:45	235	122	2.3	866.4	5.1	714	776	1143	750
13:05	255	309	2.2	878.5	8.7	1105	1403	1058	615
13:25	275	291	1.9	1174.6	7.2	1316	1266	1075	796
13:45	295	253	3.3	1241.7	6.5	1042	1270	1036	651
14:05	315	149	3.0	1206.5	5.2	690	765	1053	819
14:25	335	432	2.6	1331.4	5.7	1446	1498	1115	732
14:45	355	448	2.5	1194.4	7.8	1553	1603	1279	691
15:05	375	287	2.6	1164.1	6.9	1041	1173	1400	723
15:25	395	563	1.9	1490.4	7.3	1797	1885	1264	756
15:45	415	52	2.6	1122.4	6.1	24	41	1140	700
16:05	435	208	3.0	1349.5	6.0	829	817	1108	667
16:25	455	431	2.8	1329.5	8.0	1511	1743	956	597
16:45	475	426	3.4	1365.5	8.1	1387	1594	1060	695
17:05	495	353	2.8	1391.6	5.5	1214	1325	1266	791
17:25	515	203	3.1	1047.6	6.5	802	1036	1248	815
17:45	535	211	3.3	1123.5	6.0	764	816	1142	774
18:05	555	181	3.7	1147.0	7.0	799	803	1373	866
18:25	575	127	4.4	1221.3	6.3	512	567	1290	1055
18:45	595	****	****	****	****	****	****	877	1051



PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST ONE  
Date: NOVEMBER 20, 1983

Elapsed Time	Time	SO2 (PPB)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPB)	NOX (PPB)	AIR1	AIR2
9:30	40	26	3.1	878.8	5.5	235	243	1020	810
9:50	60	29	3.3	721.4	5.5	248	271	1107	766
10:10	80	21	2.5	870.0	5.8	25	30	1550	851
10:30	100	18	2.4	703.1	7.4	88	79	1492	895
10:50	120	25	2.3	814.6	5.3	234	263	1158	764
11:10	140	29	2.8	812.2	6.3	442	471	1226	760
11:30	160	26	2.3	758.5	6.0	206	229	1158	822
11:50	180	30	2.2	817.9	7.8	357	396	1060	616
12:10	200	40	2.5	1038.6	10.8	737	806	1234	887
12:30	220	38	2.6	899.5	5.8	500	542	1075	697
12:50	240	52	2.5	860.3	6.1	630	670	1318	757
13:10	260	65	2.4	877.0	8.1	708	750	1243	786
13:30	280	67	2.2	1054.1	6.7	554	603	1261	805
13:50	300	72	3.0	1167.4	6.3	598	664	1127	867
14:10	320	70	3.2	1267.6	6.4	506	576	1529	873
14:30	340	118	3.0	1076.4	5.9	885	950	1186	746
14:50	360	149	3.1	1009.6	7.4	968	1055	1252	653
15:10	380	185	3.1	1053.8	6.5	895	890	1189	723
15:30	400	169	2.9	946.9	6.6	801	833	1228	759
15:50	420	128	4.4	1072.5	8.3	534	768	1150	849
16:10	440	342	3.0	1282.7	8.2	1241	1682	1145	720
16:30	460	502	2.8	1360.2	6.3	1515	1698	1003	867
16:50	480	455	3.2	1364.5	5.5	1500	1519	1116	691
17:10	500	426	3.1	1188.1	7.2	1430	1582	1152	783
17:30	520	248	3.1	1155.6	7.8	1059	1253	1266	991
17:50	540	251	2.8	1168.5	6.4	951	864	1154	720
18:10	560	245	4.1	1104.1	7.3	948	802	1284	1029
18:30	560	97	3.3	1087.5	6.6	306	360	1200	1038

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE  
Test Description: TEST ONE  
Date: NOVEMBER 29, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOx (PPB)	AIR1	AIR2
8:00	10	24	2.6	611.4	5.8	5	5	1183	734
8:20	30	99	2.8	716.8	5.1	1823	1834	1069	750
8:35	45	195	3.0	794.4	4.5	1911	1969	1397	758
8:55	65	774	2.6	1164.1	6.0	2000	2000	1296	785
10:15	85	417	2.1	879.5	5.4	2000	2000	1310	640
10:35	105	311	2.7	825.9	4.3	1943	1885	1241	723
10:55	125	445	2.1	941.1	5.4	2000	2000	1217	777
11:15	145	436	2.5	1013.1	4.2	2000	2000	1222	681
11:35	165	336	2.5	874.0	5.1	1900	1931	1206	681
11:55	185	285	2.6	937.9	5.9	1739	1874	1090	707
12:15	205	405	1.9	1328.1	7.8	2000	2000	1100	651
12:35	225	414	2.6	1050.2	6.0	1854	2000	1061	746
12:55	245	376	2.6	959.3	5.3	1916	1900	1280	727
13:15	265	529	1.8	950.1	10.7	1993	2000	1051	576
13:35	285	351	3.4	1336.8	7.3	1917	2000	1108	699
13:55	305	286	3.0	1258.9	6.7	1782	1919	1140	682
14:15	325	350	3.0	1262.1	5.7	1855	1979	1344	754
14:35	345	313	3.1	1106.6	5.7	1984	1999	1071	674
14:55	365	272	2.8	1089.6	7.3	1486	1793	1247	691
15:15	385	286	2.9	1140.6	6.5	1517	1733	1241	675
15:35	405	91	3.0	1002.6	7.1	259	311	1069	610
15:55	425	258	3.8	1339.8	7.2	1444	1652	1130	738
16:15	445	190	3.8	1065.6	7.7	814	994	1153	758
16:35	465	179	3.3	1315.2	7.3	1451	1558	1223	588
16:55	485	233	4.0	1201.7	8.5	1727	1799	1057	800
17:15	505	98	3.4	1159.0	6.6	750	817	1071	738
17:35	525	85	3.5	1161.5	7.9	762	851	1215	687
17:55	545	119	3.8	987.7	6.2	1038	1142	1015	624
18:15	565	60	3.4	1207.4	7.3	225	252	1329	884
18:35	585	43	3.0	1155.0	6.8	51	61	1324	1215

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: FOUR  
Test Description: TEST ONE  
Date: NOVEMBER 29, 1993

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
9:05	15	44	2.8	725.1	7.8	1714	1843	1167	624
9:40	50	387	2.4	935.5	6.0	2000	2000	1119	709
10:00	70	438	2.7	979.7	5.3	2000	2000	1184	788
10:20	90	431	2.5	937.8	4.6	2000	2000	1331	818
10:40	110	403	2.4	937.0	5.1	2000	2000	1278	790
11:00	130	786	1.8	1048.2	5.7	2000	2000	1138	761
11:20	150	455	2.0	884.6	6.7	2000	2000	1301	826
11:40	170	433	2.3	989.0	5.0	1873	2000	1337	857
12:00	190	300	2.7	972.0	6.1	1876	1864	1220	758
12:20	210	268	2.6	940.7	5.8	1857	1871	1258	816
12:40	230	224	2.8	986.4	5.8	1870	1868	1190	804
13:00	250	255	2.7	886.5	12.8	1860	2000	1141	659
13:20	270	277	2.5	1211.2	11.2	2000	2000	1214	727
13:40	290	131	3.1	1017.3	8.6	1383	1481	1098	658
14:00	310	158	3.6	1288.9	8.4	1770	1802	1150	745
14:20	330	162	3.2	1222.2	6.6	1585	1686	1160	895
14:40	350	148	3.1	1226.5	8.3	1805	1929	1067	703
15:00	370	167	3.0	1087.8	8.1	1458	1527	1205	723
15:20	390	176	3.1	1047.3	6.6	1689	1776	1388	744
15:40	410	57	2.9	1351.2	9.2	231	265	1086	670
16:00	430	128	4.1	1286.0	8.5	1577	1876	1101	630
16:20	450	107	3.7	1154.0	8.9	1322	1385	923	556
16:40	470	84	3.8	1419.9	8.5	1379	1470	1161	641
17:00	490	93	4.2	1403.1	8.8	1253	1327	1287	863
17:20	510	89	3.6	1289.6	8.4	818	888	1162	724
17:40	530	76	3.8	1162.1	8.5	942	1050	1208	670
18:00	550	87	3.0	1259.9	8.8	889	955	1205	761
18:20	570	45	3.7	1099.5	8.7	201	220	1382	1022
18:40	590	35	3.5	881.6	8.4	37	43	1191	1016

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST TWO  
Date: NOVEMBER 30, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:35	15	222	1.1	844.3	18.7	1652	1836	515	375
8:55	35	104	1.0	788.8	17.4	618	725	848	464
9:15	55	542	1.7	961.4	17.3	1819	1823	535	379
9:35	75	458	2.8	786.4	17.4	1800	1883	588	471
9:55	95	344	1.5	735.9	15.8	1762	1853	488	471
10:15	115	315	1.4	628.9	16.1	1515	1580	549	433
10:35	135	438	1.3	844.0	16.7	1756	1853	531	445
10:55	155	553	1.1	738.8	18.6	1810	1867	568	449
11:15	175	698	1.3	847.6	15.0	1864	1842	521	379
11:35	195	830	1.2	801.6	18.5	1869	1897	480	326
11:55	215	276	1.3	581.0	14.8	1111	1221	480	319
12:15	235	355	1.2	498.4	****	1440	1526	520	421
12:35	255	591	1.0	555.3	****	1861	1867	465	373
12:55	275	788	1.2	636.9	****	1911	1882	1	341
13:15	295	783	1.3	545.4	6.8	1832	1881	386	1
13:35	315	449	1.6	418.4	6.7	1767	1812	1	373
13:55	335	182	1.0	398.9	6.4	****	****	1	1
14:15	355	153	1.0	350.2	6.3	808	899	723	149
14:35	375	92	1.0	275.1	6.7	441	496	1	1
14:55	395	110	1.1	310.5	6.7	785	852	****	****
15:15	415	129	0.9	245.5	7.8	848	809	****	****
15:35	435	75	0.9	191.2	7.5	****	****	377	375
15:45	445	****	****	****	****	****	****	****	****
16:05	465	62	0.9	282.3	6.9	****	****	364	401
16:25	485	34	0.8	265.9	7.4	****	****	754	540
16:35	495	24	1.0	207.5	148.3	0	0	1840	1780
16:55	515	32	1.3	170.7	147.9	19	26	671	768

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST TWO  
Date: NOVEMBER 30, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:20	0	23	0.7	882.5	18.0	4	4	432	345
8:40	20	171	1.4	870.8	16.9	1048	1282	575	408
9:00	40	416	1.4	821.7	17.7	1432	1583	560	368
9:20	60	742	1.6	1221.9	18.0	1940	1997	611	478
9:40	80	768	1.8	1065.6	18.1	1871	1980	615	495
10:00	100	364	1.2	593.5	17.2	1530	1663	531	149
10:20	120	437	1.3	750.2	15.0	1488	1800	537	422
10:40	140	400	1.1	889.3	18.8	1587	1736	563	494
11:00	160	541	1.3	887.5	16.1	1829	1843	508	376
11:20	180	389	1.3	598.9	15.3	1822	1898	559	415
11:40	200	273	1.4	545.3	15.9	1632	1752	553	420
12:00	220	158	1.2	418.8	17.2	846	869	512	392
12:20	240	140	1.1	402.0	****	894	876	492	407
12:40	260	125	1.4	357.4	****	1147	1266	474	382
13:00	280	194	1.4	493.3	****	1514	1631	1	261
13:20	300	178	1.5	424.1	6.6	1668	1731	34	60
13:40	320	131	1.4	487.5	6.6	1431	1488	1	263
14:00	340	108	1.1	241.0	6.3	830	883	1	1
14:20	360	89	0.8	372.2	6.4	767	824	1	202
14:40	380	58	0.9	230.6	6.5	259	290	1	1
15:00	400	88	1.1	280.7	6.8	759	783	****	****
15:20	420	86	1.0	321.6	7.7	820	888	****	****
15:40	440	84	0.9	272.7	7.4	****	****	413	418
15:50	450	55	1.0	237.9	7.3	****	****	324	355
16:10	470	48	0.9	188.7	7.4	****	****	331	333
16:30	490	36	0.9	335.7	8.0	****	****	958	788
16:40	500	****	0.8	186.1	155.0	****	****	1987	1995
17:00	520	****	1.3	364.4	152.3	****	****	650	642

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE  
Test Description: TEST TWO  
Date: NOVEMBER 30, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 25	5	22	0.6	790.3	18.4	8	8	465	386
8 45	25	23	1.0	836.4	18.4	86	108	538	386
9 05	45	24	0.9	834.1	18.8	267	290	532	413
9 25	65	36	1.1	771.7	17.6	871	934	614	438
9 45	85	30	1.3	720.0	16.5	832	916	640	531
10 05	105	27	0.9	621.6	17.3	373	410	513	391
10 25	125	39	1.3	609.9	18.3	867	927	531	411
10 45	145	73	1.3	595.4	18.4	1173	1396	526	436
11 05	165	111	1.2	636.4	17.5	1428	1450	474	346
11 25	185	194	1.3	524.8	15.6	1572	1668	460	360
11 45	205	242	1.5	625.1	16.5	1816	1970	547	386
12 05	225	293	1.2	626.1	16.8	1880	1993	435	435
12 25	245	361	1.6	461.6	****	1914	1977	454	360
12 45	265	214	1.2	474.3	****	1376	1418	380	375
13 05	285	475	1.7	448.8	****	1888	1897	1	1
13 25	305	436	1.6	422.5	7.8	1856	1897	211	68
13 45	325	395	1.6	421.0	6.8	1890	1897	1	289
14 05	345	537	1.7	609.5	6.8	1888	1897	1	1
14 25	365	453	1.5	447.2	6.8	1888	1897	174	208
14 45	385	409	1.3	435.4	6.9	1879	1876	****	****
15 05	405	464	1.6	381.8	7.4	1888	1897	****	****
15 25	425	499	1.5	332.6	8.4	1898	1897	316	320
15 55	455	358	1.3	379.7	7.4	****	****	421	443
16 15	475	****	1.3	442.7	8.4	****	****	314	268
16 45	505	****	****	****	****	****	****	****	****

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: FOUR  
Test Description: TEST TWO  
Date: NOVEMBER 30, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
9 30	10	27	0 9	780 9	16 3	22	24	509	326
9 50	30	21	0 8	833 7	18 4	165	152	618	404
9 10	50	23	1 4	807 8	16 8	503	546	594	429
9 30	70	31	1 1	804 8	16 7	539	583	587	446
9 50	90	31	1 3	739 5	15 8	480	509	609	596
10 10	110	27	1 2	673 6	15 9	548	583	570	419
10 30	130	36	1 6	682 3	17 8	743	793	548	411
10 50	150	37	1 4	642 7	17 5	967	1018	536	388
11 10	170	47	1 2	613 2	16 7	1131	1189	540	424
11 30	190	68	1 4	779 6	17 0	1295	1361	503	243
11 50	210	71	1 4	473 0	18 5	1461	1546	507	343
12 10	230	74	1 5	492 5	****	1459	1542	468	394
12 30	250	115	1 6	508 6	****	1699	1827	501	402
12 50	270	85	1 2	565 5	****	1128	1180	1	319
13 10	290	122	1 5	428 7	****	1520	1567	1	1
13 30	310	161	1 4	526 2	6 8	1646	1735	1	221
13 50	330	283	1 6	521 8	6 9	1787	1883	88	1
14 10	350	306	1 5	395 0	6 6	1898	1997	35	22
14 30	370	355	1 6	417 3	7 1	1970	1997	2	41
14 50	390	384	1 5	395 2	7 2	1858	1997	****	****
15 10	410	517	1 6	525 7	8 0	1898	1997	****	****
15 30	430	617	1 7	459 6	8 2	****	****	332	308
16 00	460	402	1 4	408 7	7 4	****	****	376	375
16 20	480	187	0 9	341 1	8 0	****	****	371	388
16 50	510	25	0 7	314 0	144 5	0	1	817	754

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST THREE  
Date: DECEMBER 1, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:00	-5	20	0.8	828.5	6.8	0	1	743	481
8:20	15	26	0.9	1074.8	6.7	21	29	290	262
8:40	35	31	0.8	1232.0	7.1	488	554	271	267
9:00	55	32	1.1	1167.0	8.2	310	340	231	248
9:20	75	46	1.0	1122.3	8.1	577	639	256	254
9:40	95	71	1.6	1092.1	7.7	840	949	264	290
10:00	115	52	0.9	1246.5	7.5	405	436	233	247
10:20	135	89	1.2	1440.2	7.2	540	629	219	267
10:40	155	137	1.2	1491.8	7.3	729	815	213	256
11:00	175	165	1.1	1464.6	7.1	822	1036	288	270
11:20	195	223	1.1	1457.0	7.2	1152	1003	199	214
11:40	215	430	1.4	1641.8	7.5	1742	1998	221	234
12:00	235	364	1.3	1671.3	6.9	1588	1670	220	259
12:20	255	134	1.2	1345.7	7.0	519	600	218	241
12:25	260	348	1.1	1581.9	7.1	1354	1706	273	370
12:45	280	126	1.1	1456.2	6.9	444	540	181	286
13:05	300	381	1.4	1578.4	7.4	1657	1935	239	314
13:25	320	386	1.4	1545.1	7.0	2015	1968	223	243
13:45	340	388	1.5	1591.0	6.8	2157	1898	228	223
14:05	360	423	1.5	1639.3	6.7	1778	2064	205	263
14:25	380	324	1.5	1655.7	6.8	1387	1682	213	269
14:45	400	173	1.2	1501.8	7.0	753	880	150	193
15:05	420	399	1.5	1659.2	7.7	1785	1894	193	198
15:25	440	438	1.4	1691.8	7.5	1865	2155	209	237
15:45	460	385	1.5	1805.8	7.5	1588	1693	171	206
16:05	480	306	1.4	1724.9	7.0	1400	1599	206	215
16:25	500	37	1.2	1581.9	6.8	692	784	210	200
16:45	520	33	1.2	1720.0	7.2	511	573	196	188



PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST THREE  
Date: DECEMBER 1, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:05	0	19	1.2	1083.6	6.8	0	1	591	516
8:25	20	21	0.8	1000.0	7.3	56	58	293	307
8:45	40	25	1.1	1129.4	8.8	531	577	244	239
9:05	60	28	1.0	1158.9	10.4	206	217	272	263
9:25	80	28	1.3	1301.1	10.2	725	789	258	265
9:45	100	38	1.5	1390.5	9.0	704	783	255	287
10:05	120	33	1.4	1171.4	8.3	500	548	209	257
10:25	140	43	1.1	1269.3	8.0	579	638	178	245
10:45	160	59	1.1	1513.8	7.8	577	639	214	266
11:05	180	68	1.1	1438.2	7.4	678	743	218	243
11:25	200	69	1.2	1333.4	7.2	672	735	193	240
11:45	220	82	1.1	1332.6	7.1	841	936	220	255
12:05	240	88	1.0	1380.2	6.7	860	937	192	270
12:30	265	96	1.1	1360.4	7.2	755	836	246	311
12:50	285	50	1.0	1334.3	6.9	126	150	195	307
13:10	305	153	1.1	1477.7	7.0	864	1161	287	346
13:30	325	217	1.2	1558.0	7.0	1248	1423	199	223
13:50	345	269	1.2	1582.3	6.8	1407	1878	201	202
14:10	365	358	1.4	1720.0	6.8	1652	2132	223	258
14:30	385	276	1.4	1633.4	6.6	1337	1371	186	213
14:50	405	273	1.4	1669.0	7.5	1236	1327	217	242
15:10	425	447	1.3	1822.5	7.6	1843	1917	176	206
15:30	445	364	1.5	1784.4	7.7	1495	1676	188	222
15:50	465	357	1.3	1642.7	7.4	1712	1459	193	183
16:10	485	185	1.2	1765.1	7.1	829	862	188	236
16:30	505	23	0.8	1452.0	5.9	1	0	204	198
16:50	525	****	****	****	****	****	****	****	****

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: THREE  
Test Description: TEST THREE  
Date: DECEMBER 1, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 10	5	386	1.6	1521.8	7.0	3885	4708	317	300
8 30	25	575	1.4	1586.1	8.0	4382	4877	295	273
8 50	45	526	1.6	1582.3	7.8	3832	4291	243	253
9 10	65	380	1.6	1438.1	11.2	2888	3335	268	268
9 30	85	457	1.5	1538.4	10.2	3514	3250	289	298
9 50	105	352	1.6	1357.8	8.8	3076	3256	251	262
10 10	125	363	1.6	1377.2	9.0	2707	2821	218	233
10 30	145	657	1.7	1698.8	9.1	4813	5199	184	225
10 50	165	536	1.7	1638.8	8.6	3741	4773	187	271
11 10	185	704	1.8	1852.3	8.4	4574	5422	191	219
11 30	205	700	1.7	1670.8	7.8	3187	5018	212	231
11 50	225	704	1.5	1808.8	7.8	4347	5320	186	242
12 10	245	933	1.5	1626.1	7.2	4248	4119	238	269
12 35	270	405	1.5	1646.3	7.7	3684	3732	264	273
12 55	290	51	0.8	1383.6	7.0	57	85	216	287
13 15	310	325	1.3	1644.4	7.2	2521	2782	269	311
13 35	330	264	1.3	1728.1	7.2	2444	2485	200	247
13 55	350	202	1.4	1701.4	7.1	2021	2152	176	221
14 15	370	358	1.5	1708.0	7.1	2754	3087	226	260
14 35	390	173	1.3	1620.1	7.2	1935	2091	200	241
14 55	410	86	1.2	1663.1	7.4	1275	1357	220	240
15 15	430	225	1.2	1601.0	7.5	2888	3086	204	230
15 35	450	188	1.3	1611.5	7.3	2882	2353	217	218
15 55	470	75	1.0	1673.8	7.0	931	1019	186	214
16 15	490	40	1.1	1513.9	7.0	128	155	176	207
16 35	510	21	1.0	1388.8	2.1	1	1	206	205

**PEDCO ENVIRONMENTAL, INC.**  
**ARMY DIESEL FORKLIFT STUDY**

**Location FOUR**  
**Test Description TEST THREE**  
**Date DECEMBER 1, 1963**

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 15	10	493	1 9	1395 2	7 3	3849	3818	289	289
8 35	30	484	2 0	1474 8	7 8	4238	4154	289	280
8 55	50	574	2 2	1489 2	8 0	4218	4316	221	244
9 15	70	456	1 8	1439 0	8 7	3055	3505	235	248
9 35	90	491	1 7	1464 0	8 8	4224	4070	221	265
9 55	110	384	1 7	1453 8	8 7	2675	2986	221	262
10 15	130	336	1 6	1603 9	8 2	2444	2628	194	243
10 35	150	417	1 6	1596 5	8 1	3220	3501	210	225
10 55	170	398	1 7	1711 3	8 1	3069	3613	218	241
11 15	190	247	1 8	1541 1	7 5	2624	2843	183	218
11 35	210	179	1 6	1808 2	7 3	2380	2439	206	280
11 55	230	165	1 6	1501 8	7 5	2207	2333	222	273
12 15	250	133	1 5	1393 5	7 3	1939	2038	235	260
12 40	275	116	1 4	1552 7	7 8	1893	1985	217	227
13 00	295	55	0 9	1458 8	7 3	323	341	186	241
13 20	315	105	1 3	1609 5	7 1	1834	1934	292	333
13 40	335	102	1 5	1593 8	7 0	1860	1956	218	287
14 00	355	106	1 5	1786 1	7 0	1894	1986	188	202
14 20	375	109	1 4	1765 3	6 9	1813	1925	218	281
14 40	395	96	1 2	1818 7	7 2	1536	1624	176	246
15 00	415	82	1 2	1730 5	7 3	1385	1470	184	236
15 20	435	81	1 2	1656 6	7 4	1590	1681	210	224
15 40	455	128	1 5	1942 8	7 7	2326	2615	185	221
16 00	475	62	1 1	1573 1	7 1	894	949	152	200
16 20	495	41	1 1	1574 2	7 2	140	149	185	235
16 40	515	38	0 9	1618 4	7 3	99	102	190	189

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST FOUR  
Date: DECEMBER 2, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:10	-10	24	1.2	1.4	8.0	13	15	121	142
8:30	10	110	1.8	6.4	6.3	1739	1913	123	137
8:50	30	406	1.9	14.7	6.8	2630	2855	114	142
9:10	50	435	1.9	5.2	6.9	2292	2766	98	114
9:30	70	851	1.9	15.6	7.4	4185	4551	102	124
9:50	90	964	1.6	17.0	7.4	5135	5705	127	138
10:10	110	574	1.7	1.7	7.2	3130	3278	183	158
10:30	130	527	1.8	7.8	7.0	2674	2984	223	204
10:50	150	612	1.7	8.6	7.2	3056	2876	294	290
11:10	170	747	1.7	21.5	7.2	3514	4524	213	201
11:30	190	791	1.6	14.9	7.1	4076	4548	268	250
11:50	210	799	1.7	14.3	7.2	4014	5063	250	280
12:10	230	778	1.7	9.2	7.1	3008	3640	178	191
12:30	250	564	1.6	25.5	6.9	2619	2888	256	270
12:50	270	397	1.6	12.4	6.7	1720	1963	147	181
13:10	290	376	1.6	6.1	6.8	1793	2285	183	163
13:30	310	431	1.8	6.0	6.7	2389	2564	175	206
13:50	330	226	1.6	7.4	6.9	1509	1744	161	152
14:10	350	284	1.7	12.8	6.6	1509	1704	312	366
14:30	370	268	1.6	3.1	6.9	1328	1527	285	358
14:50	390	****	1.1	****	6.8	1539	1491	288	343
15:10	410	131	1.4	****	6.8	921	1010	333	331
15:30	430	101	1.6	****	6.9	876	970	297	315
15:50	450	219	1.7	****	7.4	2119	2524	341	401
16:10	470	58	1.3	****	7.4	271	303	280	331

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST FOUR  
Date: DECEMBER 2, 1983

Time	Elapsed Time	SO2 (PPH)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPH)	NOX (PPH)	AIR1	AIR2
0 15	-5	22	1 2	3 2	0 1	14	14	131	180
0 35	15	471	2 0	3 5	0 8	2091	3264	110	152
0 55	35	504	1 7	6 7	7 0	2546	2646	96	116
0 15	55	762	1 8	3 8	7 2	3321	3749	94	110
0 35	75	842	1 7	17 6	7 3	3029	4351	113	140
0 55	95	733	1 4	8 8	7 5	3967	4822	106	123
10 15	115	723	1 9	21 9	7 4	3187	3409	102	141
10 35	135	697	1 8	6 9	6 9	2837	3673	197	175
10 55	155	453	1 7	8 5	7 2	2240	2438	274	271
11 15	175	382	1 8	4 0	6 9	2170	2348	270	260
11 35	195	405	1 7	18 3	6 8	2641	2759	256	248
11 55	215	296	1 5	4 1	7 1	2026	2259	234	253
12 15	235	342	1 7	35 6	6 8	1874	2083	169	173
12 35	255	379	1 7	12 8	6 7	2094	2322	195	196
12 55	275	309	1 6	4 5	6 5	1945	1996	186	206
13 15	295	275	1 5	2 5	6 9	1823	1979	193	202
13 35	315	307	1 7	18 1	6 8	1887	2119	174	206
13 55	335	308	1 7	13 5	7 0	1946	2196	235	278
14 15	355	115	1 5	12 4	6 6	1388	1506	333	347
14 35	375	84	1 7	****	6 8	1016	1091	304	364
14 55	395	88	1 8	****	6 8	1084	1225	360	420
15 15	415	180	1 7	****	6 8	1423	1570	253	279
15 35	435	65	1 5	****	7 0	694	759	370	418
15 55	455	66	1 6	****	7 3	866	924	319	393
16 15	475	42	1 1	****	7 2	215	232	248	293

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE

Test Description: TEST FOUR

Date: DECEMBER 2, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 00	-20	20	1.0	888.3	****	1	1	123	145
8 20	0	28	1.4	8.0	5.8	14	15	112	146
8 40	20	28	1.3	0.0	6.5	138	156	111	134
9 00	40	164	1.8	11.8	7.1	2885	3253	96	128
9 20	60	156	1.7	7.6	7.1	2855	3179	102	118
9 40	80	174	1.7	15.6	7.1	2550	2622	98	122
10 00	100	223	1.8	6.4	7.4	2756	2885	158	121
10 20	120	374	1.9	10.0	7.4	4101	4418	170	125
10 40	140	406	2.0	8.1	7.1	3547	3789	242	210
11 00	160	500	1.8	13.7	7.3	4277	4662	239	229
11 20	180	351	2.0	5.5	7.1	3278	3457	184	182
11 40	200	549	2.0	16.4	7.3	4310	5368	248	231
12 00	220	411	1.9	8.5	7.2	3078	3808	213	236
12 20	240	571	2.1	32.1	7.5	5237	5485	203	230
12 40	260	763	2.1	13.8	7.4	6276	6693	176	183
13 00	280	540	2.1	37.4	7.3	4803	4970	204	183
13 20	300	531	2.0	23.6	7.2	4219	4412	172	166
13 40	320	447	2.1	8.4	7.4	3775	4103	146	145
14 00	340	211	1.6	4.9	6.9	1653	1832	248	285
14 20	360	577	1.8	13.5	7.1	4505	5274	273	306
14 40	380	586	2.1	****	7.2	4741	5483	354	412
15 00	400	394	2.1	****	7.1	3658	3991	339	385
15 20	420	524	2.1	****	7.3	4283	4278	218	246
15 40	440	551	2.2	****	7.6	3982	4112	337	374
16 00	460	542	2.1	****	7.8	3764	4083	355	378
16 20	480	****	****	****	****	****	****	****	****

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location FOUR  
Test Description: TEST FOUR  
Date: DECEMBER 2, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:05	-15	20	1.0	5.7	10.9	14	17	109	138
8:25	5	22	1.1	33.4	6.3	15	17	100	134
8:45	25	29	1.3	22.8	6.3	162	154	115	128
9:05	45	126	2.2	20.6	7.0	3748	3932	90	121
9:25	65	120	1.8	50.4	7.0	3041	3161	101	122
9:45	85	104	1.6	13.9	6.9	2173	2268	126	156
10:05	105	155	1.8	37.6	7.2	2977	3176	199	169
10:25	125	175	1.8	19.6	7.0	3144	3309	187	160
10:45	145	286	2.0	20.2	7.2	3894	4080	226	233
11:05	165	236	2.1	24.6	7.3	3699	3926	221	189
11:25	185	209	1.9	7.4	7.1	2790	3071	274	216
11:45	205	363	2.0	21.8	7.3	3625	3820	271	247
12:05	225	445	2.2	1.8	7.3	4119	4400	176	187
12:25	245	516	2.2	17.4	7.4	4943	5418	178	195
12:45	265	460	2.3	8.2	7.1	4595	5038	185	221
13:05	285	481	2.2	27.4	7.4	4392	4643	176	196
13:25	305	478	2.1	27.1	7.2	4047	4600	183	214
13:45	325	146	1.7	25.6	7.1	1384	1532	201	169
14:05	345	246	1.6	44.6	6.8	1840	2044	313	346
14:25	365	652	2.3	40.2	7.3	5377	5899	296	369
14:45	385	575	2.1	****	7.3	4875	5830	343	378
15:05	405	177	1.8	****	7.0	2003	1888	267	310
15:25	425	551	1.9	****	7.5	4175	4409	220	261
15:45	445	637	2.5	****	7.9	4551	4777	318	395
16:05	465	647	2.1	****	7.9	4612	4736	313	382

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST FIVE  
Date: DECEMBER 5, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 15	0	28	0.9	888	888	7	3	227	246
8 35	20	40	1.1	888	7.5	354	317	203	276
8 55	40	70	1.3	888	7.7	1152	1231	178	202
9 15	60	123	1.7	888	7.7	1548	1762	243	284
9 35	80	124	1.6	889.5	7.8	1211	1370	204	234
9 55	100	113	1.8	709.8	14.5	1021	1117	244	270
10 15	120	95	1.5	701.7	8.5	757	847	328	284
10 35	140	169	1.6	691.8	7.7	1107	1348	220	287
10 55	160	325	2.1	780.0	7.8	1801	2161	243	232
11 15	180	319	1.7	759.0	7.4	2057	1879	289	279
11 35	200	371	2.2	834.2	7.8	2001	2337	245	282
11 55	220	424	1.9	745.7	8.0	2245	2521	294	339
12 15	240	407	2.0	866.8	7.9	1855	2156	297	273
12 35	260	460	1.8	853.4	7.6	2585	2810	354	369
12 55	280	420	1.9	778.1	7.8	1831	2007	422	490
13 15	300	398	1.7	725.5	7.8	1750	2048	330	326
13 35	320	458	1.9	783.5	7.6	2123	2200	310	347
13 55	340	474	1.9	815.9	7.5	2108	2260	333	351
14 15	360	431	1.8	731.6	7.7	2142	2292	390	443
14 35	380	301	1.6	662.7	7.7	1553	1677	282	326
14 55	400	367	1.7	611.3	7.5	1612	1827	370	447
15 15	420	359	1.5	619.7	7.4	1623	1827	361	432
15 35	440	398	1.7	753.1	7.2	2038	2262	351	381
15 55	460	341	1.6	665.3	7.2	1896	2338	331	350



PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST FIVE  
Date: DECEMBER 5, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 00	-15	35	0.7	1912.4	****	3	4	142	191
8 20	5	26	0.9	****	7.6	35	37	196	210
8 40	25	27	0.9	****	7.4	313	330	223	255
9 00	45	38	1.2	****	7.7	924	960	267	287
9 20	65	41	1.5	****	7.6	1134	1200	218	253
9 40	85	49	1.3	744.0	8.0	982	1031	249	272
10 00	105	182	1.2	849.5	7.2	1061	1337	271	334
11 00	165	54	1.6	615.5	7.8	843	1016	247	260
11 20	185	61	1.5	698.6	7.5	1016	1093	327	347
11 40	205	100	1.6	638.5	7.9	1166	1315	250	280
12 00	225	97	1.6	771.7	7.8	1137	1233	333	352
12 20	245	121	1.5	747.8	7.6	1143	1301	302	330
12 40	265	247	1.7	808.5	7.5	1714	1946	347	372
13 00	285	153	1.7	685.5	7.8	1007	1167	376	385
13 20	305	313	1.7	706.8	7.7	1636	1755	232	278
13 40	325	371	1.7	762.4	7.6	1909	2249	366	376
14 00	345	474	1.9	720.4	7.7	2151	2878	285	331
14 20	365	459	1.9	682.6	7.7	2082	2458	415	490
14 40	385	352	1.8	804.9	7.7	1991	2132	275	331
15 00	405	417	1.8	707.3	7.6	1822	2244	356	465
15 20	425	367	1.6	582.7	7.2	1799	1778	362	381
15 40	445	405	1.7	723.7	7.1	2080	2099	350	456
16 00	465	182	1.2	849.5	7.2	1061	1337	271	334

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location THREE  
Test Description: TEST FIVE  
Date: DECEMBER 5, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 05	-10	34	0.8	1920.2	****	1	2	115	147
8 25	10	1517	1.6	****	8.5	8858	7190	187	273
8 45	30	1487	2.1	****	8.4	8279	6625	136	203
8 55	50	1365	1.9	****	8.5	5814	6340	228	262
9 25	70	1668	1.9	****	8.2	6366	6632	249	248
9 45	90	1439	1.8	1075.8	8.5	5431	6097	233	246
10 05	110	1450	2.2	1219.6	13.7	5868	6264	231	287
10 25	130	1223	2.0	849.5	9.1	5025	5563	204	312
10 45	150	1304	1.8	981.9	8.4	5542	5980	214	262
11 05	170	1350	1.8	983.6	8.2	5842	5726	280	298
11 25	190	1304	1.8	969.7	8.0	5571	5351	253	264
11 45	210	1509	1.7	1003.5	8.2	5691	6182	277	290
12 05	230	1213	1.7	981.4	8.2	4222	5083	308	342
12 25	250	1158	1.7	913.9	7.8	4665	4058	347	323
12 45	270	618	1.4	699.8	7.8	2356	2400	363	374
13 05	290	832	1.4	790.3	8.0	3244	3553	321	300
13 25	310	904	1.4	777.1	7.8	3775	3984	235	227
13 45	330	664	1.5	770.8	7.6	3024	3108	336	368
14 05	350	834	1.6	764.6	7.7	3572	3702	311	340
14 25	370	276	1.4	675.4	7.6	2381	2368	416	408
14 45	390	753	1.6	740.9	7.8	4036	4141	173	242
15 05	410	255	1.2	572.4	7.6	1878	2200	422	458
15 25	430	385	1.4	806.5	7.3	3726	3862	374	374
15 45	450	125	1.0	525.2	7.0	1325	1388	351	355

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: FOUR

Test Description: TEST FIVE

Date: DECEMBER 5, 1983

Time	Elapsed Time	SO2 (PPH)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPH)	NOX (PPH)	AIR1	AIR2
8 10	-5	30	0.9	****	****	2	2	212	281
8 30	15	1160	2.0	****	8.4	8642	7182	190	233
8 50	35	1522	1.7	****	8.7	8535	8897	137	207
9 10	55	1355	2.0	****	8.5	5600	8194	257	267
9 30	75	1298	1.9	****	8.1	5257	5587	193	268
9 50	95	1292	1.9	1059.2	8.8	5003	5205	203	217
10 10	115	1106	2.0	1088.7	11.4	4511	4989	302	309
10 30	135	1197	1.8	1103.5	8.7	5203	5295	247	295
10 50	155	1081	2.0	925.9	8.2	4892	5244	204	221
11 10	175	1005	1.8	912.1	7.9	4555	4621	244	288
11 30	195	1072	1.8	935.3	8.1	4794	5103	245	239
11 50	215	1035	2.0	1019.7	8.1	4770	5034	228	210
12 10	235	752	1.8	890.6	8.0	3755	3888	328	316
12 30	255	1085	1.8	923.5	7.7	4662	4892	343	369
12 50	275	567	1.7	772.0	8.0	3008	3159	331	365
13 10	295	755	1.8	868.6	7.9	3695	3863	326	305
13 30	315	722	1.7	794.3	7.8	3778	4071	244	253
13 50	335	460	1.6	699.3	7.7	3298	3391	357	324
14 10	355	357	1.8	782.1	7.8	3425	3577	357	419
14 30	375	562	1.4	750.0	7.6	3499	3588	330	358
14 50	395	652	2.1	842.9	8.1	4596	4947	268	294
15 10	415	298	1.5	763.0	7.7	3482	3672	356	366
15 30	435	344	1.3	683.9	7.4	3762	3899	298	325
15 50	455	98	1.1	614.9	7.0	1141	1205	295	341

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST SIX  
Date: DECEMBER 6, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:15	-175	23	0.8	761.4	6.2	****	****	621	770
8:35	-155	27	0.7	834.5	6.0	****	****	855	738
8:55	-135	26	0.8	862.8	6.1	****	****	539	821
9:15	-115	28	0.7	864.9	6.0	****	****	429	516
9:35	-95	31	0.8	776.5	6.3	4	5	407	398
9:55	-75	23	1.0	691.0	6.6	5	5	418	451
10:15	-55	29	0.8	707.8	6.5	5	5	326	398
10:35	-35	26	0.6	764.7	6.5	5	5	392	563
10:55	-15	25	0.7	757.0	6.4	4	4	462	840
11:15	5	166	1.9	973.6	7.0	1655	1766	428	692
11:35	25	230	2.4	1008.6	6.8	1496	1949	482	683
11:55	45	369	2.5	1059.6	7.0	2400	2659	370	579
12:15	65	151	1.4	838.2	6.6	761	908	364	553
12:35	85	398	2.8	1033.8	6.9	2722	2952	337	585
12:55	105	437	2.8	928.9	7.0	2176	2278	418	585
13:15	125	343	2.1	1013.0	6.6	1660	1967	367	480
13:35	145	261	1.9	894.6	6.9	1253	1421	438	663
13:55	165	437	2.5	1011.1	7.0	2098	2380	268	455
14:15	185	630	3.1	1083.9	7.2	3313	3890	240	475
14:35	205	937	3.7	1199.7	7.4	4658	4876	230	416
14:55	225	565	3.0	1119.4	7.4	2963	3327	255	378
15:15	245	342	2.4	922.1	7.2	1763	1503	223	426
15:35	265	277	2.2	906.2	7.1	1319	1669	182	362
15:55	285	357	2.6	919.1	7.5	2310	2025	118	263
16:15	305	503	3.3	954.3	7.8	2576	3335	167	295
16:35	325	186	2.1	908.0	7.5	1187	1347	178	175
16:55	345	189	2.0	841.4	7.5	1010	1260	168	212
17:15	365	80	1.6	742.3	7.5	462	514	226	249
17:35	385	93	1.4	828.1	7.5	513	622	187	228
17:55	405	97	1.2	831.3	7.6	473	546	186	219
18:15	425	661	2.6	1047.0	7.8	2910	3949	182	189
18:35	445	77	0.8	785.3	7.6	224	247	168	193

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location TWO  
Test Description TEST SIX  
Date: DECEMBER 1, 1983

Time	Elapsed Time	SO2 (PPH)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPH)	NO2 (PPH)	AIR1	AIR2
8 00	-180	20	0 8	748 2	6 3	2	1	2028	1676
8 20	-170	22	0 7	748 8	6 1	****	****	883	806
8 40	-150	19	0 8	662 6	6 1	****	****	564	688
9 00	-130	26	0 8	793 0	6 3	****	****	397	527
9 20	-110	24	0 8	704 0	6 0	3	5	416	426
9 40	-90	26	0 6	736 0	6 3	3	5	427	451
10 00	-70	26	1 5	673 1	6 7	5	7	400	445
10 20	-50	24	0 8	734 8	6 4	4	7	409	444
10 40	-30	25	0 7	780 5	6 5	4	4	453	660
11 00	-10	28	0 6	687 6	6 3	4	4	483	655
11 20	10	370	2 7	1010 5	7 3	2848	3707	352	537
11 40	30	243	2 4	1028 4	6 8	1706	2158	434	584
12 00	50	1125	4 4	1242 0	7 5	5303	5500	406	633
12 20	70	1123	4 4	1385 6	7 4	5753	5888	310	507
12 40	90	844	4 9	1335 9	7 8	6265	8054	384	539
13 00	110	653	3 1	1102 0	7 1	2590	4515	400	556
13 20	130	419	2 3	840 1	6 8	1818	2306	411	640
13 40	150	447	2 3	868 6	6 9	1987	2389	415	618
14 00	170	753	3 6	1189 8	7 4	3955	4733	192	386
14 20	190	389	2 8	1081 4	6 9	2872	2848	257	443
14 40	210	492	2 8	1154 1	7 1	3211	3330	248	407
15 00	230	150	2 1	887 2	7 0	1460	1605	156	287
15 20	250	87	1 9	775 2	6 9	768	878	208	416
15 40	270	80	1 7	833 9	7 2	843	941	175	385
16 00	290	84	2 1	843 8	7 2	1081	1167	156	300
16 20	310	103	2 6	888 8	7 5	1471	1573	216	338
16 40	330	81	2 3	825 9	7 4	943	994	153	194
17 00	350	73	1 3	806 0	7 3	768	833	188	220
17 20	370	73	1 6	841 6	7 4	586	656	188	201
17 40	390	64	1 5	786 7	7 5	458	514	175	232
18 00	410	68	1 4	787 6	7 5	441	477	215	238
18 20	430	84	1 4	810 5	7 7	951	1008	202	208
18 40	450	58	1 3	786 5	7 4	288	222	181	186

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location THREE  
Test Description TEST SIX  
Date: DECEMBER 6, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 05	-185	25	0.8	788.8	6.3	****	****	2257	2189
8 25	-165	21	1.0	760.4	6.0	****	****	683	796
8 45	-145	22	0.8	669.6	6.1	****	****	702	804
9 05	-125	24	1.0	772.3	6.3	****	****	384	378
9 25	-105	28	0.9	741.6	6.2	5	6	415	428
9 45	-85	31	0.9	777.5	6.5	6	5	464	449
10 05	-65	30	1.0	762.2	6.5	5	5	424	415
10 25	-45	25	0.8	720.3	6.7	6	8	368	401
10 45	-25	20	0.8	751.9	6.4	5	5	462	663
11 05	-5	22	0.8	748.0	6.8	6	7	450	619
11 25	15	28	0.7	821.4	6.8	165	178	405	624
11 45	35	30	1.2	907.6	6.8	530	587	400	574
12 05	55	30	1.2	880.7	6.9	965	1058	372	553
12 25	75	37	1.5	752.8	6.7	951	1044	343	505
12 45	95	52	1.8	832.7	7.1	1512	1808	368	550
13 05	115	50	1.3	780.3	6.8	890	1116	431	598
13 25	135	36	1.1	785.4	6.8	280	324	393	623
13 45	155	88	1.4	891.6	7.1	1394	1648	388	567
14 05	175	212	2.2	1001.5	7.6	3525	3954	244	477
14 25	195	415	2.7	1006.7	7.7	5875	4968	217	445
14 45	215	507	3.3	1019.2	8.0	5359	6295	271	499
15 05	235	307	2.4	1097.8	7.7	3252	3415	180	328
15 25	255	190	1.9	984.9	7.4	1919	2440	199	366
15 45	275	332	2.6	958.1	7.9	3218	3693	173	311
16 05	295	464	3.0	994.5	8.0	4759	5452	153	270
16 25	315	339	2.2	892.3	7.8	3190	3761	206	328
16 45	335	433	2.6	929.8	8.0	4230	4744	198	295
17 05	355	274	2.2	1001.1	8.0	2265	3366	212	226
17 25	375	265	2.3	922.9	7.9	2317	2708	202	212
17 45	395	284	2.3	980.1	8.0	2201	3078	214	247
18 05	415	374	2.4	986.9	8.3	3414	3889	159	197
18 25	435	348	2.7	954.2	8.3	2705	3651	205	242
18 45	455	374	2.6	991.4	8.4	2989	3448	150	173

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: FOUR

Test Description: TEST SIX

Date: DECEMBER 6, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:10	-180	28	0.8	781.1	6.3	****	****	1126	1670
8:30	-160	24	0.8	887.8	6.3	****	****	633	776
8:50	-140	30	1.0	721.4	6.2	****	****	738	823
9:10	-120	27	1.3	873.5	6.3	****	****	466	438
9:30	-100	28	0.8	762.9	6.4	5	7	443	461
9:50	-80	37	0.9	823.4	6.6	8	7	457	433
10:10	-60	32	0.8	774.8	6.5	7	8	413	440
10:30	-40	30	0.8	733.1	6.8	8	7	423	554
10:50	-20	28	0.8	774.8	6.4	6	7	516	670
11:10	0	31	0.9	813.1	6.6	21	16	482	701
11:30	20	29	1.0	793.3	6.6	139	155	382	599
11:50	40	29	1.2	819.9	6.7	499	546	388	550
12:10	60	34	1.6	765.2	6.8	1061	1188	423	609
12:30	80	41	1.5	890.7	6.7	1246	1370	362	580
12:50	100	45	1.2	875.4	6.8	756	876	394	574
13:10	120	54	1.4	799.3	6.9	893	1128	374	592
13:30	140	43	1.0	786.3	6.9	584	874	394	670
13:50	160	63	1.7	844.0	7.2	1478	1639	385	585
14:10	180	98	1.9	777.6	7.2	2446	2678	274	462
14:30	200	111	1.7	908.8	7.3	2258	2524	294	489
14:50	220	125	2.2	934.8	7.3	2532	2782	256	509
15:10	240	111	1.9	996.0	7.3	1620	1857	177	324
15:30	260	91	1.7	877.3	7.2	1378	1574	213	380
15:50	280	113	2.2	857.6	7.7	1708	1946	111	263
16:10	300	207	2.2	897.7	7.7	3186	3547	164	264
16:30	320	317	2.4	909.4	8.0	3591	4090	175	180
16:50	340	470	3.1	958.1	8.5	4610	6070	146	180
17:10	360	219	2.0	946.1	7.8	1968	2245	237	237
17:30	380	162	1.7	866.4	8.1	1497	1595	194	227
17:50	400	329	2.5	863.8	8.3	2775	3246	209	244
18:10	420	345	2.4	1018.8	8.5	2888	4147	170	205
18:30	440	270	2.2	947.8	8.2	2440	2571	193	210
18:50	460	53	0.7	488.6	3.4	3	3	282	168

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST SEVEN  
Date: DECEMBER 7, 1963

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 10	5	30	0.9	710.6	6.4	49	51	256	226
8 30	25	31	1.0	738.8	8.8	58	62	232	207
8 50	45	39	1.3	774.8	8.1	178	208	237	179
9 10	65	36	1.0	692.4	7.6	48	55	223	196
9 30	85	36	1.3	738.1	7.4	138	163	233	191
9 50	105	40	1.2	721.8	7.3	108	127	235	209
10 10	125	41	1.5	755.3	10.3	162	228	205	161
10 30	145	45	1.4	659.4	7.3	249	315	161	177
10 50	165	106	1.7	721.7	7.3	1203	998	226	202
11 10	185	184	2.3	737.3	7.5	946	2233	212	188
11 30	205	212	2.4	822.5	7.4	2235	2526	223	203
11 50	225	325	2.9	859.8	7.4	2221	2778	209	187
12 10	245	339	2.8	803.8	7.4	2799	2946	210	196
12 30	265	432	3.3	929.7	7.7	3455	3601	209	187
12 50	285	432	3.2	820.2	8.2	3522	3519	169	194
13 10	305	558	3.8	973.8	8.6	4162	4879	158	176
13 30	325	487	3.0	879.7	8.6	3550	4207	131	174
13 50	345	1974	19.5	1349.4	14.8	8669	8861	171	187
14 10	365	572	4.5	891.3	9.8	4103	4831	197	160
14 30	385	399	2.8	769.1	9.2	2728	3113	174	205
14 50	405	512	3.8	929.2	10.0	2764	3455	154	155
15 10	425	352	2.4	714.9	8.9	2072	2349	130	165
15 30	445	449	3.4	798.7	****	3357	4120	130	163
15 50	465	402	3.3	876.8	****	2658	3277	159	174
16 10	485	435	3.6	769.6	****	2772	3619	151	173
16 25	500	471	3.7	709.3	9.2	3601	4210	147	162
16 45	520	577	4.0	845.0	8.5	3813	4445	153	161



FEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST SEVEN  
Date: DECEMBER 7, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
7:55	-10	27	1.0	716.9	6.2	14	13	271	207
8:15	10	30	0.9	728.3	6.9	140	139	246	244
8:35	30	33	1.0	696.0	8.9	248	269	250	201
8:55	50	32	1.2	729.3	8.3	164	176	225	176
9:15	70	33	1.2	748.2	8.0	67	66	231	204
9:35	90	34	1.5	773.7	7.8	156	177	216	192
9:55	110	33	1.9	768.9	7.5	168	185	254	213
10:15	130	43	1.5	774.3	9.3	238	264	218	189
10:35	150	36	1.1	657.9	7.3	272	332	180	175
10:55	170	36	1.4	745.1	7.0	303	349	221	211
11:15	190	48	1.1	765.3	7.1	276	311	226	211
11:35	210	49	1.5	666.6	6.9	515	587	227	207
11:55	230	56	1.6	725.3	6.8	458	527	200	187
12:15	250	56	1.4	720.6	6.8	482	566	187	190
12:35	270	72	1.6	687.4	7.0	512	585	162	181
12:55	290	86	1.6	629.2	7.3	781	1043	162	194
13:15	310	298	2.3	739.4	8.2	3854	3370	119	170
13:35	330	262	2.5	741.4	8.6	1533	1773	143	174
13:55	350	1416	21.4	1268.8	15.4	7983	8861	174	187
14:15	370	557	3.9	876.4	10.1	3694	5483	181	169
14:35	390	714	4.7	880.3	10.7	5390	5532	128	178
14:55	410	665	4.1	884.8	10.4	5299	5402	149	162
15:15	430	355	2.1	662.4	****	1983	2169	151	142
15:35	450	531	3.4	744.2	****	3520	4068	149	155
15:55	470	505	3.2	786.8	****	3201	4260	159	163
16:15	490	571	3.8	872.9	****	3573	5135	157	174
16:30	505	580	3.8	839.0	9.0	3923	4902	137	149
16:50	525	566	3.8	824.8	9.9	4047	4584	137	148

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location THREE  
Test Description: TEST SEVEN  
Date: DECEMBER 7, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 00	5	46	0.8	675.3	6.2	58	74	264	206
8 20	15	546	2.8	1049.2	12.6	2637	3003	251	215
8 40	35	400	2.3	988.3	14.1	1766	1990	239	201
9 00	55	531	2.6	948.1	13.0	2583	2770	233	191
9 20	75	477	3.1	1011.0	11.8	2566	2844	224	203
9 40	95	479	2.9	1021.0	11.9	2695	2850	231	195
10 00	115	556	3.0	1065.5	10.3	2577	3235	229	201
10 20	135	421	2.7	945.4	11.4	1698	1987	216	181
10 40	155	464	2.8	954.0	9.1	2022	2365	213	183
11 00	175	502	2.9	1033.7	8.7	2891	2776	228	202
11 20	195	727	4.2	1187.8	8.7	3586	4062	223	212
11 40	215	889	4.7	1156.4	8.3	4864	5450	234	210
12 00	235	762	4.3	1118.8	7.9	3655	4188	197	201
12 20	255	699	3.6	989.9	7.7	3522	3488	209	191
12 40	275	795	3.6	1106.6	7.8	3926	3815	166	183
13 00	295	601	3.3	1022.4	8.1	2932	3386	148	188
13 20	315	529	1.8	879.3	8.0	1345	1566	150	182
13 40	335	546	2.9	971.1	8.6	2986	3434	158	181
14 00	355	340	2.5	815.0	9.7	1804	1537	165	182
14 20	375	595	5.5	1628.0	9.5	2254	3331	197	163
14 40	395	153	1.6	712.3	8.7	444	513	148	171
15 00	415	131	1.3	678.3	8.6	242	291	131	156
15 20	435	138	1.5	753.4	****	342	421	128	155
15 40	455	125	1.8	710.4	****	323	379	157	164
16 00	475	121	1.6	661.6	****	335	379	151	173
16 20	495	140	2.2	680.5	****	586	828	160	161
16 35	510	108	2.6	661.3	7.9	138	160	151	163
16 55	530	107	1.3	497.5	7.6	33	38	138	150

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location FOUR  
Test Description: TEST SEVEN  
Date: DECEMBER 7, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 05	0	41	1.4	788 0	8 7	850	687	271	222
8 25	20	478	2.8	885 5	10 8	2161	2070	244	212
8 45	40	633	2.9	1108 1	9 8	3056	2789	218	200
9 05	60	525	3.4	1057 5	9 3	2319	2740	227	193
9 25	80	566	3.8	1095 8	9 2	2886	3715	230	194
9 45	100	687	5.0	1117 5	9 1	3157	3748	227	198
10 05	120	354	2.7	883 5	8 3	3080	2093	227	165
10 25	140	318	2.1	847 8	8 8	1402	1482	166	166
10 45	160	271	2.0	812 6	7 4	1084	1252	224	210
11 05	180	148	1.6	826 3	7 4	896	1010	201	193
11 25	200	209	2.7	829 6	7 4	1572	1618	223	206
11 45	220	160	2.4	830 7	7 1	1640	1606	218	208
12 05	240	86	1.7	819 6	6 6	556	608	216	194
12 25	260	89	1.6	907 4	6 8	576	640	203	191
12 45	280	71	1.4	700 7	7 0	305	348	143	189
13 05	300	67	1.5	779 3	7 3	359	399	158	184
13 25	320	70	1.5	751 1	7 6	305	332	132	157
13 45	340	89	1.8	794 6	7 8	652	692	161	166
14 05	360	112	1.3	825 9	8 7	537	573	164	166
14 25	380	176	4.9	848 5	9 4	1350	1577	180	186
14 45	400	121	2.5	739 4	6 7	858	910	159	156
15 05	420	85	1.4	725 1	8 4	438	455	131	162
15 25	440	107	2.5	848 5	****	837	914	129	152
15 45	460	93	2.1	784 4	****	555	588	175	187
16 05	480	97	2.1	683 6	****	624	852	142	185
16 40	515	89	2.3	679 4	7 5	407	421	151	152

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: TEST EIGHT  
Date: DECEMBER 8, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 03	0	580	2.9	934.4	****	1463	1828	502	553
8 25	20	****	2.8	1039.5	****	2502	2757	206	218
8 45	40	865	2.1	822.9	7.4	1566	1895	200	219
9 05	60	1428	2.8	1134.9	7.8	3343	3732	211	206
9 25	80	1738	2.7	1185.7	7.7	3573	4111	205	211
9 45	100	1287	2.7	1083.1	7.7	2536	3058	214	211
10 05	120	975	2.7	933.5	7.2	1980	2249	203	198
10 25	140	966	2.3	1033.3	7.5	1911	2274	212	198
10 45	160	560	2.2	842.5	7.7	1087	1321	219	221
11 05	180	953	2.6	1030.5	7.8	1977	2156	218	232
11 25	200	1773	3.1	1186.0	8.1	3711	3987	205	204
11 45	220	1739	3.3	1168.8	8.3	3105	3877	243	260
12 05	240	1861	2.8	1290.6	8.6	3822	5030	235	227
12 25	260	1510	2.7	1115.3	8.0	2615	2958	196	217
12 45	280	1518	2.8	1097.0	7.6	2179	2678	180	216
13 05	300	613	2.3	1050.2	7.6	1292	1326	252	252
13 25	320	815	2.4	1178.4	7.7	1540	1727	272	229
13 45	340	1702	3.4	1396.6	8.4	4487	4131	281	295
14 05	360	237	1.5	999.8	7.6	383	547	217	184
14 25	380	133	1.0	840.5	7.4	187	222	183	171
14 45	400	183	1.4	1008.0	7.3	377	452	195	160
15 05	420	417	1.8	1095.8	7.3	998	1178	186	163
15 25	440	114	1.3	842.6	7.1	173	180	207	159
15 45	460	348	2.0	1143.5	7.5	575	585	180	168
16 05	480	117	1.2	1017.0	7.5	101	120	228	204
16 25	500	105	1.2	1100.4	7.7	80	95	202	173
16 45	520	****	****	****	****	****	****	****	****

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location TWO  
Test Description: TEST EIGHT  
Date: DECEMBER 8, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:10	5	643	2.4	879.7	8.0	2042	2254	513	550
8:30	25	1169	4.3	956.0	8.0	2354	2987	359	230
8:50	45	1033	2.7	1033.2	7.7	2227	2521	225	221
9:10	65	1984	3.0	1316.1	8.5	5374	5813	222	214
9:30	85	1731	3.2	1234.3	7.9	3826	4210	216	207
9:50	105	1984	3.4	1421.3	8.6	5700	7006	200	199
10:10	125	871	3.0	1074.1	7.4	1880	2341	203	206
10:30	145	1326	2.7	1026.0	7.4	2863	3153	214	211
10:50	165	558	2.0	1017.8	7.9	994	1302	239	239
11:10	185	849	2.4	1030.5	7.8	1756	1686	236	224
11:30	205	1592	3.8	1221.0	8.4	3959	4514	220	263
11:50	225	112	1.6	878.1	7.8	272	301	258	242
12:10	245	1074	3.5	1194.1	8.4	3189	3667	198	207
12:30	265	86	1.4	867.6	7.5	270	298	175	206
12:50	285	112	1.4	935.9	7.3	421	472	229	231
13:10	305	78	1.2	943.0	7.3	219	242	282	300
13:30	325	918	2.7	998.1	7.7	1539	1596	269	225
13:50	345	258	2.3	1094.4	7.6	1193	1251	256	245
14:10	365	82	1.1	942.0	7.3	269	287	209	171
14:30	385	64	1.2	846.4	7.2	179	195	195	212
14:50	405	117	1.3	1047.4	7.1	413	443	228	188
15:10	425	103	1.6	1041.7	7.0	611	646	169	147
15:30	445	76	1.1	866.2	7.3	209	218	216	175
15:50	465	92	1.5	1013.7	7.4	240	255	189	174
16:10	485	80	1.2	1039.5	7.4	141	154	243	219
16:30	505	67	1.0	741.0	3.5	3	2	184	163

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location THREE  
Test Description TEST EIGHT  
Date: DECEMBER 8, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
7:55	-10	26	0.8	830.0	0.6	5	3	472	362
8:15	10	42	0.9	755.5	0.4	7	21	311	379
8:35	30	45	1.2	788.1	6.7	35	44	174	228
8:55	50	47	1.2	751.4	7.2	63	73	222	212
9:15	70	49	1.3	752.8	7.5	35	41	222	213
9:35	90	48	1.2	741.2	7.1	149	173	216	212
9:55	110	54	1.3	769.3	7.2	254	311	204	205
10:15	130	48	1.4	780.4	6.9	164	197	191	200
10:35	150	48	1.2	797.6	7.3	157	234	248	232
10:55	170	51	1.3	838.9	7.7	225	285	225	231
11:15	190	232	2.5	1038.3	8.4	2759	2943	234	216
11:35	210	260	2.3	1061.5	8.5	1783	2474	244	222
11:55	230	390	2.9	992.5	8.6	2501	3452	236	242
12:15	250	368	3.1	1134.8	8.7	2468	3331	200	201
12:35	270	391	2.3	1069.9	8.7	2678	3754	203	214
12:55	290	532	3.5	1071.5	8.7	3250	4369	224	219
13:15	310	472	3.0	988.5	8.3	3064	3784	313	286
13:35	330	447	3.1	1110.8	8.2	2981	3461	260	226
13:55	350	442	3.2	1100.1	8.4	2836	3815	268	237
14:15	370	561	3.0	1157.1	8.6	3421	4251	202	173
14:35	390	467	3.1	1162.1	8.3	3397	3836	198	201
14:55	410	456	3.1	1145.0	8.0	3056	3788	213	184
15:15	430	449	3.0	1209.5	8.1	2737	3508	197	149
15:35	450	366	2.9	1229.8	8.2	2503	2948	239	199
15:55	470	368	3.9	1332.7	8.5	4113	4806	198	163
16:15	490	640	4.0	1312.9	8.9	4597	5379	236	215
16:35	510	60	0.7	853.8	0.7	4	2	205	186

FEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location FOUR

Test Description: TEST EIGHT

Date: DECEMBER 8, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:00	-5	34	0.8	780.4	****	12	8	488	548
8:20	15	37	1.0	768.4	****	20	16	203	241
8:40	35	33	1.2	882.8	6.9	134	139	169	220
9:00	55	37	1.4	844.5	7.4	229	249	207	203
9:20	75	39	1.3	831.4	7.4	68	73	207	200
9:40	95	46	1.3	887.3	7.2	189	227	214	207
10:00	115	42	1.2	801.6	6.9	224	250	193	200
10:20	135	43	1.5	814.9	6.9	161	184	199	197
10:40	155	45	1.4	814.7	7.4	164	191	237	229
11:00	175	48	1.3	910.7	7.6	254	290	253	254
11:20	195	51	1.4	932.3	7.8	289	338	204	191
11:40	215	67	1.1	918.1	7.6	188	230	232	219
12:00	235	55	1.3	878.0	7.7	199	248	238	219
12:20	255	66	1.2	891.4	7.7	240	285	174	203
12:40	275	76	1.4	944.8	7.5	352	648	184	199
13:00	295	76	1.4	1042.9	7.5	492	596	247	245
13:20	315	101	1.7	968.5	7.5	826	739	255	299
13:40	335	295	2.7	1141.7	8.3	1925	3315	295	270
14:00	355	234	2.3	1009.8	7.9	1675	1894	245	245
14:20	375	543	3.7	1124.3	9.0	4203	5091	167	177
14:40	395	554	3.4	1249.9	8.7	3924	4730	188	179
15:00	415	444	2.8	1167.3	8.1	2979	3462	205	196
15:20	435	468	3.2	1194.5	8.3	2702	4100	220	191
15:40	455	352	3.0	1284.8	8.3	2161	2827	223	169
16:00	475	420	2.7	1203.6	8.6	3101	3635	188	172
16:20	495	414	3.3	1314.1	8.5	2621	2916	213	192
16:40	515	85	2.1	1110.9	7.7	719	873	283	187

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location ONE  
Test Description: TEST NINE  
Date: DECEMBER 9, 1983

Time	Elapsed Time	SO2 (PPH)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPH)	NO2 (PPH)	AIR1	AIR2
8:00	-10	20	1.2	814.0	7.4	8	7	400	336
8:20	10	30	1.2	774.1	6.7	217	216	288	303
8:40	30	702	1.8	1133.6	6.9	4374	4932	288	243
9:00	50	643	2.0	1009.1	7.0	4387	4667	269	213
9:20	70	126	1.5	973.1	6.8	1920	2017	341	286
9:40	90	206	1.4	928.8	6.7	1333	1413	436	373
10:00	110	204	1.3	1008.8	7.1	1437	1392	276	243
10:20	130	762	1.6	1090.9	7.4	3046	3092	310	260
10:40	150	572	1.6	989.8	7.3	2455	2696	387	317
11:00	170	780	1.6	1120.1	7.1	2881	2979	373	305
11:20	190	1069	1.5	1120.6	7.3	3389	3622	389	328
11:50	220	1142	1.8	1272.0	8.5	3137	4398	288	186
12:10	240	1670	1.7	1306.5	7.6	5183	4913	322	279
12:30	260	1448	1.8	1222.5	7.7	4808	4909	196	164
12:50	280	1621	1.8	1361.0	7.4	4725	4865	144	115
13:10	300	1397	1.7	1333.4	7.5	4449	4634	82	86
13:30	320	1383	1.6	1310.3	7.7	4707	4910	82	85
13:50	340	1410	1.9	1405.5	7.6	4439	4593	128	115
14:10	360	1477	1.9	1354.8	7.7	5025	5129	113	106
14:30	380	1545	1.8	1384.4	8.3	5048	5276	104	91
14:50	400	1621	1.7	1443.1	8.6	5237	5777	124	117
15:10	420	1250	2.0	1233.2	8.5	4477	5002	79	75
15:30	440	1421	1.8	1345.7	8.5	4692	5125	103	105
15:50	460	1517	1.7	1320.7	8.4	4886	5110	80	75
16:10	480	1096	1.6	1352.7	8.6	3414	3696	70	71
16:30	500	775	1.7	1311.1	8.8	3388	3660	66	101



PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: TWO  
Test Description: TEST NINE  
Date: DECEMBER 9, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 05	-5	20	1.1	818.4	8.8	10	8	309	320
8 15	15	27	1.1	768.0	8.5	391	395	282	281
8 45	35	758	2.2	1156.3	7.2	8270	8524	267	253
9 05	55	1186	2.1	1163.3	7.0	7173	7467	238	176
9 25	75	81	1.5	843.8	6.9	1553	1609	345	327
9 45	95	81	1.4	860.6	6.9	1218	1272	448	404
10 05	115	89	1.4	853.3	7.2	1105	1170	368	297
10 25	135	357	1.7	1002.6	7.4	2704	2827	322	262
10 45	155	232	1.7	957.2	7.3	2182	2315	416	330
11 05	175	294	1.7	977.1	7.2	2176	2321	360	313
11 25	195	538	1.7	1061.1	7.5	2807	2974	322	284
11 55	225	604	1.7	1166.0	8.0	3063	3203	316	246
12 15	245	682	1.7	1128.9	7.4	2962	3210	218	178
12 35	265	1073	1.8	1173.8	7.5	4294	4284	214	151
12 55	285	1315	1.9	1224.9	7.5	4765	4842	181	141
13 15	305	1044	1.7	1112.8	7.5	3167	3866	74	85
13 35	325	1235	1.7	1302.8	7.6	3588	4596	96	96
13 55	345	1440	1.8	1361.3	7.5	4584	5106	122	116
14 15	365	1616	1.5	1334.3	7.9	5212	5217	98	76
14 35	385	1597	1.7	1453.0	8.3	4816	5947	143	135
14 55	405	1680	1.7	1510.9	8.8	5462	5629	96	81
15 15	425	1690	1.6	1432.0	8.7	5663	6388	81	71
15 35	445	1811	1.7	1449.5	8.7	5755	6535	98	83
15 55	465	1258	1.7	1325.1	8.6	4157	4611	68	57
16 15	485	784	1.7	1290.3	8.7	2453	2660	62	74
16 35	505	33	1.1	1015.7	1.6	6	6	262	308

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: THREE  
Test Description: TEST NINE  
Date: DECEMBER 9, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 10	0	55	1 0	848.7	6.7	423	440	421	379
8 30	20	394	2 0	1034.2	6.8	2140	2413	282	255
8 50	40	423	2 2	1068.0	6.8	2136	2374	320	253
9 10	60	352	2 2	1084.6	6.8	1933	2053	235	203
9 30	80	325	1 9	1076.6	7.0	1537	1772	369	285
9 50	100	443	2 1	1155.4	7.0	2084	2068	340	314
10 10	120	434	2 0	1034.4	7.6	1930	2098	278	216
10 30	140	432	2 1	1162.5	7.5	1967	2255	360	269
10 50	160	531	2 0	1188.6	7.3	2137	2441	385	352
11 10	180	430	1 9	1107.5	7.0	1736	2014	440	370
11 30	200	648	2 1	1288.1	7.6	2478	2878	346	272
12 00	230	640	2 4	1332.6	7.9	2467	3025	300	251
12 20	250	500	2 3	1322.2	7.4	2303	2564	227	205
12 40	270	569	1 9	1308.1	7.0	2401	2667	175	124
13 00	290	572	1 8	1246.4	7.3	2342	2427	146	117
13 20	310	488	1 7	1159.4	7.2	1762	1804	83	90
13 40	330	360	1 7	1128.0	7.3	1676	1524	88	85
14 00	350	306	2 1	1221.6	7.4	1857	2063	111	106
14 20	370	176	1 6	1159.6	7.9	955	1015	91	64
14 40	390	190	1 8	1108.3	8.0	963	1058	125	120
15 00	410	159	1 5	1212.7	8.2	943	998	85	91
15 20	430	82	1 5	1196.9	8.2	482	530	88	73
15 40	450	254	2 0	1423.3	8.4	1966	2159	88	84
16 00	470	88	1 6	1165.0	8.2	500	557	63	63
16 20	490	67	1 4	1094.3	8.4	86	109	70	77
16 40	510	28	1 0	688.7	1.3	6	5	334	349

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location FOUR  
Test Description TEST NINE  
Date: DECEMBER 9, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8:15	5	193	1.7	1007.4	8.9	1468	1835	275	328
8:35	25	311	2.1	1115.4	6.7	1837	2210	298	233
8:55	45	420	2.1	1102.0	6.7	2073	2526	312	267
9:15	65	406	2.2	1173.5	7.0	2188	2378	318	280
9:35	85	415	2.0	1147.1	6.7	1705	1893	435	375
9:55	105	438	2.1	1199.0	7.0	1872	2188	310	265
10:15	125	416	1.9	1130.4	7.3	1876	2072	294	239
10:35	145	417	1.8	1112.0	7.7	1862	2092	391	285
10:55	165	320	1.6	1106.2	7.0	1505	1647	374	351
11:15	185	204	1.9	956.5	7.0	1169	1305	352	324
11:35	205	207	1.7	1129.5	7.8	1328	1453	368	294
12:05	235	207	1.9	1131.5	7.5	1445	1555	382	324
12:25	255	118	1.9	1102.4	7.3	1215	1290	162	156
12:45	275	142	1.9	1156.8	7.1	1463	1573	139	58
13:05	295	174	2.0	1306.6	7.3	1769	1877	85	107
13:25	315	140	1.9	1131.7	7.3	1440	1514	78	75
13:45	335	132	1.7	1382.2	7.4	1244	1334	119	128
14:05	355	118	1.9	1271.7	7.4	1444	1528	112	101
14:25	375	105	1.7	1154.2	7.9	1010	1059	84	55
14:45	395	80	1.7	1372.1	8.1	886	935	135	130
15:05	415	216	2.1	1305.8	8.3	1822	1819	97	97
15:25	435	79	1.8	1201.6	8.2	964	1026	98	96
15:45	455	161	2.3	1411.7	8.5	2217	2353	90	87
16:05	475	67	1.8	1244.7	8.3	776	822	72	82
16:25	495	65	1.4	1120.1	8.6	532	543	70	82

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE

Test Description: WAREHOUSE TEST 1

Date: DECEMBER 13, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 05	5	83	0 7	858 3	7 6	****	****	388	435
8 15	15	79	0 5	831 2	7 4	****	****	371	374
8 25	25	73	0 7	595 6	7 5	****	****	380	445
8 35	35	****	0 5	731 9	7 1	****	****	413	409
8 45	45	56	0 5	632 8	7 3	****	****	445	628
9 00	60	101	1 3	525 2	8 0	1843	1744	430	538
9 10	70	328	3 6	845 8	9 7	3625	4128	457	521
9 20	80	624	4 9	960 2	10 4	6375	6703	390	416
9 30	90	536	4 4	849 2	10 2	5407	5503	432	457
9 40	100	591	4 7	871 8	10 4	6025	6070	433	445
9 50	110	588	4 5	878 7	10 2	5068	6156	429	448
10 00	120	861	5 3	977 2	10 6	8567	8161	469	488
10 10	130	436	3 4	716 8	9 4	4736	4789	365	408
10 20	140	624	4 2	822 9	9 5	6468	6664	421	487
10 30	150	773	4 6	879 5	9 9	5523	4830	430	472
10 40	160	730	4 8	983 6	9 9	4825	4804	469	544
10 50	170	771	4 5	927 0	9 6	6349	7261	474	526
11 00	180	788	4 5	922 3	10 0	7257	8079	403	448
11 10	190	179	1 7	674 0	7 9	1171	1381	437	593
11 20	200	131	0 7	619 5	7 7	136	158	528	669
11 30	210	110	0 6	435 3	1 4	0	0	471	586
11 40	220	101	0 7	597 5	7 7	6	19	459	649
11 50	230	98	0 8	776 6	7 6	0	1	2140	1747
12 00	240	94	0 8	705 9	7 6	0	1	2231	1798
12 10	250	96	0 8	611 1	7 8	0	0	2243	1876
12 20	260	103	0 7	651 2	7 7	0	2	187	305

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location THREE  
Test Description WAREHOUSE TEST 1  
Date: DECEMBER 13, 1983

Time	Elapsed Time	SO2 (PPH)	CO (PPH)	CO2 (PPH)	THC (PPH)	NO (PPH)	NOX (PPH)	AIR1	AIR2
8:00	0	85	1.7	883.8	0.1	****	****	361	401
8:10	10	90	0.8	848.4	7.7	****	****	413	520
8:20	20	98	0.7	558.5	7.5	****	****	332	413
8:30	30	85	0.6	641.9	7.4	****	****	377	464
8:40	40	67	0.8	729.8	7.2	****	****	2164	1858
8:55	55	81	0.8	537.2	7.1	****	****	537	627
9:05	65	239	1.8	799.6	8.1	2896	2730	362	423
9:15	75	614	2.3	1067.1	8.8	4415	4469	361	442
9:25	85	623	2.1	1045.2	9.0	4418	4432	436	440
9:35	95	747	2.3	967.1	8.8	5245	5086	451	505
9:45	105	668	2.5	1000.1	9.1	4789	4756	389	444
9:55	115	547	2.7	933.7	9.5	4564	4218	367	372
10:05	125	534	2.2	927.2	8.8	3806	3896	371	398
10:15	135	516	2.4	829.3	8.9	3994	4064	416	493
10:25	145	398	1.5	769.6	8.1	3021	3103	463	445
10:35	155	493	1.4	833.9	8.2	****	****	446	508
10:45	165	507	1.6	865.4	8.1	3081	3342	448	510
10:55	175	575	1.7	759.0	8.2	2913	3520	383	437
11:05	185	384	1.9	823.9	8.4	2250	2588	435	514
11:15	195	124	1.2	574.8	7.7	316	371	474	596
11:25	205	152	1.0	441.2	1.5	30	47	505	653
11:35	215	99	0.7	522.9	8.1	2	8	432	618
11:45	225	668	2.8	831.4	8.6	5629	5512	1934	1194
11:55	235	598	4.2	1134.5	9.4	6571	7984	2186	1769
12:05	245	165	1.5	615.6	7.8	1076	1211	2246	1872
12:15	255	2720	0.5	663.1	7.6	14	45	1418	1285
12:25	265	****	0.7	554.7	7.6	****	****	85	88

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location ONE  
Test Description WAREHOUSE TEST 2  
Date: DECEMBER 13, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
12 25	-3	112	0.6	576.4	7.8	0	1	120	124
12 35	7	704	3.8	853.1	9.4	2483	3133	120	135
12 45	17	876	4.5	986.9	10.0	3187	3842	95	114
12 55	27	739	5.4	1110.8	10.5	3378	4162	92	87
13 05	37	783	5.7	1114.5	10.6	3141	3815	92	81
13 15	47	844	5.3	928.4	10.8	3711	3893	72	61
13 25	57	301	3.6	880.9	9.3	1574	1782	79	106
13 35	67	550	3.5	927.7	10.0	1863	2263	73	70
13 45	77	547	4.1	723.0	9.6	2382	2705	61	50
14 00	92	497	3.5	906.5	9.8	1957	2201	47	46
14 10	102	851	5.2	1038.3	10.2	7703	9945	60	58
14 20	112	884	6.2	1158.8	10.6	9350	9573	54	52
14 30	122	567	4.9	934.1	9.8	6904	7759	52	55
14 40	132	838	4.7	1083.3	9.8	6662	8094	48	48
14 50	142	862	5.3	940.0	10.2	6514	6888	51	46
15 00	152	749	4.7	989.1	9.8	6056	6977	70	75
15 10	162	633	6.6	936.8	9.6	6005	6306	54	67
15 20	172	753	4.7	40032.4	9.5	6860	7698	69	71
15 30	182	709	4.9	946.9	10.0	5990	6787	57	50
15 40	192	757	4.9	923.1	10.2	6578	7309	51	57
15 50	202	874	5.5	947.0	25.6	7616	8404	46	56
16 00	212	790	5.2	1149.2	10.1	7615	8517	53	48
16 10	222	657	4.5	932.4	10.1	6099	6350	44	51
16 20	232	886	5.6	1082.1	10.9	7036	9068	65	68
16 30	242	739	5.7	1000.6	11.0	5858	7260	79	76
16 40	252	1237	15.6	1189.3	13.0	7037	10066	99	71
16 50	262	1230	17.6	1111.6	13.5	6363	9619	95	56

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE

Test Description WAREHOUSE TEST 2

Date: DECEMBER 13, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
12:30	2	381	1.4	844.0	7.7	825	940	82	104
12:40	12	720	2.3	898.7	8.6	1655	1936	135	156
12:50	22	723	2.4	878.3	8.6	1966	2211	94	125
13:00	32	800	2.9	1048.5	9.1	2448	2718	73	102
13:10	42	998	2.9	1106.6	9.1	2452	3417	70	82
13:20	52	415	2.3	895.8	8.9	2059	2302	80	84
13:30	62	467	1.8	849.1	8.7	1095	1231	58	83
13:40	72	721	2.2	1006.0	8.7	2018	2434	57	62
13:50	82	823	2.5	1187.7	8.9	2680	2888	47	45
14:05	97	770	2.3	1004.7	8.6	4597	5360	54	47
14:15	107	769	2.3	945.0	8.5	4557	4855	61	62
14:25	117	825	2.3	917.3	8.5	5358	5661	51	58
14:35	127	255	1.5	787.6	8.0	1709	1869	24	43
14:45	137	747	1.8	823.8	8.2	2860	3608	47	54
14:55	147	793	2.3	1028.6	8.3	4987	5091	42	59
15:05	157	789	2.4	868.4	8.5	3774	4099	56	65
15:15	167	674	2.2	959.5	8.4	3560	4029	64	55
15:25	177	845	2.5	1014.7	8.8	4833	5574	62	70
15:35	187	583	2.3	1110.2	8.6	4109	4643	52	42
15:45	197	734	2.7	1104.2	8.9	4669	5456	49	58
15:55	207	672	2.5	984.0	8.2	4625	5129	48	54
16:05	217	672	2.1	947.8	8.5	4062	4661	59	61
16:15	227	816	2.6	822.4	8.8	4688	5117	59	54
16:25	237	873	2.4	1107.8	9.1	4577	4736	75	67
16:35	247	817	4.5	1068.4	9.9	3371	4726	67	60
16:45	257	892	5.0	1079.5	10.5	2893	4074	86	63
16:55	267	754	6.3	1111.5	11.3	3069	4231	64	49

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: WAREHOUSE TEST 3  
Date: DECEMBER 14, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8 15	3	67	0.8	774.4	10.1	3	3	487	748
8 25	13	142	1.5	942.8	7.3	1046	1387	153	134
8 35	23	690	4.6	1321.1	9.1	7100	8866	143	151
8 45	33	606	5.2	1282.3	9.7	6002	7238	187	156
8 55	43	592	4.9	1178.4	9.5	5462	6070	217	172
9 05	53	826	5.6	1247.5	10.3	6810	8793	184	174
9 15	63	787	5.7	1310.6	10.3	6632	8007	159	156
9 25	73	609	5.0	1199.5	10.2	5780	7861	152	143
9 35	83	850	5.9	1264.7	10.8	7271	9097	159	152
9 45	93	701	5.7	1392.8	10.5	7591	8673	133	148
9 55	103	931	6.7	1506.8	11.0	9169	11122	153	159
10 05	113	764	4.8	1296.9	10.4	7157	7938	164	183
10 15	123	831	6.1	1361.9	11.1	8414	10230	170	151
10 25	133	873	6.2	1420.6	11.2	8839	10216	136	145
10 35	143	895	5.9	1332.4	11.0	7887	9696	122	138
10 45	153	574	4.8	1199.5	10.3	5452	6664	152	172
10 55	163	730	6.5	1287.4	10.5	6128	7155	162	166
11 05	173	802	4.9	1370.7	10.4	6600	7468	148	143
11 15	183	793	5.0	1306.1	10.6	5901	7386	156	163
11 25	193	821	5.9	1350.0	10.2	7219	8661	146	158
11 35	203	1008	7.1	1314.6	10.9	8739	10383	130	153
11 45	213	820	6.7	1489.8	10.6	9386	9717	146	171
11 55	223	997	6.3	1392.2	10.4	8315	11049	148	151
12 05	233	809	5.1	1352.5	9.8	6509	8331	157	180
12 15	243	891	5.8	1390.0	10.2	6955	9059	188	161
12 25	253	743	5.4	1261.0	10.8	4607	6144	471	170
12 35	263	386	3.2	1025.6	9.6	1843	2337	2152	1766
12 45	273	185	1.0	997.8	8.2	86	125	2070	1778
12 55	283	127	0.7	854.5	1.3	1	0	2075	1894



PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE

Test Description: WAREHOUSE TEST 3

Date: DECEMBER 14, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:10	-2	72	1.1	938.8	24.2	3	2	881	863
8:20	8	105	0.8	787.8	7.0	2	1	170	200
8:30	18	328	1.6	1018.5	7.3	1135	1478	151	128
8:40	28	741	3.0	1325.2	8.3	4200	4468	148	123
8:50	38	762	2.8	1248.6	8.4	4115	4684	175	153
9:00	48	636	2.8	1433.0	8.4	4046	4521	135	152
9:10	58	707	2.8	1426.8	8.8	4735	4680	164	161
9:20	68	825	3.1	1539.9	9.2	5634	6404	138	166
9:30	78	4187	2.4	1355.6	8.8	5268	5870	178	180
9:40	88	708	3.0	1324.1	8.8	5547	6351	168	156
9:50	98	782	2.8	1257.4	9.0	4889	5784	147	155
10:00	108	677	2.7	1287.8	8.8	4455	5065	170	157
10:10	118	680	2.4	1107.8	8.7	4145	4548	155	176
10:20	128	688	2.6	1238.8	8.2	3854	4403	141	165
10:30	138	680	2.8	1208.9	26.5	4112	4654	141	140
10:40	148	884	2.8	1338.5	10.8	4441	5328	148	141
10:50	158	864	2.8	1428.7	8.0	4378	5357	133	145
11:00	168	780	2.7	1387.8	8.8	4482	5150	150	143
11:10	178	720	2.7	1435.3	8.0	4570	5081	152	146
11:20	188	611	2.6	1307.3	8.5	4176	4723	134	178
11:30	198	596	2.4	1215.5	8.0	4425	4881	103	137
11:40	208	652	2.5	1288.1	8.3	4272	4818	108	153
11:50	218	585	2.4	1122.8	8.2	3680	4000	156	180
12:00	228	631	2.6	1278.7	8.1	3838	4282	137	150
12:10	238	870	2.6	1207.7	8.1	3648	4342	147	194
12:20	248	803	2.8	1382.8	8.6	5084	5878	150	174
12:30	258	818	2.8	1414.2	8.0	6052	6758	1414	1253
12:40	268	201	1.4	886.2	8.4	653	773	2144	1784
12:50	278	165	1.0	818.6	1.7	51	80	2055	1848
13:00	288	137	0.8	800.8	7.5	2	10	2174	1935

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: WAREHOUSE TEST 4  
Date: DECEMBER 14, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
13:05	-2	105	0.8	822.8	7.4	3	2	2139	1041
13:15	8	93	0.8	837.7	7.4	3	6	228	133
13:25	18	184	1.0	1008.1	7.2	202	263	117	106
13:35	28	781	2.8	1358.9	8.2	3774	4316	141	128
13:45	38	835	3.3	1484.8	8.5	4888	5317	138	150
13:55	48	685	3.0	1370.5	8.3	3883	4913	147	160
14:05	58	704	2.7	1447.6	8.1	4007	4812	154	177
14:15	68	828	3.4	1320.8	8.3	4898	5441	162	163
14:25	78	1108	3.5	1521.4	8.5	5756	6426	153	134
14:35	88	1077	3.5	1587.5	8.9	5445	6201	135	117
14:45	98	1138	4.2	1683.2	8.2	5960	6583	148	123
14:55	108	1425	4.4	1731.4	8.6	7147	7843	156	147
15:05	118	1140	4.2	1741.1	8.6	6221	7214	180	176
15:15	128	1086	4.2	1688.8	8.7	6607	6900	157	106
15:25	138	1002	6.4	1618.3	8.8	5670	5881	195	187
15:35	148	729	3.4	1437.0	8.3	4336	5164	166	154
15:45	158	761	3.7	1419.6	8.1	4785	5597	165	147
15:55	168	898	3.8	1551.2	8.8	5435	6323	153	156
16:05	178	804	3.8	1468.3	8.8	4642	5414	153	120
16:15	188	796	3.8	1537.5	8.0	4756	5412	112	112
16:25	198	802	3.2	1464.4	8.0	4819	5548	78	71
16:35	208	1216	3.3	1540.0	8.2	5356	6128	240	213
16:45	218	1250	4.1	1691.8	8.5	5852	6345	230	232
16:55	228	1224	4.1	1761.2	8.3	6177	6713	225	242
17:05	238	1103	3.7	1624.0	8.1	4656	4886	204	167
17:15	248	828	2.9	1578.9	8.3	4406	5311	206	222
17:25	258	135	0.5	764.8	1.0	1	0	880	179

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: THREE

Test Description: WAREHOUSE TEST 4

Date: DECEMBER 14, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
13 10	3	156	0.8	942.4	7.2	6	10	714	432
13 20	13	142	0.8	988.7	7.2	38	43	145	130
13 30	23	715	3.8	1137.6	8.6	4855	9038	122	160
13 40	33	1016	6.0	1523.8	10.0	8450	10877	107	137
13 50	43	730	5.8	1461.7	10.2	8508	9546	147	138
14 00	53	683	6.3	1426.8	9.8	8437	9665	152	147
14 10	63	776	6.8	1566.5	10.3	10978	11015	151	152
14 20	73	583	5.7	1399.5	9.7	8970	8372	188	176
14 30	83	633	5.7	1420.6	10.2	6714	7879	133	97
14 40	93	881	6.3	1478.9	10.5	7680	8333	146	136
14 50	103	589	5.4	1310.6	10.4	5613	6390	150	178
15 00	113	570	5.1	1404.6	10.4	4833	6089	163	153
15 10	123	876	5.2	1239.7	10.8	5565	6660	185	149
15 20	133	635	4.6	1247.5	10.6	4456	5561	203	176
15 30	143	891	4.8	1237.6	10.6	5702	6540	180	184
15 40	153	744	4.9	1429.9	10.3	6442	7612	143	150
15 50	163	877	6.4	1486.6	10.7	7877	9895	161	153
16 00	173	624	5.1	1284.8	9.9	6319	7618	154	163
16 10	183	869	5.3	1329.6	9.8	7469	8380	95	99
16 20	193	666	5.1	1404.9	10.1	6357	7122	111	83
16 30	203	860	6.0	1360.3	10.7	8453	9369	189	150
16 40	213	626	4.5	1288.4	10.2	5594	5301	267	258
16 50	223	802	4.6	1302.3	10.1	987	985	243	211
17 00	233	603	3.7	1246.5	9.8	4285	5313	218	196
17 10	243	571	3.9	1283.3	10.1	3005	2949	229	214
17 20	253	439	3.5	1187.7	9.9	3850	4512	218	181

PEDCO ENVIRONMENTAL, INC  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: WAREHOUSE TEST 3  
Date: DECEMBER 15, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPH)	CO2 (PPH)	TMC (PPH)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
8 00	-27	117	0.7	728.5	14.9	389	367	383	52
8 10	-17	133	0.7	859.8	6.7	492	565	109	100
8 20	-7	103	0.6	895.7	8.6	181	168	80	91
8 30	3	972	1.6	824.0	7.5	2166	2600	113	78
8 40	13	1802	2.2	1027.0	8.2	4529	3338	59	72
8 50	23	1668	2.0	1039.1	8.4	4593	3216	69	61
9 00	33	1681	2.3	1114.1	8.5	4808	3736	88	61
9 10	43	1988	2.4	1142.1	8.5	5234	4021	91	63
9 20	53	3488	3.4	1443.0	9.0	7775	8073	108	84
9 30	63	2567	2.8	1488.2	8.6	6397	7045	116	91
9 40	73	2545	2.6	1318.2	8.7	6658	7088	122	106
9 50	83	2390	2.8	1381.3	8.8	4924	4868	79	67
10 00	93	2268	2.6	1215.0	8.8	4598	3048	101	48
10 10	103	1449	6.5	1007.5	8.6	3754	3878	85	37
10 20	113	1969	2.1	1160.7	8.6	3947	4380	88	36
10 30	123	1303	1.9	1006.4	8.6	3051	3582	100	35
10 40	133	1464	1.9	1026.0	8.4	3465	3898	82	52
10 50	143	2048	2.3	1185.6	8.7	3001	5560	73	49
11 00	153	1946	2.5	1139.6	8.8	4382	5411	54	52
11 10	163	1611	2.3	1044.6	8.8	4343	4950	58	50
11 20	173	3580	3.8	1319.5	9.4	6404	7162	54	65
11 30	183	1336	3.0	1155.2	9.1	4842	5986	71	346
11 40	193	381	2.0	817.9	8.5	2037	2305	1563	1408
11 50	203	150	0.9	701.9	7.6	214	271	2248	1788
12 00	213	103	0.8	681.6	7.3	6	34	2277	1818

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: THREE

Test Description: WAREHOUSE TEST 3

Date: DECEMBER 13, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
8:05	-22	586	1.5	793.7	7.3	1613	1613	103	94
8:15	-12	101	0.7	712.7	6.5	146	178	113	116
8:25	-2	755	2.7	865.3	7.5	3835	4468	76	70
8:35	0	1322	3.8	1088.6	8.5	8791	7618	79	88
8:45	16	1242	3.4	962.6	9.0	6275	6885	73	65
8:55	28	1104	3.3	1011.2	8.8	5142	6320	89	55
9:05	38	1003	2.7	1032.9	8.8	4445	5165	101	82
9:15	48	1011	2.9	973.4	9.0	4329	4053	103	74
9:25	56	1102	3.6	904.8	9.2	4370	5189	107	80
9:35	68	4302	3.0	1038.2	9.4	4085	5703	121	89
9:45	78	1522	3.8	1144.3	9.9	5973	6835	107	93
9:55	88	1462	3.6	1022.1	9.8	5377	6414	86	43
10:05	98	1490	3.8	1035.9	9.9	6148	6878	85	43
10:15	108	1418	3.3	976.1	9.6	5200	5961	56	35
10:25	118	998	3.0	1001.8	9.4	3726	4753	65	45
10:35	128	1000	2.8	902.2	10.4	3739	4933	82	47
10:45	138	1067	2.7	898.6	2.4	4003	4561	90	67
10:55	148	1149	3.4	1045.3	9.4	3806	5007	48	49
11:05	158	1239	3.1	1040.1	9.5	3783	5862	44	57
11:15	168	1067	2.7	892.1	9.2	4124	4773	49	61
11:25	178	515	1.9	860.3	8.8	2253	2682	74	71
11:35	188	882	1.6	973.0	8.2	1835	2152	504	645
11:45	196	158	0.8	697.0	7.6	96	126	2244	1795
11:55	208	86	0.6	585.4	1.2	0	0	2230	1767

PEDCO ENVIRONMENTAL, INC.  
ARMY DIESEL FORKLIFT STUDY

Location: ONE  
Test Description: WAREHOUSE TEST 6  
Date: DECEMBER 15, 1983

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NOX (PPB)	AIR1	AIR2
12:05	-18	110	0.6	754.0	7.4	2	11	1110	1136
12:15	-8	142	0.5	817.2	7.4	19	22	67	89
12:25	2	2007	4.0	1173.9	8.6	5360	6548	59	83
12:35	12	2186	5.1	1193.8	10.8	7677	9068	48	74
12:45	22	1416	4.2	1095.1	10.2	5130	6648	66	104
12:55	32	906	3.0	969.9	9.6	3385	4541	127	119
13:05	42	1258	3.2	1091.2	9.7	4030	5392	113	97
13:15	52	1583	3.2	1134.8	10.0	6062	8030	111	95
13:25	62	1723	3.8	1184.5	10.1	7286	8551	130	100
13:35	72	2198	5.6	1499.6	11.1	9733	11376	130	106
13:45	82	1777	4.8	1311.1	10.9	7849	9757	121	96
13:55	92	2047	5.5	1404.9	11.5	9161	10332	158	124
14:05	102	2298	5.8	1501.7	11.9	10221	11677	154	128
14:15	112	1920	5.2	1220.9	11.7	8079	9154	122	81
14:25	122	1358	3.9	1032.0	10.6	5894	6295	137	103
14:35	132	1067	2.6	914.6	9.6	3814	4652	133	113
14:45	142	2368	4.4	1215.5	10.9	8975	10501	82	83
14:55	152	2259	5.0	1351.9	11.2	10283	11442	118	89
15:05	162	1670	5.1	1212.6	11.2	7976	9595	98	92
15:15	172	2863	5.8	1502.7	11.9	12400	12984	117	93

**PEDCO ENVIRONMENTAL, INC.**  
**ARMY DIESEL FORKLIFT STUDY**

**Location: THREE**

**Test Description: WAREHOUSE TEST 6**

**Date: DECEMBER 15, 1983**

Time	Elapsed Time	SO2 (PPB)	CO (PPM)	CO2 (PPM)	THC (PPM)	NO (PPB)	NO2 (PPB)	AIR1	AIR2
12:10	-13	108	0.5	710.3	7.4	1	2	104	680
12:20	-3	905	1.2	958.8	7.4	980	831	83	105
12:30	7	1663	2.2	1062.4	8.3	2978	3108	56	79
12:40	17	1586	1.9	1215.0	8.7	3047	3497	56	93
12:50	27	882	1.3	928.8	8.1	1889	2104	86	117
13:00	37	939	1.3	873.4	8.3	1949	2160	95	102
13:10	47	1350	1.4	1037.9	8.6	2482	2747	109	108
13:20	57	1382	1.4	1054.4	8.2	2558	2788	117	96
13:30	67	1567	1.4	1035.0	8.6	2750	2920	148	110
13:40	77	1643	1.3	1078.8	8.5	3081	3348	144	110
13:50	87	1013	1.0	878.0	8.3	2024	2244	136	112
14:00	97	1092	1.1	949.0	8.8	2043	2377	144	117
14:10	107	1227	1.3	1030.6	9.0	2162	2584	140	111
14:20	117	1145	1.2	1058.4	9.3	2211	2652	128	104
14:30	127	1117	1.2	912.1	8.6	2283	2420	146	122
14:40	137	908	1.1	974.6	8.7	1827	2159	117	112
14:50	147	1544	1.4	1085.0	9.0	2772	3068	101	83
15:00	157	1457	1.2	1065.3	9.0	2662	2812	99	84
15:10	167	1112	1.2	991.4	9.0	2251	2308	110	87
15:20	177	800	0.8	987.9	8.8	1481	1809	143	105

APPENDIX C  
STATISTICAL ANALYSIS



## NOTES ON THE STATISTICAL ANALYSIS

The following description summarizes the approach taken in the statistical analysis of the continuous air monitoring data.

- 1) The variances of the data on each forklift were compared by use of a standard "F" test with the following calculation:

$$\text{Calculated } F = \frac{\sigma_1^2}{\sigma_2^2}$$

The calculated F value was compared with the table value at a 0.05 level of significance for the appropriate degrees of freedom.

- 2) When results of the first test indicated similar variances ( $p > 0.05$ ), the apparent difference in air monitoring data between the two forklifts was tested by using a pooled variance to calculate a standard error and Student "t" value according to the following calculations:

$$\text{Pooled variance} = \sigma_p^2 = \frac{\Sigma(x_1 - \bar{x}_1)^2 + \Sigma(x_2 - \bar{x}_2)^2}{n_1 + n_2 - 2}$$

$$\text{Standard error} = \sigma_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{\sigma_p^2}{n_1} + \frac{\sigma_p^2}{n_1}}$$

$$\text{Student } t = t = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sigma_{\bar{x}_1 - \bar{x}_2}}$$

The calculated t value was compared with the table value for the appropriate degrees of freedom. The comparison was made at a 0.05 level of significance for a one-tailed test.

- 3) When results of the first test indicated different variances ( $p < 0.05$ ), the difference in air monitoring data between the two forklifts was tested by use of a modified Behrens-Fisher t test.

Standard error  $\sigma_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$

Blevens-Fisher  $t = t' = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sigma_{\bar{x}_1 - \bar{x}_2}}$

The calculated t' value was compared with the table value for the appropriate degrees of freedom. The comparison was made at a 0.05 level of significance for a one-tailed test.

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Diesel engine	Nitrogen dioxide	Particulate															
exhaust pollutants	Nitric oxide	PAH															
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Carbon dioxide	Sulfur dioxide	Industrial hygiene															
Nitrogen oxides (NO <sub>x</sub> )		Total hydrocarbons															
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Indoor air quality was monitored in Stradley-type ammunition magazines during the use of diesel-powered forklifts. The monitoring took place during storage and handling operations. The primary test vehicles were a Still forklift powered by a Deutz (F3L912W) diesel engine and a Hyster forklift powered by a Perkins (4.2032) diesel engine. Both breathing zone (personal) and continuous monitoring data were collected during the operation of the two vehicles. Total suspended particulates, polycyclic																	

20. (continued)

aromatic hydrocarbons, carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, and oxides of nitrogen, sulfuric acid as total sulfates, total hydrocarbons, and odorants were monitored. Test results indicated that the impact of diesel exhaust on magazine air quality depends largely on the operations being performed. The warehousing operations presented the greater potential risk to the health and safety of Army personnel. Nitrogen dioxide was the only exhaust component of those measured that presents a potentially serious health risk. A statistical test of the air quality data collected during warehousing operations indicated that the operation of the Still/Deutz vehicle is significantly cleaner than that of the Hyster/Perkins vehicle. Additional testing is proposed to better quantify personnel exposures and magazine air quality during the use of the Still/Deutz vehicle.

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