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USAFOEHL REPORT

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DIESEL EMISSION SURVEY AT DOVER AFB DE

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November 1986

Final Report

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I. INTRODUCTION

HQ MAC/SGPB requested the USAF Occupational and Environmental Health Laboratory (USAFOEHL) support a USAF Hospital Dover/SGPB request for a survey of the 436 Aerial Port Squadron (APS) truck off-load section. The survey was conducted from 7-10 January 1986 to evaluate the concentrations of carbon monoxide (CO) and other exhaust pollutants resulting from the use of diesel and propane powered forklifts during peak off-load periods. The dates in January were selected because when it is cold outside the doors to the docks are kept closed except during loading and off-loading activity. This results in reduced natural ventilation and higher contaminant concentrations than would occur on warmer days when the doors are usually left open.

II. DISCUSSION

A. BACKGROUND

Levels of carbon monoxide (CO) in the 436 APS truck off-load section, Dover AFB DE were assigned a Risk Assessment Code (RAC) of 3 (IIC) in July 1981. The results of continuous area air monitoring and personnel dosimetry established that forklift operators were being exposed to levels of CO above the 50 parts per million (ppm) threshold limit value (TLV). A working group was formed to seek a solution to the CO problem. The Bioenvironmental Engineer (BEE) recommended the installation of exhaust fans along the roof of the loading and unloading dock to reduce the CO concentration. The working group decided this approach would be too expensive. Instead, they decided to replace gasoline powered forklifts with diesel and propane powered forklifts and to install catalytic converters to the exhaust of diesel forklifts.

Limited air sampling conducted in February 1983 during the phase out of gasoline powered forklifts indicated a reduction of CO concentrations to approximately one-half the 50 ppm TLV. However, in a 6 May 1983 letter, the base BEE noted that, "this past winter there were more complaints of throat irritation and the 'smoky blue haze' than previous years." In a 23 September 1985 letter, the Dover base BEE wrote that gasoline forklifts were no longer being used inside the aerial port. Also, all diesel forklifts had been equipped with "OXYCAT" Catalytic Purifiers. These units are designed to catalytically oxidize CO. However, members of the USAFOEHL/ECH survey team were informed that some of these units had been removed and none of the units still in place had ever had the pellets replaced as recommended by the manufacturer. The forklifts used by the Aerial Port are identified in Table 1.

B. SAMPLING AND ANALYSIS

Air sampling and personnel dosimetry were designed to measure the air concentrations of carbon monoxide (CO), nitrogen dioxide (NO₂), nitric oxide (NO), total hydrocarbons (THC), benzene, and total aldehydes as expected contaminants in diesel exhaust.¹ Screening for sulfur dioxide (SO₂) was conducted using detector tubes because it interferes with the analytical measurement of nitrogen oxides (NO_x) collected with the Palmes device.²

Table 1: Aerial Port Forklifts

Type of Vehicle	Number
10 K Diesel Forklift	5
4 K Diesel Forklift	7
4 K Propane Forklift	6
4 K Gasoline Forklift	2*

* Outdoor use only

1. Carbon Monoxide

Ecoalyzer 6000 units were used with chart recorders to obtain continuous real-time measurements of CO concentrations. The Ecoalyzer 6000 units were field calibrated using a lecture bottle of 50 ppm CO span gas. These instruments use electrochemical sensing cells. Carbon monoxide is electrochemically oxidized to carbon dioxide at a catalytic electrode in an aqueous sulfuric acid electrolyte.¹ The current resulting from the collection of the ions generated by the oxidation of carbon monoxide is proportional to the partial pressure of carbon monoxide in the air sampled.

A Foxboro MIRAN 1B portable gas analyzer was also used to obtain real-time measurements of CO levels. The MIRAN 1B uses the absorption of infrared (IR) energy at a selected wavelength to determine the concentration of contaminant gases. According to Beer's law, the absorption of the IR energy is proportional to the number of atoms of the absorbing species in the pathlength of the IR beam. The MIRAN 1B uses a microprocessor to control adjustments of the IR beams' wavelength and the pathlength between the IR source and detector. Carbon monoxide is analyzed at a wavelength of 4.7 microns. The MIRAN instrument was not used to obtain continuous recorded readings of the CO concentration. Instead, it was used to spot-check the CO levels during forklift operations at several locations.

2. Nitrogen Oxides

Nitrogen dioxide (NO₂) and total nitrogen oxides (NO_x) samples were collected with Palmes device passive diffusion dosimeter tubes. In the first of two types of Palmes devices, NO₂ is collected on stainless steel screens treated with triethanolamine (TEA).² In a second Palmes device, nitric oxide (NO) is converted to NO₂ by reaction with chromic acid on a treated filter.³ The NO₂, representing total nitrogen oxides (NO₂ and NO), is then collected on TEA treated stainless steel screens just as in the first Palmes device. To sample for NO, these devices must be used in pairs with the NO concentration being defined by the difference between the measured concentrations of total nitrogen oxides (NO₂ + NO) and nitrogen dioxide (NO₂). In both dosimeters, the collected NO₂ reacts with the TEA to produce a nitrite ion. In the analysis, the nitrite ion is desorbed from the screens and the amount present determined by a colorimetric technique using a wavelength of 540 nanometers (nm).³

3. Total Hydrocarbons and Benzene

These compounds were collected using passive dosimeter badges, 3M Organic Vapor Monitors 3500. These badges rely on diffusion to expose contaminant molecules to a charcoal adsorbent. The collected organic contaminants were desorbed with a solvent and analyzed by gas chromatography. The USAFOEHL Analytical Services Division (USAFOEHL/SA) performed the analysis according to the instructions and data presented in the 3M Compound Guide Notebook.⁶ Total hydrocarbons were analyzed and reported as n-hexane equivalent.

4. Aldehydes

Total aldehydes were sampled using two separate methods. In the first method, the total airborne aldehydes were collected in a midget impinger containing 20 milliliters (ml) of 0.05 percent aqueous solution of 3-methyl-2-benzothiazolone hydrazone hydrochloride (MBTH) at a flow rate of 500 cubic centimeters per minute (cc/min). The resulting azine solution was then oxidized with a ferric chloride-sulfamic acid solution, yielding a blue cationic dye. This resulting blue dye was read spectrophotometrically at 628 nm. Most known interferences were not gaseous, or water soluble, and should not interfere with the analysis of water soluble aliphatic aldehydes in the atmosphere.⁷ As the length of chain increases in the aldehydes, the method sensitivity decreases. Therefore, this method gives low results for aldehydes other than formaldehyde.⁸ The analytical results were compared to the formaldehyde permissible exposure level.

In the second method, formaldehyde samples were collected in a midget impinger containing 20 ml of a 1.0% sodium bisulfite solution at a flow rate of 500 cc/min for one hour. The sample was spectrophotometrically analyzed at 580 nm following color development with chromotropic acid and sulfuric acid. For this method, little interference is seen from other aldehydes. The sampling and analysis protocol for this method was developed by USAFOEHL/SA.⁹ The method is a modification of the NIOSH Chromotropic Acid Method (NIOSH Method 3500). The analysis was performed by USAFOEHL/SA.

Mine Safety Appliances, Inc. (MSA) aldehyde detector tubes and a Universal Tester^R sampling pump were used to obtain real-time estimates of aldehyde concentrations.

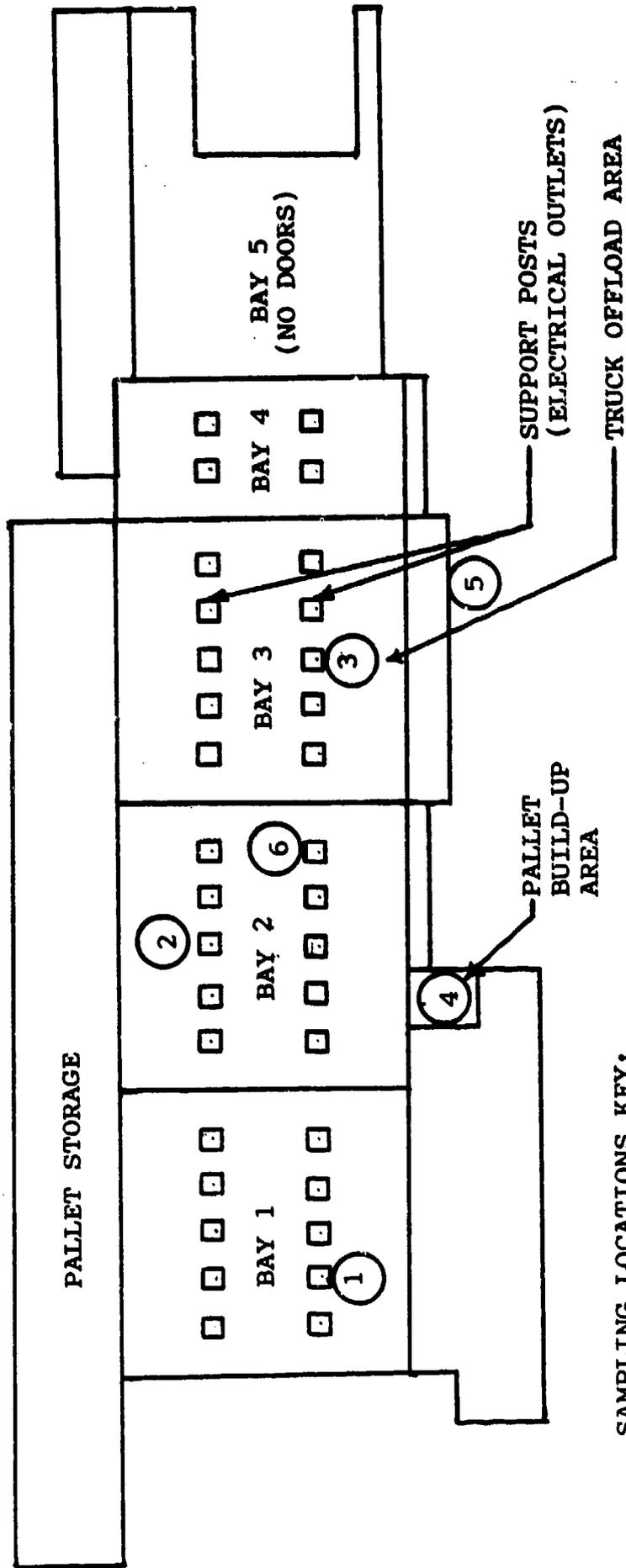
5. Sulfur Dioxide

The MSA Universal Tester pump and sulfur dioxide detector tubes were used to estimate the SO₂ air concentrations based on the length of stain produced by the reaction of SO₂ with the acid base indicator phenol sulfine-phthalein.

C. SURVEY PROTOCOL

Area sampling locations were chosen to satisfy two criteria: (1) where forklift activity was expected to be higher and (2) where electrical outlets were available to run the Ecolyzer CO monitors. Figure 1 is a diagram of the Aerial Port showing designated sample locations:

FLIGHTLINE SIDE



SAMPLING LOCATIONS KEY:

①, ②, and ③: Area Monitoring Locations

④, ⑤, and ⑥: Carbon Monoxide Monitoring with MIRAN 1B

SAMPLING LOCATIONS FOR THE 436 AERIAL PORT SQUADRON FACILITY

Figure 1

Personnel breathing zone samples for NO₂, NO, THC, and benzene were collected using dosimeters attached to workers collars and/or shirt pockets. The MIRAN 1B infrared gas analyzer was used to obtain real-time measurements of CO levels at various locations during forklift operations.

D. APPLICABLE STANDARDS

Air Force Occupational Safety and Health (AFOSH) Standard 161-8, Permissible Exposure Limits (PELs) for Chemical Substances, specifies that the PELs for all workers will be the most recent values of the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV).¹⁰ If a separate AFOSH Standard is published for a specific substance, the PEL specified therein takes precedence over the ACGIH TLV referenced in AFOSH 161-8. The applicable TLVs for the substances sampled are summarized in Table 2.

TABLE 2: PERMISSIBLE EXPOSURE LIMITS*

Chemical	TLV-TWA		TLV-STEL	
	ppm	mg/m ³	ppm	mg/m ³
Carbon monoxide	50	55	400	440
Benzene**	1	3	5	15
Formaldehyde	1, A2	1.5, A2	2, A2	3, A2
Nitrogen Dioxide	3	6	5	10
Nitrogen Oxide	25	30	(35)	(45)

*Except as noted, values are from the ACGIH 1985-86 TLV Booklet. Benzene is also A2 in the 85-86 and 86-87 TLV Book

** AFOSH STD 161-7

A2 denotes Appendix A2 of the ACGIH 1985-86 TLV Booklet, a list of suspected carcinogens

() denotes a STEL value to be deleted, ACGIH 1985-86 TLV Booklet, notice of intended changes

The ACGIH publication, Documentation of TLVs suggests that mixtures of NO, NO₂, and CO should be assumed to have additive effects based on their mechanisms of action.¹¹

E. RESULTS

Measured concentrations of all contaminants surveyed were below the PELs. Results for measurements of nitrogen oxides, formaldehyde, aldehydes (reported as formaldehyde equivalent), total hydrocarbons (reported as n-hexane equivalent), and benzene are summarized in Table 3. A narrative

summary of carbon monoxide area sampling measurements is presented below. Because the levels generally were well below the 25 ppm action level, time weighted average (TWA) concentrations were not calculated from the strip chart output. No sulfur dioxide was detected using MSA detector tubes.

TABLE 3: MEASURED AIR CONCENTRATIONS

Substance	Number Samples	Mean (ppm)	Standard Deviation (ppm)	Range (ppm)
NO ₂	7	0.176	0.038	0.134-0.223
NO	7	0.043	0.027	0.019-0.093
THC	15	0.751	0.850	0.317-3.73
Formaldehydes Na(SO ₂) ₂	7	0.21	0.24	<0.05 -0.73
Aldehydes (MBTH)	7	0.20	0.32	<0.01 -0.91
Benzene	15	ND*	-	-

*ND - None detected (limit of detection ranged from 0.6 to 0.8 mg/m³).

Area sampling for carbon monoxide using two Ecolyzer 6000 model units indicated exposure levels were generally under 15 ppm at the sampling locations on the support post in Bay 3. Two short duration peaks of 28 ppm were recorded at this location. Recorded levels obtained on 10 Jan 86 in Bay 1 were in the 10 to 20 ppm range. An ecolyzer in Bay 2 recorded similar CO concentrations except from 1000 to 1430 on 8 Jan 86. During this period, the CO concentration ranged from 30 to 40 ppm with an approximately ten minute period slightly above 50 ppm.

The MIRAN 1B infrared gas analyzer was used to measure CO concentrations during various operations on the evening of 10 Jan 86. Readings taken in the pallet buildup section of the truckside load area of Bay 2 during a half hour period when pallets were being brought in and rearranged, ranged from 4-16 ppm. Breathing zone samples for a 4K diesel operator on an idling forklift in the middle of Bay 2 of the aeroport were about 25 ppm. The maximum observed concentration approximately three feet behind the exhaust outlet of the same 4K diesel forklift was 737 ppm. A high of 1500 ppm was observed in the exhaust stream approximately three feet behind a propane powered forklift. The measurements of CO concentration obtained behind the forklifts were taken to estimate the relative CO source strengths of the diesel and propane powered forklifts. They are not representative of any expected worker exposures.

During off-loading of a tractor trailer using a 4K propane powered forklift, the real-time concentration of CO was monitored with the MIRAN 1B. Observations were made along the side walls of the truck trailer when the forklift was entering or leaving the trailer and in the breathing zone in the area vacated immediately after the forklift backed out of the trailer. The peak breathing zone concentration of CO observed with the MIRAN 1B was 160 ppm, well below the STEL of 400 ppm. For this particular operation, the driver was only in the trailer briefly to pick up pallets and back out of the truck. Conversations with one of the drivers revealed that parts of some shipments must be hand-stacked on pallets before being unloaded with a forklift. Drivers sometimes keep the forklifts idling in the trailer during these operations to help the stackers by moving the pallets in closer to the items being stacked on the pallets as loading progresses.

III. CONCLUSIONS

As stated earlier, all contaminant concentrations measured were below the respective TLVs. However, the time period surveyed was not representative of peak freight off-load activity. During the presurvey, USAFOEHL personnel were told that Thursdays and Fridays usually were the busiest days. However, during the actual survey from 7-10 Jan 86, the off-load activities were minimal all day Thursday and through the day-shift on Friday as aerial port personnel cleaned-up to prepare for a VIP visitor expected on Friday afternoon, 10 Jan 86. Aerial port personnel also stated that activity was low during the early part of the week.

Measurements of CO levels inside a tractor trailer during unloading of pallets with a propane powered forklift indicate a need for either some local exhaust ventilation to remove diesel exhaust or administrative controls to ensure that forklift operators and other personnel do not spend excessive amounts of time inside a trailer.

USAFOEHL had earlier taken the position that an industrial hygiene survey of an area using diesel vehicles could be accomplished adequately by measurement of CO levels alone.¹² This position was based on survey results of facilities using a mixed fleet of gasoline and diesel powered forklifts. However, an Environmental Protection Agency (EPA) publication on mobile source emission factors (EF) provides the emission factors shown in Table 4.¹³

The ratios of the emission factors to the TLVs (EF/TLV) show that the CO TLV would be more likely exceeded than the NO₂ or NO TLVs for gasoline powered vehicles. On the other hand, for diesel powered vehicles, the NO₂ or NO would be more likely to cause an overexposure than CO. Mr Vernon Markworth of Southwest Research Institute has stated that in ventilation calculations for mining applications of diesel powered vehicles (30, 40, and 100 brakehorsepower units), NO₂ is always the contaminant requiring the greatest ventilation rates.¹⁴ A USAFOEHL/ECH survey of munitions storage bunkers at the Medina Annex, Lackland AFB TX, where only diesel forklifts were used inside the bunkers supports this position.¹⁵ Although none of the area samples produced 8-hr TWAs above the action level, the NO₂ levels were

consistently a greater percentage of the allowable TLV than the CO levels. Therefore, levels of both NO_x and CO should be measured when surveying diesel exhaust emissions.

TABLE 4: HEAVY DUTY VEHICLE EMISSION FACTORS

Chemical	TLV (mg/m ³)	Diesel Vehicles		Gasoline Vehicles	
		EF (g/mi)	EF/TLV	EF (g/mi)	EF/TLV
CO	55	9.5	0.17	97.71	1.78
NO ₂ }	6	}	}3.4*	}	}0.8*
}NO _x		}20.5	}	}4.80	}
NO }	30	}	}0.68**	}	}0.16**

* Computed using the assumption that all of the NO_x is emitted as NO₂ (e.g., 20.5/6 = 3.4).

** Computed using the assumption that all of the NO_x is emitted as NO (e.g., 20.5/30 = 0.68).

IV. RECOMMENDATIONS

A. Although the measured concentrations of all sampled contaminants were below the permissible exposure limits, the addition of increased dilution ventilation, as originally recommended by the base bioenvironmental engineer, would reduce the visible haze and workers' complaints of odors and irritation. There appeared to be little difference between the temperature inside the aerial port and the temperature outside, implying that there would be little loss of tempered air from the increase in dilution ventilation.

B. The greatest potential for exceeding permissible exposure limits--either STELs or TWAs--occurs when the forklifts are operated inside a truck trailer. To control this potential, the aerial port squadron should either adopt administrative controls to limit the amount of time an operating forklift spends inside a trailer or install exhaust extensions to forklifts while they are operating inside trailers. Recommend a maximum period of 15 minutes inside a trailer with a forklift operating followed by a minimum of 45 minutes outside the trailer. There should be a maximum of four such exposures in a day. If this would adversely impact off-load activities, a longer exposure period might be justified by collecting more short term exposure measurements to better define short term exposures. Carbon monoxide and nitrogen oxides dosimeters could be used to better define these short term worker exposures resulting from off-load operations.

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