EXPOSURE ASSESSMENT OF HEAVY-EQUIPMENT OPERATORS TO DIESEL PARTICULATE MATTER

by

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Abstract

The OSHA/MSHA *Hazard Alert* that was released in January 2013regarding the carcinogenicity of diesel particulate matter suggested that employers monitor the diesel particulate matter exposure of at risk employees. The at risk employees identified at an elemental phosphorous plant included heavy equipment operators, locomotive operators and heavy duty equipment mechanics. OSHA recommends sampling for the gas phase components (i.e. CO and NO_2) of diesel exhaust to determine if at risk employees are exposed to diesel particulate matter. A literature review suggested that the extrapolation of diesel particulate matter from CO or NO_2 levels may not accurately assess exposure to diesel particulate matter.

Area monitoring for carbon monoxide, nitrogen dioxide and diesel particulate matter (elemental carbon) levels was conducted to assess the exposure of at risk employees. All three diesel exhaust constituents (CO, NO_2 and EC) were sampled at the same time within the cab or work area of the at risk employees.

A total of 13 samples were collected and analyzed. The statistical analysis of the data collected suggested that nitrogen dioxide time weighted average levels may serve as a predictor of diesel particulate matter, but carbon monoxide time weighted average measurement is not an accurate predictor of diesel particulate matter exposure.

An accurate assessment of workplace exposure to diesel particulate matter, carbon monoxide and nitrogen dioxide must be directly measured rather than extrapolated from indirect measurements. The methods for sample collection and analysis may include direct read instruments, sampling pumps and filter cassettes, or other approved methods of detection.

Keywords: Diesel Particulate Matter, Elemental Carbon, Heavy Equipment Operators

Dedication

I dedicate this research to my wife Annie and our three sons.

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Glossary of Terms

Carbon Monoxide	**CO**	An odorless and colorless gas that causes headaches, nausea and confusion. Affects the cardiovascular system and the central nervous system.
Diesel Exhaust	**DE**	A mixture of particulate, vapor and gas phase components that result from the internal combustion of diesel fuel.
Diesel Particulate Matter	**DPM**	The solid phase component of diesel exhaust.
Elemental Carbon	**EC**	The component that is measured in NIOSH method 5040 as a surrogate for diesel particulate matter. Carbon chains that are not bound to elements other than carbon.
Nitrogen Dioxide	**NO_2**	A diesel exhaust gas that causes eye irritation decreased pulmonary function, chest pain and pulmonary edema.
Occupational Exposure Limit	**OEL**	A health-based workplace standard to protect workers from adverse exposure.
Organic Carbon	**OC**	Carbon bound to organic compounds like hydrocarbons.
Time Weighted Average	**TWA**	Average exposure for an individual over a given working period, as determined by sampling at given times during the period.
Peak		The maximum reading of a direct read instrument during a sampling time period.
Permissible Exposure Limit	**PEL**	The permissible concentration in air of a substance to which nearly all workers may be repeatedly exposed 8 hours a day, 40 hours a week, for 30 years without adverse effects.
Short Term Exposure Limit	**STEL**	Maximum concentration for continuous 15-minute period. A STEL is allowed four times a day, with at least 60 minutes between exposures.
Threshold Limit Value	**TLV**	Used by the American Conference of Governmental Industrial Hygienists (ACGIH) to designate degree of exposure to contaminants.
Total Carbon	**TC**	The sum of elemental carbon and organic carbon.

1. Introduction

Diesel exhaust, including diesel particulate matter, was classified as a known human carcinogen in June of 2012 by the International Agency for Research on Cancer, a division of the World Health Organization. In response to the classification of diesel exhaust/diesel particulate matter as “carcinogenic to humans” (Group 1 classification) the Occupational Safety and Health Administration (OSHA) and the Mining Safety and Health Administration (MSHA) published a *Hazard Alert* (OSHA, 2013). The OSHA/MSHA *Hazard Alert* advised employers to evaluate employee exposure to diesel particulate matter (OSHA, 2013). The OSHA/MSHA *Hazard Alert* did not establish an occupational exposure limit for diesel particulate matter. To evaluate employee exposure to diesel particulate matter, OSHA recommends monitoring for diesel exhaust constituents. Diesel exhaust constituents with established occupational exposure limits include carbon monoxide and nitrogen dioxide (OSHA, 2013).

OSHA does not have a permissible exposure limit (PEL) for diesel particulate matter. The current OSHA recommendation to evaluate diesel exhaust exposure for General Industry, Agriculture, Construction and Maritime Operations includes monitoring for the known gas phase constituents of diesel exhaust (OSHA, 2013). Some of the gases present in diesel exhaust that have established OSHA PELs include carbon monoxide (CO) and nitrogen dioxide (NO_2). The measurement of CO and NO_2 concentrations is readily performed with direct read instrumentation. Quantification of carbon monoxide and nitrogen dioxide concentrations is an established industrial hygiene practice to evaluate the exposure of employees to these harmful gases. The presence of carbon monoxide, nitrogen dioxide and particulate matter in diesel exhaust emissions suggests that the concentrations of carbon monoxide, nitrogen dioxide and particulate matter may be correlated (Stewart, 2010). The result of a study conducted by researchers at West Virginia University suggests that the carbon monoxide/particulate matter correlation is unique for each engine type and perhaps for each engine (Clark, 1999).

A diesel exhaust exposure assessment was developed for an elemental phosphorous plant located in Soda Springs, Idaho. The Soda Springs elemental phosphorous plant operates as an OSHA certified Voluntary Protection Program (VPP) Star site. The OSHA VPP Star certification indicates that the Soda Springs plant actively abides by OSHA standards and recommendations. OSHA VPP Star sites are recognized as industry leaders for the active engagement of employee health and safety programs (OSHA, 2013). The status of operating an OSHA VPP Star facility compelled the Soda Springs elemental phosphorous site to assess the exposure of heavy equipment operators to diesel exhaust and diesel particulate matter.

Individuals that work in construction, mining, transportation (semi-truck drivers) and agriculture are at an increased risk of exposure to diesel powered equipment (OSHA, 2013). A cohort study conducted by the National Institute for Occupational Safety and Health (NIOSH) and the National Cancer Institute (NCI) recognized that diesel exhaust exposure above ground is linked to the operation of forklift trucks, locomotives and heavy equipment (Attfield, 2012). Worker exposures to diesel exhaust/diesel particulate matter in outdoor environments are lower than underground, enclosed work environments (Attfield, 2012).

Exposure to diesel exhaust and diesel particulate matter may result in short-term and long-term detrimental health effects (OSHA, 2013). The health effects of acute exposure to concentrations of diesel exhaust components above the OSHA PEL may include headaches, dizziness and irritation of the eyes, nose and throat (OSHA, 2013). Chronic exposure to the gases and particles found in diesel exhaust and diesel particulate may increase the risk of cardiovascular/cardiopulmonary complications and lung cancer (OSHA, 2013).

1.1. Background

The OSHA/MSHA Hazard Alert recommends that employers assess employee exposure to diesel exhaust and diesel particulate matter (OSHA, 2013). The industrial hygiene assessment of exposure to diesel exhaust is complex because no single constituent of diesel exhaust is considered a unique marker of diesel exhaust exposure (Pronk, Coble, & Stewart, 2009). Diesel exhaust contains solid soot particles and gas phase components (AFSCME, 2011). An International Agency for Research on Cancer (IARC) workgroup recognized that exposure to the gas-phase constituents such as CO and NO_2 did not result in an increased incidence of respiratory tumors in the animal populations that were tested (Benbrahim-Talaa, 2012). However, the IARC workgroup evaluated epidemiologic research and concluded that the particulate phase of diesel fuel combustion is, "carcinogenic to humans" (Benbrahim-Talaa, 2012). The results of the IARC classification of diesel exhaust as carcinogenic, led to an increased awareness of diesel exhaust exposure. The IARC classification of diesel exhaust supports a recommendation from the National Institute for Occupational Safety and Health (NIOSH) to reduce employee exposure to diesel exhaust especially diesel particulate matter (Birch, Monitoring of Diesel Particulate Exhaust in the Workplace, 2003).

During the summer months of 2013 an exposure assessment of off-road (no highway use) heavy equipment operators to diesel exhaust occurred. The physical location of the exposure assessment is 1853 Highway 34, Soda Springs, Idaho. The need for this exposure assessment stems from the classification of diesel exhaust as carcinogenic to humans by the IARC.

1.2. Literature Review

The recognition of the mutagenicity of diesel particulate matter was first recognized by Kotin et al. (Kotin, 1955). Aromatic hydrocarbons were recognized as carcinogens and the presence of aromatic hydrocarbons in diesel exhaust was acknowledged (Kotin, 1955). The findings of the research conducted by Kotin et al. in 1955, led to a multitude of studies regarding the health effects, particularly carcinogenicity, of diesel exhaust exposure. Mauderly (2001) suggests that the research conducted surrounding the health effects of diesel exhaust exposure is second only to cigarette smoke. Historical epidemiological research that attempts to link respiratory system-related morbidity and mortality to diesel exhaust exposure are generally tainted by confounding factors (Hesterberg, 2012). The confounding factors of epidemiologic studies, that attribute lung cancer to diesel exhaust exposure, include exposure to other known respiratory system carcinogens like cigarette smoke, asbestos and radon (Hesterberg, 2012).

A retrospective case study conducted by investigators at the National Institute for Occupational Health and Safety (NIOSH) and the National Cancer Institute (NCI) investigated the relationship of diesel exhaust exposure and lung cancer mortality rates (Silverman, 2012). The findings of the NIOSH-NCI study indicates that lung cancer risk increases with increased exposure to diesel exhaust (Benbrahim-Talaa, 2012).

One of the challenges of assessing diesel exhaust exposure is determining which diesel exhaust constituent to measure. For the NIOSH-NCI study, investigators selected elemental carbon as a diesel exhaust surrogate (Stewart, 2010). Elemental carbon was selected as a surrogate to quantify historic diesel particulate matter exposures because of the specificity of the NIOSH analytical method 5040 (Birch, Diesel Particulate Matter (as Elemental Carbon): Method 5040, 2003). However, the lack of historic elemental carbon measurement records led NIOSH-NCI investigators to extrapolate elemental carbon exposure from historic recorded measurements of carbon monoxide (Stewart, 2010). The extrapolation of elemental carbon exposure from carbon monoxide data is a questionable scientific practice (Hesterberg, 2012). Therefore, Hesterberg et al. (2012) dispute the validity of the scientific research methods used by NIOSH-NCI investigators to classify the US miner diesel exhaust exposure.

The use of carbon monoxide as a surrogate for diesel exhaust elemental carbon exposure, by the NIOSH-NCI researchers has been criticized by other reputable researchers. Hesterberg et al. (2012) noted that the use of carbon monoxide as a surrogate for diesel exhaust elemental carbon had not been performed previously. In addition, the review of over 100 publications failed to identify an epidemiologic study that substituted carbon monoxide as a surrogate for diesel exhaust elemental carbon exposure (Hesterberg, 2012).

1.3. Research Goals

An exposure assessment of heavy-equipment operators to CO, NO_2 and DPM was conducted at an elemental phosphorous plant. The study was performed in Southeast Idaho during 2013. The objectives of the study were the following:

1. Establish a correlation coefficient for the diesel exhaust gases (CO and NO_2) and diesel particulate matter as represented by elemental carbon NIOSH method 5040.
2. Establish baseline exposure measurements for operators of heavy equipment to carbon monoxide, nitrogen dioxide and diesel particulate matter as measured by elemental carbon NIOSH method 5040.

Research question #1 Are elemental carbon concentrations, as determined by NIOSH method 5040, correlated with NO_2 and CO concentrations?

Research question #2 Is the concentration in parts per million (ppm) of CO, inside the operator cab of heavy equipment at the Monsanto Soda Springs plant, equal to or greater than the ACGIH threshold limit value of 25 ppm?

Research question #3 Is the concentration in parts per million (ppm) of NO_2, inside the operator cab of heavy equipment at the Monsanto Soda Springs plant, equal to or greater than the ACGIH threshold limit value of 3 ppm?

1.4. Research Hypotheses

One of the current methods recommended by OSHA to evaluate diesel exhaust exposure including diesel particulate matter is measuring carbon monoxide and nitrogen dioxide exposure. The following six hypotheses were developed to provide direction for the research methods, sampling procedures and statistical analysis. The null hypotheses are designated as Ho and the research hypotheses are designated as Ha.

Ho_1 The time weighted average of carbon monoxide is not a statistically significant predictor of the time weighted average for elemental carbon exposure. Statistical significance for the regression equation is determined with a p value ≤ 0.05.

Ha_1 The time weighted average of carbon monoxide is a statistically significant predictor of elemental carbon exposure. Statistical significance for the regression equation is determined with a p value ≤ 0.05.

Ho_2 The peak measurement of carbon monoxide is not a statistically significant predictor of the elemental carbon time weighted average. Statistical significance is determined by a p value ≤ 0.05.

Ha_2 The peak measurement of carbon monoxide is a statistically significant predictor of the elemental carbon time weighted average. Statistical significance is determined by a p value ≤ 0.05.

Ho_3 The time weighted average of nitrogen dioxide is not a statistically significant predictor of the time weighted average for elemental carbon exposure. Statistical significance for the regression equation is determined with a p value ≤ 0.05.

Ha_3 The time weighted average of carbon monoxide is a statistically significant predictor of elemental carbon exposure. Statistical significance for the regression equation is determined with a p value ≤ 0.05.

Ho_4 The peak measurement of nitrogen dioxide is not a statistically significant predictor of the elemental carbon time weighted average. Statistical significance is determined by a p value ≤ 0.05.

Ha_4 The peak measurement of nitrogen dioxide is a statistically significant predictor of the elemental carbon time weighted average. Statistical significance is determined by a p value ≤ 0.05.

Ho_5 The time weighted average of carbon monoxide is ≤ 25 ppm. A one sample t-test with a p value ≤ 0.05 will indicate statistical significance.

Ha_5 The time weighted average of carbon monoxide is not ≤ 25 ppm. A one sample t-test with a p value ≤ 0.05 will indicate statistical significance.

Ho_6 The time weighted average of nitrogen dioxide is ≤ 3 ppm. A one sample t-test with a p value ≤ 0.05 will indicate statistical significance.

Ha_6 The time weighted average of nitrogen dioxide is not ≤ 3 ppm. A one sample t-test with a p value ≤ 0.05 will indicate statistical significance.

1.5. Toxicology

The toxic effects of exposure to diesel exhaust and diesel particulate matter are classified as being both non-carcinogenic and carcinogenic (Hesterberg, 2012). Generally, non-carcinogenic toxic effects are associated with diesel exhaust gases. The carcinogenic effects of diesel exhaust are associated with diesel particulate. Animal studies demonstrate that rats develop lung tumors when exposed to diesel exhaust. The exposure conditions that resulted in rats developing lung tumors required diesel exhaust exposure at elevated concentrations for extended periods of time (Hesterberg, 2012). The results of the diesel exhaust 'lung overload' rat bio-assay may not be predictive of the increased risk to humans of developing lung tumors from diesel exhaust exposure (Hesterberg, 2012).

1.5.1. Non-carcinogenic Effects

Epidemiologic studies indicate that non-carcinogenic morbidity is associated with diesel exhaust exposure. The symptoms associated with diesel exhaust exposure include sputum production, chest tightness, eye and nose irritation, wheezing and exacerbation of asthma (See, 2006). Individuals with pre-existing risk factors such as high blood pressure, chronic obstructive pulmonary disorder, or other respiratory and cardiovascular disorders, may be negatively affected by exposure to diesel exhaust (Nemmar, 2008).

1.5.2. Carcinogenic Effects

The constituent of diesel exhaust that is carcinogenic is difficult to isolate (Betha, 2011). The numbers of chemicals bound to the carbonaceous particulate of diesel exhaust include polycyclic aromatic hydrocarbons (PAHs), metals, and various organic and inorganic compounds (Betha, 2011). However, as noted by Garshick et al. (2012), the biologic mechanisms for cancer development associated with diesel exhaust elemental carbon exposure are not known. Therefore, Garshick et al. (2012) consider elemental carbon a marker for diesel exhaust exposure, but not itself a carcinogenic substance.

Recognized carcinogenic compounds are found in diesel exhaust at various concentrations. The known carcinogenic compounds found in diesel exhaust include: benzene, formaldehyde and chrysene (OSHA, 2013). These carcinogenic compounds may be present on the surface of elemental carbon particulates. Elemental carbon may function as a vehicle to transport carcinogenic compounds to humans. The size of the elemental carbon vehicle dictates the deposition of particles in the respiratory tract (Garshick, 2012). The deposition of elemental carbon contaminated with carcinogenic compounds, may also occur on the skin and in the upper regions of the respiratory tract (Oberdorster, 2005).

The NIOSH-NCI miners study was influential in the decision of the IARC committee to classify diesel exhaust and diesel particulate matter as Class 1 carcinogenic substances (Benbrahim-Talaa, 2012).

1.6. At-risk Occupational Groups

Occupations that expose workers to diesel exhaust/diesel particulate matter include operating heavy equipment, mining, railroad workers, truck drivers, farm workers and diesel engine mechanics (OSHA, 2013). The OSHA/ MSHA *Hazard Alert* suggests that employers monitor workers to determine if engineering controls need to be implemented to protect workers from exposure to diesel exhaust and diesel particulate matter (OSHA, 2013).

The heavy equipment operators and heavy equipment mechanics at the Soda Springs phosphorous plant are the employees with the highest probability of being exposed to diesel exhaust. There is no concern for pedestrians to be exposed to measurable concentrations of diesel exhaust and diesel particulate matter. Pedestrian traffic is not permitted near heavy equipment operating areas.

1.7. Occupational Exposure Limits

Diesel exhaust is composed of multiple constituents. Previous studies have evaluated exposure to diesel exhaust by monitoring gas-phase exhaust components such as carbon monoxide, carbon dioxide and nitrogen dioxide (Benbrahim-Talaa, 2012). The health implications associated with exposure to carbon monoxide and nitrogen dioxide, are documented (OSHA, 2013). Symptoms associated with exposure to carbon monoxide include: headache, nausea and syncope (CDC, 2010). Exposure to nitrogen dioxide may result in the following health effects: irritation of the eyes, nose and throat; chest pain and pulmonary edema (CDC, 2010). The health effects of carbon monoxide and nitrogen dioxide have resulted in permissible exposure limits established by the Occupational Safety and Health Association.

The International Agency for Research on Cancer (IARC) classified diesel exhaust as a known human carcinogen in June 2012 (Benbrahim-Talaa, 2012). However, the dose of diesel exhaust particulate that results in deleterious health effects in humans is not well understood. Therefore, there is not an established Permissible Exposure Limit for diesel exhaust particulate.

The quantity and size of particulate found in diesel exhaust is variable. This is due primarily to the numerous variables associated with diesel grade and diesel engine combustion efficiency. The variables that contribute to inhalable diesel particulate matter include, duration of exposure, fuel type, engine maintenance schedules, engine age, implementation of exhaust particulate filters and operating environment (Birch, 2003).

The occupational exposure limits for carbon monoxide and nitrogen dioxide are found in Table I. The American Conference of Governmental Industrial Hygienists (ACGIH) generally recommends threshold limit values (TLVs) that provide the most protection with respect to individual exposure. The policy for the Soda Springs elemental phosphorous plant is to implement the most conservative exposure limits.

Table I: Occupational Exposure Limits for CO and NO_2

Substance	**Agency**		
	OSHA (ppm)	**NIOSH (ppm)**	**ACGIH (ppm)**
Carbon Monoxide (CO)	50	35	25
Nitrogen Dioxide (NO_2)	5 (ceiling)	1 (STEL)	3

In 2001, ACGIH proposed an exposure limit for diesel particulate matter of 20µg/m^3. The ACGIH proposed exposure limit has been withdrawn and is not currently being investigated (ACGIH, 2013). (Please find Appendix E to view the correspondence from ACGIH Science Group).

1.8. Exposure Controls

Engineering controls have effectively reduced the exposure of heavy equipment operators to diesel exhaust particulate (Pronk, Coble, & Stewart, 2009). Engineering controls include isolating the operator with air-conditioned cabs and closed windows (AFSCME, 2011). All of the heavy equipment at the Soda Springs elemental phosphorous plant has operator cabs with air conditioning. The equipment cab windows are fixed and not capable of being opened. The doors have weather stripping to provide a seal to isolate the heavy equipment operator's environment. The results of a previous exposure assessment to elemental carbon demonstrated exposures less than 25 µg/m^3 for operators of heavy equipment with operator cabs in place (Pronk, Coble, & Stewart, 2009).

2. Methodology

In 2003, a NIOSH researcher, M. Eileen Birch, published recommendations for the, *Monitoring of Diesel Particulate Exhaust in the Workplace.* The document published by Birch, provided insight to the collection of elemental carbon to be analyzed by NIOSH method 5040. Elemental carbon is considered a surrogate for the detection of diesel exhaust particulate (Birch, 2003). In addition to the NIOSH method 5040, OSHA considers monitoring for carbon monoxide and nitrogen dioxide as justified means for detecting diesel exhaust particulate. The sampling methods for Diesel Particulate Matter (DPM) will be performed according to the NIOSH method 5040. Carbon monoxide and nitrogen dioxide time weighted averages (TWAs) and peaks were quantified with direct read Gas Badge Pro instruments manufactured by Industrial Scientific.

2.1. Sampling Locations

The 13 work areas monitored for the diesel exhaust constituents elemental carbon, carbon monoxide and nitrogen dioxide included 11 pieces of diesel-powered heavy equipment. Two samples of the heavy-equipment mechanic shop were also performed.

2.1.1. Plant Location

The elemental phosphorous plant is located in Soda Springs, Idaho. Physical address: 1853 Highway 34 Soda Springs, Idaho. The elevation of the plant is 5,774 feet. The heavy equipment is operated in an outdoor environment.

2.1.2. Heavy Equipment

The heavy equipment at the elemental phosphorous Soda Springs plant is used primarily to manage raw material usage and storage. Nine of the eleven pieces of heavy equipment are common types of machinery that may be found in any ore handling site. Two of the pieces of equipment are custom built and referred to as pot carriers. The list of equipment found in Table II represents diesel powered equipment that is used daily at the elemental phosphorous plant in Soda Springs, Idaho.

Table II: List of Heavy Equipment Sampled

Equipment Sampled
Pot Carrier #15
Pot Carrier #17
Loader 988 H #28
Loader 988 H #32
773 Haul Truck #18
Loader 988 H #29
Water truck #20
930 Loader #26
14 H Grader
Vactor Truck
Locomotive

The areas represented in Table III were selected because the heavy-equipment mechanic shop is the only building within the plant that can enclose heavy equipment. One sample was collected on the shop main floor level at a height of 5 feet 8 inches. The other sample was collected in the personal locker area located on the second floor of the heavy equipment shop at a height of 5 feet 8 inches.

Table III: Work Areas Sampled

Areas Sampled
HEG Shop 2nd Level (Locker Area)
HEG Shop Main Floor (Filter Storage Rack)

2.2. Sampling Equipment

A Gil Air personal air sampler by Gilian® (Figure 1) was attached to a 37-millimeter untared quartz filter. Pre-calibration and post-calibration of the Gil Air personal air sampling pump was performed with a Gilian calibrator.

Figure 1: Gilian Personal Air Sampling Pump (iPhone 4 used to demonstrate size of pump)

A 37-millimeter untared quartz filter (Figure 2) was used to collect diesel particulate matter as required by NIOSH method 5040. The 37-millimeter untared quartz filters were supplied by Bureau Veritas North America, Inc.

Figure 2: Quartz 37-millimeter filter cassette

Two Gas Badge Pro personal gas monitors, made by Industrial Scientific, were attached to the tubing that connects the sampling pump to the 37-millimeter filter cassette (see Figure 3). One of the Gas Badge Pro monitors will monitor the work area environment for CO (Figure 4). The other Gas Badge Pro monitor will monitor the work area environment for NO_2 (Figure 5).

Figure 3: Experiment Sampling Train

Figure 4: Industrial Scientific Carbon Monoxide (CO) monitor

Figure 5: Industrial Scientific Nitrogen Dioxide (NO_2) monitor

2.3. Sampling Strategy

Thirteen individual samples were collected for diesel particulate matter, nitrogen dioxide and carbon monoxide. The sampling devices were placed in the work area of heavy equipment operators and heavy equipment mechanics. The sampling devices were not attached to the heavy equipment operators or mechanics. An area sample of the operator cab is likely representative of heavy equipment operator personal exposure (Pronk, Coble, & Stewart, 2009). The purpose of this sampling strategy was to assess the exposure of heavy equipment operators and heavy equipment mechanics to carbon monoxide, nitrogen dioxide, and diesel particulate matter. Heavy equipment operators and mechanics at the Soda Springs, Idaho phosphorous plant work 12-hour shifts, which are from 6 am to 6 pm and 6pm to 6 am. The heavy equipment operators exit the cab for break at 9:00, 12:00 and 3:00 respectively. Operators may also exit the cab to perform routine maintenance. During the summer, heavy equipment operators turn off the engine prior to exiting the cab. The Gil Air sampling pumps ran continuously for the entire 12-hour work shift.

There is one piece of heavy equipment known as the Vactor Truck that idles frequently during the day. The vactor truck (Figure 6) is used to remove particulate from dust collection systems in the plant. The vactor truck engine idles during the vacuuming process and the operator is frequently moving in and out of the cab to hook up hoses and monitor gauges during the vacuuming procedure. The potential for diesel exhaust and diesel particulate matter exposure to the operator of the vactor truck may be greater than the potential exposure of other heavy equipment operators.

Figure 6: Vactor Truck

Heavy-equipment mechanics work in an enclosed environment and perform routine maintenance on heavy equipment. The typical tasks for heavy-equipment mechanics include changing oil, oil filters, air filters, hydraulic hoses and other equipment maintenance tasks. Heavy-equipment mechanics are generally exposed to engine exhaust when the heavy equipment is moved in or out of the enclosed shop. Routine maintenance activities do not require the heavy equipment to idle in the shop (Crane, 2013).

2.4. Sample Analysis

The analysis of the samples collected with the direct read instruments was conducted immediately after the completion of the 12-hour shift. The Gas Badge Pro direct-read gas monitors calculate the time weighted average and peak. The Gas Badge Pro provides instantaneous digital results.

2.4.1. Carbon Monoxide

CO results were retrieved from the Gas Badge Pro monitor at the end of each 12-hour shift. The monitor recorded the CO gas peak, TWA and STEL. Calibration of the instrument was performed as recommended by the Gas Badge Pro operator manual. The calibration system for the Gas Badge Pro is a DS-2 docking station provided by Industrial Scientific.

2.4.2. Nitrogen Dioxide

NO_2 results were retrieved from the Gas Badge Pro monitor at the end of each 12-hour shift. The monitor recorded the NO_2 gas peak, time weighted average (TWA) and short term exposure limit (STEL). Calibration of the instrument was performed as recommended by the Gas Badge Pro operator manual. The calibration system for the Gas Badge Pro is a DS2 docking station provided by Industrial Scientific.

2.4.3. Diesel Particulate Matter Sample Analysis

The quantitative analysis of diesel particulate matter is based on the thermal-optical analysis technique (Birch, Monitoring of Diesel Particulate Exhaust in the Workplace, 2003). The thermal-optical analysis has the capability of quantifying elemental carbon concentration and organic carbon concentration. The sum of elemental carbon and organic carbon results in a total carbon concentration (Birch, Monitoring of Diesel Particulate Exhaust in the Workplace, 2003). The specific methodology implemented to perform the quantitative analysis of elemental carbon can be found in Appendix D.

Bureau Veritas North America, Inc. analyzed the 37-millimeter quartz filter, diesel particulate matter cassettes.

2.5. Quality Control

The Gas Badge Pro devices were calibrated and bump tested as recommended by the manufacturer, Industrial Scientific.

The Gil Air sampling pumps were pre-calibrated at a flow rate of 2.0 liters per minute. The calibrator used was a Gilibrator™ 2 by Gilian® Serial number 0209531-S. Post-calibration of the Gil Air sampling pumps was performed to verify the sample collection flow rate. The average sample flow rate was obtained from the average of the pre-calibration flow rate and the post-calibration flow rate (Appendix F).

2.6. Environmental Conditions during Sampling

The environmental conditions during the sampling period were average for the time of year. The average daytime high for the six days when samples were collected was 85 ˚F with a daytime high of 92 ˚F and daytime low of 81 ˚F. Sampling was also conducted during the night shift that starts at 6:00 pm and ends at 6:00 am. The average night shift temperature was 53 ˚F with a nighttime high of 59 ˚F and a nighttime low of 46 ˚F.

The atmospheric pressure at 5,774 feet elevation obtained for the six days of sampling was 617 mm Hg. The range of atmospheric pressure was 619 mm Hg to 615 mm Hg. Wind speed and wind direction were not recorded. The variation in weather conditions during the summer was not considered to be a critical determinant of the results that were obtained.

3. Results

To assess the exposure of heavy-equipment operators to diesel exhaust fumes and particulate matter a sampling strategy was developed and followed. The objectives of the exposure assessment are presented in two research questions.

Research question #1 Are elemental carbon concentrations, as determined by NIOSH method 5040, correlated with NO_2 and CO concentrations?

Research question #2 Are the concentrations in parts per million (ppm) of Nitrogen Dioxide and Carbon Monoxide gases, inside the operator cab of heavy equipment at the Monsanto Soda Springs plant, equal to or greater than the ACGIH threshold limit value?

Research question #3 Research question #3: Is the concentration in parts per million (ppm) of NO_2, inside the operator cab of heavy equipment at the Monsanto Soda Springs plant, equal to or greater than the ACGIH threshold limit value of 3 ppm?

The results of the sampling exercises are presented in Table IV.

Table IV: Sampling Results: Mean, Median and Standard Deviation

Equipment/Area Sampled	Date Sampled	CO TWA (ppm)	CO Peak (ppm)	NO2 TWA (ppm)	NO2 Peak (ppm)	EC TWA (µg/m3)
Pot Carrier #15	7/9/2013	0	5	0	0.6	12
Pot Carrier #17	7/9/2013	0	6	0	0	3
Loader 988 H #28	7/9/2013	0	6	0	0.5	7.7
Loader 988 H #32	7/10/2013	0	0	0	0	<2
773 Haul Truck #18	7/10/2013	0	0	0	0.6	<2
Loader 988 H #29	7/16/2013	0	0	0	0	<2
Water truck #20	7/16/2013	0	4	0	0.8	<2
930 Loader #26	7/17/2013	2	14	0	0.5	4.1
14 H Grader	7/17/2013	0	4	0	0	4.7
Vactor Truck	7/23/2013	0	20	0.1	1.1	280
Locomotive	7/23/2013	0	0	0	0	7.3
HEG Shop (Locker Area)	7/30/2013	0	0	0	0.5	5
HEG Shop (Filter Storage Rack)	7/30/2013	0	0	0	0.5	9.4
Mean		**0.153846154**	**4.538461538**	**0.007692308**	**0.392307692**	**37.02222222**
Median		**0**	**4**	**0**	**0.5**	**7.3**
Standard Deviation		**0.554700196**	**6.172727444**	**0.02773501**	**0.361620285**	**91.16059699**

4. Statistical Analysis of Results

The statistical analysis of the data collected was performed with Minitab 16 software. Hypotheses H_1 through H_4 were tested with regression analysis. Hypotheses H_5 and H_6 were tested with one-sample t-tests.

4.1. Correlation of Elemental Carbon TWA versus Carbon Monoxide TWA

The independent variable, carbon monoxide TWA was evaluated for statistical significance as a predictor for elemental carbon TWA. The results of the statistical analysis suggest that carbon monoxide TWA is not a statistically significant predictor for elemental carbon TWA levels. The p value, 0.784 is greater than the alpha level of 0.05. The R-Squared value of 0.0% indicates that none of the variation of the elemental carbon TWA can be explained by the carbon monoxide TWA. The result of this statistical test fails to reject the null hypothesis Ho_1. The measurement of carbon monoxide TWA levels cannot be used to predict elemental carbon TWA levels.

4.2. Correlation of Elemental Carbon TWA versus Carbon Monoxide Peak

The independent variable, carbon monoxide peak was evaluated for statistical significance as a predictor for elemental carbon TWA. The results of the statistical analysis suggest that carbon monoxide peak levels are statistically significant predictors for elemental carbon TWA levels. The p value, 0.003 is less than the alpha level of 0.05. The R-Squared value of 53.3% indicates that 53% of the variation of elemental carbon levels can be explained by the peak values for carbon monoxide. The result of this statistical test rejects the null hypothesis Ho_2 in favor of the alternative hypothesis Ha_2. The measurement of carbon monoxide peak levels may provide statistically significant predictive value in the evaluation of employee exposure to elemental carbon TWA levels.

The histogram found in the 4 in 1 plot of Figure 7 represents a bell shape, however there are outliers. Sample size (n=13) may contribute to the separation of the bars in the histogram. Increasing sample size could fill in the gaps and strengthen the correlation of the carbon monoxide peak and elemental carbon TWA relationship.

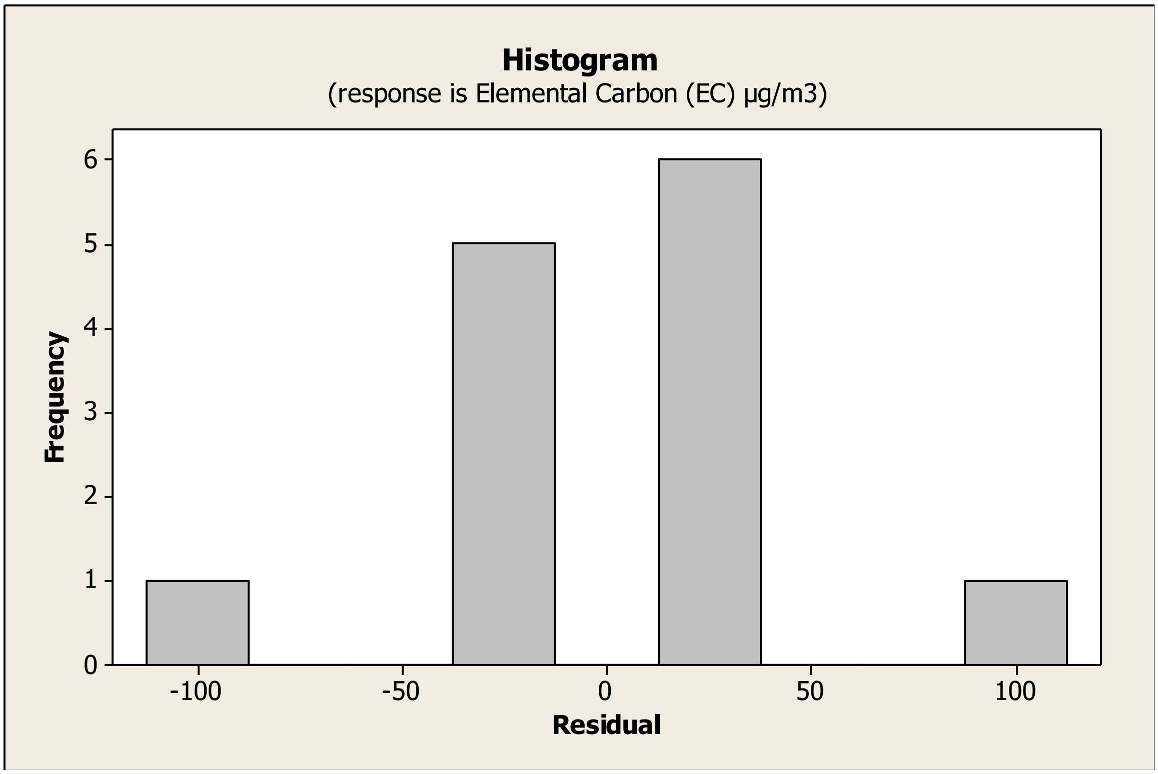

Figure 7: Histogram plot of the Elemental Carbon TWA versus Carbon Monoxide Peak

4.3. Correlation of Elemental Carbon TWA versus Nitrogen Dioxide TWA

The independent variable, nitrogen dioxide TWA was evaluated for statistical significance as a predictor for elemental carbon TWA. The results of the statistical analysis suggest that nitrogen dioxide TWA levels are statistically significant predictors for elemental carbon TWA levels. The p value, 0.000 is less than the alpha level of 0.05. The R-Squared value of 99.7% indicates that 99.7% of the variation of elemental carbon levels can be explained by nitrogen dioxide TWA levels. The result of this statistical test rejects the null hypothesis Ho_3

in favor of the alternative hypothesis Ha_3. The measurement of nitrogen dioxide TWA levels provides statistically significant predictive value in the evaluation of employee exposure to elemental carbon TWA levels.

The normal probability plot found in Figure 8 demonstrates a linear relationship. Skewness in the histogram is the result of the nitrogen dioxide TWA value equal to 0 ppm and the elemental carbon TWA is less than 2.0 µg/m^3. The skewness exists because of the correlation of nitrogen dioxide TWA values equal to 0 ppm and elemental carbon TWA levels that are greater than 2.0 µg/m^3.

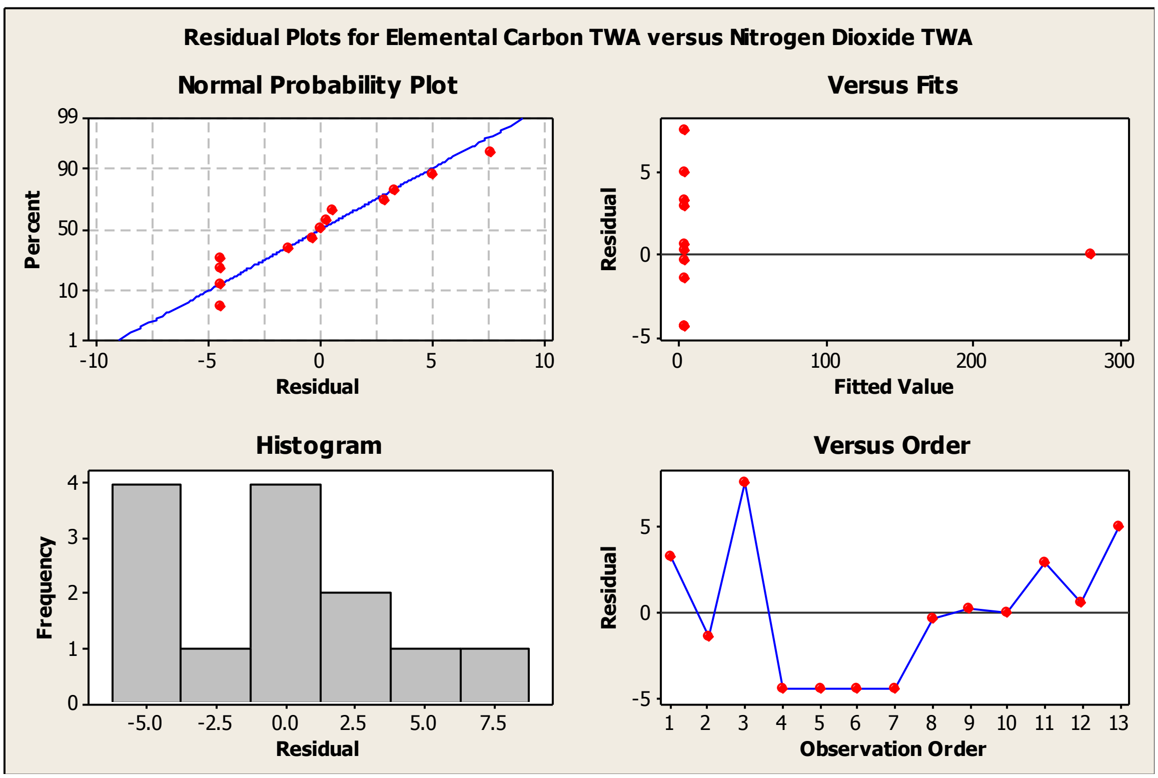

Figure 8: 4-in-1 plot of Elemental Carbon TWA vs. Nitrogen Dioxide TWA

4.4. Correlation of Elemental Carbon TWA versus Nitrogen Dioxide Peak

The independent variable, nitrogen dioxide peak was evaluated for statistical significance as a predictor for elemental carbon TWA. The results of the statistical analysis suggest that nitrogen dioxide peak levels are statistically significant predictors for elemental carbon TWA levels. The p value, 0.032 is less than the alpha level of 0.05. The R-Squared value of 29.5% indicates that 29.5% of the variation of elemental carbon levels can be explained by nitrogen dioxide peak levels. The result of this statistical test rejects the null hypothesis Ho_4 in favor of the alternative hypothesis Ha_4. The measurement of nitrogen dioxide peak levels provides statistically significant predictive value in the evaluation of employee exposure to elemental carbon TWA levels.

The R-Squared value of 29.5% indicates that the statistical significance of the nitrogen dioxide peak and elemental carbon TWA is weak. The use of nitrogen dioxide peak levels to predict elemental carbon TWA levels may not be reliable. The p value of 0.032 for the correlation of elemental carbon levels versus nitrogen dioxide peak levels may be attributed to the specific Gas Badge Pro monitor used to obtain the results. The alternative hypothesis Ha_4 is accepted based on the alpha level of 0.05 that was selected. The practical significance of the correlation represented by the relationship of elemental carbon TWA versus nitrogen dioxide peak is questionable.

4.5. Exposure Assessment for Gas Phase Diesel Exhaust Components

Hypotheses H_5 and H_6 are an evaluation of carbon monoxide TWA levels and nitrogen dioxide TWA levels. Diesel exhaust is a complex mixture of particles, vapors and gas phase components (Birch, 2003). Two of the common gases found in diesel exhaust and other combustion processes are nitrogen dioxide and carbon monoxide.

Occupational exposure limits established by ACGIH are known as threshold limit values or TLVs. TLVs are thresholds that provide guidance to Industrial Hygienists in order to evaluate the risk associated with exposure to substances in the workplace. Carbon monoxide and nitrogen dioxide both have TLVs. The statistical tool used to evaluate employee exposures is a directional one-sample t-test. The exposure assessment of the heavy equipment group operators and mechanics at an elemental phosphorous plant yielded the following results.

4.5.1. Carbon Monoxide TWA Directional One Sample t-Tests

The ACGIH TLV for carbon monoxide is 25 ppm TWA. The p value of 1.0 is greater than the alpha level (0.05) and indicates that the null hypothesis Ho_5 fails to be rejected. The mean carbon monoxide TWA was 0.154 ppm with a standard deviation of 0.555. All of the carbon monoxide TWA samples collected were less than 25 ppm TWA. The histogram in Figure 9 illustrates that 12 of the 13 samples had a value of 0 ppm TWA. One of the samples had a value of 2.0 ppm TWA.

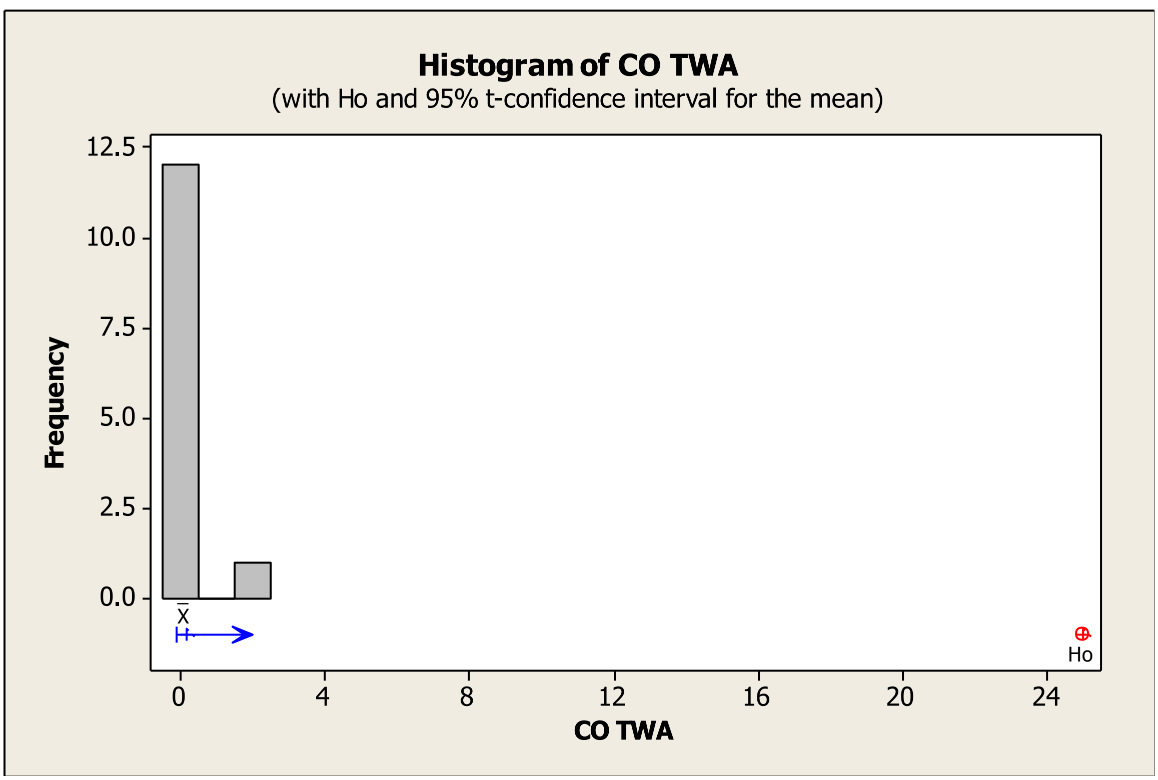

Figure 9: Histogram of Carbon Monoxide TWA

4.5.2. Nitrogen Dioxide TWA Directional One Sample t-Test

The ACGIH TLV for nitrogen dioxide is 3 ppm TWA. The p value of 1.0 is greater than the alpha level (0.05) and indicates that the null hypothesis Ho_6 fails to be rejected. The mean nitrogen dioxide TWA was 0.00769 ppm with a standard deviation of 0.02774. All of the nitrogen dioxide TWA samples collected were less than 3 ppm TWA. The histogram in Figure 10 illustrates that 12 of the 13 samples had a value of 0 ppm. One of the samples had a value of 2.0 ppm TWA.

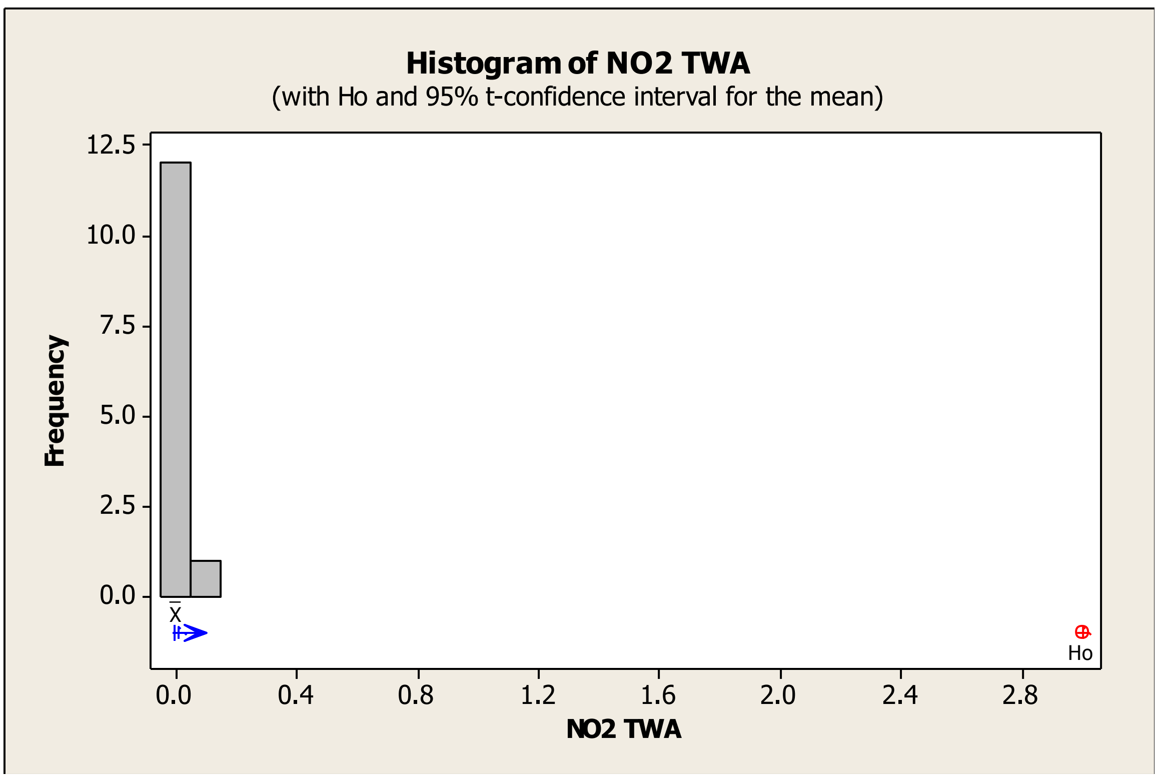

Figure 10: Histogram of Nitrogen Dioxide TWA

5. Discussion

The results of the study we conducted are supported by results obtained by Pronk et al. (2009) that indicated the lowest levels of exposure to diesel exhaust particulate were found in workers that were separated from the source by an enclosed area like a cab. Of the samples collected for our study, 12 of the 13 samples obtained had a diesel particulate matter exposure less than or equal to 12 $\mu g/m^3$ as determined by elemental carbon concentrations. One of the samples collected was greater than 12 $\mu g/m^3$. The sample that was greater than 12 $\mu g/m^3$ yielded a measured elemental carbon level of 280 $\mu g/m^3$. This sample was collected from the Vactor Truck.

The operation of the Vactor Truck requires the engine to idle during the collection of particulate from the multiple bag-houses in the elemental phosphorous plant. The particulate is predominantly silica and coke fines. There is not any data available for the range of sizes of particulate collected in the bag-houses. The particulate collected from the bag-houses is transferred to the Vactor Truck. The Vactor Truck has a specific dump station where the particulate is emptied from the Vactor Truck collection tank. The particulate is dry when it is loaded into the Vactor Truck and when the particulate is unloaded. After the particulate is unloaded, water is added to the particulate to reduce fugitive dust emissions. Currently, a yearly respirable silica dust protocol is followed for exposure monitoring of the Vactor Truck operators to respirable silica dust. One of the concerns related to the diesel particulate matter exposure of the Vactor Truck operator is the interference that may result from the presence of coke fines. Coke fines are the carbonaceous residue remaining after partial oxidation of coal (Appendix G). The size of the coke fines is variable and the range of sizes is unknown. A follow-up sample for diesel particulate matter exposure to the Vactor Truck operator will be conducted with a size-selective sampling device to assess the respirable concentration of elemental carbon exposure for the Vactor Truck operators.

The regression analyses of the results of our study identified statistically significant correlations of elemental carbon and the diesel exhaust gases: carbon monoxide and nitrogen dioxide. A summary of the statistical analyses results is presented in Table V.

Table V: Summary of Statistical Analyses Elemental Carbon vs. Independent Variables

	Independent Variables			
	CO TWA	**NO_2 TWA**	**CO Peak**	**NO_2 Peak**
Alpha Level	0.05	0.05	0.05	0.05
P Value	0.785	0.000	0.003	0.032
R-Squared	0.0%	99.7%	53.3%	29.5%
Statistically-Significant Predictor	No	Yes	Yes	Yes

Based on the results of our study, the current OSHA recommendation for the assessment of diesel exhaust exposure may lead to inaccurate diesel particulate matter exposure assessments. The current OSHA recommendation for evaluating worker exposure to diesel particulate matter for general industry indicates that employers should monitor for carbon monoxide and nitrogen dioxide to evaluate the exposure of employees to diesel exhaust (OSHA, 2013). The statistical results of our study suggest that elemental carbon diesel particulate exposure cannot be predicted from the direct-read measurement of a carbon monoxide TWA.

The extrapolation of elemental carbon concentrations from historic carbon monoxide levels was used by NIOSH-NCI researchers to estimate the exposure of miners to diesel exhaust based on historic carbon monoxide levels (Attfield, 2012). The NIOSH-NCI US miners study correlated the incidence of deaths attributed to lung cancer, with exposure to diesel exhaust particulate. The extrapolation of diesel particulate matter exposure levels from historic carbon monoxide levels by NIOSH-NCI researchers has been criticized by Hesterberg et al (2012).

Hesterberg et al. argue that the presence of carbon monoxide may not always be the result of diesel fuel combustion. Therefore, the extrapolation of diesel particulate matter levels from carbon monoxide levels may not accurately reflect the presence of diesel exhaust particulate. The results of the exposure assessment that we conducted suggests that the extrapolation of elemental carbon exposure from the time weighted average of carbon monoxide is not a reliable indicator of elemental carbon exposure. However, the carbon monoxide peak measurement may indeed be a useful predictor of diesel exhaust elemental carbon exposure levels.

The measurement of a TWA nitrogen dioxide level is a statistically significant predictor of the diesel exhaust surrogate elemental carbon. Therefore, the results of our study indicate that exposure to diesel exhaust may be predicted from the TWA measurement of nitrogen dioxide.

6. Conclusions

The number of variables that influence the concentration of diesel exhaust fumes and particulates are immense. Influential variables include: engine age, fuel grade, maintenance schedule, exhaust filtration, particulate filtration and operating environment. The scope of the study we conducted did not include or exclude equipment based on the influential variables mentioned above. Primarily, because there may be no end to the number of variables that could influence the concentration of diesel exhaust fumes in an outdoor environment.

Exposure monitoring for diesel exhaust particulate should include the measurement of elemental carbon based on NIOSH method 5040. The OSHA recommendation should clearly indicate that the accurate assessment of diesel particulate matter is achieved from NIOSH method 5040. Carbon monoxide and nitrogen dioxide levels obtained in the cab of heavy equipment should not be deemed reliable measurements of diesel particulate matter exposure. Therefore, exposure assessments for carbon monoxide, nitrogen dioxide and diesel particulate matter (elemental carbon) should be conducted individually.

The enclosure of heavy equipment operators with properly sealed cabs provides effective protection from diesel exhaust gases and diesel exhaust particulates. All of the diesel exhaust gas samples collected for our study indicate that heavy equipment operator exposures are below the ACGIH TLVs for carbon monoxide and nitrogen dioxide. The ACGIH TLVs are the most protective guideline for the allowed exposure to carbon monoxide and nitrogen dioxide. ACGIH does not have a TLV for exposure to diesel exhaust particulate. The current position of ACGIH regarding diesel exhaust particulate exposure is found in Appendix E.

6.1. Limitations

One of the limitations of the study we conducted is the limited sample size of the heavy equipment sampled. Two or three samples from each type of equipment may have strengthened the statistical results obtained. However, the similarities of the equipment sampled include operating environment, maintenance schedules and fuel grade. Therefore, we were able to identify an outlier (Vactor Truck) and develop a strategy to follow up with additional sample collection.

Sampling at other work sites under similar conditions may yield similar results. However, sampling at work sites where conditions are different, i.e. no operator cab, equipment greater than 10 years old and irregular engine maintenance may yield significantly different results than the ones we obtained from our study.

6.2. Future Research

The baseline exposure assessment of heavy-equipment operators to carbon monoxide, nitrogen dioxide and diesel particulate matter (surrogate elemental carbon) provided the groundwork for future research and future exposure assessments.

1. Future research could include the use of size-selective devices (cyclone, impactor, and 37-mm open face) to compare elemental carbon results. The use of size-selective devices would be of considerable interest to the elemental phosphorous plant to differentiate other sources of elemental carbon at the plant. The size-selective devices would estimate the amount of respirable elemental carbon that could be inhaled into the alveolar gas exchange region of the lungs. The use of the 37-mm open-face cassette was used for the baseline measurement in this study because the cost of the sampling media and laboratory analysis was the least expensive sampling method.
2. Use a real-time diesel particulate matter monitor with a data-logging function in series with real time NO_2 and CO monitors. Technology is advancing and real-

time diesel particulate matter monitors are available. The use of the real-time diesel particulate matter monitors could be utilized to provide valuable information regarding the peak exposure times for heavy-equipment operators.

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8. Appendix A: Directional One Sample t-Test Results

One-Sample T: CO TWA

Test of mu = 25 vs > 25

Variable	N	Mean	StDev	SE Mean	95% Lower Bound	T	P
CO TWA	13	0.154	0.555	0.154	-0.120	-161.50	1.000

One-Sample T: NO2 TWA

Test of mu = 3 vs > 3

Variable	N	Mean	StDev	SE Mean	95% Lower Bound	T	P
NO2 TWA	13	0.00769	0.02774	0.00769	-0.00602	-389.00	1.000

9. Appendix B: Regression Equation Statistics Results

Regression Analysis: Elemental Carbon (EC) µg/m3 versus CO TWA

The regression equation is

```
Elemental Carbon (EC) µg/m3 = 27.4 - 11.7 CO TWA


Predictor    Coef  SE Coef      T      P
Constant    27.43    22.99   1.19  0.258
CO TWA     -11.66    41.45  -0.28  0.784


S = 79.6444   R-Sq = 0.7%   R-Sq(adj) = 0.0%
```

Analysis of Variance

```
Source          DF     SS    MS     F      P
Regression       1    502   502  0.08  0.784
Residual Error  11  69775  6343
Total           12  70278
```

Regression Analysis: Elemental Carbon (EC) µg/m3 versus NO2 TWA

The regression equation is

Elemental Carbon (EC) µg/m3 = 4.43 + 2756 NO2 TWA

```
Predictor     Coef  SE Coef      T      P
Constant     4.433    1.174   3.78  0.003
NO2 TWA    2755.67    42.34  65.09  0.000


S = 4.06746   R-Sq = 99.7%   R-Sq(adj) = 99.7%
```

Analysis of Variance

```
Source          DF     SS     MS        F      P
Regression       1  70096  70096  4236.86  0.000
Residual Error  11    182     17
Total           12  70278
```

Regression Analysis: Elemental Carbon (EC) µg/m3 versus CO Peak (ppm)

The regression equation is

```
Elemental Carbon (EC) µg/m3 = - 16.9 + 9.38 CO Peak (ppm)


Predictor         Coef  SE Coef      T      P
Constant        -16.93    18.26  -0.93  0.374
CO Peak (ppm)    9.379    2.445   3.84  0.003


S = 52.2759   R-Sq = 57.2%   R-Sq(adj) = 53.3%
```

Analysis of Variance

```
Source          DF     SS     MS      F      P
Regression       1  40217  40217  14.72  0.003
Residual Error  11  30060   2733
Total           12  70278
```

Regression Analysis: Elemental Carbon (EC) µg/m3 versus NO2 Peak (ppm)

The regression equation is

```
Elemental Carbon (EC) µg/m3 = - 23.8 + 126 NO2 Peak (ppm)


Predictor          Coef  SE Coef      T      P
Constant         -23.76    26.88  -0.88  0.395
NO2 Peak (ppm)   125.91    51.28   2.46  0.032


S = 64.2437   R-Sq = 35.4%   R-Sq(adj) = 29.5%
```

Analysis of Variance

```
Source          DF     SS     MS     F      P
Regression       1  24878  24878  6.03  0.032
Residual Error  11  45400   4127
Total           12  70278
```

10. Appendix C: Sampling Results

Table VI: Nitrogen Dioxide Sampling Results

		NO2	NO2 Serial Number (SN)	NO2 Serial Number (SN)
Equipment/Area Sampled	**Date Sampled**	**Peak/TWA/STEL (ppm)**	**SN: 09120Z4008**	**SN: 13060FP001**
Pot Carrier #15	7/9/2013	0.6/0.0	NO2 13-03	
Pot Carrier #17	7/9/2013	0.0/0.0		NO2 13-02
Loader 988 H #28	7/9/2013	0.5/0.0	NO2 13-01	
Loader 988 H #32	7/10/2013	0.0/0.0		NO2 13-04
773 Haul Truck #18	7/10/2013	0.6/0.0	NO2 13-05	
Loader 988 H #29	7/16/2013	0.0/0.0		NO2 13-06
Water truck #20	7/16/2013	0.8/0.0	NO2 13-07	
930 Loader #26	7/17/2013	0.5/0.0	NO2 13-08	
14 H Grader	7/17/2013	0.0/0.0		NO2 13-09
Vactor Truck	7/23/2013	1.1/0.1	NO2 13-10	
Locomotive	7/23/2013	0.0/0.0		NO2 13-11
HEG Shop (Locker Area)	7/30/2013	0.5/0.0/0.1		NO2 13-12
HEG Shop (Filter Storage Rack)	7/30/2013	0.5/0.0/0.1	NO2 13-13	

Table VII: Carbon Monoxide Sampling Results

		Carbon Monoxide (CO)	CO Monitor Serial Numbers (SN)		
Equipment/Area Sampled	**Date Sampled**	**Peak/TWA/STEL (ppm)**	**SN: 11062RT009**	**SN: 10061SZ015**	**SN: 070602W062**
Pot Carrier #15	7/9/2013	5.0/0.0	CO 13-10		
Pot Carrier #17	7/9/2013	6.0/0.0			CO 13-11
Loader 988 H #28	7/9/2013	6.0/0.0	CO 13-09		
Loader 988 H #32	7/10/2013	0.0/0.0			CO 13-12
773 Haul Truck #18	7/10/2013	0.0/0.0	CO 13-13		
Loader 988 H #29	7/16/2013	0.0/0.0			CO 13-14
Water truck #20	7/16/2013	4.0/0.0		CO 13-15	
930 Loader #26	7/17/2013	14/2.0/6.0		CO 13-16	
14 H Grader	7/17/2013	4.0/0.0			CO 13-17
Vactor Truck	7/23/2013	20/0.0			CO 13-19
Locomotive	7/23/2013	0.0/0.0		CO 13-18	
HEG Shop (Locker Area)	7/30/2013	0.0/0.0	CO 13-21		
HEG Shop (Filter Storage Rack)	7/30/2013	0.0/0.0			CO 13-20

Table VIII: Elemental Carbon Sampling Results

Diesel Particulate Matter (DPM)			
Equipment/Area Sampled	**Date Sampled**	**Elemental Carbon (EC) µg/m3**	**DPM Sample Number**
Loader 988 H #28	7/9/2013	7.7	DPM 13-01
Pot Carrier #17	7/9/2013	3	DPM 13-02
Pot Carrier #15	7/9/2013	12	DPM 13-03
Loader 988 H #32	7/10/2013	<2	DPM 13-04
773 Haul Truck #18	7/10/2013	<2	DPM 13-05
Loader 988 H #29	7/16/2013	<2	DPM 13-06
Water truck #20	7/16/2013	<2	DPM 13-07
930 Loader #26	7/17/2013	4.1	DPM 13-08
14 H Grader	7/17/2013	4.7	DPM 13-09
Vactor Truck	7/23/2013	280	DPM 13-10
Locomotive	7/23/2013	7.3	DPM 13-11
HEG Shop (Locker Area)	7/30/2013	5	DPM 13-12
HEG Shop (Filter Storage Rack)	7/30/2013	9.4	DPM 13-13
37 mm Quartz Filter Blank	7/30/2013	<2	DPM BLANK

11. Appendix D: NIOSH 5040 Method

DIESEL PARTICULATE MATTER (as Elemental Carbon) **5040**

C AW: 12.01 CAS: none RTECS: none

METHOD: 5040: Issue 3	**EVALUATION: FULL**	**Issue 1: 15 May 1996** **Issue 3: 15 March 2003**

OSHA: no PEL
NIOSH: no REL
ACGIH: 20 µg/m³ as elemental carbon (proposed [1])

PROPERTIES: nonvolatile solid

SYNONYMS (related terms): diesel particulate matter, diesel exhaust, diesel soot, diesel emissions

SAMPLING		**MEASUREMENT**	
SAMPLER:	FILTER: quartz-fiber, 37-mm; size-selective sampler may be required [2].	**TECHNIQUE:**	Thermal-optical analysis; flame ionization detector (FID)
FLOW RATE:	2 to 4 L/min (typical)	**ANALYTE:**	Elemental carbon (EC). Total carbon is determined, but an EC exposure marker was proposed. See [2] for details.
VOL-MIN: **-MAX:**	142 L @ 40 µg/m³ 19 m³ (for filter load of ~ 90 µg/cm²)		
SHIPMENT:	Routine	**FILTER PUNCH SIZE:**	1.5 cm² (or other [2])
SAMPLE STABILITY:	Stable	**CALIBRATION:**	Methane injection
BLANKS:	2 to 10 field blanks per set	**RANGE:**	1 to 105 µg per filter portion (See also [2].)
		ESTIMATED LOD:	0.3 µg per filter portion
		PRECISION ($\bar{S}_r$):	0.19 @ 1 µg C, 0.01 @ 10 to 72 µg C

ACCURACY	
RANGE STUDIED:	23 to 240 µg/m³ (See also ref. [2].)
BIAS:	None (See also ref. [2].)
OVERALL PRECISION ($\hat{S}_{rT}$):	0.085 at 23 µg/m³ (See also ref. [2].)
ACCURACY:	± 16.7% at 23 µg/m³ (See also ref. [2].)

APPLICABILITY: The working range is approximately 6 to 630 µg/m³, with an LOD of ~ 2 µg/m³ for a 960-L air sample collected on a 37-mm filter with a 1.5 cm² punch from the sample filter. If a lower LOD is desired, a larger sample volume and/or 25-mm filter may be used (e.g., a 1920-L sample on 25-mm filter gives an LOD of 0.4 µg/m³). The split between organic carbon (OC) and EC may be inaccurate if the sample transmittance is too low. The EC loading at which this occurs depends on laser intensity. In general, the OC-EC split may be inaccurate when EC loadings are above 20 µg/cm². High loadings can give low (and variable) EC results because the transmittance remains low and relatively constant until some of the EC is oxidized. The split should be reassigned (prior to EC peak) in such cases [3]. An upper EC limit of 800 µg/m³ (90 µg/cm²) can be determined.

INTERFERENCES: Total carbon (as OC and EC) is determined by the method, but EC was recommended as a measure of workplace exposure because OC interferences may be present [2, 3]. Cigarette smoke and carbonates ordinarily do not interfere in the EC determination. Less than 1% of the carbon in cigarette smoke is elemental. If heavy loadings of carbonate are anticipated, a size-selective sampler (impactor and/or cyclone) should be used [2]. For measurement of diesel-source EC in coal mines, a cyclone and impactor with a submicrometer cutpoint are required to minimize collection of coal dust. A cyclone and/or impactor may be necessary in other workplaces if EC-containing dusts are present.

OTHER METHODS: Other methods for determination of EC and OC have been employed, but these are not equivalent to the method described herein. Information on other methods is summarized elsewhere [2].

12. Appendix E: ACGIH Diesel Exhaust Particulate: Current Position

Dillon Hansen,

First, allow me to apologize for the delay in this response, and thank you for your patients.

As for your question, The TLV-CS Committee withdrew Diesel exhaust particulate from the Notice of Intended Change. Currently, the Committee is not actively working on the substance, nor is it on the Under Study List. There is, however, a recommended TLV for Diesel fuel, as total hydrocarbons, that was reviewed in 2007. The current recommended TLV-TWA for that substance is 100 mg/m3.

You can learn more about the TLV-CS Committee's recommendation by read in the ACGIH Documentation, which is available for purchase online at http://www.acgih.org/store/ or through Customer Service at (513) 742-2020. For your reference, the publication number for this compound is #7DOC-701.

Please note that ACGIH publications are to be used as guidelines, not as official standards. They are designed to present current information with regard to the subject matter covered. They are distributed with the understanding that ACGIH and its Committees, collectively or individually, assume no responsibility for any inadvertent misinformation, for inadvertent omissions, or for the results in the use of these publications.

Thank you for your interest in ACGIH.

Best regards,

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13. Appendix F: Pre-Cal and Post Cal

Equipment/Area Sampled	Pump Number	Pre-Cal (Ave) lpm	Post-Cal (Ave) lpm	Q (Ave) lpm
Loader 988 H #28	11199	2	1.95	1.97
Pot Carrier #17	11198	2	2	2
Pot Carrier #15	617	2	1.97	1.98
Loader 988 H #32	11198	2.05	2.12	2.09
773 Haul Truck #18	617	2.01	2.09	2.05
Loader 988 H #29	11194	2.09	2.08	2.08
Water truck #20	11212	2	2	2
930 Loader #26	617	2.08	2.06	2.07
14 H Grader	11199	2.05	2.06	2.05
Vactor Truck	11194	2.09	2.04	2.06
Locomotive	11199	2.04	1.99	2.02
HEG Shop (Locker Area)	11199	2	2.02	2.01
HEG Shop (Filter Storage Rack)	11194	2	2	2
37 mm Quartz Filter Blank				

14. Appendix G: Coke Fines MSDS

MONSANTO Company

Material Safety Data

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: Coke and/or Coke Fines DATE: February 12, 2004

CHEMICAL NAME: carbon

MONSANTO COMPANY, 800 N. LINDBERGH BLVD., ST. LOUIS, MO 63167

FOR CHEMICAL EMERGENCY, SPILL LEAK, FIRE, EXPOSURE, OR ACCIDENT
Call CHEMTREC - Day or Night - 1-800-424-9300 Toll free in the continental U.S., Hawaii, Puerto Rico, Canada, Alaska, or Virgin Islands. For calls originating elsewhere: 703-527-3887 (collect calls accepted)

For additional non-emergency information, call: 1-314-694-1000

2. COMPOSITION/INFORMATION ON INGREDIENTS

COMPONENT	CAS NO.	% BY WEIGHT
coke	65996-77-2	100

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

APPEARANCE AND ODOR: black solid; essentially odorless

NO SIGNIFICANT HAZARDS ASSOCIATED WITH THIS MATERIAL.

POTENTIAL HEALTH EFFECTS

LIKELY ROUTES OF EXPOSURE: Skin contact and inhalation

EYE CONTACT: This product is no more than slightly irritating to the eye based on available information with a similar material.

SKIN CONTACT: This product is no more than slightly irritating to the skin and no more than slightly toxic when absorbed based on available information with a similar material.

INHALATION: No information.

SIGNATURE PAGE

This is to certify that the thesis prepared by Dillon S. Hansen entitled "Exposure Assessment of Heavy Equipment Operators to Diesel Particulate Matter" has been examined and approved for acceptance by the Department of Industrial Hygiene, Montana Tech of The University of Montana, on this 11th day of December, 2013.

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