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DIESELS IN THE OCCUPATIONAL ENVIRONMENT: AN ENVIRONMENTAL PERSPECTIVE

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INTRODUCTION

This presentation examines some aspects of diesel power in the workplace. I'll start with some background information including some interesting facts about the history of the diesel engine and its applications. This will be followed by our methods for selecting exhaust compounds for comparison, the rationale for their selection, and our techniques for combining data from different studies of diesel environments.

The focus of the presentation will be the results of these comparisons. I'll then discuss how emission controls can be used for improving air quality and minimizing worker exposures.

And finally, I will offer some thoughts and suggestions on the future use of diesel engines in the workplace.

HISTORY AND APPLICATION OF DIESEL POWER

In 1892, the German engineer Rudolph Diesel designed and developed a new type of engine that was capable of spontaneous combustion of liquid fuel without requiring spark ignition. This new engine differed from the conventional gasoline engine principally in the method used to introduce and ignite the fuel. Gas engines, which were introduced about 30 years earlier, draw a mixture of air and fuel into a combustion chamber where it is compressed, then ignited by an electric spark. In diesel engines, air alone is compressed in the chamber; then a charge of fuel is sprayed into the chamber and ignition is accomplished by the heat of compression.

Interestingly, Dr. Diesel presumably thought that any fuel would be suitable for combustion under high compression temperatures; however, his efforts to burn pulverized coal, the cheapest conceivable fuel, were unsuccessful.

The thermal efficiency and fuel economy of Diesel's engine proved to be better than any other existing power plant at the turn of the century and it therefore attracted considerable interest for industrial purposes. The diesel engine was first brought to the United States in 1898 by Adolph Busch, a U.S. brewer, who thought it would provide cheap power for factories. These first engines were large and heavy (weighing 450 lbs. per horsepower) and were entirely unsuited for mobile or portable equipment.

The diesel engine was eventually developed into a highly efficient, lightweight power unit during the 1920's. The engine became the predominant power plant for submarines during World War I because of its high reliability and economical use of a fuel less volatile than gasoline.

The first diesel engine that was small enough and light enough for automotive application was built in Germany in 1922 and opened up numerous fields of application. Coupled with the technology of modern transmissions, torque converters, and rubber tires, high-speed diesel engines in motor vehicles began to reach a level of sophistication in the 1940's. Since the diesel engine is built so ruggedly that operational failures are uncommon, this engine was the most prevalent power plant for military equipment on the ground and at sea during World War II.

After the war, the diesel engine became the conventional power unit for all railway purposes in the U.S., all heavy construction machinery, most highway trucks and buses and for farm equipment. The diesel engine has had only limited use in passenger automobiles where its greater weight and initial cost combine with its less smooth running qualities to partially offset its reliability and low cost of operation.

As for diesel power in the mining industry, diesel engines were first introduced into a European mine in 1927 and were in wide use in German, Belgian, and French coal mines by 1930. The use of diesel equipment in the United States' underground mining industry has steadily increased since the introduction of a diesel haulage truck in a Pennsylvania limestone mine in 1939. Its durability, high thermal efficiency, mobility, and ability to burn a relatively nonvolatile fuel are especially important for its mining applications.

The use of diesel equipment in underground coal mines has lagged behind its use in hard-rock mines because of increased safety concerns over the presence of potentially explosive methane gas and dusts in coal mines, resistance by the United Mine Workers of America because of health concerns and the availability and abundance of electricity typically found near coal mining areas.

In summary then, the diesel engine has become a highly developed, heavy-duty power unit which is now a predominant source of industrial power throughout the world principally because it can burn a low-grade fuel more efficiently and therefore cheaper than other internal-combustion or steam power engines. This and its record of high reliability and long life, are especially important for industrial and transportation applications. Its usage underground has been pursued primarily because of its associated higher levels of productivity, its convenience and its durability compared to electric units. Its ability to burn a low volatile fuel and its relatively low emission characteristics make it safer to use in mines than gasoline engines.

While the diesel engine offers the most efficient and reliable powerplant that is presently suitable for mobile vehicles, it has been considered to be smokey, noisy and odorous; therefore, the economic considerations of the diesel engine have sometimes not been coupled with its social acceptability.

More important though, is the increased attention concerning the possible adverse health effects associated with its use in the workplace. Several symposia and workshops have been held to specifically review and discuss the measurement, control and health effects of diesel pollutants.

These occupational health concerns arise primarily because the exhaust from diesel engines contain several pollutants which may be hazardous to the worker's health.

METHODS

Carbon dioxide, carbon monoxide and nitrogen dioxide are the three compounds we chose to focus on for our comparison of environments using diesel engines.

Carbon dioxide was picked since it's generated proportionate to fuel consumption and has been suggested as a surrogate measure of the total diesel exhaust burden.

Carbon monoxide was selected since it's produced during fuel rich conditions and is an indicator of incomplete combustion.

Nitrogen dioxide was chosen since it relates to fuel lean conditions and further, as an eye and respiratory irritant, it ranks as one of the most toxic components of diesel exhaust.

Although diesel particulate is a concern, it is not included in our comparisons since it was impossible to resolve between diesel particulate and other aerosols in most studies of diesel environments.

Having selected these compounds, our next challenge was how to simplify the information in the literature for comparing exhaust levels in different workplaces. "Average", "mean", "median", "range", and "maximum" are all used as indicators of results from either short-term or full-shift sampling.

With this situation in mind, we decided to present results from a number of studies in a simple, digestible manner (see Figure 1). Workplaces have been separated into three distinct groups: coal mines, non-coal mines (which include both metal and nonmetal mines), and non-mines (or "general industry").

The range of sampling results is indicated by the length of each bar and arrows refer to the mean or median level reported from specific studies. I should mention that a "mean" value was sometimes calculated from the universe of individual measurements and sometimes from average group (eg. plant or job category) values. While this distinction is not indicated on the graphs, a general comparison of pollutant levels reported from several environments is kept simple and practical.

As can be imagined, a variety of occupational exposures to diesel exhaust has resulted from the widespread use of diesel engines for industrial, mining and transportation applications.

For this presentation, results have been extracted from surveys in: underground coal mines, metal and mineral ore mines, heavy equipment operations, engine repair shops for both transit buses and for railroad locomotives, ammunition warehouses using diesel forklifts, and even in submarines using auxillary diesel engines.

Figure 3 presents the results from carbon monoxide measurements. The upper limits of the two plots for mining environments are maximum values from short-term detector tubes. The time-weighted-average concentrations, which are represented by the arrow positions, are more appropriate for comparison to NIOSH recommended standards and ACGIH TLVs.

As shown in here and in Figure 2, the results from several studies suggests that diesel equipment is generally operated in the workplace without exposing workers to unsafe levels of CO and CO_2.

A graph of the reported levels of nitrogen dioxide is shown in Figure 4. As for CO and CO2, the highest levels of NO_2 in the mining industry are usually found in metal and non-metal mines.

As seen in this graph, there are several more general industry studies in which NO_2 levels have been measured besides those cited for CO and CO_2 levels. The more recognized health concerns for NO_2 exposure is probably responsible for the increased attention.

The Gamble citation is of a study of bus repair garages and 0.26 ppm is the value averaged over season and garage; Apol has reported NIOSH sampling results also from bus repair shops.

The Navy study reported exposure levels over 24-hour periods in a diesel-powered submarine. The authors also noted that cigarette smoking may have contributed to the ambient NO_2 levels in this confined environment.

Ziskind measured maximum in-cab concentrations during road tests of a trucking fleet. While the authors stated that "50% of the idling vehicles had concentrations above .5 ppm" it was not clear for how long these excursions lasted.

The EL Batawi citation refers to a 3-month study of 2 bus garages in Alexandria, Egypt during winter conditions and a study of 2 locomotive engine repair houses by Battigelli summarizes exhaust concentrations averaged over winter and summer periods.

The NO_2 levels reported here, in particular from some of the non-mining surveys, may be relatively high since many of these particular studies were prompted by worker complaints of suspectedly high emission levels. As seen by the dashed-lines indicating NIOSH and ACGIH exposure limits, excessive exposures to NO_2 occured in several of the study environments. The study by Gamble and Jones in salt mines, for example, indicated worker exposures above the TLV ceiling limit of 5 ppm.

The two Piacitelli citations in the coal mining plot demonstrate that while time-weighted-average levels may be within exposure limits, higher short-term excursions do occur and are cause for health concern.

As shown here and by the other graphs as well, it appears that coal mines generally have lower pollutant levels as compared to non-coal mines. This is because of the stricter ventilation requirements and exhaust gas restrictions specified by MSHA to prevent ignition and explosion of methane and dusts in underground coal mines. It appears that the worst case exposures to diesel exhaust occur in non-coal mines which are less regulated for specific diesel usage.

RESULTS OF STUDY COMPARISONS

In Figure 2, carbon dioxide levels are plotted which indicate pronounced differences both within and between different environments. Since CO_2 levels give a general indication of the degree of diesel usage and of ventilation conditions, these reported levels "rank" the relative exposures to diesel emissions in the various study environments.

The dashed line indicates the 5000 ppm TLV for carbon dioxide. In a rare situation, the NIOSH recommended exposure limit is higher at 10,000 ppm.

Before proceeding, some background information on the studies cited in this graph and in the graphs to follow is probably necessary (refer to Table I)..

The Robertson study was conducted in 12 underground coal mines in the United Kingdom in which diesel locomotives and haulage vehicles were used. The authors cited shot-firing in these conventional mining sections as a confounding source of such pollutants as CO, CO_2 and NO_2. While occasional excursions of these gases were observed immediately after blasting, the primary source of these pollutants was thought to be from diesel engine usage. The 2200 ppm value plotted was the highest of the grab samples collected by Robertson.

Ames and Hearl reported environmental results from 6 U.S. coal mines using diesel equipment for face haulage and the NIOSH study reported by Piacitelli includes follow-up results from 4 of these same mines which had been studied 5 years earlier.

Studies from non-coal mines include one by Attfield who reported results from 13 underground salt, potash and trona mines using diesel equipment; Attfield also reported a NIOSH study of 8 underground metal mines.

Reinbold and others from Michigan Tech University measured exhaust levels in 2 underground metal mines and the Johnson citation involves another study of one of these same mines.

Sutton has summarized MSHA & NIOSH sampling results from a variety of metal and non-metal mines using diesel equipment.

And finally, the lone citation for results in non-mining workplaces in this graph is from an Army contracted study of pollutant levels in ammunitions magazines in which diesel forklifts were operated.

One final point concerning this graph. MSHA, the Bureau of Mines and others have studied the correlation between various diesel exhaust pollutants to assess whether it's practical and appropriate to monitor only one parameter to detect general deterioration in air quality. From these efforts, CO_2 is suggested as a "tracer" constituent since correlations have been shown to exist between it and other pollutants in undiluted engine exhausts.

A suggested control strategy is therefore to supply adequate ventilation air as determined by CO_2 measurements, so that toxicant levels are within recommended exposure criteria. Johnson has suggested, for example, that a CO_2 concentration higher than 1500 ppm may suggest the need for corrective action relative to changing the ventilation system. Using this criteria, ventilation refinements appear to be necessary in the metal mining industry.

Figure 3 presents the results from carbon monoxide measurements. The upper limits of the two plots for mining environments are maximum values from short-term detector tubes. The time-weighted-average concentrations, which are represented by the arrow positions, are more appropriate for comparison to NIOSH recommended standards and ACGIH TLVs.

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To generalize the data seen in Figures 2-4, although CO_2 and CO are toxic at high concentrations, the data from several studies suggest that these gaseous pollutants are controlled within ACGIH-TLVs and NIOSH recommended standards. The occupational health hazards from these pollutants may therefore be considered minimal.

However, excursions over TLV and NIOSH ceiling limits of NO_2, an irritating gas with well-recognized deleterious health effects, have been shown in several work environments, particularly underground.

And while I have not compared particulate levels in these workplaces, primarily because most measurement techniques do not distinguish between particulate matter originating from diesel exhaust and that from other sources (such as coal), laboratory measurements of raw undiluted exhaust from diesel engines indicate particulate concentrations in the range of 100-150 mg/M^3.

From a health perspective, particulate emissions from diesel engines are of special concern from several aspects.

First, most diesel particulate is respirable in size and suggests an inherent propensity to cause irritation and lung fibrosis, to affect pulmonary function and possibly mediate chronic lung disease such as emphysema.

Second, its carbonaceous composition acts as a tenacious site for adsorption of organic substances and other compounds (some of which are mutagenic and/or carcinogenic). These particulates thereby act as carriers of such toxins to the lower regions of the lung where their long residence time may increase the risk of lung cancer.

And finally, diesel particulates are an aesthetic concern because they promote formation of haze and smog and cause decreased visibility. In combination with other pollutants, they also produce an unpleasant odor.

Therefore, diesel particulates, oxides of nitrogen and carbon monoxide appear to be the primary pollutants to control based on the health considerations and on exposure levels in the workplace. Particular attention should be directed to reducing particulate and NO_2 levels.

CONTROL OF DIESEL EMISSIONS

This leads into a discussion of methods for controlling diesel emissions. Basically, control can be accomplished either by reducing the emission levels generated or providing enough ventilation air to dilute pollutants to safe levels.

Although ventilation can be used to dilute these pollutants from virtually any initial concentration in the exhaust, the health hazards are minimized as the amount of toxicants emitted from the engine is reduced. It's therefore preferrable to reduce--to the extent most technically feasible--the amounts of pollutants generated.

Most of the following discussion of control is particularly suited for diesel engines used in underground mines since the emissions in these confined environments suggest the most serious health risks.

Basically, resultant exhaust emissions can be affected during three phases of the diesel combustion process: when the fuel and air mixture is first injected into the engine; during combustion in the main chamber; and after the combustion by-products have been emitted from the chamber.

Modifications to the fuel and air intake system can effectively reduce certain exhaust components.

In the IDI of "indirect injection" engine, fuel is first injected into a pre-chamber prior to the main combustion cylinder. (This is different from DI or "direct injection" of the fuel and air into the main cylinder). The turbulent mixing of fuel and air in the pre-chamber provides for better oxidation of the fuel and therefore lower CO emissions. IDI engines also operate at lower peak combustion temperatures and therefore reduce NO_x formation as well. Their effect on particulate, CO_2 and SO_2 emissions is insignificant.

Peripheral to intake modification, is EGR or "exhaust gas recirculation" which is the controlled recirculation of a fraction of the cooled exhaust gases into the engine intake. This recycling raises the fuel:air ratio and is quite effective in reducing amounts of NO_2 produced.

Properly controlling the in-cylinder combustion process can also result in more favorable exhaust emissions.

For example, when water is injected into the combustion cylinder or emulsified in the diesel fuel, the compression temperature and oxygen concentration are lowered therefore suppressing NO_x and particulate emissions. Many engineers think that water injection is the ultimate answer to the NO_2 problem since significant reductions are possible without increasing concentrations of other toxic emissions and without increasing fuel consumption.

Generally, diesel engines used underground are "derated." This simply means that the fuel:air ratio is adjusted so that an excess of air is available to favor complete combustion; in other words, the engine is tuned "lean." This results in lower emission of CO and particulate matter, but also reduces the maximum power available from the engine.

Controlling the exhausts after their emission from the combustion cylinder can be accomplished by several methods.

Water scrubbers have been used for about half a century on engines in underground coal mines because of their effectiveness as an exhaust gas cooler and as a flame arrestor. Initially, little attention was given to the effect of scrubbing on particulate or gaseous emissions.

Performance tests have since shown that water scrubbers are quite effiecient for trapping gases that are soluble in water, such as NO_2 and SO_2. CO is water insoluble and therefore not significantly absorbed. Diesel particulates are not easily wetted and their retention in wet scrubbers is difficult. However, venturi-design scrubbers (as opposed to the more simple baffle-batch or packed-bed designs) have been shown to capture up to 70% of the particulate emitted.

Because of their large physical size and frequent service requirements, water scrubbers are not commonly used other than for mining applications.

Dry scrubbers using metal oxidation catalysts have been used for many years as emission controls particularly on engines used underground. The main advantages of this type of scrubber are:

- its ability to oxidize CO to relatively harmless CO_2,
- its favorable effect on reducing exhaust odor,
- its easy installation on mobile equipment,
- and its low maintenance requirement.

The oxidation catalyst however, may also result in the oxidation of a fraction of the NO to NO_2. Since the NO_x problem is therefore worsened considerably and since oxy-catalysts have no effect on particulate reduction, their use, especially if alone, has been seroiusly questioned. At best, some engineers suggest a combination of catalytic and water scrubbers operating in series to utilize the advantages and minimize the problems of both.

For several years now, ceramic filters have proven useful and durable for controlling the relatively low particulate found in automotive exhausts. Improvements in these filters to reduce the much higher particulate emissions from heavy-duty diesel engines have only been recent. Particulate trapping devices, such as the "ceramic wall flow filter" have now attracted considerable attention because of their high efficiency for particulate removal, compact size, and relatively low cost.

Another approach to controlling pollutant emissions is to add design features to the vehicle which help to dilute and disperse them quickly from the operator's position. This can mean using simple approaches like positioning the exhaust pipe outlet so that emissions are discharged into the engine cooling fan or by installing ellaborate devices such as on-vehicle fan systems and fume diluters which also help to route exhausts at high velocities away from the immediate work area. This approach is especially effective for minimizing the occurence of short-term excursions of pollutant levels.

When considering which control techniques to use, it's important to realize that a device which reduces one exhaust constituent may cause an increase in a second, or an unacceptable change in performance. Therefore, every engine modification requires an assessment of the benefits gained versus the deleterious effects resultant from such a change.

Also in connection with the use of emission controls, maintenance is critically important for ensuring that the engine and its emission control devices are operating as intended. Operators should anticipate and satisfy the need for well-organized, tightly disciplined maintenance procedures.

In the end, it appears that engine designs and emission treatment devices are available to effectively limit the amounts of toxic materials that workplace ventilation systems must handle.

Since diesel pollutants cannot be <u>totally</u> eliminated, it is necessary to operate the engine with a flow of air continuously passing over the vehicle to ensure their adequate dilution. As an approximate rule, many countries have adopted a standard of about 100 cfm per horsepower as a required ventilation rate for a diesel engine. Alcock has shown, for example, that the resultant NO_2 concentration from a 100 hp engine under typical operating modes and diluted with 10,000 cfm of air is about 0.5 ppm, or about one-half of the most conservative exposure criteria. The 100 cfm/hp is a general rule only and may not apply to all engines in all situations.

Special attention should be given to avoiding excursions of pollutants, such as NO_2 which has a recommended 1 ppm ceiling value which should never be exceeded, for adequate health protection.

SUMMARY

The diesel engine finds applications whereever its greater weight, initial cost and its less-smooth running operation are offset by its lower cost of operation. With the increased diesel usage and the higher engine power ratings proposed to meet increasing production goals, the health and safety considerations in the workplace (particularly in confined environments such as underground mines) are becoming more important.

In particular, diesel emissions present both a nuisance and potential health hazard to those exposed. Study results indicate that the impact of diesel exhaust on air quality depends largely on the operations being performed, the emission controls applied, and the amount of pollutant dilution provided by ventilation.

Therefore, an increased understanding of the critical pollutants and how to reduce them by currently available control systems can clearly improve the air quality in the environments using diesel engines.

Clearly, the controls to reduce NO_2 and diesel particulate should be emphasized. Therefore, in choosing the ideal engine for the worst case situation, such as for underground use, a derated indirect injection engine with a venturi scrubber and ceramic filter appears to be most favorable for minimizing emissions of health significance. The application of EGR and water injection techniques should further reduce emissions, particularly NO_2.

If ventilation is then effectively used to control the toxicants emitted from a properly designed engine, the potential health hazards from the use of diesels in the workplace are minimized.

So it all comes down to good news-bad news. The bad news is that pollutants with both recognized and unknown health effects are emitted from diesel engines. The good news is that control technology is available for effectively minimizing the worker's exposure to such pollutants.

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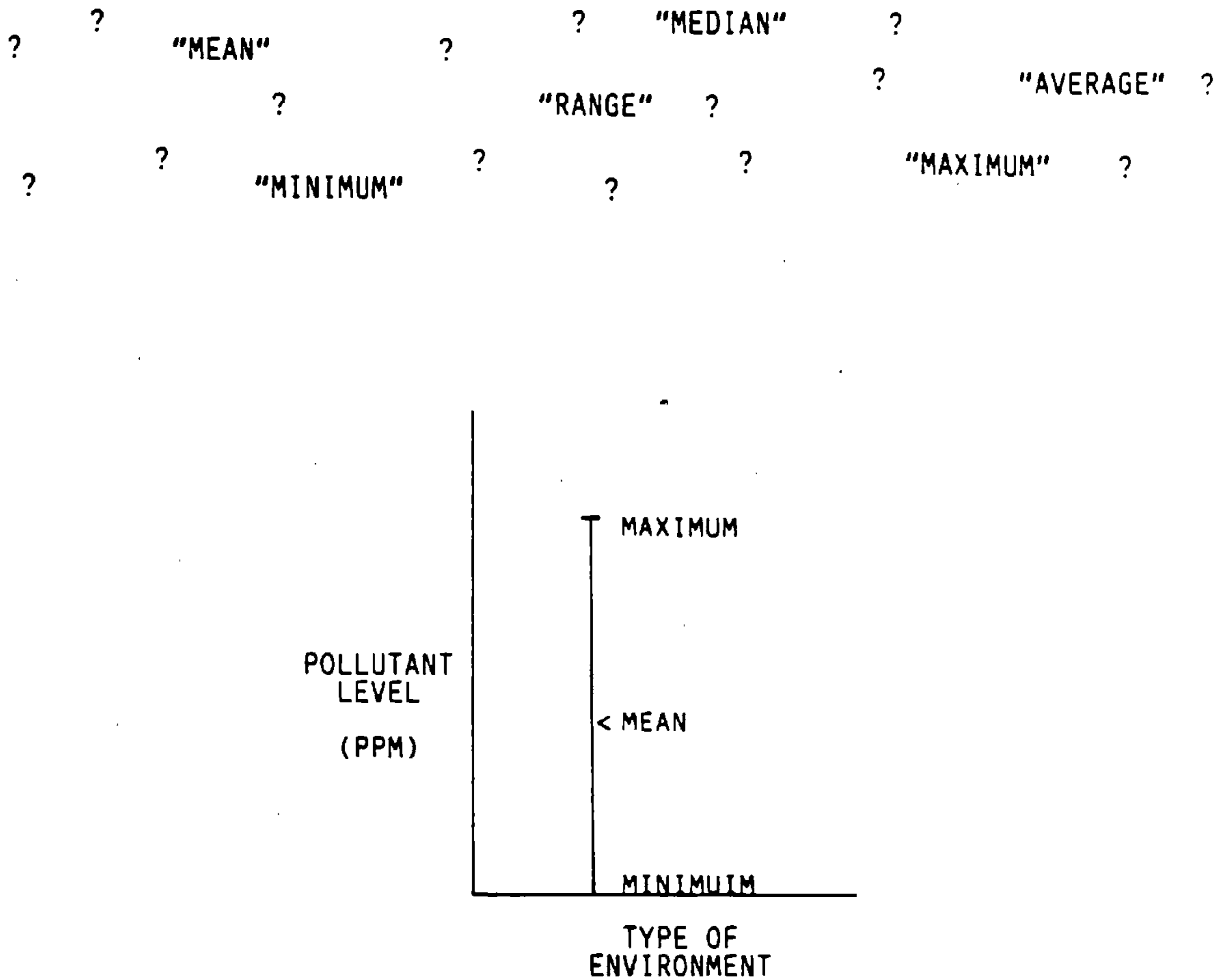
TABLE I

SUMMARY OF STUDIES

AUTHOR	WORKPLACE	SAMPLING STRATEGY
	Coal Mines	
Robertson	12 coal mines	grab area full-shift area
Ames	6 coal mines	grab area full-shift area full-shift personal
Piacitelli	4 coal mines	full-shift area
	Non-Coal Mines	
Attfield	13 non-metal mines	grab area full-shift area
Gamble	2 salt mines	full-shift personal
Fischer	1 trona mine	grab area
Attfield	8 metal mines	grab area full-shift area
Reinbold	2 metal mines	grab area
Johnson	1 metal mine	grab area
Cornwell	1 metal mine	full-shift area full-shift personal
McCawley	1 metal surface mine	full-shift personal
	General Industry	
Gamble	4 bus repair garages	full-shift personal
Apol	3 bus repair shops	full-shift area
El Batawi	2 bus repair shops	full-shift area
Battigelli	2 locomotive garages	full-shift area
Ziskind	53 highway truck cabs	continuous area
U.S. Navy	diesel submarine	full-shift area
U.S. Army	ammunitions magazines	grab area full-shift area

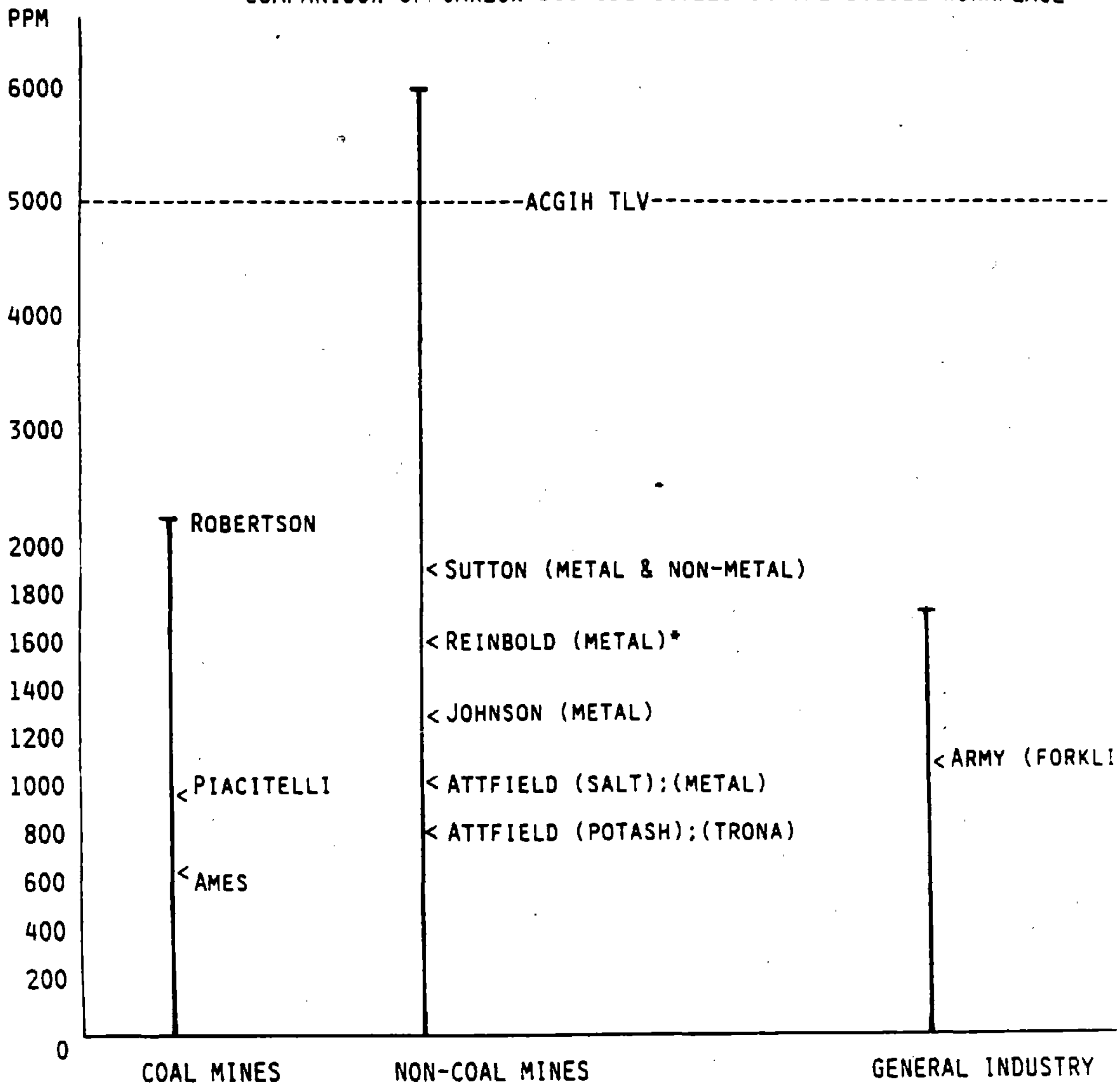
FIGURE 1



"MEAN"
"MEDIAN"
"RANGE"
"AVERAGE"
"MINIMUM"
"MAXIMUM"
POLLUTANT LEVEL
(PPM)
MAXIMUM
< MEAN
MINIMUIM
TYPE OF ENVIRONMENT

FIGURE 2

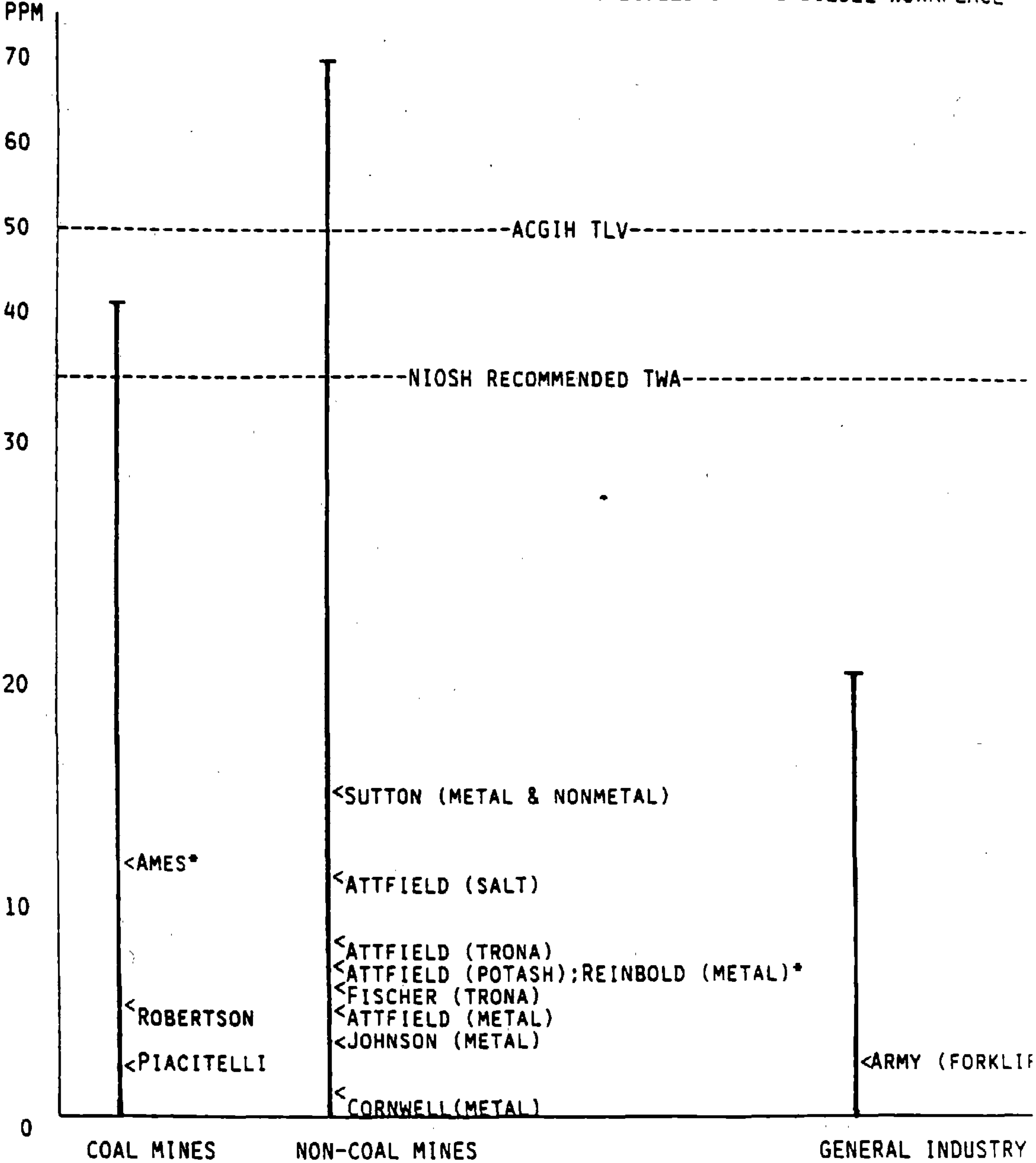
COMPARISON OF CARBON DIOXIDE LEVELS IN THE DIESEL WORKPLACE



* STUDY IN WHICH MAXIMUM VALUE WAS MEASURED

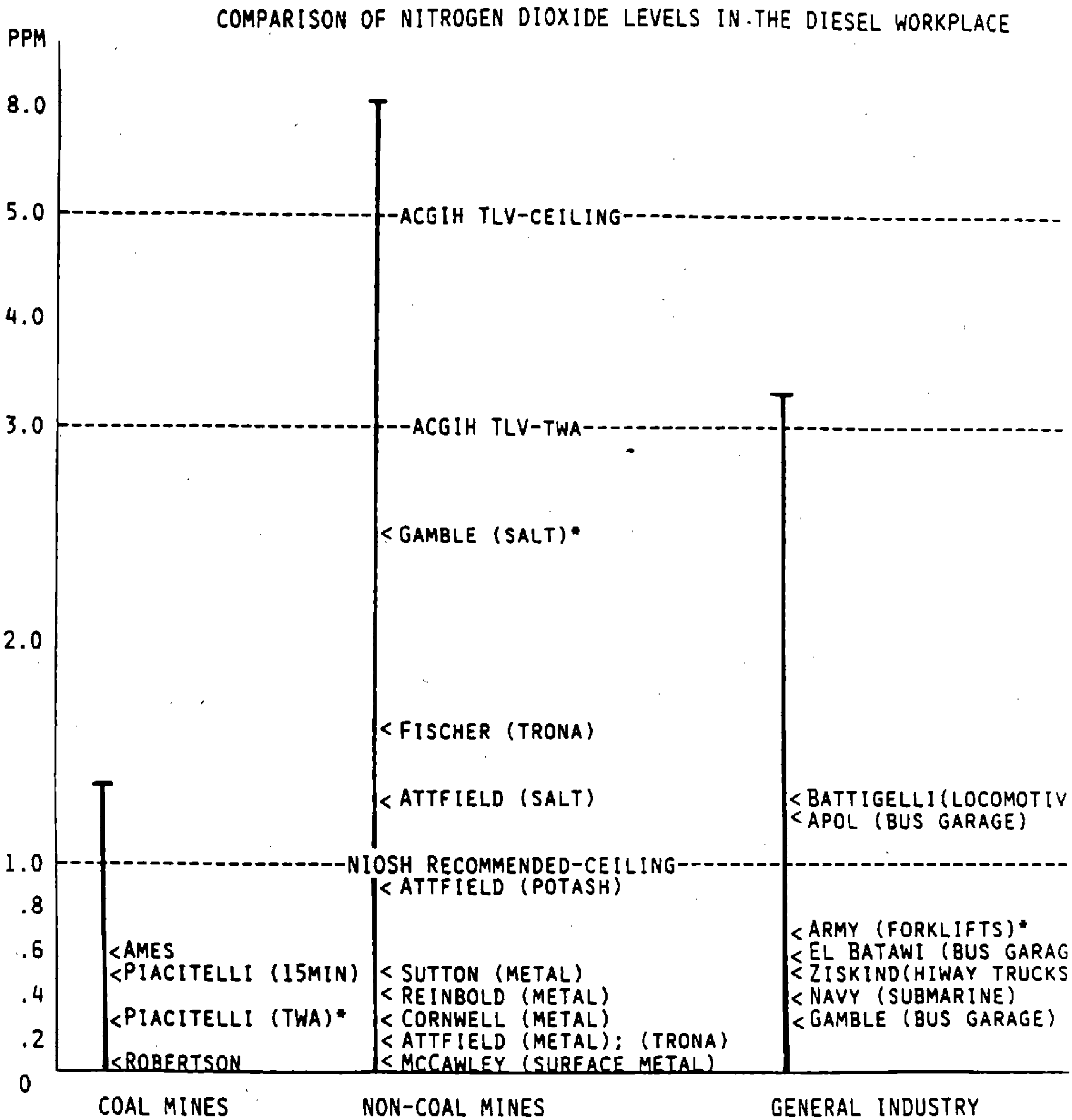
FIGURE 3

COMPARISON OF CARBON MONOXIDE LEVELS IN THE DIESEL WORKPLACE



* STUDY IN WHICH MAXIMUM VALUE WAS MEASURED

FIGURE 4



* STUDY IN WHICH MAXIMUM VALUE WAS MEASURED

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5. Report Date 85/05/21

6.

7. Author(s) Piacitelli, G. M., W. G. Jones, J. F. Gamble and R. J. Timko

8. Performing Organization Rept. No.

9. Performing Organization Name and Address Division of Respiratory Disease Studies, NIOSH, Morgantown, West Virginia

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15. Supplementary Notes

16. Abstract (Limit: 200 words) Following a brief review of the history and applications of diesel power, some aspects of diesel power in the workplace were investigated. The diesel engine has become a highly developed, heavy duty power unit which is a predominant source of industrial power throughout the world, primarily since it can burn a low grade fuel more efficiently and therefore cheaper than other internal combustion or stem power engines. Levels of carbon-dioxide (124389), carbon-monoxide (630080), and nitrogen-dioxide (10102440) (NO2) in environments using diesel engines were compared. Studies of the operation of such equipment had been conducted in underground coal mines, metal and mineral ore mines, heavy equipment operations, engine repair shops for both transit buses and for railroad locomotives, ammunition warehouses using diesel forklifts, and submarines using auxiliary diesel engines. Results of an analysis of these studies indicated that the impact of diesel exhaust on air quality depends on the operations being performed, the emission controls applied and the amount of dilution provided by ventilation. NO2 and diesel particulates were considered to be the critical pollutants. Various methods of reducing the emission levels were discussed.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms Equipment-operators, Construction-industry, Mining-industry, Diesel-engines, Diesel-exhausts, Airborne-particles, Mining-equipment, Transportation-industry, Underground-mining

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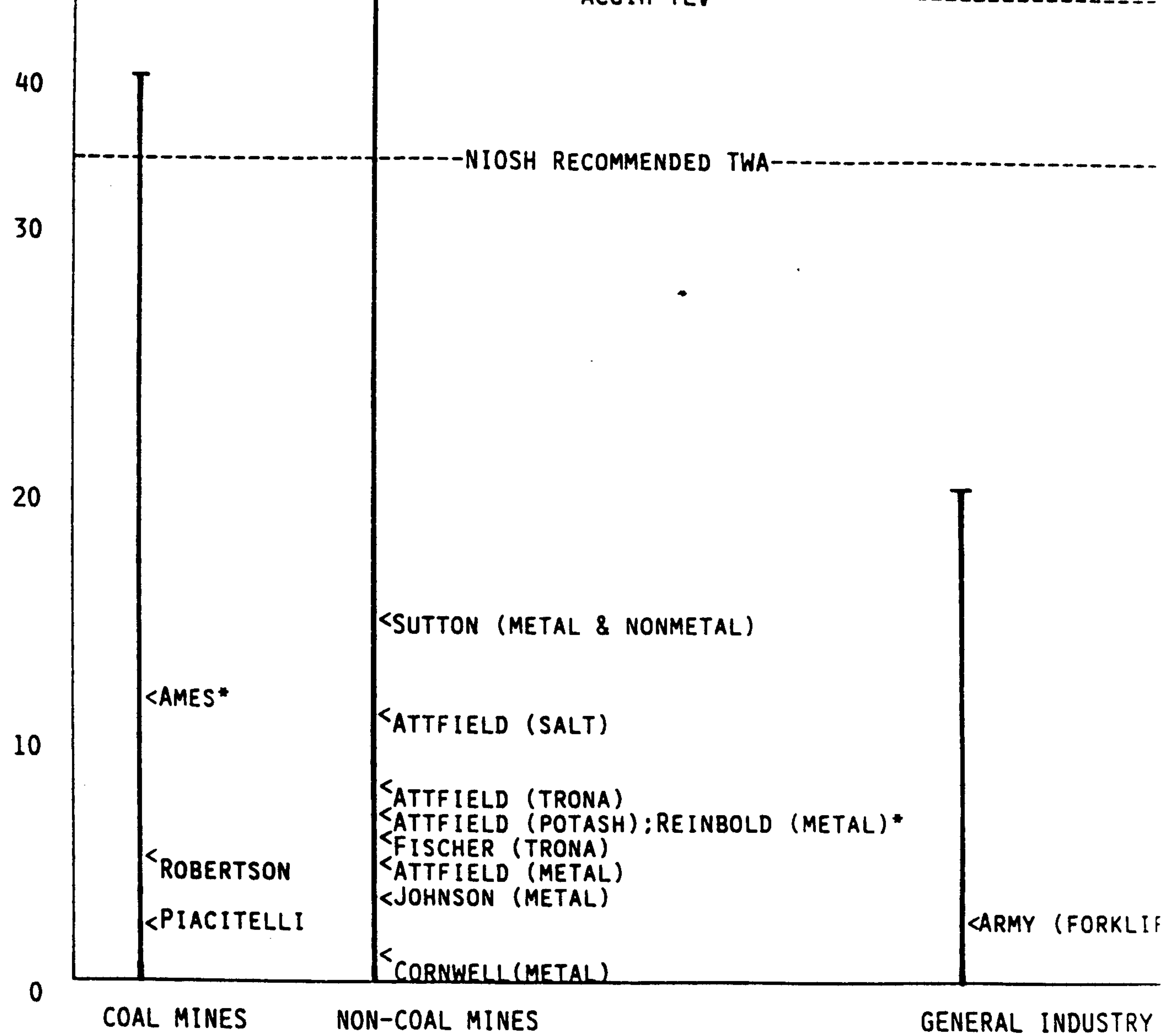

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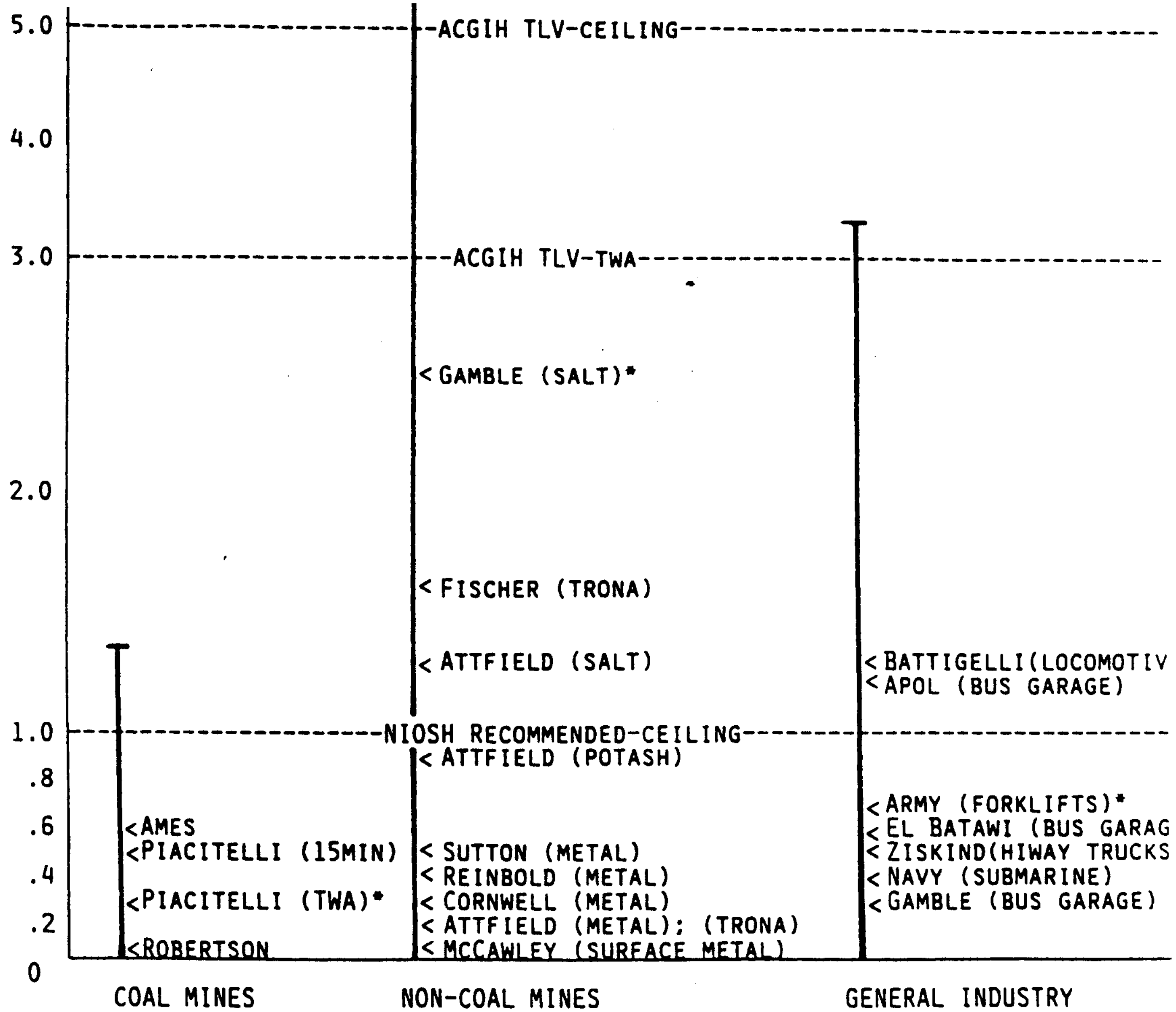

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