82-122

NIOSH

PROCEEDINGS OF A WORKSHOP ON THE USE OF DIESEL EQUIPMENT IN UNDERGROUND COAL MINES

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

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A WORKSHOP ON THE USE OF DIESEL EQUIPMENT IN UNDERGROUND COAL MINES

MORGANTOWN, WEST VIRGINIA

SEPTEMBER 19-23, 1977

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Respiratory Disease Studies
Morgantown, WV 26505

October 1982

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NIOSH Project Officer
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DHHS (NIOSH) Publication No. 82-122

ABSTRACT

This document is the proceedings of a workshop sponsored by the National Institute for Occupational Safety and Health (NIOSH) to explore the health and safety issues associated with using diesel equipment in underground coal mining. The workshop held was held in Morgantown, West Virginia, on September 19-22, 1977. Workshop participants included representatives of industry, labor, government, and academia from the United States and seven foreign nations.

The workshop proceedings contains presentations highlighting each country's experience in using diesel equipment in underground coal mining. It also contains summaries of work group discussions on four topics: Emissions and control technology, environmental characterization and pollution interaction, health effects, and safety and productivity.

CONTENTS

CONTENTS (continued)

The Use of Diesel Engines in Underground Coal Mining: The NIOSH Viewpoint

Edward Baier
Deputy Director
National Institute for Occupational Safety and Health
Rockville, Maryland

On behalf of the National Institute for Occupational Safety and Health, I am happy to add my welcome to you here today. I am especially pleased to welcome participants from other countries to the United States. We're very happy that you could be here with us to share your country's experience with diesel-powered equipment in underground mines.

The National Institute for Occupational Safety and Health (NIOSH) was created by Congress primarily to perform research and provide technical services and consultation. We operate under four Acts: the Public Health Service Act, the Coal Mine Health and Safety Act of 1969, the Occupational Safety and Health Act of 1970, and the Toxic Substances Control Act. Part of our function under the Coal Mine Health and Safety Act is to make recommendations to MESA, the Mining Enforcement and Safety Administration, for health standards in the coal mining industry. Accordingly, the Administrator of MESA asked us whether diesel engines should be prohibited in underground coal mines because of adverse health effects.

In preparing our reply, we already knew that there were toxic substances, including carcinogens, in diesel exhaust; however, we could find no adequate studies to determine whether or not these toxic exhaust components, at concentrations and in combinations found in mines and in combination with coal mine dust, would result in adverse health effects to miners after a working lifetime of exposure. Also, we were not aware of any data which supported the claim that diesel engines provided an increase in safety compared to electrical systems.

Consequently, we did not feel that NIOSH could make a recommendation one way or the other, but we did resolve to conduct studies and accumulate data on this subject as rapidly as possible. This workshop is part of that continuing effort.

NIOSH has several ongoing research projects related to this subject. In a joint effort with MESA, we are studying the effects of diesel exhaust and silica on non-coal miners working underground. NIOSH has conducted medical examinations on over 5000 men in 21 mines, while MESA has collected relevant environmental data. The results from this work should be available in about a year.

A retrospective mortality study of 12,600 non-coal miners is nearing completion. A component of this study is an attempt to determine standard mortality ratios for cohorts with varying degrees of exposure to diesel exhaust. We expect this work to be ready for publication in about nine months.

We have also collected medical and some environmental data from five dieselized coal mines. The field work was completed this summer, and we are presently analyzing the data. More detailed environmental investigations will also be conducted in these mines during this coming year. The results should be available at the end of the next fiscal year. It should be noted that most of these mines have only been using diesels for about six years. Because of this limitation, and the small population of exposed miners available for epidemiologic study, the results of this work may be inconclusive.

In the next fiscal year, NIOSH is also planning an experimental animal study of exposure to diesel exhaust and coal dust to assess any adverse health effects. This project will take several hundreds of thousands of dollars and more than three years to complete. The situation then is that available data appear to be inadequate for our purpose. Some of you, however, may take exception to that conclusion. That is why you have been invited to participate in this workshop.

Although NIOSH has not made a recommendation to MESA, we have expressed concern, which we feel is well justified. Unfortunately, it has been interpreted by some that NIOSH has already arrived at a final recommendation. NIOSH is an Institute dedicated to the principles of preventive medicine. Protecting the health and safety of workers is our only objective. Therefore, we are cautious in our advice, but we intend to address this issue openly and to make conclusions and recommendations based upon the best available scientific data--data which will be collected and analyzed not only by NIOSH, but hopefully by many of you in this room.

While NIOSH has made recommendations for the maximum occupational exposure to some of the constituents of diesel engine emissions on a pure basis, we are concerned about the possible adverse health effects from long term exposure to combinations of diesel exhaust components and coal mine dust. Without further scientific evidence we cannot state with any confidence that adherence to individual standards will provide adequate protection when mixed exposures occur. The occupational health community has recognized this problem for many years.

Another concern is the risk of mutagenesis and carcinogenesis from exposure to the combination of diesel emissions and coal mine dust. Very little conclusive information is available on the long term carcinogenic potential from mixed exposures. Known carcinogens, polynuclear organics, are of course present in diesel emissions.

We also know that respirable coal mine dust and diesel-generated particulate may act as condensation nuclei for the polynuclear aromatic hydrocarbons and, thereby, in combination, alter the health effect. Again, we have no conclusive evidence to support or to reject this hypothesis. However, the fact that other irritant gases do adsorb to respirable-sized particulate and do potentiate their effect is the basis for our concern.

It was our purpose in setting up this workshop to gather, in one place, persons with state-of-the-art knowledge in health, safety, and production research related to the use of diesel engines in underground coal mines. It is hoped that from the results of this workshop priority research can be identified and initiated to fill important gaps in our knowledge in this area. The issue facing us is obviously complex and the consequences of a wrong decision made in the absence of substantive and confirmatory data are possibly grave. Your responsibility as work group participants is to objectively determine the facts and to identify the research needs.

I wish you well in this endeavor.

Thank you.

QUESTIONS AND ANSWERS

QUESTION: How do safety and productivity fit in with the concerns of NIOSH?

BAIER: A basic issue investigated by NIOSH is: "Do you want to use diesel equipment underground?" The more diesel equipment used, the more health effects of diesel usage need to be considered. If diesel equipment wasn't being used, then there would be no need to study health effects. The mandate of NIOSH does not include economic feasibility. The study of health issues relating to diesels is not limited to diesel usage underground, but involves diesel use everywhere.

QUESTION: Does data exist on the safety of diesel usage versus electrical equipment?

BAIER: Data exists, but it has not been fully analyzed at the present time.

QUESTION: Why is NIOSH involved with diesel operations in mines?

BAIER: The role of NIOSH is to investigate health issues. The major concern is the introduction of diesel equipment into the mines. If more diesel equipment is going to be used, then we must study health effects now. The question is how much money to spend studying diesel effects. Will the use of diesel equipment be a long term trend? Health priority basis is needed. The size of populations exposed, risk factors, and severity of effects need to be investigated. NIOSH wants to study data from other countries. It often takes substantial time periods for health effects to show up.

QUESTION: Hasn't NIOSH already decided to limit the use of diesel equipment underground?

BAIER: No, that's not correct. NIOSH has an open mind on the issue.

QUESTION: What is the relationship between the Environmental Protection Agency and NIOSH.

BAIER: The EPA is independent of NIOSH. NIOSH is part of the Department of Health, Education, and Welfare. NIOSH is part of the Center for Disease Control, which is one of the five parts of Health. Under the Toxic Substances Control Act, which the EPA administers, NIOSH is empowered to do certain things. They include: 1) developing a list of priority substances for research, 2) developing a list of toxic substances, and 3) developing protocol for epidemiology in studying certain substances. The Occupational Health and

Safety Act created: 1) the Occupational Safety and Health Administration, 2) NIOSH, and 3) a review committee. NIOSH does research to develop criteria for safety and health. These criteria are enforced by the Occupational Safety and Health Administration. Under the Coal Mine Health and Safety Act, NIOSH sets health standards which are enforced by the Department of the Interior. Under the Public Health Service Act, NIOSH is involved in the preventive medicine side of public health.

THE FEDERAL VIEWPOINT (MESA)

Robert E. Barrett
Administrator, Mining Enforcement and Safety Administration
Arlington, VA

I am pleased to be a part of this workshop on the use of diesel equipment in underground mines. Your presence indicates your concern, and you probably have significant questions regarding the operation of diesel equipment underground -- relative to production, efficiency, and above all, the possible health and safety hazards involved.

The Mining Enforcement and Safety Administration (MESA) has responsibility for the enforcement of regulations designed for the protection of the health and safety of all miners in this country. Two Federal laws provide this responsibility and authority: the Federal Coal Mine Health and Safety Act of 1969 and the Federal Metal and Nonmetallic Mine Safety Act which was passed in 1966. Thus the agency's interest and jurisdiction extend into all aspects of mining -- insofar as the health and safety of the miners is concerned. To carry out our mandate and the activities essential to safety and health protection in both coal and metal and nonmetal mining, we have major enforcement organizations within MESA, headed by Assistant Administrators, which deal with health and safety in coal mines and in metal and nonmetal mines. I make this point here because to date the use of diesel equipment in metal and nonmetal, or noncoal mines, far exceeds the use in coal mines in this country. Thus the experience with diesel operation underground in these two MESA organizations varies accordingly.

In addition, within the MESA organization there are strong programs of technical support, and of education and training, which fortify the promotion of health and safety within the mining industry, as well as aid in carrying out the regulatory programs.

At this point I should like to recall the Symposium on the Use of Diesel-Powered Equipment in Underground Mining, held in Pittsburgh on January 30 and 31, 1973. That Symposium was sponsored by the Health and Safety Activity of the Bureau of Mines, MESA's predecessor organization. In planning and conducting the Symposium, the Bureau had major assistance from the American Mining Congress, the United Mine Workers of America, the National Independent Coal Operators Association, and the Bituminous Coal Operators Association. Papers were devoted to the general subjects of the diesel engine, the place of the diesel engine in underground mining, health protection using diesels underground, and safety in the use of diesel equipment. Two program participants of that meeting represented NIOSH, our host at this workshop. I expect that an appreciable number of people in this audience also may have attended that Symposium. The proceedings are available as Bureau of Mines publication IC-8666, published in 1975.

It appears to me that one of the purposes of this meeting is to establish clearly just what are the major health and safety issues or problems associated with operation of diesel equipment underground. Hopefully, the results of this seminar should aid NIOSH in planning and setting research goals involving the health aspects of diesel operation underground - and in turn, will aid MESA in its regulatory, technical assistance, and educational programs. In this connection, I should like to describe some of the actions engaged in to date by MESA and outline certain areas where we feel problems and questions exist and where further study and consultation among all concerned parties -- including equipment manufacturers, mine operators, labor health researchers and officials, and enforcement agencies -- are required.

In January 1976, in response to our request, we received an opinion from the Associate Solicitor for Mine Health and Safety of the Department of the Interior that the provisions of the Federal Coal Mine Health and Safety Act of 1969, and implementing regulations, do not contain any requirement that diesel-powered equipment used in coal mines be permissible or otherwise approved by MESA. However, such equipment used underground must be operated in accordance with the requirements of mandatory health and safety standards (30 CFR, Parts 70 and 75). These standards pertain to potential ignition and fire hazards, mechanical and electrical hazards, ventilation, dust exposure, threshold limit values for toxic or objectionable gases, noise exposure, and a requirement that mobile and stationary equipment be maintained in safe operating condition, to name some examples. In addition, there are requirements pertaining to the storage of oil, including diesel fuel, underground.

In March 1976, on request, we furnished the United Mine Workers of America (UMWA) a listing of diesel equipment operated in underground coal mines. This equipment consisted of 114 pieces in 22 underground coal mines located in three coal mine health and safety districts, with a majority, or 68 percent, of such equipment located in District 9, specifically the States of Colorado, Wyoming, and Utah. By July 1977, the total had increased to 162 pieces of diesel equipment in 28 underground coal mines, with the vast majority, or 95 percent, of such equipment still in District 9, and with all of the increase in that District also.

At a MESA/NIOSH meeting chaired jointly by the Director of NIOSH (Dr. John Finklea) and myself, MESA requested from NIOSH a statement on the health significance of the operation of diesel equipment underground. In June of 1976, Dr. Finklea informed MESA of the NIOSH position on the possible health implications of exposure to diesel exhausts which was that NIOSH remains concerned about the possible enhanced health hazard effects of long term exposure to a combination of coal dust and the gases and vapors of diesel exhaust namely the pulmonary irritants such as nitrogen dioxide and certain organic compounds.

Although individual standards exist for coal dust, nitrogen dioxide, and certain other gases and vapors present in diesel exhaust, the main concern is that the adsorption of certain irritant gases to respirable-sized particles may potentiate or magnify their effect on lung tissues. With reference to individual standards, NIOSH states: "Although standards exist for coal dust and nitrogen dioxide, these are based upon controlling health effects of single exposures. We cannot, with any confidence, state that adherence to these standards individually are protective when mixed exposures occur."

To shed further light on this matter, NIOSH and MESA have under way a joint study of the health status of underground miners who have been exposed to diesel exhaust over a period of years. This medical environmental study is being carried out in metal and nonmetal mines and should provide valuable and needed information on the possible long term effects of diesel exhaust. More detailed information on this environmental study will be provided in this conference by Dr. Goodwin of our Metal and Nonmetal Mine Health and Safety organization who is on the program for tomorrow.

Additionally, NIOSH plans a cross-sectional study of miners working in coal mines where diesel equipment is utilized, for comparison with coal miners not exposed to diesel exhaust. NIOSH indicated that the results of these studies should allow an appraisal and provide some evidence for a decision on whether or not diesel usage in underground coal mines poses a significant health problem.

Finally, NIOSH advised that the coal mining industry should be worried of the possible health implications, and that ". . . further introduction of diesel equipment into underground coal mines pending completion of these studies might result in future economic disruption should their use pose an unacceptable health risk."

Following receipt of the NIOSH position on the possible health implications of exposure to diesel exhausts, MESA sent a bulletin to all coal mine operators to inform them of the NIOSH position, including the possibility of the combined and increased effects of respirable coal mine dust and diesel exhaust gases; the pending health studies of NIOSH; and that current standards for coal dust and individual gases may not be completely protective. The cautionary statement of NIOSH with reference to further introduction of diesel equipment into coal mines was repeated. A similar letter, or bulletin, was sent to all coal miners in the fall of 1976 through the Coal Mine Health and Safety Offices of MESA. MESA believes that the entire mining community should be kept informed of the possible health hazards related to diesel equipment operation in underground mining.

In underground metal and nonmetal mines, the introduction of diesel power started in earnest after World War II. It is now difficult to find an underground mine of any size without at least one diesel-powered piece of equipment. We do not have complete data on the rate that diesels have been introduced over this period, but in mines surveyed in 1970 and 1971 to determine the extent of diesel usage, we found that there were about 3,000 units in about 350 mines. We conducted a similar survey in 1976 and at that time we found about 4,400 units in about 400 mines, or an increase of roughly 50 percent. Thus, about 60 percent of all U.S. underground noncoal mines contain diesel equipment. In the latter survey approximately 3,000 of the units were used in production or haulage, and the rest were service or utility vehicles. Diesel engines are an established energy source for noncoal mines and their use is increasing. Because of this we have entered into a joint epidemiological study with NIOSH to try to determine the health effects of miners from long term exposure to diesel exhaust. I will discuss this again, but first I'd like to discuss our regulations for diesel usage.

We have two categories of regulations. One treats the approval and testing of diesel-powered equipment and is directed to the manufacturers of equipment. The other category of regulations is directed to the mine operator and addresses work practices and the mine environment.

The approval and testing regulations cover diesel mine locomotives, mobile diesel-powered equipment for noncoal mines, and mobile diesel-powered transportation equipmnent for gassy noncoal mines and tunnels. These regulations are found in Title 30, Code of Federal Regulations (CFR), Parts 31, 32, and 36, respectively.

Each of these regulations considers four possible hazards:

1. Toxic or objectionable gases discharged in the exhaust of the engine,

2. Ignition of methane air mixtures by the engines or by electrical equipment,

3. Fire hazards presented by coal dust or other combustible material in contact with the equipment, and

4. Mechanical hazards.

Equipment approved for use where methane may be encountered, such as in gassy mines, must offer adequate protection against all four of these hazards. Equipment for use in noncoal mines in which the underground atmosphere contains less than 0.25 percent methane will be granted approval under Part 32 when proven by test to offer adequate protection against toxic gases and to minimize the fire hazard presented by engine fuel oil under normal operating conditions. We have been working for several years now to consolidate these regulations and to include more comprehensive tests for all potential hazards.

In the safety and health regulations applicable to mine operators, those pertaining to gassy mines (30 CFR Part 57.21) require that only permissible equipment be permitted beyond the last open crosscut. This means that only diesels having approval under Part 31 or 36 are allowed to be used beyond the last open crosscut. Other than this, no regulations restrict diesel usage to only approved units. However, there are several regulations which can be applied to correct hazards associated with diesel equipment or diesel usage. As far as air quality is concerned, the primary focus for both the approval and testing and the usage is that known toxic agents in the exhaust be diluted below their respective threshold limit values. The toxic gases explicitly covered in the approval and testing schedules are carbon monoxide; oxides of nitrogen; carbon dioxide; aldehydes; and, depending on the fuel, oxides of sulfur.

Most air quality testing in the workplace is made for carbon monoxide and oxides of nitrogen. The most dangerous condition affecting air quality in operating diesel engines underground is lack of adequate ventilation. This may seem obvious, but the person operating the equipment is very rarely aware of the composition of the atmosphere in which he is working. Also, if a diesel engine operates in stagnant air, the oxygen concentration will be reduced, which results in an almost exponential increase in the production of carbon monoxide. In one case, two miners were killed when they operated a diesel in a poorly ventilated heading. The engine had continued to run until it ran out of fuel. Let me return to the study I mentioned earlier that is being conducted jointly by NIOSH and MESA. Even though we are generally able to control exposures to the commonly recognized toxic gases below their respective threshold limit values, there are other substances in diesel exhaust which may be harmful. Particularly, we are concerned that one or more of these substances inhaled over a working miner's life may result in disease. The study was designed to cover about 20 mines employing about 7,000 miners. The mines were selected depending on the extent of diesel usage and the silica content of the rock being mined. The mines were divided into one of four categories depending on whether they had low or high silica and whether there was low or high diesel usage. By comparing the miners' health in the four categories, an overall conclusion can be drawn about the effects of diesel exhausts, silica, and mixed exposure. Extensive environmental surveys were also made in each of these mines. Medical examinations were provided to determine the prevalence of respiratory ailments. NIOSH conducted the medical examinations and MESA did the environmental measurements. As part of this study, NIOSH is also conducting a mortality study of 14,000 miners which had been included in an earlier (1958-1960) study of silicosis among underground metal miners.

One area of uncertainty in dealing with the potential health hazards of diesel usage underground is that relating to the measurement and analysis of mine atmospheres for diesel exhaust gas components. In particular, I am referring here to nitrogen oxides measured not with the elaborate instrumentation as used in a testing facility, but using portable instruments needed for determination in the mine environment. Commercially available portable and direct-reading instruments for the most part are fragile and do not perform well in the mining environment. Therefore, we often have to utilize and rely on the readings from gas detector tubes or nitrogen dioxide dosimeters. However, if gas detector tubes are to be used for both nitrogen dioxide (NO_2) and Nitric oxide (NO) -- and if we are to distinguish between these components, as I think we should -- different techniques of sampling are called for. The problems relate to the form of the threshold limit values or TLV's, which are incorporated in our regulations and to the selection of a sampling instrument or method which is consistent with these limits. Thus, there is still a need to improve methods for determination of nitrogen oxides in mines so that we can properly enforce the standards that we have. This is just an example of an area where we need further clarification from health and environmental specialists in order to properly evaluate the environment of diesel usage underground.

Another area which we feel should be given attention in the evaluation of diesel operation underground -- and which is of special interest to MESA in developing necessary and realistic regulations for controlling hazards -- is that of ventilation and control equipment for removal and dilution of exhaust gases. This is, of course, related to the contaminants emitted and the potential health hazards they present. Other questions that need to be answered are: What is the proper basis for setting ventilation rates where diesel equipment is operated underground? Should other control equipment such as scrubbers and catalysts be required? Can a practical scheme for measuring and evaluating the potential hazard of diesel exhaust gases be devised? What means or devices are essential to assure safety in operation? In a workshop such as this, such questions can be re-examined and alternative answers considered.

Perhaps this workshop can throw light on the matter of the health significance of the myriad of diesel exhaust components other than nitrogen oxides and carbon monoxide which have been identified and measured, both in undiluted and diluted diesel exhaust streams, using elaborate, sophisticated instrumentation in laboratory testing. These include particulate matter, sulfates, and organic compounds. The occupational hazard of these components has not been quantified, and thus the need for measurement and evaluation in the mining environment is not known.

We in MESA work cooperatively with both NIOSH and the Bureau of Mines in matters relating to mining health and safety. We are confident that an improved understanding of the health and safety aspects of diesel operation in underground mines will come out of this workshop. Hopefully, direction toward better evaluation and control of the mining environment will also result--to the benefit of all miners. We thank NIOSH for arranging this workshop. We know we will benefit from the proceedings and hope we can make a contribution too.

Thank you.

QUESTIONS, ANSWERS, AND COMMENTS

QUESTION: Are different priorities given to different areas of study of underground diesel usage?

BARRETT: There is no significance to the order in which the areas addressed in granting approval were presented.

QUESTION: Is it fair to the American miners at this time to say that MESA has no position on the use of fuel equipment underground?

BARRETT: MESA is open-minded now. There are no trade-off's as far as safety and health are concerned. MESA will go with what NIOSH recommends.

COMMENT: Some studies have demonstrated that diesel exhaust emissions have affected the standard mortality rates. There may be a lung and stomach cancer potential.

BARRETT: The Coal Mine Health and Safety Act of 1969 says to look into alternative sources of energy for underground equipment. The diesel is one of these.

COMMENT: We are not focusing on the health of the miner in his lifetime. We also need to consider diesel emissions and inherited genetic defects.

COMMENT: There is no point in causing alarm over the possibility of inherited genetic effects at this time.

BARRETT: There are many concerns related to diesel use underground that need investigation.

QUESTION: Are statistical studies available?

BARRETT: Yes. Many have been published.

QUESTION: Is there any data on persons preoccupied before accidents?

BARRETT: No, it would be impossible to collect.

U.S. BUREAU OF MINES DIESEL RESEARCH

Presented by
R. W. Van Dolah, Research Director
Pittsburgh Mining and Safety Research Center
Bureau of Mines, U.S. Department of the Interior

The goal of the U.S. Bureau of Mines diesel research program is the safe utilization of diesels underground. The interacting parameters that must be controlled to achieve that goal are shown in Figure 1 by the overlapping circles which form a triangle. The left-hand side of the triangle represents those MESA regulations that specify the quantity of dilution air, and hence the mine ventilation requirements, needed to obtain an acceptable air quality based upon the actual emissions from a particular diesel engine. The items in the base of the triangle represent the actual pollutant concentrations from the engine and its control system when new, during the deterioration of the engine and due to use, and as affected by maintenance of the engine and its control system. The right-hand side of the triangle addresses the various alternatives for the control of emissions, and basically represents the operator's choice between better maintenance and/or increased ventilation to maintain the proper air quality.

The Bureau's research program is divided into five functional areas that address the points identified above. Specifically, these are emissions control, emissions characterization, field studies, instrumentation and monitoring, and noise.

In the area of emissions control we have emphasized the evaluation of existing and prototype control systems and the development and evaluation of some innovative systems that are applicable to this problem. Examples of the types of emission control activities are described below:

1. Catalytic: The Bureau has been accumulating data on gases and particulate emissions from various catalytic converters; as an example, comparisons have been made between the monolithic and pelletized-bed-type catalysts.

2. Scrubbers: Candidate scrubbing systems are currently under evaluation. These include the prototypes by Texaco and Ricardo

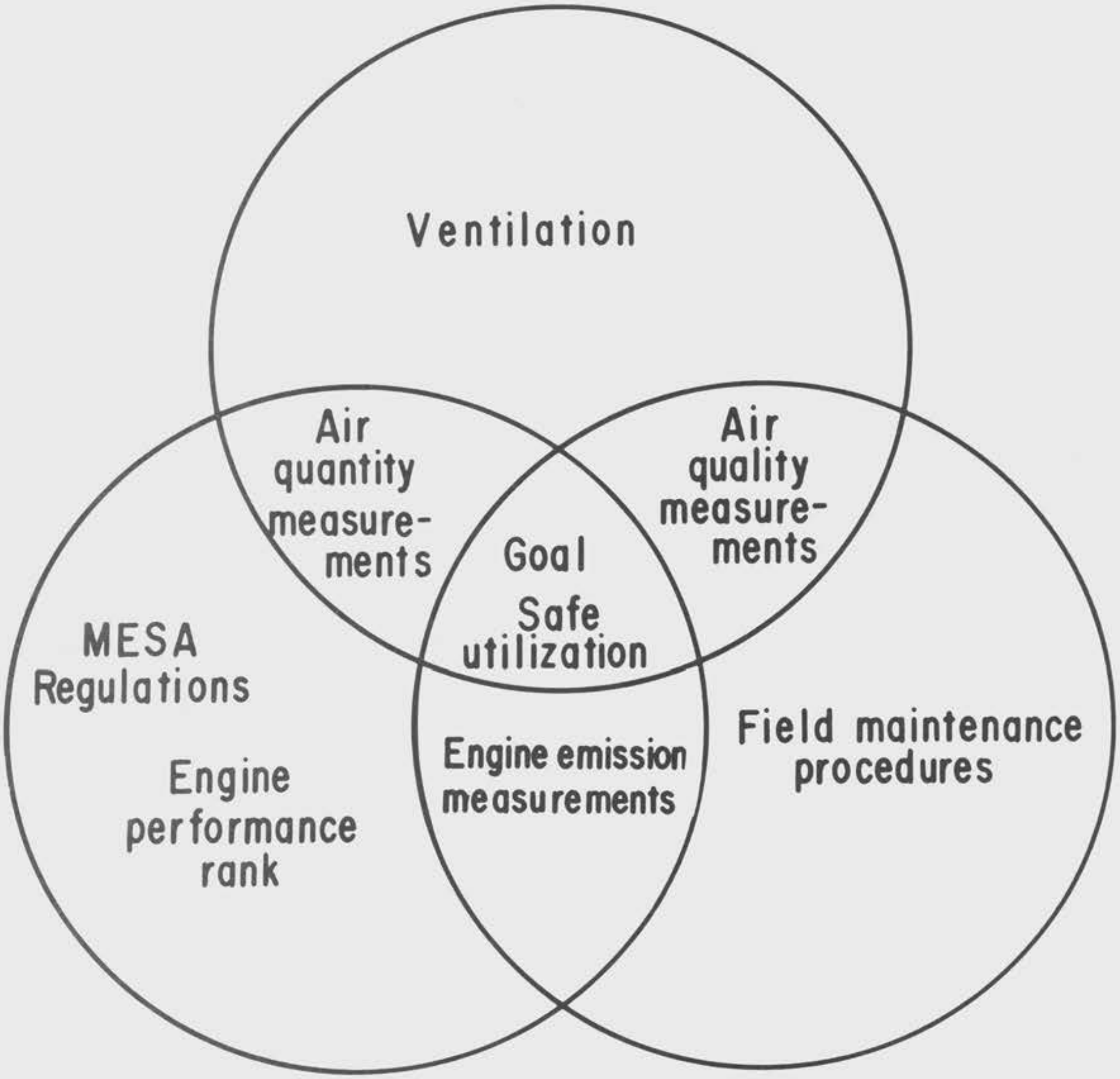

Figure 1. Interacting parameters that have an effect on the utilization of diesels underground.

Engineering and a wetted-bed scrubber which has been extensively studied by the Bureau's Respirable Dust Group for the control of respirable coal dust. The Texaco scrubber consists of an aluminum-oxide-coated steel wool bed. It has a minimum operating temperature of 850F. Preliminary results show that particulate removal efficiency is about 60 to 70 percent. Some problems may be encountered as a result of an increasing back pressure, a function of long-term operation; this pressure buildup is currently under investigation.

Figure 2 shows an engineering prototype of a wetted-bed scrubber which has been extensively evaluated underground for the control of respirable coal dust. For that application the system is extremely efficient, with particulate removals in excess of 99 percent. However, because the size range of diesel particulates is somewhat smaller than that of respirable coal dust, removal efficiency for diesels would not be anticipated to be as high. But the system has the unique feature of minimal pressure drop, so modified configurations may be possible which could increase its efficiency in removal of the smaller diesel particulates. Laboratory trials are presently under way on this type of technology.

3. Alternate Fuels: We have been accumulating data on alternate fuels, such as low-sulfur diesel fuels and other types of fuels such as methanol, for the diesel engine underground. At this time the only feasible emission control via fuels appears to be from the use of special low-sulfur fuels, and this fuel only reduces the sulfur component in the exhaust.

4. New Engines: Presently we have under evaluation new diesel engine systems. These include a new exhaust conditioning system by Jeffrey and a new water-cooled Deutz engine on which the manufacturer's preliminary data show significantly reduced emissions from models previously evaluated.

5. External Combustion: We have been actively investigating external combustion engines such as a steam engine that will be used to power shuttle cars and Stirling cycle engines for applications where reduced emissions are important.

Figure 3 shows a prototype of a steam engine which is being fitted to a Jeffrey Ramcar for trials underground. This particular technology, if successful, should result in emissions that are only about 1/10 those of a state-of-the-art diesel system.

In the highlighted area of Figure 4 covering MESA regulations, the certification of new engines and the ranking of engine performance based on emission levels are the input parameters in the portion of the triangle that we are discussing. The rank of the engine, as determined by MESA tests, is specified by the quantity of emissions that will result from this particular powerplant relative to others with the same approximate horsepower. The mine operator, knowing his power requirements, can then trade the emissions level against ventilation in order to meet safe working

Figure 2. Engineering prototype of a wetted-bed scrubber.

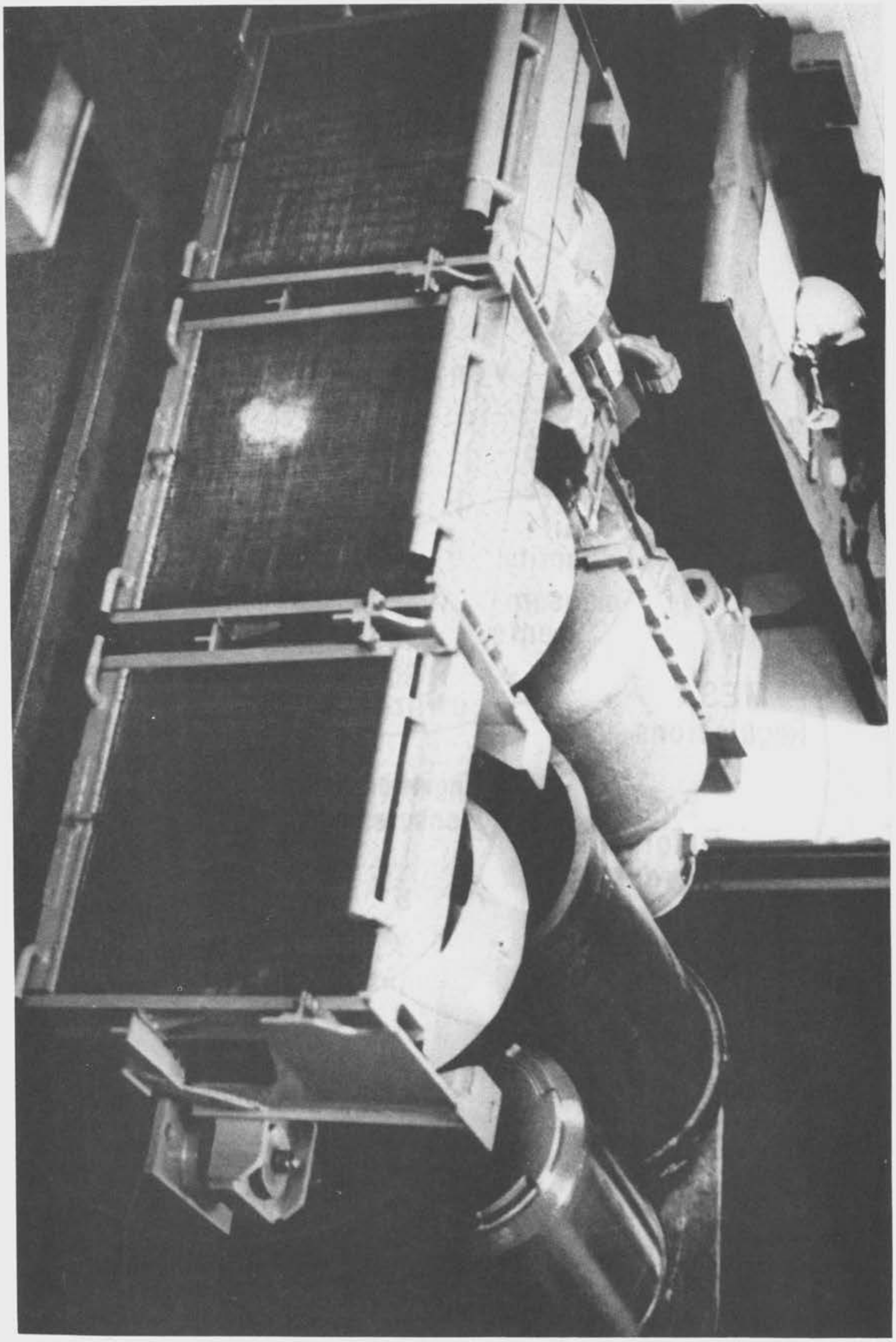

Figure 3. Prototype steam engine for use in a Ramcar.

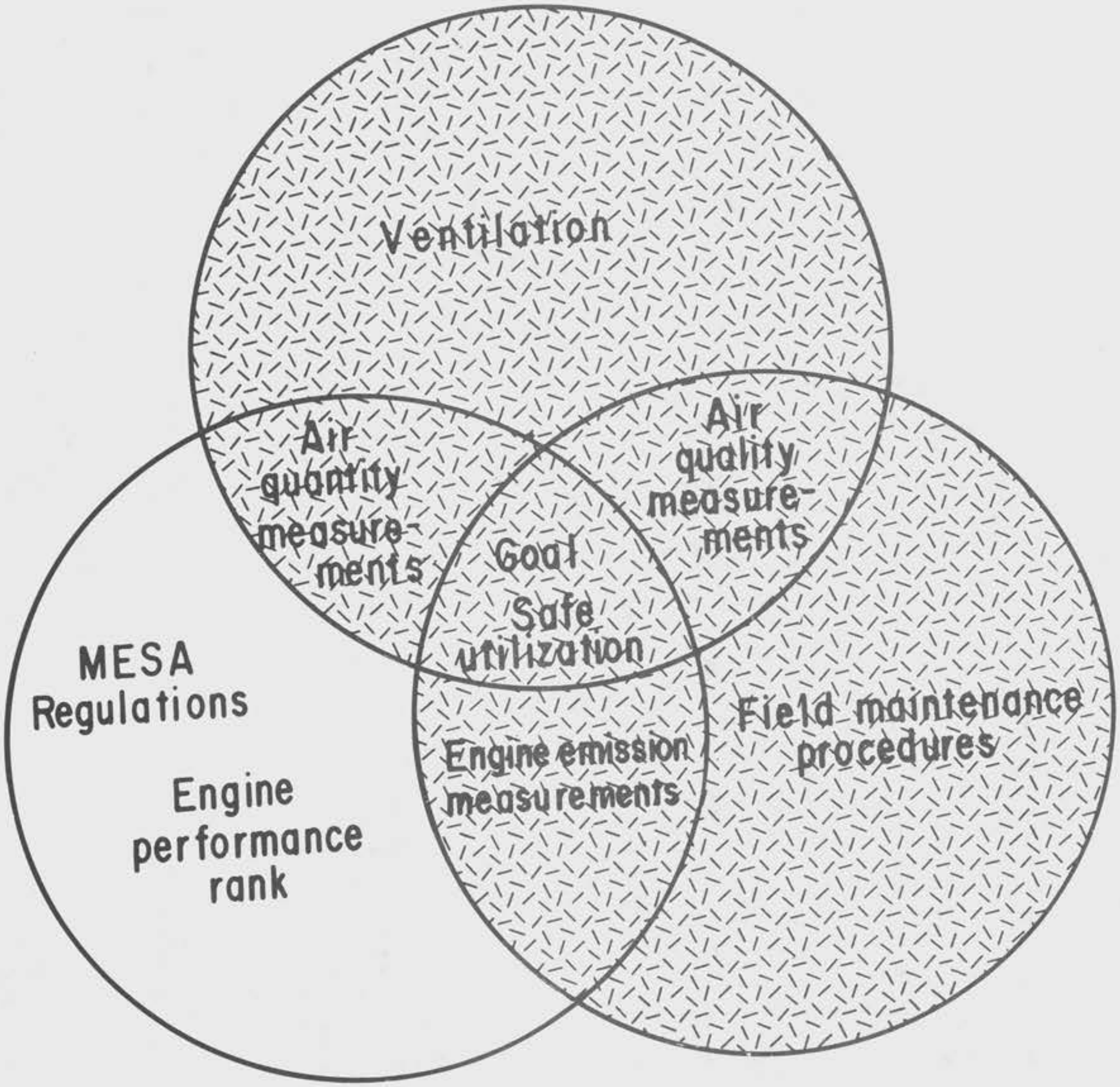

Figure 4. Highlighted area: The role of MESA regulations.

conditions. One should note that it is the highest observed concentration level of the toxicant relative to the accepted allowable level (8-hour time weighted average or TLV) for that species that controls the amount of dilution air required, and that somewhat surprisingly, especially with catalytic converters, it is not CO but rather NOx or CO_2 that typically constitutes the limiting parameters.

Emissions characterization is the second category under active investigation. In the emissions characterization program, the following work has been completed or is presently under way:

1. Analytical Procedures: The Bureau has emphasized the development of reproducible analytical procedures. These procedures have been successfully demonstrated in round-robin trials. Included in this work are SO_2 and SO_3 determinations and improved methods for determining polynuclear aromatics (PNA's). Some of the PNA procedures that currently have been reduced from interest are the specific determination of benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), and other polycyclics.

2. Laboratory Evaluation: Using these analytical procedures, laboratory evaluations of candidate diesel engines, including the emissions control system, have been under way.

3. Field Studies: Principally through our program at Michigan Technological University, exhaust gas analysis under controlled load conditions in the field will be investigated. Hardware development for this investigation has been completed, and field studies will begin shortly. Earlier investigations have provided an assessment of the extent of the emissions problem in selected operations.

In Figure 5, the highlighted portion of the triangle addresses measurement of engine emissions relative to certification and the effects of these in terms of field use. The deterioration of engines as a function of time and the type of maintenance is important in terms of the safe utilization of diesels underground. Through our field studies we expect to identify what happens to engine emissions in the field relative to emission levels obtained in the laboratory during certification tests.

The effect of exhaust conditioning systems is illustrated in Figure 6, which shows emission levels of a diesel without an exhaust control and with two candidate catalytic exhaust treatment systems. This type of data has been obtained in more detail in order that we may quantify the performance of these types of exhaust conditioning systems.

In the highlighted portion of Figure 7 of the triangle we represent the effect of field maintenance on the actual engine emissions. Preliminary data have shown that, even after overhaul at a field shop, there is considerable variability in the performance and emissions of a used engine compared to its performance when received new from the factory. Additional

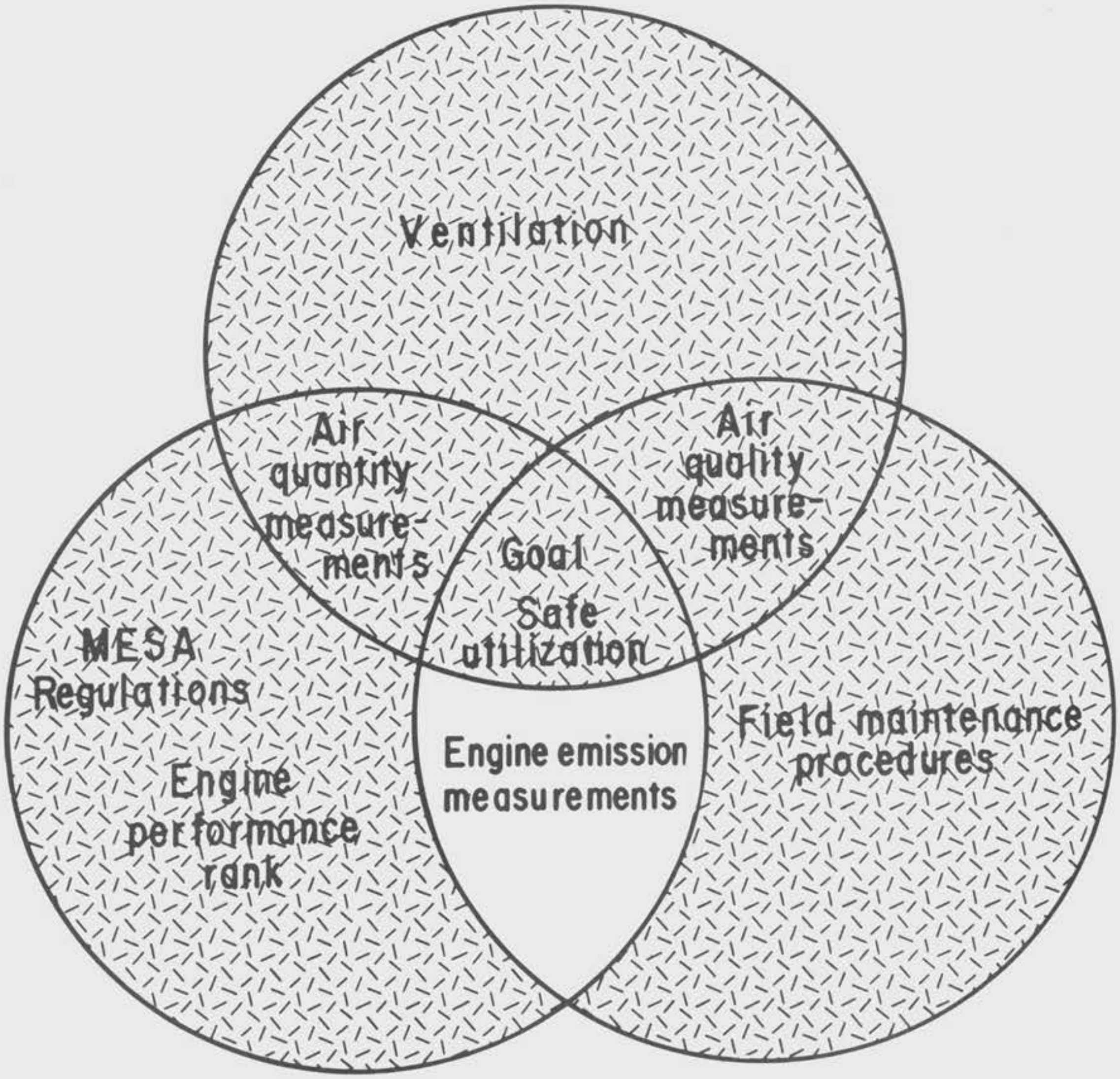

Figure 5. Highlighted area: The effect of engine emissions.

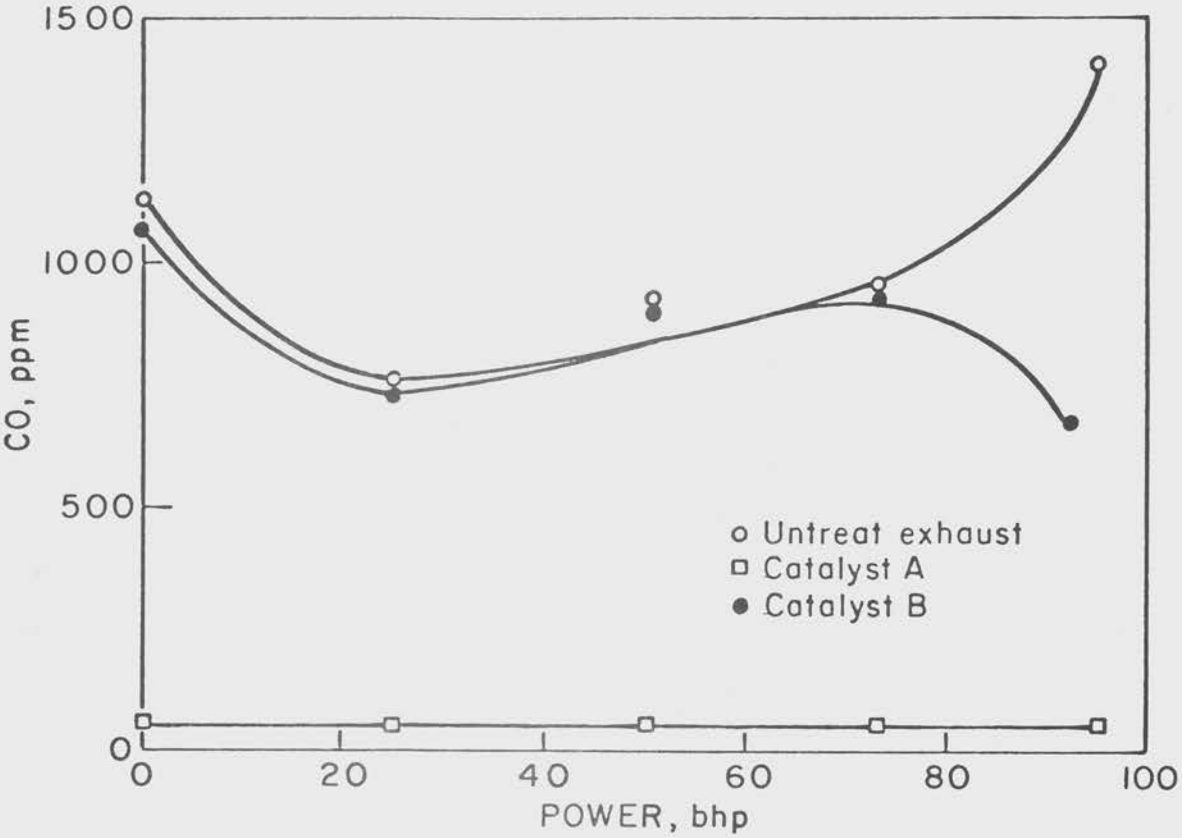

Figure 6. Effect of two candidate catalytic exhaust treatment systems.

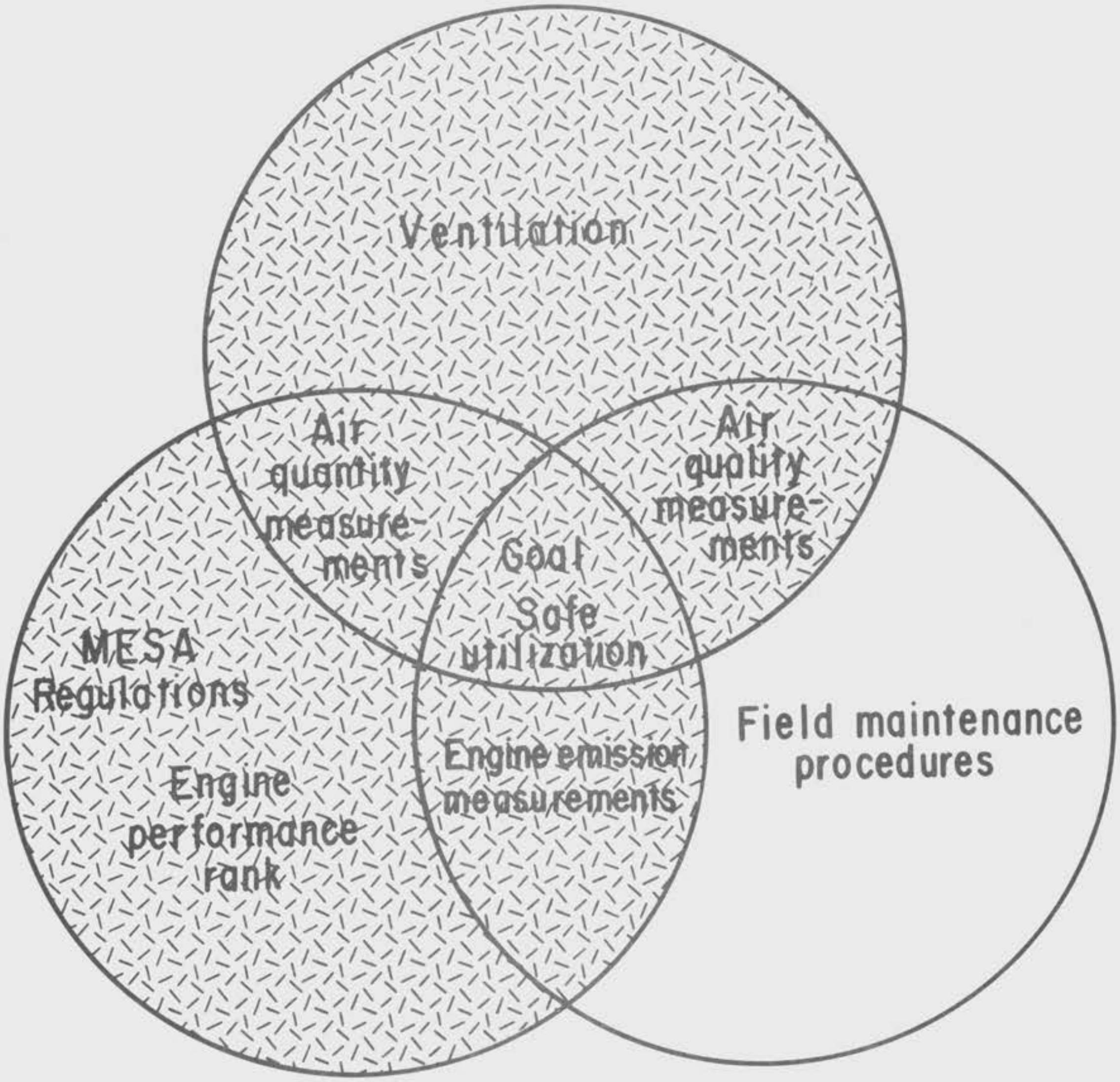

Figure 7. Highlighted area: The role that field maintenance plays in overall emission levels.

data in this area will identify the critical factors of overhaul that require special attention.

The entire base of the triangle is highlighted in Figure 8 to identify all of the factors that affect the diesel engine as a pollutant source. To sum up, these factors are (1) its manufacturer and MESA certified emissions when new, (2) the effect of use and age, and (3) the effect of maintenance.

The third area under investigation is that of field studies, which are addressing the following areas:

1. Sampling Procedures: Our research program is directed towards determining what, when, where, and how to sample in order to develop the methodology that can be used to assure that safe working conditions are maintained for all personnel underground.

2. Instrument Evaluation: In addition to supporting the development of sampling procedures and methodology, the field studies provide an opportunity for the evaluation of developmental instrumentation with encouraging results that will be described in more detail below.

3. Ventilation: Studies include the effects of dispersion and dilution and the field validation of analytical studies of ventilation models. Much of the work is being done in metal as well as coal mines because of the availability of diesel sources in a variety of ventilation systems. One point of interest is that the results to date show that some of the emission components that are measured in the exhaust stack do not appear in the mine air. Investigation of how these substances are being absorbed or their concentration reduced is the subject of further study.

4. Methodology: As discussed above, this emphasis is on how to sample effectively and to use computer models for air quality prediction and ventilation planning and the verification of both in the field.

The majority of the measurements are being taken by Michigan Technological University under a U.S. Bureau of Mines contract; work is now proceeding to study similar situations in dieselized coal mines. Included in this work is the in-mine assessment of handheld and portable instruments and the development of sampling methodology through analysis of the measurements.

Two aspects of exhaust emission control are ventilation and workplace air quality measurements to emphasize their importance in meeting the objective of a safe and healthful work environment. Figure 9 highlights the right-hand leg of the triangle and represents the trade-off's that are available to the mine operator for obtaining and maintaining proper air quality.

The left-hand leg of the triangle, Figure 10, pertains to MESA approval procedures and to the ventilation air quality that is specified in the

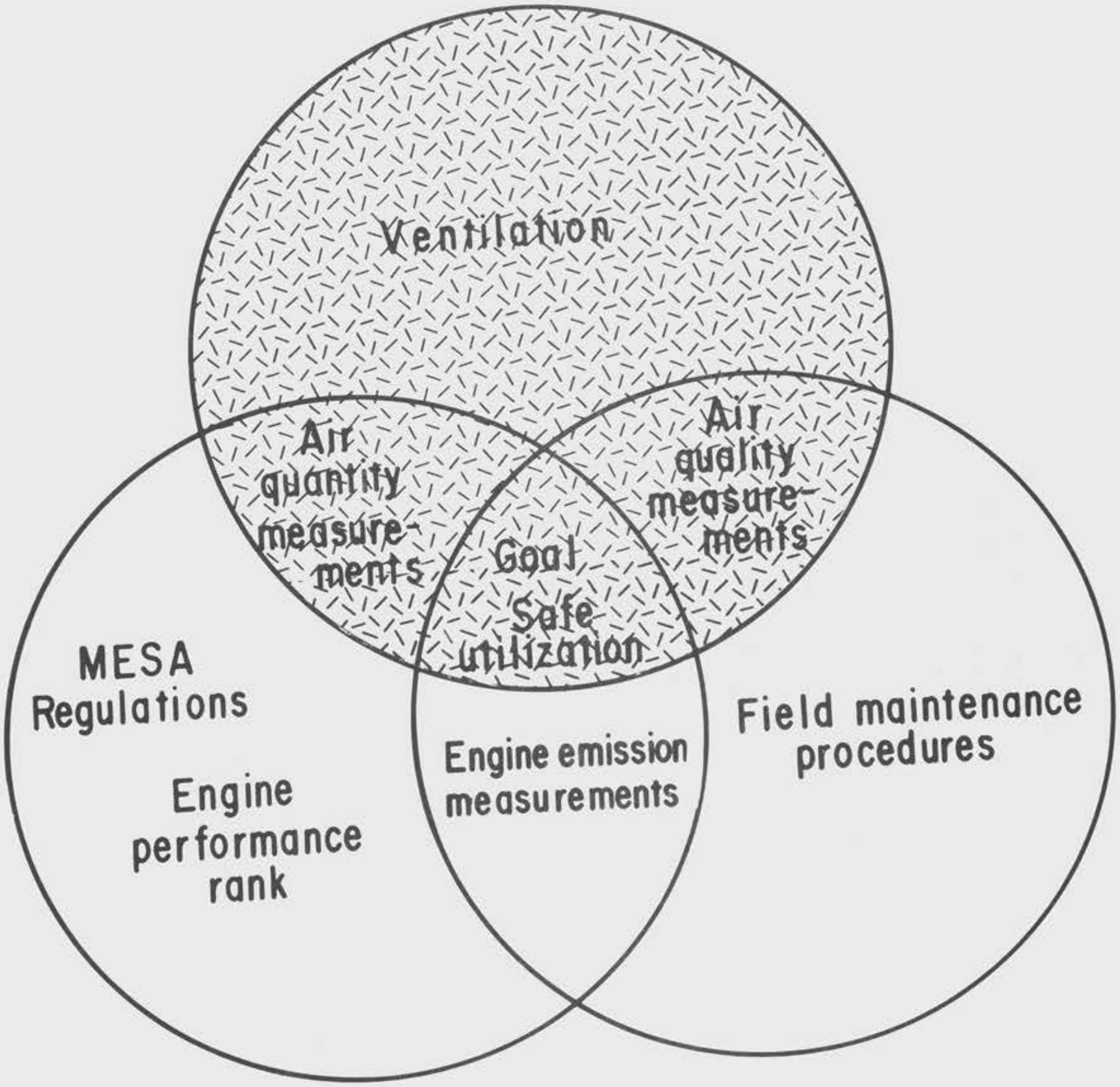

Figure 8. Highlighted area: The factors that affect the diesel engine as a pollutant source.

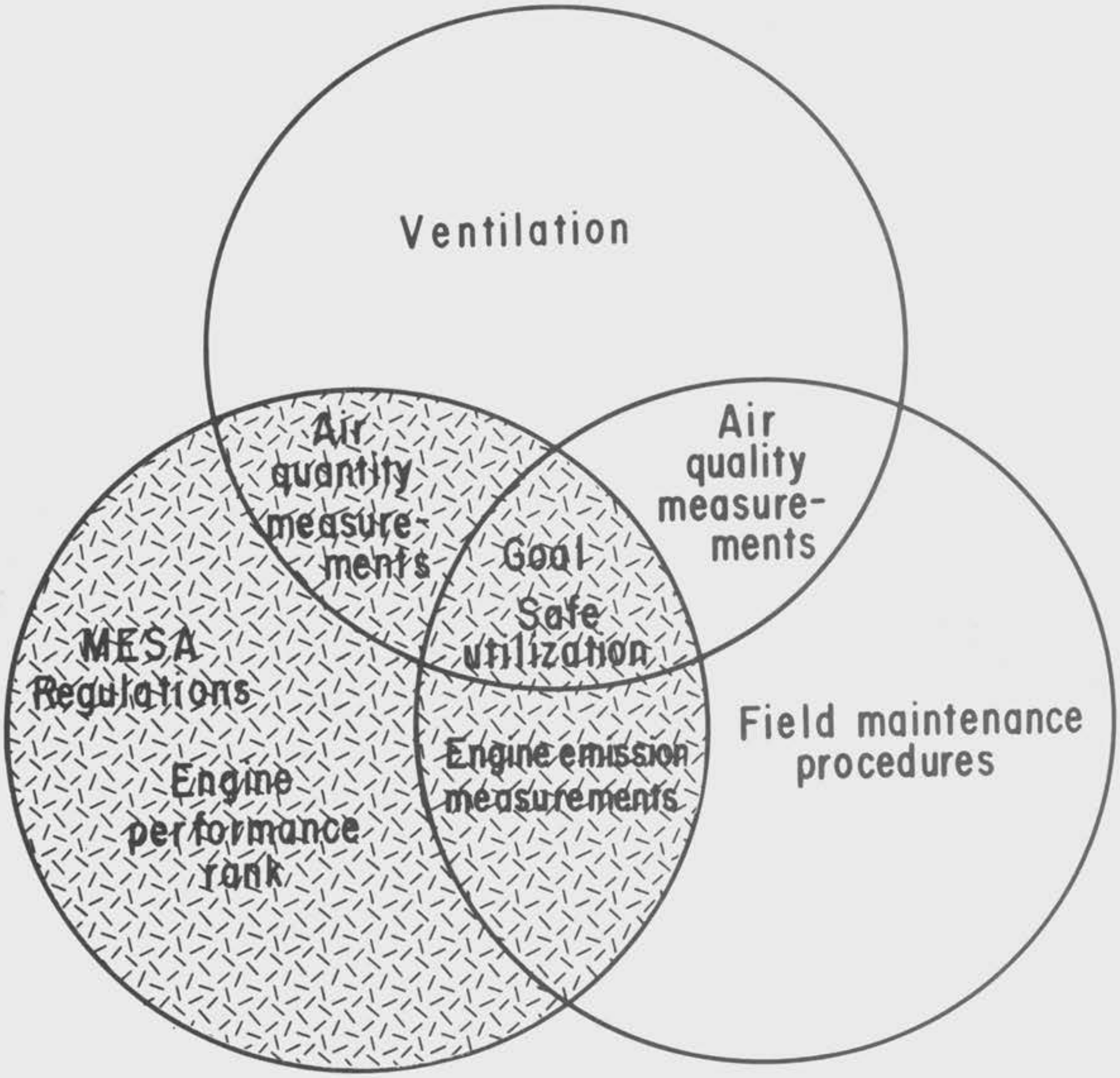

Figure 9. Highlighted area: The trade offs that are available to the mine operator to maintain proper air quality.

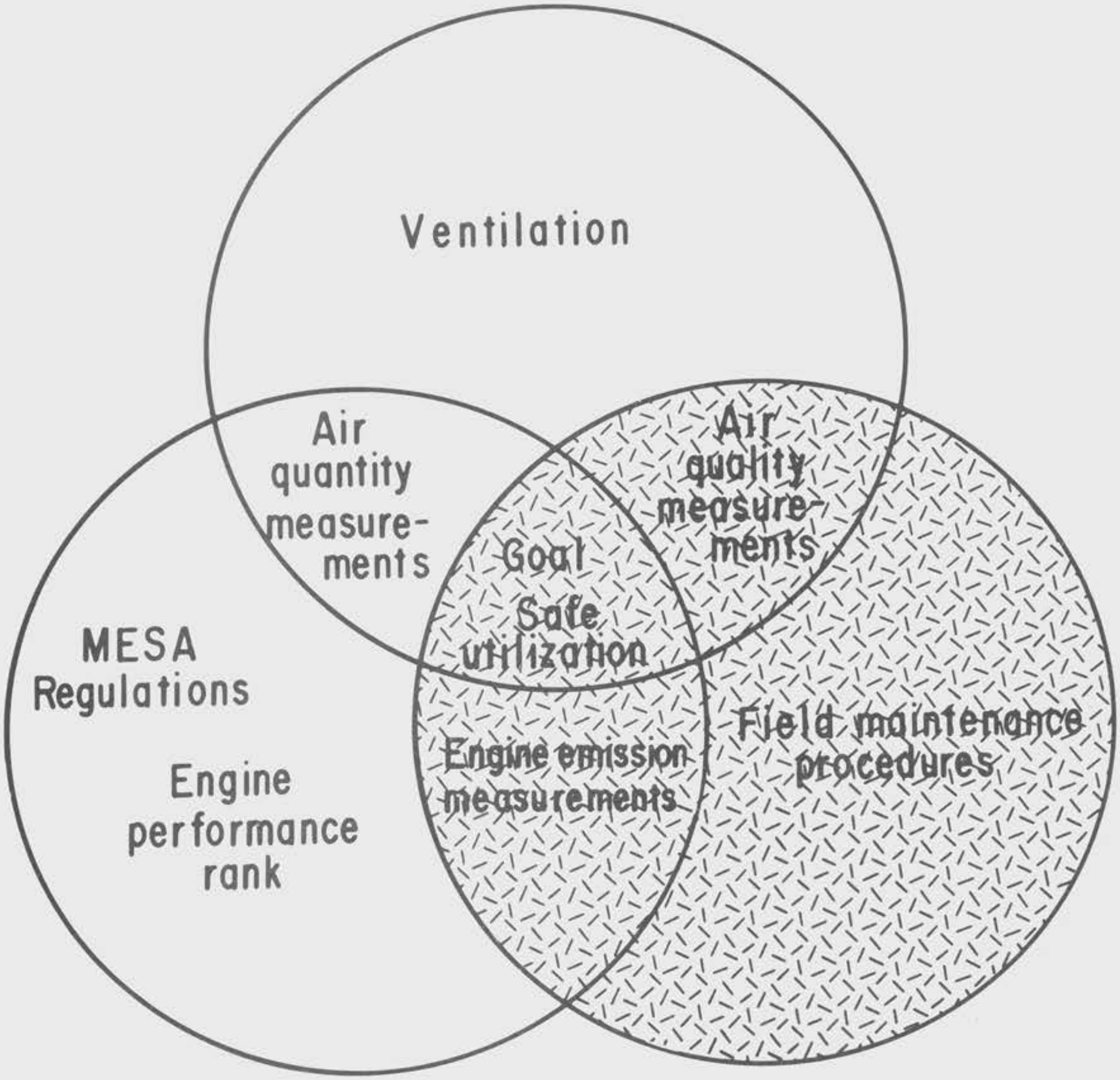

Figure 10. Highlighted area: The role of the approval procedures in the establishment of air quantity for a given engine system.

engine approval as computed from the emissions of the engine when new. The previous discussion has covered the point of this specified ventilation requirement in relation to the deterioration of the engine subsequent to the initial approval.

The next major area of Bureau research pertains to instrumentation and monitoring which is divided into the following areas:

1. Hand-held: For spot inspections by company and MESA personnel to ascertain air quality.
2. Dosimeters: To be worn by personnel underground to determine integrated quantity-level measurements for an entire shift.
3. Vehicle: For use on board vehicles to identify undesirable levels of toxicants, principally CO_2, in the vicinity of the vehicle and its operator.
4. Area: To be used with, or in lieu of, personal and hand-held monitors to ascertain acceptable air quality underground.

The primary device used for underground measurements is the length-of-stain tube. The Bureau has conducted extensive evaluations of these, and the overall error of the device under mine conditions is approximately ± 25 percent; however, the significant portion of this error is due to the observer. The Bureau has evaluated an optical stain tube reader that significantly reduces the error; however, the cost and complexity of making measurements with length-of-stain tubes is substantial and has prompted the development of alternative means of gas detection.

Significant progress has been made in the use of electrochemical sensors for the determination of underground air quality. Shown here (Figure 11) is a prototype carbon monoxide detector (General Electric fuel cell) which has undergone extensive laboratory and field trials with excellent results; both stability and calibration have been maintained after months of underground use. The same type of technology is presently being adapted to other gases including NO, NO_2, SO_2, and H_2S. An alternate technology is being pursued for the measurement of CO_2.

The problems of underground instrumentation from a human factor viewpoint are considerable, particularly considering that for the foreseeable future each toxicant will require its own detecting device and dictate that every effort be made to minimize the size and weight of devices to be carried by mine personnel. Dosimetry is one approach to reducing package size. Shown in Figure 12 is a nitrogen dioxide dosimeter that can be worn by the miner. At the end of the shift the device is analyzed to determine the dose of nitrogen dioxide obtained during that particular shift.

Shown in Figure 13 is a typical installation of a CO_2 monitor with the warning and meter display in the operator's cockpit; this device has been successfully evaluated in a number of operating mines. Several small

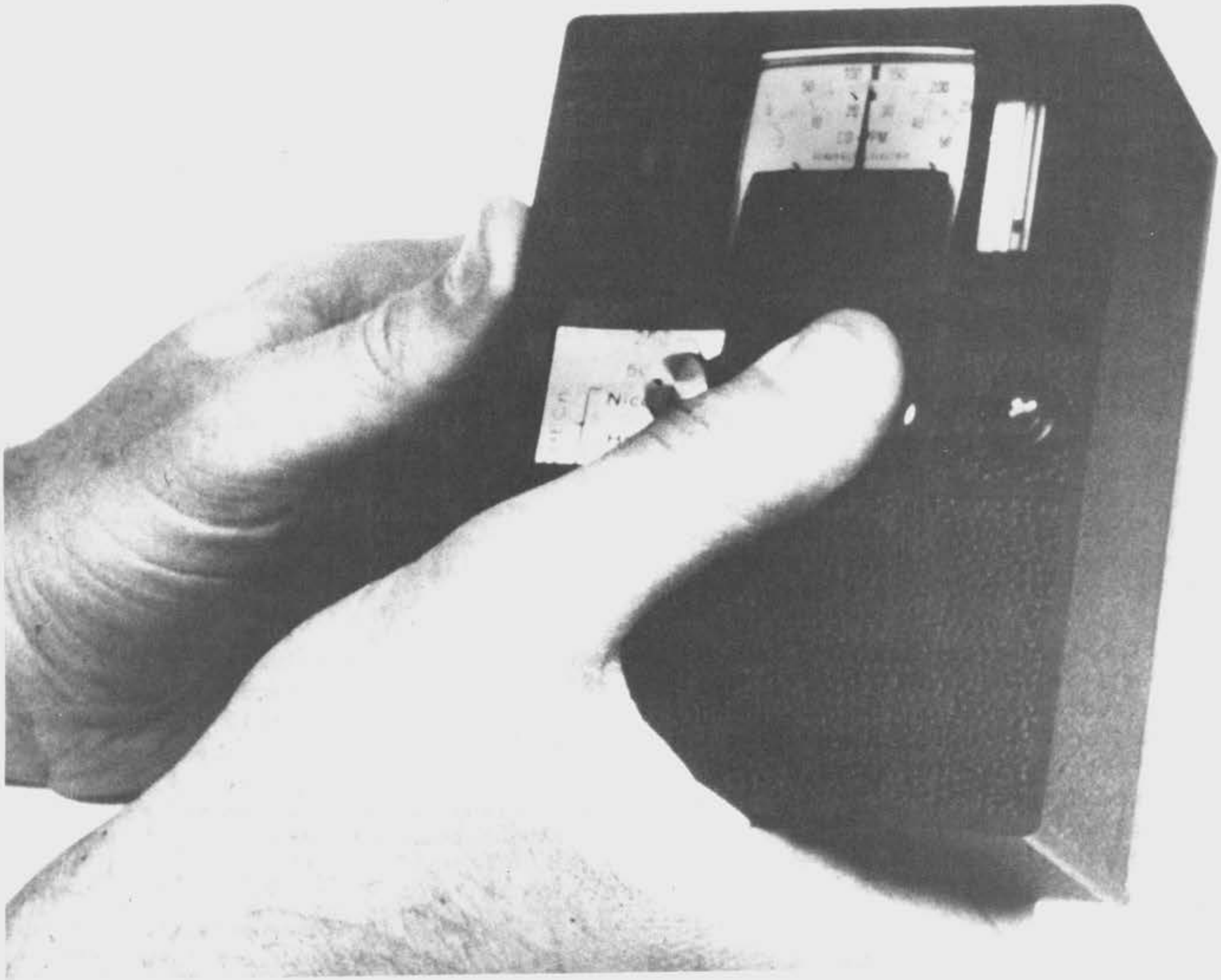

Figure 11. Prototype electrochemical carbon monoxide detector for underground use.

Figure 12. Nitrogen dioxide dosimeter for full shift exposure measurements.

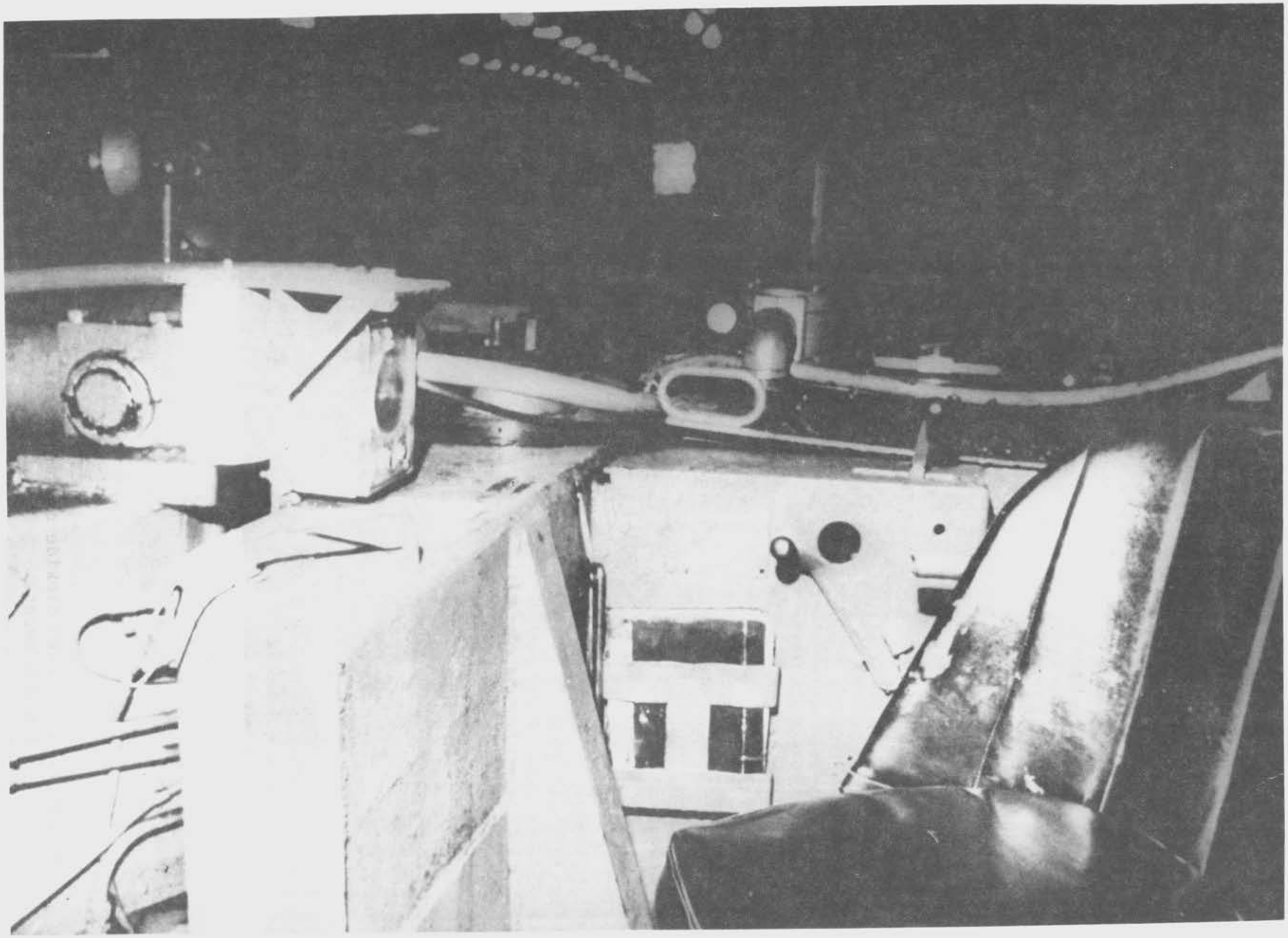

Figure 13. Machine mounted CO_2 monitor.

engineering changes are being made, and the device will be used in extended underground trials.

The Bureau has an extensive program in area monitoring, and Figure 14 shows one device developed under Bureau funding that is now commercially available. This particular station monitors three parameters: air flow, carbon monoxide, and methane. Similar technology has been adapted to other system configurations and is being evaluated in operating mines.

The fifth area is that of noise control; the principal activities have been directed toward the identification of noise sources and the development of procedures to control these sources. In the case of a load-haul-dump operation, which commonly used diesel-powered vehicles, initial unabated noise levels are 98 to 100 dBA. After modification, the noise levels were reduced to approximately 90 dBA. A noise control package for a Wagner load-haul-dump is now commercially available based on the results of this research.

In another example, a German dispatch vehicle was modified to reduce personal noise levels from 98 to 88 dBA, which keeps the miners in compliance for an 8-hour exposure.

This paper has been a brief overview of the Bureau program; in summary, the progress consists of developmental engineering, analytical work, and field investigations, covering three of the four areas to be reviewed by the working groups this week. We welcome the identification of gaps in these areas that should be addressed. This work, in conjunction with the epidemiological and medical work of NIOSH, should permit a positive assessment of the potential hazards and the development of adequate control technology for the use of diesel-powered vehicles in underground mining operations.

QUESTIONS AND ANSWERS:

QUESTION: We don't get anywhere with non-polluting engines until we have a duty cycle. Is there a cycle being developed which is suitable to mine applications?

(Dr. Van Dolah deferred the question to John N. Murphy, Research Supervisor, Pittsburgh Mining and Safety Research, U.S. Bureau of Mines.)

MURPHY: We have accumulated considerable industrial engineering data on cycles on the surface and are in the process of reducing this to better quantify the types of operating cycles diesels go through. Based on this data we will be better able to provide input into the physical operating cycles of diesels.

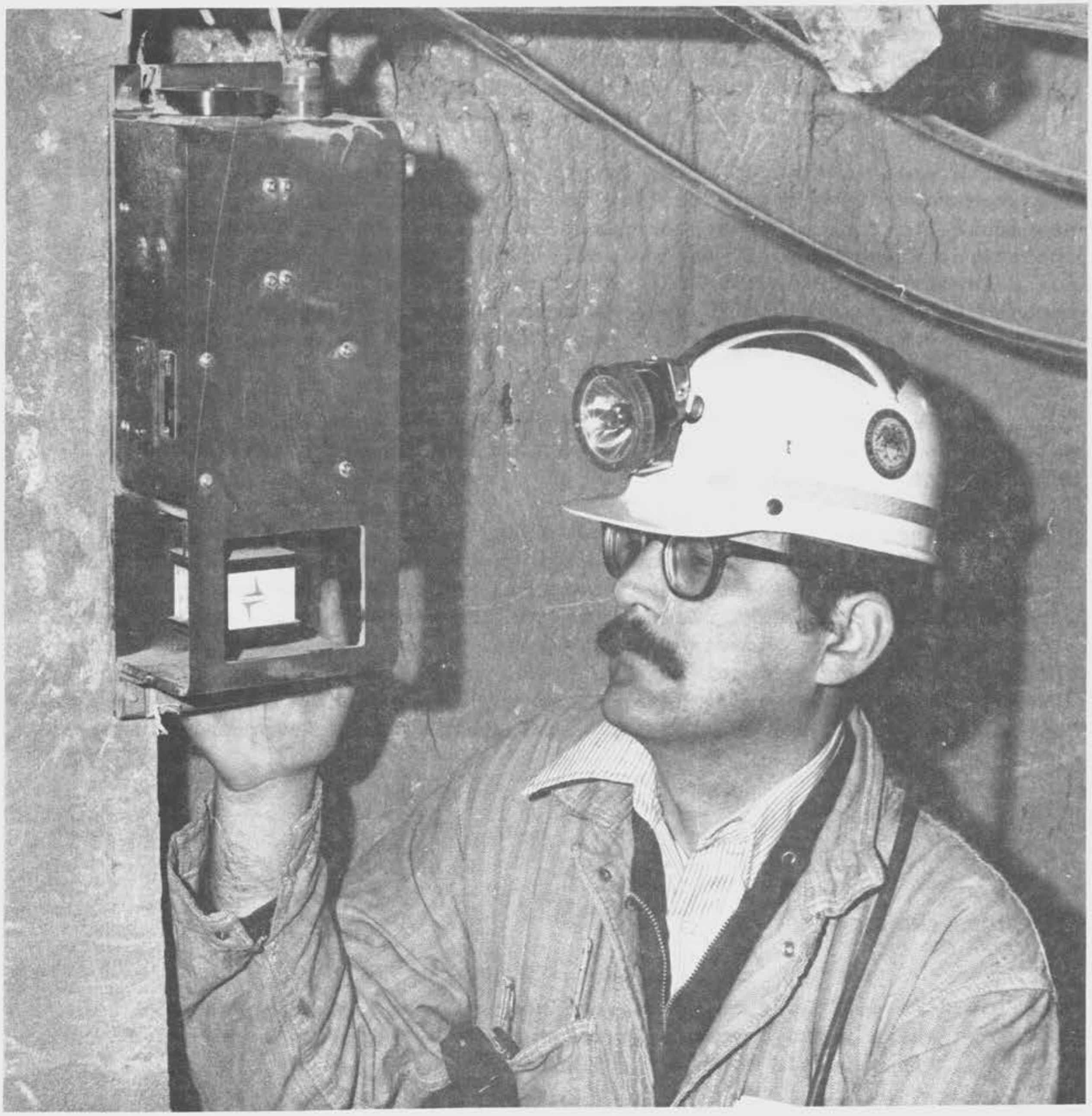

Figure 14. Mine monitor station which measures air flow, carbon monoxide and methane.

EXPERIENCE IN THE USE OF DIESEL EQUIPMENT IN NEW SOUTH WALES COAL MINES

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INTRODUCTION

In 1976, Australia produced 83.1 million tons of black coal of which 40.8 million tons came from underground mines and 42.3 million tons from open cuts. New South Wales was by far the largest producer of underground coal with 35.7 million tons, followed by Queensland 4.3 million tons, Western Australia 0.6 million tons and Tasmania 0.2 million tons.

This paper is concerned essentially with experience in New South Wales but statistics on the use of diesel equipment from other States are also included. There are no significant differences between requirements for approval and operation of diesel equipment between the various States.

MINING METHODS

Australia, like the United States of America, produces most of its underground coal by the highly mechanized bord and pillar or room and pillar system. In recent years Australia has introduced both the longwall and shortwall systems but the amount of coal won by these systems in 1976 accounted for only 4.2 percent of total underground production.

The thickness of coal seams in New South Wales varies from one meter to nine meters, with 77 percent of production coming from coal seams in the range two to five meters. Grades are generally flat to slightly inclined with the steepest now being mined lying at about 1 in 3 1/2 in only a few cases. Even at this grade, off-track diesel vehicles are used.

Ventilation is by the exhaust system, with faces ventilated by means of line brattice or face fans with tubing. The depth of the seams now being worked varies from outcrop to approximately 550 meters.

Physical and mining conditions and safety legislation in the United States closely resemble those in Australia.

HISTORY OF THE USE OF DIESEL ENGINES UNDERGROUND

There are references in technical literature as far back as 1912 to the use of seven Petter compression ignition type engines being used underground to drive pumps. Although safeguards, if any, would be crude in those days, there are no known references to accidents resulting from their use. In 1926, legislation was introduced in New South Wales prohibiting the use of internal combustion engines underground. This legislation was amended in 1941 when the following Rule was inserted into the Coal Mines Regulation Act:

> "An internal combustion engine shall not be allowed underground in any mine unless it is of the compression ignition type with safeguards and is installed and used as approved by the Chief Inspector."

It is significant that when the Act was amended to permit the use of diesel engines underground another rule was also introduced requiring the provision of underground man transport.

The first diesel engine in this era was used for locomotive hauled man transport at Mount Keira Colliery and was introduced shortly after the Act was amended. This was a 10 ton, locally-built, locomotive powered by a Gardner 5 L.W. engine developing 80 bhp. The design largely followed British practice where diesel locomotives had been in use for some years. For practical purposes Australian experience with diesel engines in underground coal mines can therefore be regarded as from 1941. Diesel equipment in underground coal mines consisted only of rail-mounted locomotives, ranging in sizes up to 25 tons and 204 bhp, and were used for coal haulage as well as men and materials transport.

While there is no evidence of adverse effects from diesel fumes on locomotive crews over the long period from 1941 to the present time, it is conceded that these units were confined to main intake roads where adequate ventilation was passing. A more severe test came in 1966 when diesel shuttle cars were introduced into face areas. These were followed by other diesel units, both track-mounted and pneumatic-tired, which have been used in large numbers and for a variety of purposes including face haulage, men and materials transport, personnel cars, roof drills, rock dusters, tractors and front end loaders. Table I indicates the number of units in use in Australia as of December 31, 1976.

Off-Track Equipment

The growth in the use of off-track diesel-powered equipment can be attributed to the following factors:

1. Coal transport is now almost exclusively by belt conveyor systems. Rail tracks which are costly to install would therefore be required only for the transport of men and materials.

TABLE I

DIESEL EQUIPMENT IN UNDERGROUND MINES

District	Shuttle Cars	Tractors	Men and Materials Transporters	Front End Loaders	Locomotives & Rail Mounted Personnel Cars	Misc.	Total
Cessnock - North West	8	7	30	32	15	5	97
South Coast	10	13	53	50	126	-	252
West	-	-	15	-	2	-	17
Newcastle	25	6	15	31	31	1	109
NSW Total	43	26	113	113	174	6	475
Queensland	12	-	52	8	14	3	89
Western Australia	-	5	2	25	-	2	34
Tasmania	-	-	1	-	-	-	1
TOTALS	55	31	168	146	188	11	599

2. Even if rail tracks are laid for men and materials, they do not extend to the face area and off-track vehicles are required from the end of the rail tracks to the face. The piggyback system in which off-track vehicles are loaded onto rail-mounted flat tops, where seam height permits, is one way of overcoming this problem.

3. Men and materials are frequently required to be transported to areas where the normal rail track would not, in normal circumstances, be provided.

4. Traditionally, the trailing cable of the shuttle car has been recognized as a major hazard in coal face transport. The introduction of diesel shuttle cars was therefore heralded as a major step forward in safe working by eliminating the trailing cable.

The choice of motive power for off-track equipment is limited to electric batteries, electric cable reels, or diesels. Diesel units are more flexible than cable reel units and handle adverse grades better and have a longer range than battery units. Cable reel units, still more limited in range, are usually limited to roof drills and shuttle cars.

In recent years, interest in diesel shuttle cars has waned, and the number used on face haulage of coal has declined. The reasons for this situation will be discussed separately as it is significant that the use of this type of unit has lost favor while other types of diesel units have made such outstanding advances.

Rail-Mounted Equipment

Concurrent with the increase in the use of off-track equipment there has been a remarkable increase in the number of rail-mounted vehicles.

Before conveyor haulage became widespread, rail transport of coal was normally by means of locomotives or rope systems hauling trains of cars or tubs. These systems were also used for men and materials transport. Regulations governing the installation and use of trolley wire systems are more onerous in N.S.W. than in the U.S.A. and there are now only two such installations in use.

Effect of Reduced Hours

In July 1970, the Coal Industry Tribunal brought down a decision which reduced the mine worker's weekly hours of work from 40 to 35, in two stages. From August 14, 1970, there was a reduction to 37.5 hours per week, and from June 30, 1971, to 35 hours per week. The working time is measured portal to portal. The total reduction, therefore, was 1/8th of the former hours. The effect on production, however, was more severe. For example, if travelling time from portal to face had been half an hour each way, and this would by no means be the longest, the effective working time at the face would be 8 hours less 0.5 hour meal break, and less total travelling time of one hour which leaves 6.5 hours. If the working day is reduced to 7 hours the effective face working time would be reduced to 5.5 hours so that the loss would be 1/6.5 and not 1/8. This caused management to look closely at the possibility of reducing travelling times. In one case where battery-locomotive-hauled man trips were replaced by self-propelled, diesel, rail-mounted, transport cars, travelling time was reduced from one hour to half an hour. These vehicles can travel up to 18 miles per hour. There was therefore a considerable incentive to install these diesel units.

Until the Tribunal's decision was given, the unions would only permit production on one shift per day except in special circumstances. The decision incorporated permission to produce coal on 24 hours per day. Shift arrangements vary from mine to mine; most work four shifts per day including one shift for maintenance. This major change demanded that greater attention be paid to the transport of men and materials and their separation from coal transport.

With the continuing development of face mechanization, it became evident that the most efficient method of getting men to the face was to employ vehicles which would transport a complete face crew without the need of shunting or uncoupling trains or transferring to another system. The self-propelled,diesel,rail-mounted,personnel car capable of carrying 10 to 20 men then became popular.

Much attention has also been given to the transport of materials underground. In hand mining days, timber and other materials were normally transported on the same haulage system as that used for coal. Special timber trolleys were employed and particularly with rope systems, due to the narrow gauge and long over-hang of timber, derailments were frequent and men were required to accompany these trolleys. Delays due to the transport of materials resulted in consequent delays on the coal transport system, unless the materials were transported on a non-production shift.

The introduction of conveyor belt systems and multi-shift production required a separate system for transport of men and materials.

There has been considerable debate as to whether rail track systems should be provided to the sections with distribution from this point onward by off-track equipment or whether rubber-tired vehicles should be provided for the whole of the distance.

In both these systems diesel units have their place. In rail track systems, locomotives or self-propelled man transport vehicles are widely used, and on off-track systems, a wide variety of tractors, materials transporters, personnel cars, and other utility vehicles have literally mushroomed.

A very popular unit is the front-end type loader. This may be used for transporting materials, for cleaning up falls or for other general utility purposes. Some are fitted with special attachments such as cranes, dozer plates, etc. These were originally developed from farm type tractors suitably flameproofed. The early units were light and had only small wheels on the front with larger driving wheels on the rear. It soon became apparent that the front wheels which carried most of the load had to be increased in size, and refinements have been added from time to time to make them more robust and at the same time more maneuverable.

Shuttle Cars

The shuttle car was first introduced into New South Wales mines in 1966. It presented a problem which had not been previously encountered since it was required to be in the face area for the whole of the working shift. The conveyor belt onto which the shuttle car discharges its load is always in the intake airway so that all fumes generated must pass over the face workers. Table I indicates that there were 55 diesel shuttle cars in use at the time of survey. Only a few are now used on regular coal haulage.

When they were first introduced there were complaints from the face crews regarding diesel fumes and as a consequence the Joint Coal Board, which is responsible for the health of all coal mine workers in New South Wales, decided that as a precautionary measure the health of workmen employed in the vicinity of diesel equipment should be closely watched.

THE NEW SOUTH WALES JOINT COAL BOARD'S MEDICAL SCHEME

The Joint Coal Board was established in 1947 when the industry was in a most unsatisfactory condition in relation to the health and safety of workmen, industrial relations, availability of capital, and antiquated mining methods. Insofar as health and safety were concerned, coal workers' pneumoconiosis was widespread, and the insurance company covering workers' compensation insurance was insolvent. Unlike America, coal workers' pneumoconiosis had been recognized in New South Wales as a compensable disease since 1926. The largest number of claims for this cause came from the South Coast district where a high rank coking coal is produced, but there were also significant numbers in other districts. The impact of insurance premiums in the South Coast district was having a serious effect on the economics of mining in this important, expanding steel-making center. One of the earliest actions taken by the Board was to establish a medical scheme which conducted a sample survey of mine workers in 1948. The results are shown in Table II.

The sample represented about 10 percent of the work force. Several mines had an incidence of pneumoconiosis well above the relevant district average. The medical scheme, which had the full support of the mining unions, provided for the compulsory examination of all new entrants to the mining industry and the routine examination, at two yearly intervals, of all mine workers. Concurrently, dust control measures, including provision of adequate ventilation to the face and wetting the coal by water sprays, were introduced. The measures adopted have been so successful that the position has now been reached where no new cases of disabling pneumoconiosis are being made. The results of the most recent survey are shown in Table III.

TABLE II

PERCENT PNEUMOCONIOSIS PREVALENCE 1948
(Approximately 10 Percent Survey of Industry)

Progressive Massive Fibrosis	Pneumoconiosis X-ray Category 2 or Worse	Pneumoconiosis Category 1	All Pneumoconiosis	Number Examined
0.7	4.5	11.5	16	1,555

TABLE III

PERCENT PNEUMOCONIOSIS PREVALENCE 1970-73--ALMOST COMPLETE SURVEY

Progressive Massive Fibrosis	Pneumoconiosis X-ray Category 2 or Worse	Pneumoconiosis Category 1	All Pneumoconiosis	Number Examined
0	0.08	3.0	3.0	13,099

With the introduction of diesel equipment at the face in 1966, the Medical Branch was therefore well equipped to investigate the hazards to health from this use. Records of medical checks on workmen were available from 1948 and special expertise on chest examinations had been developed. The possible physiological effects of diesel fumes were investigated and it was decided that a special annual medical check would be carried out on face workers where diesel shuttle cars were in use.

In a letter to this Institute in January 1977, Dr. H. I. McKenzie, a Joint Coal Board Medical Officer, reported:

> "We have medically examined a batch of personnel operating or working the vicinity of diesel equipment at regular intervals as a special project and have found no increase in chronic bronchitis or emphysema ratings compared with a control group, nor have their respiratory function tests (FEV_1 and VC) shown any reductions.
>
> "From study of data derived from our autopsy series we are reasonably sure that there is an association between emphysema and nitrogen dioxide. As you know, emphysema is, by and large, a condition which develops at a slow rate (but the rate tends to accelerate as the disease progresses) over a period of many years.
>
> "We believe that the oxides of nitrogen are concentrated by adsorption on the surface of coal dust particles. If any particles of dust in the respirable range are retained in the lung then the area of lodgement is exposed to a considerable concentrated 'dose' of oxides. The subjects we have investigated specifically in our autopsy series had heavy exposure to fumes produced by shot-firing in the old days. To date we have insufficient numbers in the autopsy series but as we are still collecting material we should, in time, be able to clarify the matter. It goes without saying that we have no adequate autopsy material which we could use to compare diesel fume exposure and degree of emphysema since diesel equipment has been a relatively recent (1966) innovation, i.e. 'recent' compared with the average time required to produce significant grades of emphysema.
>
> "As you may recall our working miners are routinely subjected to a full medical examination at regular intervals (two-yearly)."

A communication from the Board's Chief Medical Officer, Dr. M. Glick, received by me in July this year states:

> "That following inspections and air sampling the findings did not indicate a health hazard.

> "Nevertheless, a closer watch was kept on men working in the vicinity of diesel operated equipment. Such men were examined annually and to date there is no reason to believe that the health of these men is being affected by their proximity to diesel powered equipment.
>
> "In answer to the question relating to the harmful effects of the combination of fumes discharged from diesel powered equipment and airborne coal dust, we have no information. However, since our dust suppression techniques are achieving satisfactory airborne dust levels, it is reasonable to suppose that in our mines the mixture of diesel exhaust and dust levels not greater than 175 particles per cc in the 1-5 micron range is not giving rise to a health hazard."

DIESEL LEGISLATION AND PRACTICE

Practices relating to flameproofing in New South Wales closely follow those adopted in the United Kingdom and the United States, with the exception that in New South Wales plate flame traps are not required on the exhuast side of the engine as the exhaust conditioners are considered adequate for the purpose. Flameproof testing is carried out by the Department of Mines or at workshops approved by the Department. The Department stipulates the minimum amount of ventilation that must be provided for each diesel unit operating in a ventilating split as a result of analyses carried out on samples of exhaust gases taken before they enter the conditioners. Safety controls include shut down devices operated by excessive cooling water temperature, low lubricating oil pressure, and low water level in exhaust conditioners with thermal probes where spray cooling is employed in the exhaust.

Some catalytic scrubbers have been in use since November 1976 and are reported to be giving good results. In view of the short experience, however, this can only be taken as indicative. Such scrubbers are most effective at high temperatures and since it is necessary for exhaust gases to be cooled before discharge into the airway, the scrubbers are installed as close as practicable to the manifold. The catalytic unit is constructed of a cellular ceramic with platinum inclusions.

Typical shift, four weekly and monthly tests are described in the Appendix, "Rules and Special Conditions Governing the Use of Diesel Powered Scooptrams".

Engines are normally derated, but with the catalytic scrubber full rating can be permitted. One manufacturer has also achieved full rating of a particular engine by redesign of the manifold to give a larger exhaust port diameter while still retaining the required flame path distance.

There have been many types of diesel engines in use on flameproof units including Hercules, John Deere, Cummins, Gardner, Caterpillar, Deutz, Ford, BMW, Rolls Royce, Rover, Ruston & Hornsby, Volvo and Perkins. In general, indirect combustion engines have better characteristics than the direct combustion type regarding discharge of toxic gases. It has not been found difficult to comply with exhaust emission standards, but the degree of derating varies and each engine has different characteristics.

DIESEL SHUTTLE CARS AND FRONT-END LOADERS

Special consideration of our experience with these two types of vehicles is warranted since they are used over relatively short distances close to and on the intake side of the face area. Front-end loaders are normally only used for coal loading, hauling and dumping in relatively small mines or under special conditions but are a most useful unit for cleaning up falls or spillage. There are, however, three mines which use this method quite successfully for normal coal production and there are no objections by workmen to their use.

Our experience with shuttle cars is the more important and will be dealt with in detail since these units have not achieved the acceptance initially anticipated. Comments regarding diesel fumes, however, apply both to front-end loaders and shuttle cars.

Advantages of diesel cars over cable reel cars include:

1. Greater Flexibility

    a. The range of a cable reel car is limited by the length of cable reel, normally about 160 meters. There are no such constraints with diesel cars.

    b. One diesel car can be used for materials handling and also a spare for coal haulage; in the event of breakdown of a face unit the spare unit could be substituted at short notice.

    c. If more than two cars are required for one face unit the diesel can be more readily accommodated. This can be important in the case of multi-heading development.

2. Safety

    The trailing cable of shuttle cars has long been recognized as one of the most potentially dangerous items used in the face area. The introduction of the diesel car appeared to be an acceptable means of eliminating this hazard.

The disadvantages include:

1. Diesel Fumes

    At first, men objected to the fumes and were apprehensive as to the physiological effects, but as previously noted, our Medical Division has concluded that there is no evidence of adverse effects during the past 11 years that they have been in use.

2. Maintenance

While times required for refuelling, changing or cleaning flametraps, and checking operation of safety controls are not in themselves long, they do add up to significant delays in total, especially in multi-shift working where crews change at the face. Of more consequence, however, the diesel engine requires a greater amount of mechanical maintenance, and time out for exhaust gas emission testing. These times must be compared with those for the trailing cable unit where electrical maintenance on the car is not onerous but trailing cable problems can be significant. The various times have not been quantified as for other reasons the cars have not achieved the success hoped for.

REASONS FOR NON ACCEPTANCE OF DIESEL SHUTTLE CARS

It was unfortunate that when these shuttle cars were introduced in 1966 the only flameproof engine of suitable size available was the Hercules. This engine was heavily derated, was under-powered, and it was difficult to ensure that emission standards were complied with. Over-heating problems were encountered and this was accentuated by the fact that the units were used in muddy conditions which tended to clog the radiators. The engine was mounted on the extremity of the chassis remote from the operator; the units were therefore out of balance, and in addition the radiators frequently dipped into the mud. In some later models the engines were moved to a location on the driver's side between the wheels, but constraints of height still required the radiator to be installed close to the floor. Thus, while the machine was better balanced, little advantage in relation to clogging of the radiators was obtained.

The engines also proved difficult to maintain. The limited space around the engines left little room for adjustment and repairs. Further, when diesel units were first introduced into face areas, specialist diesel mechanics were not always readily available. Operating problems included starting difficulties. Starting was by means of compressed air, and when the supply ran out a compressor had to be brought to the section.

Caterpillar engines were later installed in some units and gave better results but still working space around the engine was limited. However, by this time interest in diesel shuttle cars was waning and the size of the engine selected had to conform with the constraints of the space available.

Some shuttle cars are still used for regular coal haulage but the majority are now used for materials handling with intermittent use on coal haulage in the event of breakdown in the cable reel units.

While no new diesel shuttle cars have been made for some years, several materials handling units with conveyor chains have been introduced and bear a strong resemblance to the shuttle car. For coal haulage, however, reliability is the prime concern.

There is now available a wide range of diesel engines which can be flameproofed. These include at least one designed for marine work which is of more squat design. It is a turbo-charged unit and has a higher power rating. The view has been expressed on more than one occasion recently that diesel shuttle cars are likely to come into favor again. One manufacturer of mining equipment, who also has an interest in a proposed mining venture, recently informed me that if the venture proceeds the mine would be laid out for diesel shuttle car coal haulage.

I have discussed the matter of diesel fumes with a number of operators who have used diesel shuttle cars at the face but have now discontinued their use on regular coal haulage, and all confirm that the reason for their withdrawal had nothing to do with diesel fumes. In every case objections were by the management and related to unreliability and high maintenance.

Noise

A survey of noise levels in the New South Wales coal industry was carried out in 1972-74 by R. Lauder and myself. With regard to transport equipment, the highest readings were obtained from large diesel front-end loaders which gave readings ranging from 92-106 dBA. Small units recorded readings in the range 86-96 dBA. Shuttle cars, whether diesel or electric, fell within the range 80-93 dBA. Some of the electric cars were surprisingly high and were influenced by noise pump motors. It is considered that more attention to design features could reduce the noise levels of both electric and diesel units to acceptable levels.

Roadway Surfaces

The condition of underground roadways is of great concern in relation to the use of any type of off-track equipment. Vehicles are too often required to run on roadways which are deeply rutted and covered with water and mud. Cases have been noted where units capable of travelling at 30 km/h are required to travel at less than walking pace because of the condition of the roads. This not only leads to waste of valuable time, but the wear and tear on the vehicles is excessive and in particular, places excessive strain on chassis, mountings, and joints. It is potentially hazardous and certainly uncomfortable for personnel. These conditions would not be tolerated on surface operations and a research project into the construction of proper roadway surfaces would be warranted, both from the safety and economic aspects. This matter is being considered in New South Wales at the moment and the services of a competent road building engineer could well be employed to advantage.

FIRES DUE TO TRANSPORT VEHICLES

Results of a recent study of fires on underground transport vehicles from the period July 1, 1969,to June 30, 1974, are shown in Table IV.

Details of the number of vehicles in each classification during those years are not readily available.

The number of fires on battery equipment is surprisingly large. Fires on cable reel shuttle cars include those attributed to the trailing cables but do not include fires in control boxes or other parts of the electrical reticulation system.

The majority of the fires on both the shuttle cars and diesel units originated in the brakes, and action is now being taken to ensure that the braking systems are of adequate design. It may be of interest to note that in 1967 the Coal Mines Regulation Act was amended to require the use of approved fire resistant hydraulic fluids in the braking systems of shuttle cars and personnel cars.

Only one of the fires reached dangerous proportions and occurred on a materials transporter. It originated in the brakes and the fire spread after the unit had been left unattended.

CONCLUSIONS

1. The history of the use of diesel equipment in New South Wales coal mines has been very satisfactory, dating back to 1941.
2. Diesel shuttle cars have not lived up to expectations but lack of general acceptance has been due to factors other than safety or health considerations connected with the diesel engine.
3. There is every probability that with the availability of more suitable diesel engines, more experienced diesel mechanics, and more efficient braking systems, the diesel shuttle car may yet find acceptance.
4. The use of diesel equipment is readily accepted by the workmen.
5. Although the health of workmen associated with diesel equipment has been closely monitored since 1966, there is no evidence of any hazard to health.

ACKNOWLEDGEMENTS

The kind invitation and the conditions attached thereto of the National Institute for Occupational Safety and Health, Morgantown, West Virginia, is gratefully acknowledged.

Appreciation is also expressed to the Joint Coal Board for permission to present this paper and to take part in the Workshop, and to the Department of Mines in the various States who supplied statistical data.

TABLE IV

FIRES ON UNDERGROUND TRANSPORT VEHICLES 1969-1974

Battery locomotives	21
Diesel locomotives, shuttle cars and personnel cars	61
Cable reel shuttle cars	82
Battery shuttle cars	28

APPENDIX

RULES AND SPECIAL CONDITIONS GOVERNING THE USE OF DIESEL-POWERED SCOOPTRAMS

The approval to operate diesel-powered equipment as specified in the attached letter of approval* is given in accordance with general Rule 5A, Section 54 of the Coal Mines Regulation Act, 1912, as amended and is subject to the following rules and special conditions. These Special Conditions are in addition to and not in substitution for the provisions of the Coal Mines Regulation Act, 1912, as amended, and of the Rules and Regulations made thereunder:

GENERAL

(1) Each scooptram shall comply with the specifications approved by the N.S.W. Mines Department and shall be numbered.

(2) The flameproof electrical equipment on a scooptram shall be subject to and maintained in accordance with the provisions of the Act which relate to flameproof enclosures. The flameproof parts of the engine, including the inlet and exhaust systems, shall be maintained in accordance with the approved specifications of the scooptram and shall be kept securely closed and sealed while the engine is in operation.

(3) Engine adjustments shall be verified by the manufacturer as being correct before each scooptram is put into operation.

DRIVING

(4) A scrooptram shall not be driven in the mine otherwise than by an appointed driver, or a person who is authorized by the Manager to receive instruction in driving under the supervision of an appointed driver. An "appointed driver" means a person who has

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*Potential users of diesel equipment in underground mines must apply to the N.S.W. Mines Department. If the request is approved, the mine operator receives a letter of approval specifying certain conditions under which the equipment must be used.

been appointed as a driver by the Manager. A copy of these Conditions shall be issued to each appointed driver.

(5) A scooptram shall operate only on such grades that it can safely be controlled under all circumstances of speed and load.

(6) The driver of a scooptram shall adhere strictly to these rules and to the instructions issued by the management governing the operation of the scooptram and shall at all times take all reasonable precautions for the safe working thereof.

VENTILATION AND CONTROL OF EXHAUST GASES

(7) The use of the scooptram underground shall be restricted to roadways and working places where positive (controlled flow) ventilation is maintained. A scooptram shall not be shunted or stood in any unventilated dead-end.

(8) Not more than two scooptrams shall be operated at the same time in a single air split.

(9) A scooptram shall not be used in any place where there is not for the time being a sufficient current of air to render the gas from its exhaust harmless, but in any case, the quantity of air passing along any part of a roadway in which a scooptram operates shall not be less than the quantity specified in the attached letter of approval.

(10) Once at least in each working shift whilst a scooptram is in normal operation, the atmosphere of the roadways along which it is operating shall be tested with an approved detector or detectors capable of detecting ten parts per million of carbon monoxide, one part per million of oxides of nitrogen, and 0.5 percent methane. The results of these tests shall be recorded. Tests shall normally be made approximately ten feet from the scooptram and approximately five feet from the floor on the return air side.

(11) Where, in any working place or road in which a scooptram is in use, there is found in the general air a concentration of carbon monoxide greater than 50 parts per milion, or of oxides of nitrogen greater than 5 parts per million, or of a methane of 1.25 percent or greater, immediate steps shall be taken to disperse the said concentration, and the engine shall not be operated until it is found that the concentrations of these gases are below the limits specified.

OPERATING CONDITIONS AND EXAMINATIONS

(12) The requirements of Regulation 27 (a) of the Seventh Schedule of the Act in relation to the operation of electrical equipment

shall, for the purpose of these conditions, also apply to diesel scooptrams.

(13) In any gassy place, the roadways in which a scooptram has to operate during a shift shall be inspected for inflammable gas twice during that shift by a competent person using a locked oil flame safety lamp and the results shall be recorded. The person making the inspection shall take adequate precautions to prevent a scooptram entering or operating in any roadway or place where he detects inflammable gas. For the purposes of this condition, a "gassy place" shall be defined in the Act with the exception of paragraph "c" of that definition.

(14) A scooptram shall not be used in a dry and dusty place.

(15) The engine of a scooptram shall not be left running while the scooptram is unattended.

(16) An approved fire extinguisher shall be maintained ready for immediate use on the scooptram.

(17) During the course of examinations, adjustments, repairs or other maintenance work on the chassis or undercarriage of the scooptram or engine, the engine shall not be in operation.

(18) A scooptram shall not be used in the mine if:

(a) it has any defect liable to affect its safe running, or

(b) it is not maintained in proper working order or replenished with all necessary oil and consumable stores, or

(c) flameproof devices do not comply with rules and conditions herein, or

(d) the exhaust contains black smoke.

(19) Once at least in every working shift, the exhaust conditioner shall be drained and refilled to the required level with clean water by an authorized person.

(20) Once at least in every day, a competent person shall examine each scooptram used during that period in accordance with General Rule 5 of the Act, and the flame trap fitted to the exhaust opening of the engine, if any shall be detached and replaced by a trap in clean condition. If any defect likely to affect the safe working is detected, he shall suspend operations until the defect is remedied.

(21) Before the start of each working shift, a test shall be made to determine the operation of the low water cut-off switch between the conditioner make-up tank and the exhaust conditioner. The

test shall be such that the engine is caused to stop by the operation of the low water cut-off switch. The scooptram shall not be used if the cut-off switch fails to stop the engine.

(22) Once at least in every week a competent person shall examine each scooptram and shall clean the accessible working parts, see that they are in proper working order, and shall clean the inlet and exhaust protective plate devices and valves as often as it is found necessary to maintain their safe and efficient operation, and shall ensure that all heated surfaces are regularly cleaned of combustible materials. All material used for cleaning the engine shall be placed in the special container provided for the purpose and removed from time to time as it becomes necessary.

(23) Once at least in every week, the braking system of each scooptram shall be examined and tested by a competent person, and the said test shall include application of the brakes on the maximum operating down grade when travelling in a direction in favour of the load to ensure that the scooptram can be brought to rest within a reasonable distance. Immediately after any repairs or adjustment to the braking system of any scooptram, an examination and test shall be made as provided aforesaid.

(24) Once in every four weeks the undiluted and unconditioned exhaust gases of each scooptram shall be sampled and analyzed and should the carbon monoxide content be found to exceed 1,500 parts per million, or the oxides of nitrogen content be found to exceed 1,000 parts per million, the scooptram shall not be used until the quality of the exhaust gases has been brought within the limits above specified. A copy of the results of these analyses shall be forwarded immediately to the District Inspector. The samples of exhaust gases shall be taken when the engine is being run:

(a) at maximum speed on full load;

(b) at normal idling speed on no load.

Analysis of undiluted exhaust gas samples by the use of Drager sampling tubes is permitted, subject to the following:

(c) The sampling shall pass through an approved cooler prior to entering the Drager sampling tube.

(d) The monthly report required under (25) below shall be noted as a Drager tube determination.

(e) In the event of any doubt or dispute regarding the result of determination by Drager tubes, laboratory chemical analysis of undiluted exhaust samples shall be carried out.

(f) Once each six months, laboratory chemical analysis of undiluted exhaust gas samples shall be carried out.

(25) Reports of the examinations and tests required under these Rules shall be recorded without delay in books to be kept at the mine for the purpose.

FUEL OIL

(26) The oil used as fuel shall be of best quality and shall contain not more than 0.3 percent sulfur and have a flash point of not less than 150F determined in the manner indicated in the current British Standard (Institute of Petroleum) specifications.

REFUELLING

(27) Refuelling arrangements for each scooptram shall be carried out in compliance with the requirements of the District Inspector.

NOTIFICATION

(28) The Manager shall notify the District Inspector immediately of the commencement or the discontinuance of use of scooptrams in a district of the mine.

GENERAL MAINTENANCE

(29) The maintenance of diesel scooptrams in approved conditions shall be delegated only to authorized competent persons appointed by the Manager.

(30) Engine intake and exhaust systems shall be inspected visually at least once each working shift.

(31) Maintenance, inspection and repair work shall be done in accordance with instructions of the manufacturer. Records shall be kept of maintenance, inspection and repair work.

MAINTENANCE OF ENGINE-FUEL-INJECTION SYSTEM

(32) Injection nozzles shall be maintained in proper operating condition. Particular attention shall be given to preventing imperfect atomization or distribution of the fuel. Replacements of worn or broken injection valves shall be identical with those on the engine when the diesel machine was approved.

(33) The engine fuel pump shall be sealed or locked to prevent tampering. The seal shall be broken only by an authorized person, when necessary for adjustment, after which the pump shall be resealed.

(34) Service or adjustment required to be done on the fuel pump shall only be carried out by the manufacturer or by service facilities approved by the engine manufacturer or his agent. The fuel pump shall be set to deliver not more than the maximum quantity of fuel specified.

INSPECTION AND MAINTENANCE OF ENGINE-INTAKE SYSTEM

(35) The engine-intake system, including flame arrester, air cleaner, and all joints shall be inspected at intervals according to the manufacturer's maintenance instructions. Inspection of the engine-intake system shall include tightness of all joints and cleanliness of flame-arrester surfaces.

(36) Periodic measurements shall be made of the vacuum in the engine intake system to determine whether the air cleaner and flame-arrester require cleaning.

(37) The air cleaner of the engine-intake system shall be maintained in accordance with the manufacturer's instructions. The normal oil-filling level shall not be exceeded.

INSPECTION AND MAINTENANCE OF ENGINE-EXHAUST SYSTEM

(38) The engine-exhaust system, including flame arrester, conditioner or cooling boxes, shut-off mechanism, water spray, and exhaust-dilution system shall be inspected at intervals, according to the manufacturer's general maintenance instructions.

(39) Periodic measurements shall be made of the positive pressure in the engine-exhaust system to determine whether the exhaust flame arrester, if fitted, requires cleaning.

(40) Float valves shall be serviced at intervals according to the manufacturer's instructions to maintain them in good operating condition.

(41) Functioning of the fuel shut-off mechanism, actuated by the exhaust gas temperature, shall be tested at least once every three months. This test shall be made in a safe place in a main intake airway.

VARIATION OF CONDITIONS

(42) These Conditions may be added to or varied at the discretion of the Chief Inspector of Coal Mines.

QUESTIONS AND ANSWERS

QUESTION: How were the inferences made from the collected data? If the data gives no evidence of cancer in 15 to 20 years, we cannot be sure it is safe. Asbestos takes 25 years for its harmful effects to show. The data should include the number of workers studied, the duration of their exposure, and medical inferences involved. What was the follow-up study and was it adequate? Is there enough data to make decisions? Are the studies published? If complete data is not available, how can inferences be made and their validity judged?

CLARK: The medical records were recently put into a computer. I am willing to make available what I can. I encourage further suggestions and correspondence about the data.

MOBILE POWER IN BRITISH COAL MINES

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SUMMARY

This paper reviews the present forms of power used for transport in British coal mines with particular reference to the safety requirements for diesel engines and the problems in operating them. It is expected that there will be increased need for mobile power in the future, and an outline is given of the research and development in progress to improve diesels and to explore other possible power sources.

INTRODUCTION

A number of good papers on British transport practice and the use of diesel power have appeared in recent years (1-6) and the aim of this paper is not to repeat this information but to be complementary, placing particular emphasis on expected future requirements and on the research and development being mounted so as to meet them.

During 1976-77, the National Coal Board produced 106 million tons from its 238 deep mines with a payroll of 242,000 men. Many of these mines are 100 years or more old and were not laid out with modern transport in mind. Whereas a great deal of reconstruction has of course been done, a certain legacy of tortuous roadways cannot wholly be avoided. New mines are notably level as the coal seams permit, but even with these, strata conditions in the United Kingdom do not permit very large and wide openings to stand. A typical inbye roadway would be an arched one, 12 feet wide and 9 feet high, precluding the use of large vehicles. Ninety-five percent of the coal is mined by longwall faces, only two or three mines being on stall and pillar methods.

For coal transport, the belt conveyor is becoming the standard means, right from the face to the shaft bottom. Although locomotive-hauled trains are still used for coal at quite a number of pits, it is no longer believed that there is a certain distance above which this is the more economical form of transport. Higher strength belt reinforcement and cable belts have made possible conveyor runs of five miles, and runs of ten miles are being proposed for new complexes. The same belt is quite often used for man-riding outbye, but there are only a few installations where two-way riding on belts is possible, and in any case this is not a suitable form of transport for materials of any weight. This paper is largely concerned with the transport of men and material, and for these by far the most common method is rope haulage of vehicles on conventional rail track. This is labour-intensive, but it is non-polluting and has the great advantage of being able to cope with gradients. Its serious disadvantages are the need for transfer of vehicles or the trans-shipment of loads from one haulage to the next and the accident liability.

Other trains on conventional tracks are propelled by diesel locomotives, of which the National Coal Board (NCB) now has 617 in use, or battery locos of which there are 337. Electric trolley locomotives, in spite of their widespread use in other countries, are permitted in the United Kingdom only under extremely stringent conditions. There have only been three installations, all in workings now closed, although two new installations are now under consideration. The locomotive statistics include some installations with special track on which the vehicles are captive. Such designs (Figure 1) have gained some popularity for use inbye. There is at present, however, very little use of overhead monorails.

About 80 free-steered diesel tractors and underground supply vehicles are in service, but the numbers of these have not been increasing in the last year or two, largely because of difficulties with soft floors. There are about 50 cable-reel shuttle cars in connection with the stall and pillar working mentioned above, and on conventional longwall districts there are a few training-cable crawler vehicles used for transport to the face. Mention must also be made of the pit pony. These have very largely been dispensed with in recent years for humanitarian reasons, but a few are still at work in certain pits; they are very well liked and useful for light material transport duties.

Last year, 1976-77, there were 38 fatal accidents and 515 other serious ones, giving a rate of 0.07 and 0.98 per 100,000 man shifts respectively (including both underground and surface work). These are the lowest figures ever and it is justifiable to take pride in them, but they were achieved only by continuous engineering improvement and careful attention to safety and personnel at all levels. It is intended that this attention be intensified so as to produce still better figures. Over one third of all accidents occured on transport work (8) which is some indication of the need for more engineering attention. However, these accidents were derailments, runaways and incidents of that nature. There has been no known instance of harmful results of fumes.

Further, about 17 percent of the payroll are employed on transport duties. In addition, men on coalface or tunnelling work, some 50 percent of the total, spend on average 1 1/2 hours from a shift time of 7 1/4 hours travelling to their place of work from the shaft bottom and back. One might say, therefore, that a further 10 percent of the payroll is wasted in travelling. The average distance from the shaft bottom to a coalface is at present about 2 1/4 miles, of which riding facilities are provided for 1 1/2 miles. Owing to

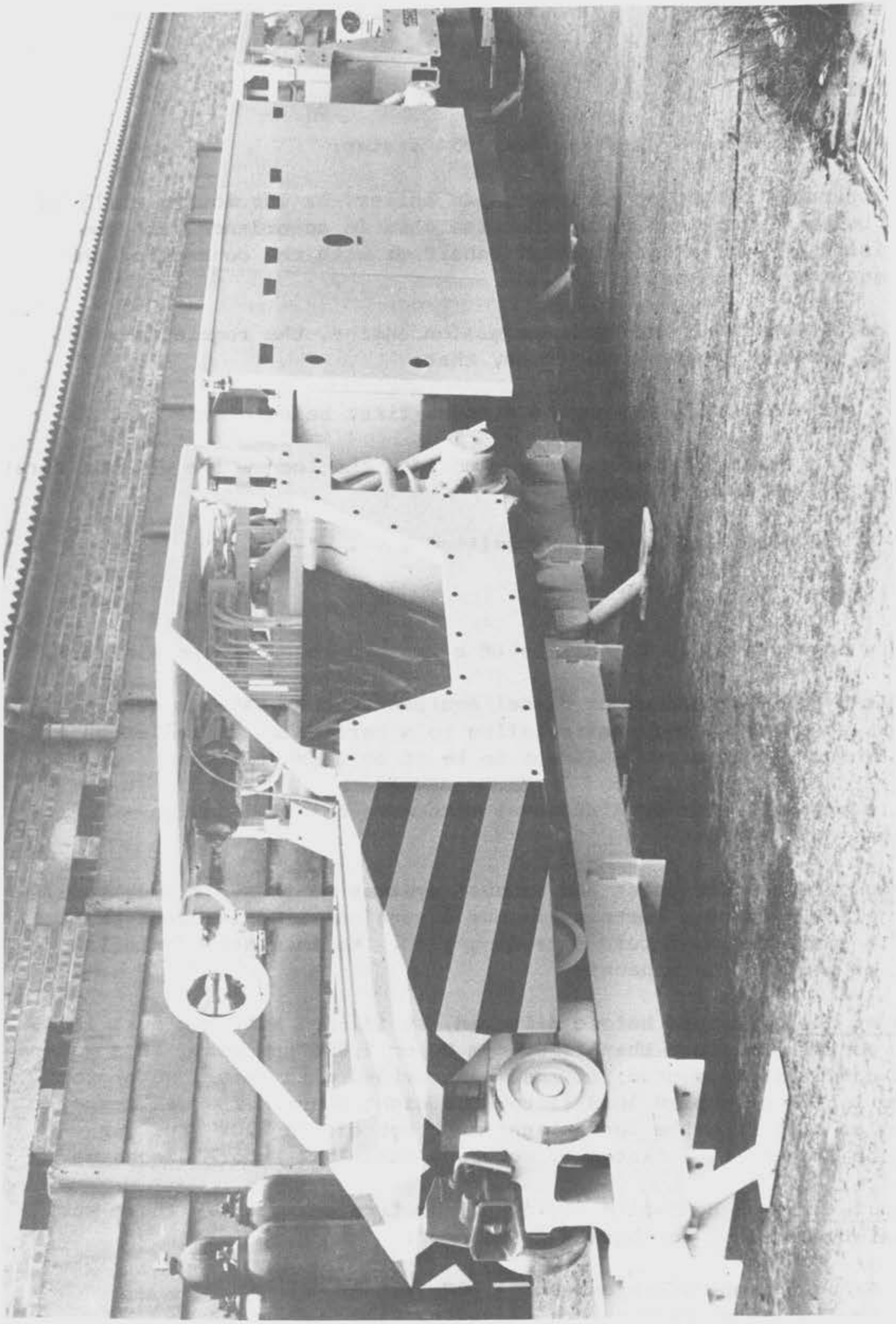

Figure 1. Becorit Captive Rail Locomotive, powered by MWM 100 hp diesel driving through hydrostatic transmission to polyurethane-tired wheels gripping rail webs.

the gradual extension of each working, continuous efforts to introduce man-riding are needed.

SAFETY REQUIREMENTS

Section 83 of the Mines & Quarries Act 1954 states:

> "No internal combustion engine, steam boiler, or locomotive shall be used below ground in a mine otherwise than in accordance with the provision of regulations in that behalf or with the consent of the Minister or an inspector."

For a locomotive with an internal combustion engine, the regulations (9) require, in respect of design features, that:

> ". . . no air enters the engine without first being cleaned
>
> . . . no exhaust gases are expelled from the locomotive without first being cooled and diluted; and
>
> . . . no flames or sparks are emitted . . . ."

and also that:

> "Every locomotive . . . shall be of a type approved by the Minister."

For trackless vehicles and other diesel equipment, there are no general regulations at present, but ones relating to a particular installation are made, and these too require equipment to be of an approved type.

The requirements (10) for type approval make more detailed design stipulations, including:

> Flameproofing - The inlet and exhaust systems must have flame traps, and joints must have certain minimum dimensions. No external part may have a surface temperature exceeding 150C. No insulating material must be used on the exhaust.
>
> Exhaust Gas - The gas before dilution, at idling, half and full load, must contain not more than 1,500 ppm CO or 1,000 ppm NOx. If a water bath conditioner is used, it must be provided with enough water for operation at one-third load factor for eight hours. The gas temperature at exit from the conditioner must not exceed 70C. The gas must be diluted by a factor of not less than 15:1 before discharge.
>
> Other features - Hydraulic fluid must be fire resistant. There must be safety cut-outs to operate in case of:
>
> Exhaust temperature exceeding 70C
> Cooling water temperature exceeding 112C
> Low water level in conditioner box

Hydrokinetic transmission temperature exceeding 110C
Hydraulic reservoir temperature exceeding 85C
Compressed air temperature exceeding 160C

Electric starting is not permissible

Noise level must not exceed 90 dBA with engine at full speed, allowing for wheel/track noise.

No external component may contain more than 15 percent of light alloys. (This is to avoid the possibility of an incendive spark when struck by rusty steel. This requirement makes it very difficult to use production diesel engines which have aluminum pumps etc., but permission has been obtained in some cases to use aluminum alloy if sprayed with metallic zinc.)

After a proposal has been checked to see that the requirements are complied with, testing is carried out by the Safety in Mines Research Establishment. This includes checks on the ability of the manifolds, etc. to contain an internal explosion (of a pentane/air mixture) without propagation to a methane/air atmosphere outside.

In addition, the requirements of the Health and Safety at Work Act (1974) will certainly apply to vehicles and engines as they do to any other manufactured item. This new legislation, which is only just starting to take effect in British engineering, makes it very clear indeed that the designer and manufacturer of any item must take full responsibility for accident or illness resulting from use of their equipment, so long as it has been used in a reasonable manner.

When the design of a vehicle has been approved, it must still be put to use in a proper manner, and the regulations continue with further requirements:

Daily flame trap cleaning.

Weekly brake testing.

Use of approved fuel only.

Exhaust gas sampling (CO may be up to 2000 ppm, but NOx levels are limited as explained above) every 90 days.

Ventilation so as to ensure that the CO in the general body of the air does not exceed 50 ppm (shut-down limit 100 ppm).

Shut-down of diesels if the methane content exceeds 1.25 percent.

Engine to be shut down whenever vehicle is stationary (unless for a brief period or for testing purposes).

It will be noticed that the general regulations restrict the amount of CO in the general body of the air but make no provision in respect to oxides of nitrogen. Recent local regulations for trackless vehicles have, in fact, imposed a limit of 3 ppm on the NO_2 concentration in the general body of the air.

DIESEL USAGE

The diesel vehicles in use by the NCB all have 4-stroke engines of water-cooled, naturally-aspirated types, both direct and indirect injection. The requirements for fire resistant fluid are met by using non-toxic phosphate ester in torque converters and invert emulsion (60 percent oil, 40 percent water) in hydrostatic transmissions. In some cases, type approval has only been obtained by considerable derating of the engine by comparison with its running conditions for surface use. Underground, the limit for CO in the exhaust is only occasionally approached and, if it is, this is quite a useful indication that maintenance is required. The NOx limit causes more difficulty on account of lack of understanding of how to adjust the engine so as to rectify an excess. The limit for CO in the general body of air is satisfied by using diesels only in well-ventilated roadways. A minimum air supply of 160 cfm per bhp is usually specified.

The small number of powered vehicles in use, in relation to the size of the work force, is certainly indicative of the scope for further mechanization of transport operations. It may be contrasted, for example, with the ready availability of equipment such as forklift trucks in general surface industry and factories. Both economics and the psychological attitude likely in the miner of the future will require that he should be able to ride virtually all the way to his place of work and, further, that most handling and other work should be powered, preferably without the need to couple up to an electrical main supply for minor jobs. Thus the availability of mobile power units is implied. The realization of this problem and attempts to solve it have been growing rapidly in recent years and the following examples may be quoted.

The NCB/MSA Rock-duster is an adaptation of an original electrically-powered unit which has been provided with a 6 hp single-cylinder water-cooled diesel. This makes a very convenient machine, of which about 20 are in service so far. It is also interesting as it is the first example of the use of a diesel engine other than to propel a vehicle.

The Hunslet Track Locomotive (Figure 2) does not break any new ground so far as the diesel drive is concerned but should greatly extend the field of application of diesel locos to gradients steeper than the present limit of 1 in 15. It will normally run on conventional wheels and track, but when the rack drive is engaged it can traverse much steeper gradients, possibly up to 1 in 4. A prototype is now undergoing tests which have proved successful so far. Nine others are on order.

Another approach is the use of high-friction-rubber-tired wheels on conventional track. This has been proved satisfactory on gradients of up to 1 in 10 with electric "Pony" locomotives (Figure 3) for several years and now a diesel-powered version of these is to be produced.

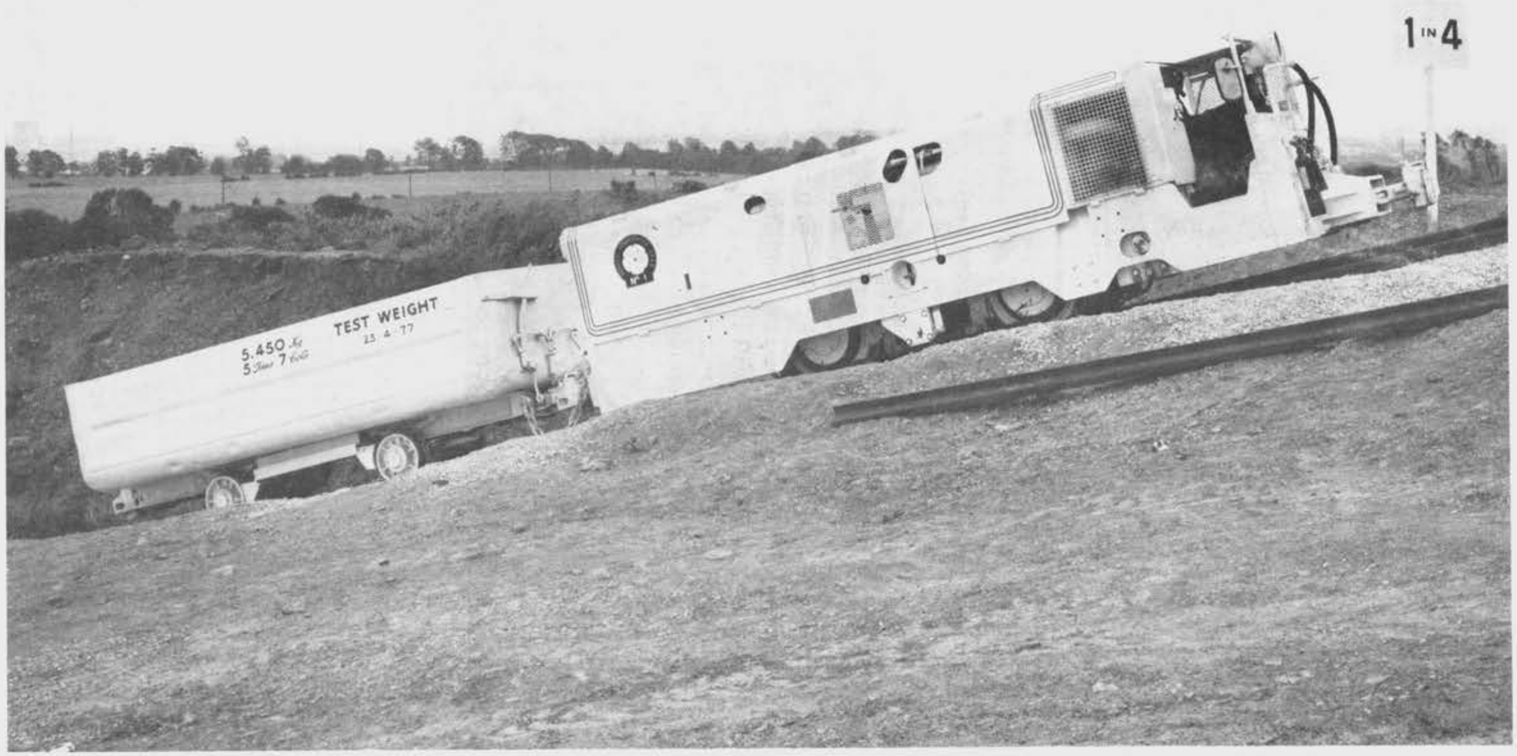

Figure 2. Hunslet rack/adhesion locomotive.

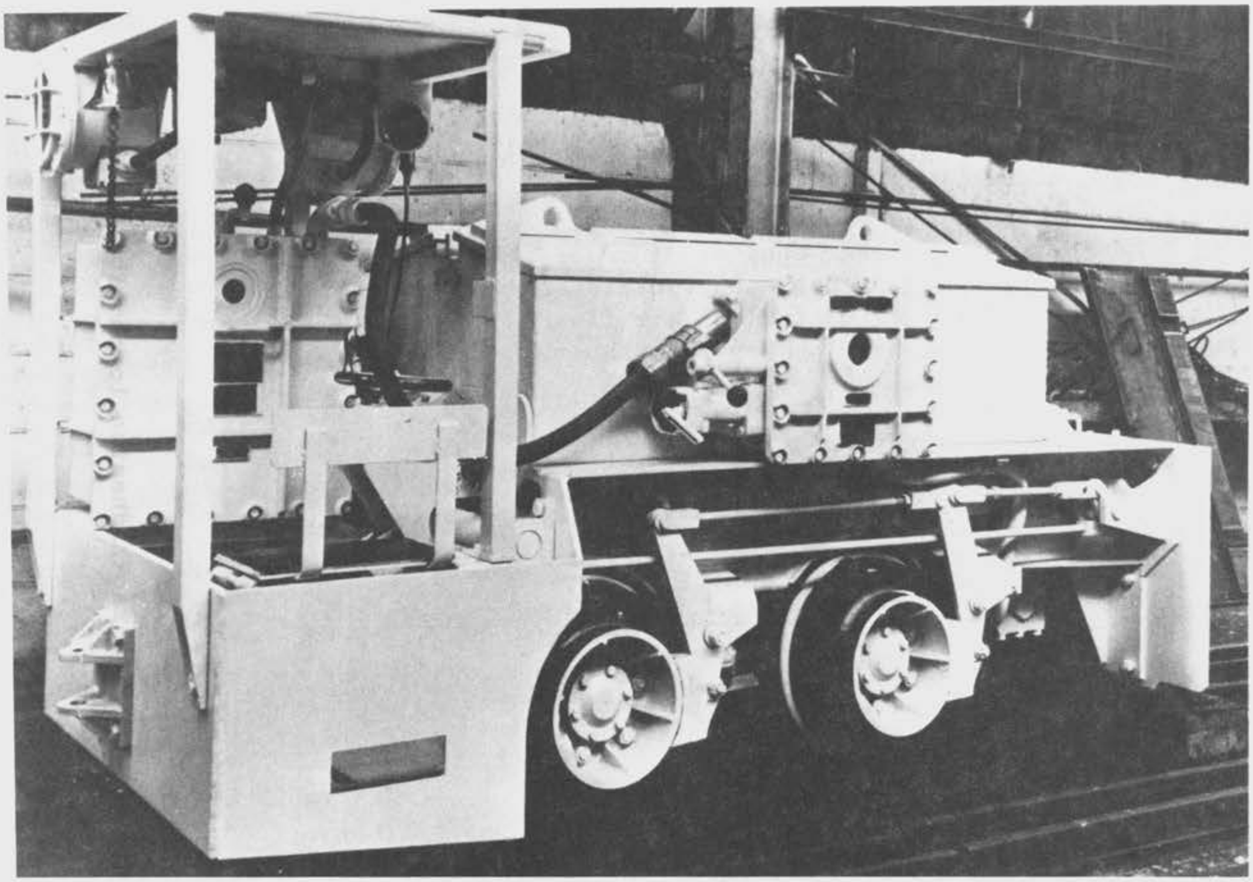

Figure 3. Clayton Rubber-Tired "Pony" Locomotive. This model is powered by an 11 hp electric motor and battery. A version with a flameproof diesel engine is under development.

The difficulties with diesel tractors were mentioned above. The problems were largely due to poor floors and wet conditions. The MRDE development program includes another attempt to introduce free-steered vehicles. Several American load-haul-dump trucks and a personnel carrier are being converted to British standards and coordinated with this is a study of methods of grading and surfacing mine floors.

DIESEL PROBLEM AREAS

Probably a point in favour of British longwall systems, as compared with stall and pillar working or other multiple-entry methods, is that the ventilation circuit is relatively simple. All old workings and similar areas likely to be poorly ventilated are stopped off so that no diesel vehicle would enter. But if the envisaged large increase in mobile power is to be met by using diesel engines, some of them will have to serve working places with more restricted ventilation than at present. Table I below gives some examples of typical air flow rates and the maximum diesel power that could be used if the 150 cfm bhp rule is adhered to.

TABLE I
Typical Airflow Rates and Corresponding Maximum Diesel Power Allowable

Location	Airflow, c.f.m.	Max. diesel b.h.p.
Heading	5,000 - 10,000	33 - 66
Longwall district	20,000	133
Whole pit	500,000	3,300

Sometimes there are reasons preventing ventilation being increased beyond figures such as these, and some of the situations could constitute a severe restriction on diesel usage. For example, 25 hp tractors have proved by no means over-powered, but literal interpretation of the above figures would mean that even these should only be used one at a time in certain headings.

To see whether it would be reasonable to suggest that the 150 cfm per bhp standard might be relaxed, the Threshold Limit Values (TLV's) (11) for the various gases involved are set out in Table II. The TLV's usually quoted are those permitted for protracted exposure 8 hours per day, the current British figures being the same as the American ACGIH ones. In the case of CO2 and CO there are often significant quantities present in mine air quite apart from diesel exhaust and allowance is made for these. The ventilation per horse-power required in each case is then calculated on the basis of an

TABLE II

THRESHOLD LIMIT VALUES (TLV'S) AND MINIMUM VENTILATION REQUIREMENTS

	TLV (ppm)				Min. ventilation (cfm/bhp)	
Gas	8 hour	Short-term	Ambient	In neat exhaust	8 hour TLV	Short-term TLV
CO_2	5,000	12,500[a]	2,000	100,000	75	21
CO	50	400	10	2,000	112	12
NO	25	35	-	900	81	58
NO_2	3[b]	5	-	100[c]	75	45
SO_2	5	5	-	215[d]	96	96

Notes: [a] The limit imposed by the Mines and Quarries Act. The short-term TLV is 15,000 ppm.

[b] The figure used in certain local regulations.

[c] On the basis of 10 percent of NOx being NO_2.

[d] If the fuel contains 0.5 percent S (12).

exhaust flow from the engine(s) of 2.25 cfm/bhp and the expected or the maximum allowed concentration of each gas. Neat exhaust and total airflow only are considered: the primary dilution within a locomotive is not relevant to this argument.

As Hurn (13) pointed out, the CO_2 production is irreducible for any engine burning an organic fuel. It is noteworthy that the ventilation requirements of the other gases on the 8-hour basis are of the same order as the 75 cfm/bhp required by CO_2. Therefore, there is no point in attempts to obtain great reductions in their levels. Improvement might be needed, however, if the possible synergistic effect of all the pollutants combined had to be allowed for. Also, the production of NO_2 is known from only a very few results so far. If there proved to be conditions under which it formed more than the 10 percent of the NOx total which has been assumed, the results could be serious.

The most important conclusion is that there seems no more than a comfortable safety factor between the requirement based on CO_2 and the 150 cfm/bhp standards if the diesels concerned are running continuously at full power. It may well be argued, though, that mine diesels usually operate at quite a low load factor so that, depending on what this factor is, considerably more diesel power could safely be allowed.

If this were done, it could possibly be that all the engines would be working at the same time occasionally. "Short-term TLV" figures are quoted, and presumably the total diesel horsepower allowable should be calculated using those. This is the basis of the last column of Table II. From this it appears that CO should be no problem. Nor should SO_2 , bearing in mind that fuel of less than 0.5 percent sulphur content may be available and also that much of the sulfurous emission should dissolve in the conditioner box water. The oxides of nitrogen figures still stand out, but depending on the success of attempts to lower these, and allowing a safety factor, an absolute minimum ventilation of, say, 40 cfm installed horsepower might be achievable.

This figure would still only permit 125 hp in a 5,000 cfm heading, a significant restriction and an absolute one for this form of power.

Emissions of particulates or of unburned fuel have not yet been given study specific to the mining application in the United Kingdom, except that obviously an engine emitting smoke or smell is given urgent maintenance attention.

Other emissions are those of heat and moisture. Virtually all the energy put into a mine in any form inevitably appears as heat. While it is true that the amount of this heat is approximately trebled if a diesel engine replaces an electric motor, the total diesel power envisaged in the future is such that heat produced would be a problem only in special circumstances. Again, exhaust gas, especially after it has been water cooled, will increase the humidity of the air, but in most cases other water is present which the air would pick up in any case.

Noise is another matter. The diesel engine is inherently noisy, and the extensive noise surveys carried out recently in British pits have included measurements of the sound levels of diesel locomotives and other vehicles. Results have ranged from 88 to 105 dBA. Some drivers may therefore be subjected to an excessive L_{eq} unless they wear ear-muffs, and this may make it difficult for them to hear warning signals unless the pitch and loudness of these are carefully designed. There may even be a noise problem for passengers. Trapped-rail diesel locomotives are more compact and less massive than conventional ones, and the noise levels of those that have been tested are towards the high end of the range. There is, of course, plenty of experience in silencing diesels for surface applications, but it is not always easy to apply these techniques to underground vehicles. A plastic insulating cover, for example, would be highly unsuitable.

The most serious problems felt in the United Kingdom in respect to diesels have yet to be mentioned. The derating and the multitude of safety features which have been mentioned above, which must be applied to small numbers of engines as distinct from quantity production, increase the cost of a complete engine of given output power by a factor of 5 or more compared with a standard unit. Its size is increased too, although there is a premium on compactness for mine use. Even more serious is the heavy maintenance requirement. The conditioner box has to be refilled frequently. The flame traps must be cleaned at the end of every shift and this is an uncongenial task. The maintenance schedule calls for a range of future checks as well, and the whole system including the many automatic cut-outs requires a great deal of care and attention. The more exacting checks require a highly experienced fitter. and men of this calibre find it easy to get alternative employment maintaining diesels on the surface. These factors, even more than questions of pollution, are liable to set a limit to the amount of diesel usage in British mines.

THE RESEARCH RESPONSE

The Safety in Mines Research Establishment at Buxton (under the Department of Energy) has carried out acceptance testing of diesel engines for many years and has done much work on the principles of flameproofing. Otherwise, however, the British mining establishments have not devoted much effort to research or development into diesel operation until recently, when a number of projects have started in response to the urgent need to improve transport.

An extensive program of bench testing has commenced on a direct injection engine of a widely-used type (Perkins 4-236). This will first of all have the objective of establishing the emission pattern over the full range of operating conditions, with particular reference to the production of the oxides of nitrogen. Then, adjustments to the running conditions will be made so as to obtain minimum emission of NO2. Varying the injection timing and water emulsification with the fuel and possibly exhaust gas recirculation will be tried. All this will be carried out virtually regardless of the effect on CO, unburned fuel, and particulate emissions. The final step will be the control of these by means of a catalytic convertor (14). The emphasis will be, if possible, on finding a range of operating conditions giving low emission without requiring too critical adjustment, so as to be less demanding on maintenance than at present. Possibly also, other suggestions for improving the engine system may emerge during the program of tests. Proposals relevant to a direct-injection engine can no doubt also be applied to indirect-injection ones if desired.

The work on the assessment of noise from diesel vehicles and on the development of pitworthy silencing means has already been mentioned. This is planned to continue.

While considerations of the safety and health of mine workers underlie much of the NCB research program, work on physiological factors as such is now concentrated at the Institute of Occupational Medicine, Edinburgh. Work there on the effect of nitrous fumes commenced with a pilot investigation using Drager absorption tubes. The result of this indicated that there were indeed some peaks of concentration but these were due to the use of explosives. For locomotive drivers, although there were occasional readings comparable with the maximum allowable, the mean shift exposures were very low. However, further investigation was warranted (15).

An instrument (Figures 4a and b) was developed which is a fitment to the dust sampling instruments which are already in widespread use, both as personal instruments worn by men and in the stationary mode. These contain three small tubes. In the first of these, NO_2 is absorbed in triethanolamine. There follows a tube containing chromium trioxide in which any NO present is oxidized to NO_2. A third tube absorbs this in the same manner as the first, so that both gases may be assessed. This is done in the laboratory by colorimetric means. Well over a thousand readings have been obtained with these instruments and the overall mean NO figure was 0.6 ppm with the maximum of 7 ppm. The figures for NO_2 were 0.06 ppm mean and 2 ppm maximum. The figures for diesel load drivers were above the average but still only 1.9 ppm NO and 0.45 ppm NO_2. Unfortunately the instrument does not give a reading of peak concentrations and there seems no immediate liklihood of a suitable portable instrument for this purpose becoming available. These figures do not give cause for serious alarm, though the study will certainly continue.

The work of the Institute already includes a great deal of work on the effect of dust on respiratory disability. It would obviously be desirable to know more about the effect of nitrous fumes on the lungs and about the effects when toxic gases and dust are present together. Work on this has commenced, but a meaningful correlation will be a formidable task. It will also be desirable to know more about what happens to the gases after they are generated underground. For example, the rate of oxidation of NO to NO_2 would seem to be significant. Three ppm of NO_2 is created in 25 minutes from a concentration of 20 ppm of NO (16). On the other hand, NO_2 is a very reactive and soluable gas, and mechanisms may well be at work which decrease its concentration. In particular, it appears that it can be absorbed into coal dust rapidly and in large quantities. Investigation into this is also continuing.

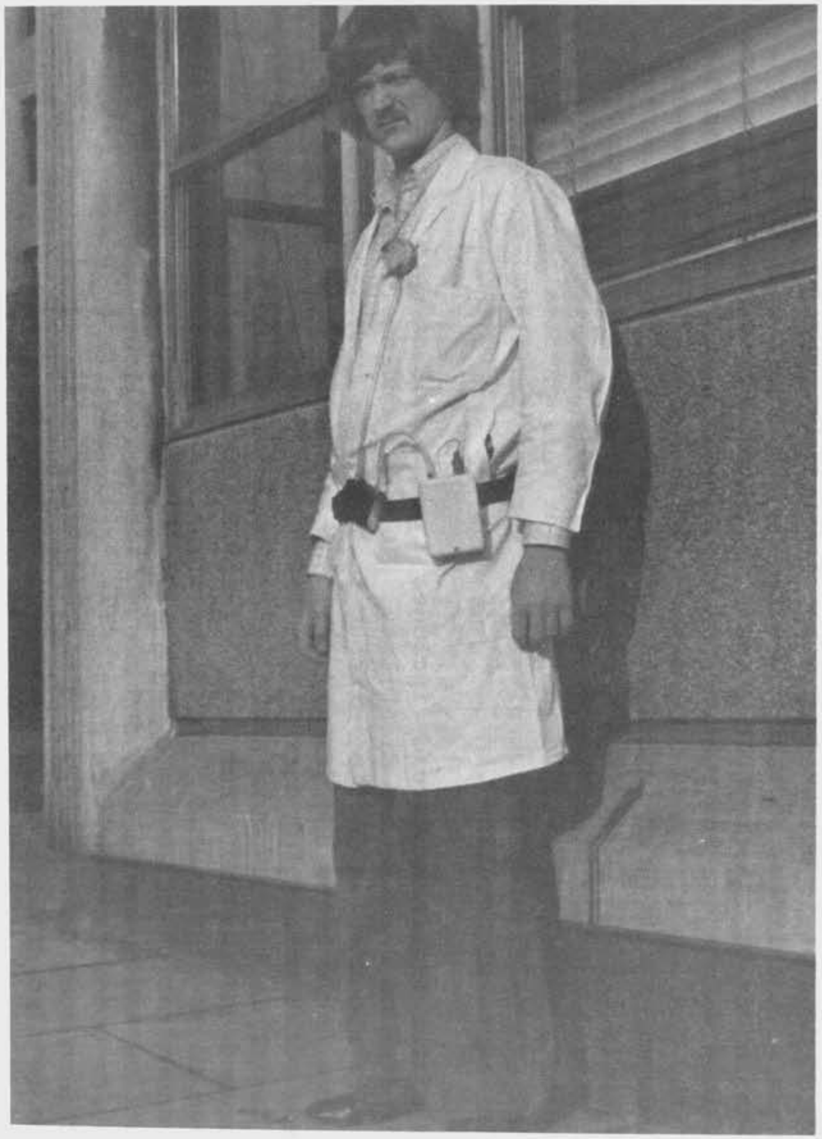

Figure 4a. Institute of Occupational Medicine Nitrous Fume Sampling Attachment fitted to a personal dust sampler.

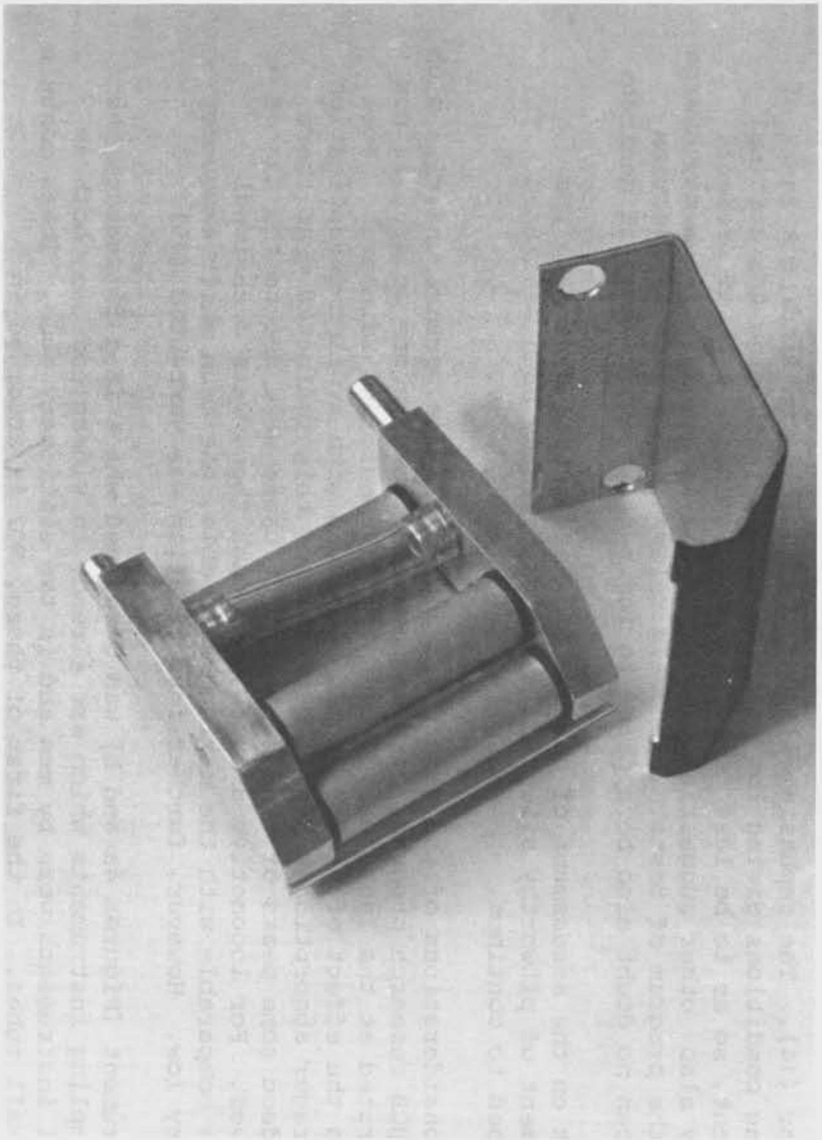

Figure 4b. Institute of Occupational Medicine Nitrous Fume Sampling Attachment fitted to a personal dust sampler.

The NCB has under way a major program of comprehensive monitoring of machine operation and of environmental factors. Environmental monitoring is aimed chiefly at keeping checks on the mine ventilation system so as to give warning of fire or outbursts of methane. This will no doubt contribute indirectly to the safe running of diesel engines, but measurements specifically for this purpose, although under consideration, are not being given priority and there is little progress as yet.

The remote monitoring method in most widespread use at the present moment is the tube bundle sytem (17) with which over 100 collieries are equipped. This uses small-bore plastic pipes laid from a number of sampling points up to an instrument station on the surface. It is very simple and effective but it has the disadvantage that there is between 1/2 hour and 3 hours delay before a reading is obtained at the surface. Also, measurement of NO2 is not possible because the gas tends to be absorbed by the plastic pipes. Apart from this, the system can in principle be used with any type of gas analysis. In practice, the measurements made are those of CO, CH4 and occasionally oxygen.

The MRDE system (18) is based on underground instruments which may be used independently but are designed to be capable of transmitting their readings electrically to the surface. It uses standardized power supply units and signal voltages for interchangeability. The instruments so far in service are monitors for methane, airflow, and smoke (using an ionization principle). Instruments for CO, dust, temperature, humidity, and oxygen are under development. A wide-ranging survey of types of transducers is in progress and it is hoped that measurement of CO2 and oxides of nitrogen will be possible in due course.

ALTERNATIVE POWER SOURCES

Parallel to the exploitation and improvement of diesel engines is a study, intended to be as comprehensive as possible, of alternative novel forms of power storage or supply.

In view of the widespread use of rope haulage, it is hoped that design improvements can be introduced in this area. These may include better vehicles and track, safer and more labor-saving means of transfer from one haulage to the next, extension of the use of wire or radio remote control, and trials of clamping and releasing vehicles from the rope after the manner of a cable street-car.

Another existing power source which it is hoped can be improved is that of battery electric storage. The sodium/sulphur battery is at last approaching the stage of commercial availability and it offers substantially increased capacity as compared with lead/acid. Also, it does not evolve hydrogen when working or being recharged.

Mechanical energy storage in a flywheel or compressed gas and thermal storage have been considered but rejected because it is not possible to store enough energy for a reasonable amount of work. However, this category also includes liquid nitrogen energy storage (19), which is proving extremely promising for certain purposes (Figure 5). The liquid is stored in an insulated vessel and boiled by atmospheric heat to produce a pressurized gas. It is essentially a limited power system, but it is proving extremely suitable for hand tools. The cost of the liquified gas, though high, is not prohibitive. For propelling a vehicle, a high pressure multistage expansion motor will be required to use the gas efficiently and this is under development. It is hoped to be able to drive a small (say 10 hp) manriding vehicle for 10 to 15 miles on one filling of a 230 litre tank. The great attractions of the system are its almost complete freedom from maintenance and from pollution. Its safety in use should apply even in high methane concentrations such as might be required for rescue duties, and the only conceivable danger, that of oxygen dilution, is very far away with the expected power ratings to be used.

For supplying substantial powers over a long period there is no real alternative to using the chemical energy in a fuel to drive a heat engine. The Stirling engine potentially offers several advantages over the diesel. It uses steady-state external combustion which could give much less pollution; it is quieter and it has better drive characteristics. It is proposed to obtain a rotary Stirling motor for trial, initially on the surface, development prototypes now being available from Sweden. An alternative embodiment of the system would be in a direct-acting hydraulic pump, readily adaptable to a mine device with hydrostatic drive. Such a design is being studied but it has not been used for any other application and a special development for mining will be needed. The Rankine cycle, preferably working on steam, is another possibility and the progress of the USBM steam ram-car will be followed with great interest. Each of these heat engines requires a flame-proof combustion chamber, which should not present any serious technical problem, but a possible useful refinement which is being studied is that of catalytically assisted combustion.

The absolute restriction on fuel-burning imposed by the CO2 limit implies that power economy should be borne in mind in vehicle design. Also, the duty cycles of vehicles and machines should be studied so as to enable the best use to be made of the permitted power and it is planned to do this. Also, it is possible that the requirements of a particular task may reveal advantages in a hybrid drive, combining two otherwise standard forms of power. Obviously, increase of complexity would need to be watched, but it would seem that the following might be worthy of study:

Battery-electric with mobile charging generator driven by a heat engine.

Rope-hauled vehicle with liquid nitrogen power for negotiating junctions and for material handling.

Trolley-wire electric with battery or flameproof diesel.

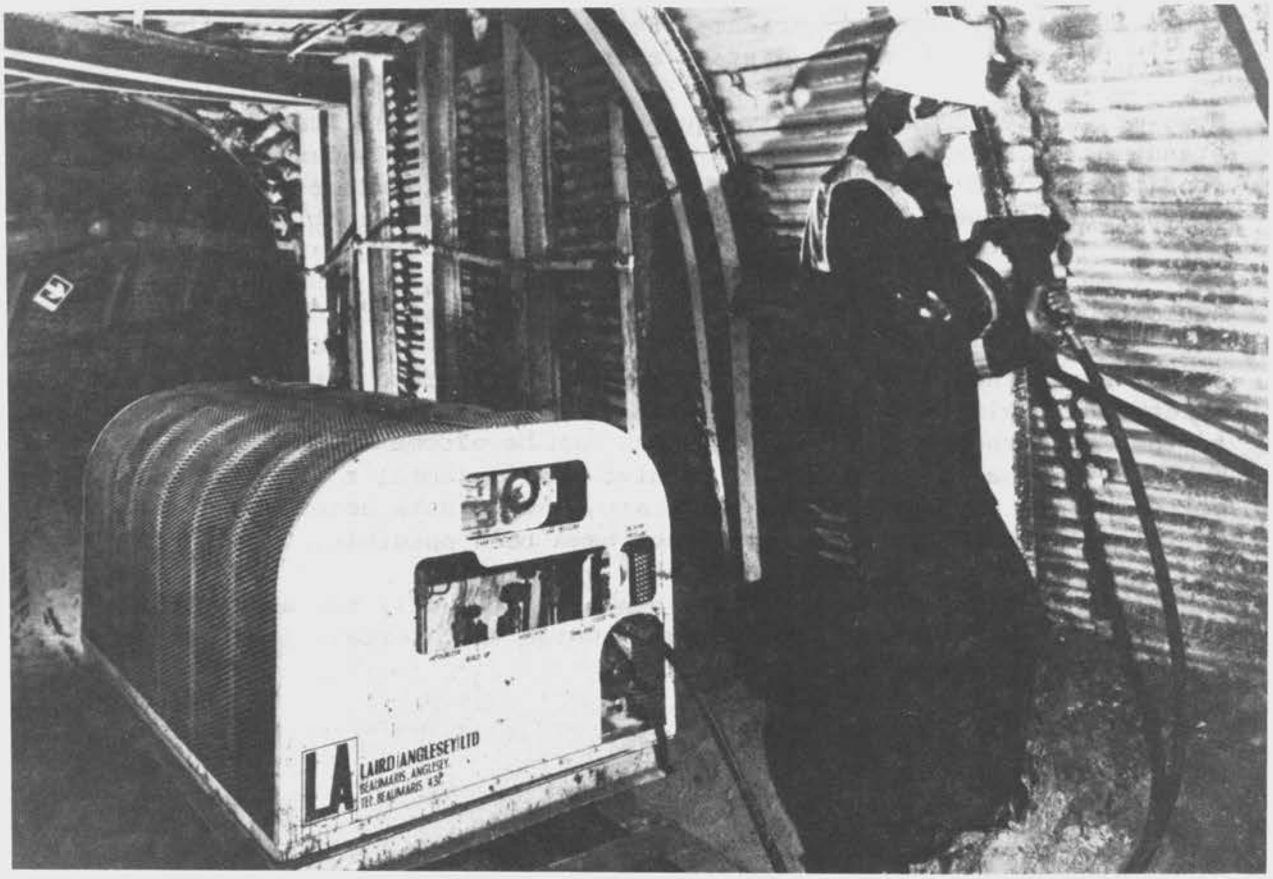

Figure 5. Underground liquid nitrogen power pack.

CONCLUSIONS

The current British scene is thus one of active transport development on a number of different fronts. As a mobile power source the diesel engine leads the field at the moment and its exploitation is likely to increase during the next few years. Unavoidable atmospheric pollution will set a clearly defined limit to the amount of diesel power which can be used, but there is already ample experience of intensive use to indicate that any health hazard is at most a distant correlation.

However, a diesel engine fully equipped to meet United Kingdom coal mining standards is bulky and extremely awkward to maintain under the difficult conditions found underground. This, rather than fears of health hazards, is the chief reason why improvements are now being sought.

ACKNOWLEDGEMENTS

The author's thanks are due to the National Institute for Occupational Safety and Health for their invitation to participate in this Symposium and to the NCB Director of Mining Research and Development for permission to publish this paper. The author is also most grateful to many of his colleagues in the NCB, H M Inspectorate, and private companies, without whose assistance this paper would not have been possible.

The paper contains the author's personal views and is not an official statement of NCB policy. It should be noted that certain items referred to are the subject of patent applications.

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QUESTIONS AND ANSWERS AND COMMENTS

COMMENT: In this country we took solace in the fact that tests showed no higher incidence of lung cancer among miners when compared to the general population. Larger studies found a higher rate for lung cancer among coal miners and a very greatly elevated tendency for stomach cancer. These studies should be used as an alarm in Britain, and other techniques other than X-ray examinations should be used for lung cancer checks. The report of the coal board (British) does not refer to health conditions in terms of exposure to diesel motors and included no ventilation studies. It is difficult to conclude from this evidence that there is no health hazard in 40 years exposure to diesel emissions.

QUESTION: You found incidences of cancer among miners less than among the average population. Is this a result of good ventilation so that the mine air is better than ambient air, or because of a lack of studies on diesel engine emission effects?

KIBBLE: A point that should be made is that many mines have few operating diesels. Also, the ventilation is very good.

QUESTION: Is the data presented a breakdown of the total picture? What was the time of exposure?

KIBBLE: Data on all the miners is recorded. Correlations were not studied.

COMMENT: It appears that the British only have data on safety, and they have no data on health.

COMMENT: Lung cancer studies among British miners came out in the late 40's or early 50's and were generated by concern over pneumoconiosis. No reports have been published since that time. These papers make no reference to any relationship between health and diesel emissions.

COMMENT: I cannot be convinced about the conclusions (British) until I see the data.

COMMENT: Once the data is seen, what can be inferred?

COMMENT: There is a difference between breathing diesel emissions in confined quarters and in open air.

A discussion on the availability of data followed. Many persons wanted the speaker to make available contact with the medical personnel who made the conclusions based on the data.

CANADIAN DIESEL EXPERIENCE

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Canada Centre for Mineral and Energy Technology (CANMET)
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INTRODUCTION

By world standards, Canada has a large underground mining industry. Mineral operations predominate, but some four million tons of coal were mined last year by underground methods. Most of the Canadian experience with diesels underground has been gained in the mineral sector although diesels have been used in Canadian coal mines for almost thirty years (1).

Diesel engines have never gained the popularity in Canadian coal mines that they currently enjoy in mineral operations. A recent survey (2,3) has estimated that 75 percent of the free underground world-wide mineral production is won by trackless methods. Canada follows this trend, and at present "trackless" is synonymous with "diesel-powered" in Canadian mineral mines, although in the last few years a number of trailing-cable-equipped LHD's have been put in service.

In the last five years a number of diesel-powered trackless mining vehicles have been approved for use in Canadian coal mines. These vehicles include load-haul-dump (LHD) units, shuttle cars, and utility vehicles. This type of equipment is common in mineral mines but represents a shift away from the railbound diesel haulage units which have a considerable history in Europe (4). This new generation of diesel coal mining equipment (5) incorporates many design improvements which have been developed as a result of extensive use in the mineral industry.

The similarities in equipment and development between the new generation of diesel-powered coal mining vehicles and the existing mineral mining vehicles suggest that much can be learned from a review of mineral mining experience. Such a review was prepared for presentation at a recent mines accident prevention association meeting (6). This report summarizes diesel engine fundamentals, exhaust emissions, typical tailpipe concentrations, mine sampling results and exhaust treatment systems. A review is made of changes between the tailpipe and mine exit, and suggestions are given to reduce vehicle operator exposure. Copies of this review have been sent to the symposium organizers; additional copies can be obtained by writing to the authors directly at: Energy Mines & Resources, CANMET, Mining Research Lab., 55 Booth Street, Ottawa, Ontario, K1A 0G1.

UNDERGROUND DIESEL EQUIPMENT

A recent article estimated the 1976 worldwide population of diesels underground at 10,000 units (7). As of July 1977 there were 3,151 diesel units underground in Canada. This equipment is broken down by size and type in Table I. A more detailed breakdown of the diesel equipment in use within the Province of British Columbia is given in Table II to demonstrate the wide-ranging applications of diesel-powered vehicles in Canadian underground mines.

At present there are 40 diesel-powered units in Canadian underground coal mines with a total rated brake horsepower of 3674. Nineteen of these units are railbound locomotives of European manufacture while the remaining 21 vehicles are trackless LHD's, shuttle cars, and utility vehicles. This equipment is broken down by size and type in Table III.

FLAMEPROOFNESS CONSIDERATIONS

A diesel engine is an internal combustion engine. The steps taken to flameproof a diesel engine for use in an underground coal mine are designed to ensure that the internal combustion cannot communicate to the surroundings and ignite coal dust or methane. Surface temperatures are limited to 150C under all circumstances to ensure that the spontaneous ignition of oil coal dust layers will not occur. By eliminating hot surfaces and internal explosion propogations to the surroundings, the engine is prevented from becoming a potential ignition source underground.

Canadian flameproof diesel requirements differ somewhat from the U.S. regulations laid out in Title 30, Part 36, of the Code of Federal Regulations. Canadian experience suggests that a mechanical (i.e., spaced plate type) exhaust flame arrester is needed as a reliable safety feature because of water level control problems in the exhaust conditioner. Light alloy external components are prohibited but guarding is permitted in some instances for components which are essential and cannot be manufactured from alternate materials. Fire-resistant hydraulic fluids and machine-mounted fire suppression systems are already mandatory in one province and will likely soon become national requirements.

In addition to these differences there are a number of areas where we feel that diesel-powered equipment might represent an explosion hazard. While we have no scientific test results to support these feelings we have not seen any technical reports to dissuade our concerns.

Crankcase Explosions

High localized temperatures can be reached in diesel crankcases (i.e., from overheated bearings). Such a hot spot can initiate oil mist in the crankcase. Dilution of the lube oil by fuel can aggravate this condition by reducing the flash point of the mixture. Such explosions are apparently fairly frequent in marine diesels (8,9). The high metal surface area to

Table I. The Breakdown of Diesel Powered Underground Equipment in Canada During July 1977

Equipment Type	Number of units in service with rated engine power					
	0-50 bhp	50-100 bhp	100-200 bhp	200-300 bhp	+300 bhp	unknown bhp
LHD's	47	406	619	119	16	34
Production haulage vehicles (trucks, locomotives, etc.)	236	181	142	62	74	8
Light duty vehicles (personnel carriers, drill jumboes, service vehicles, etc.	372	645	161	14	3	12
TOTAL 3151	655	1,232	922	195	93	54

Table II. The Breakdown of Diesel Powered Underground Equipment in British Columbia During 1976

Equipment	Number of Units Operated	Total Brake Horsepower
Locomotives	16	875
Load-Haul Dump Vehicles	71	8487
Standard front-end loaders	7	1865
Ore and waste carriers	19	3278
Tractors	10	860
Drilling jumbos and platforms	32	1884
Graders	6	419
Service and personnel vehicles	32	1777
Forklifts	2	94
Welder	1	49
TOTAL	196	19588

Table III. The Breakdown of Diesel Powered Underground Coal Equipment in Canada During July 1977

	0-50 bhp	50-100 bhp	100-200 bhp	200-300 bhp	300 bhp
LHD's	-	3	5	-	-
Production haulage vehicles (trucks, locomotives, etc.)	1	26	-	-	-
Light duty vehicles (personnel carriers, drill jumbos, service vehicles, etc.)	-	5	-	-	-
TOTAL 40	1	34	5	-	-

crankcase volume relationship in small diesel engines such as those used in underground applications may effectively quench any initiated explosion; however, we have not seen any scientific documentation to support this view.

On large marine applications, oil mist monitors, inert gas devices for purging into the crankcase, and flame-arrester-equipped relief valves are commercially available. Summers-Smith (8) states that if the crankcase is capable of withstanding an internal pressure of 8 bar, there is no need to take additional protective measures.

Friction and Impact Surfaces

Brake pads, clutch facings, and the starter pinion gear are external components which must rapidly dissipate large amounts of energy. Overheating and sparking, which could initiate coal dust or methane explosions, may occur. This problem may be more severe if diesel-powered coal mining equipment becomes larger. Brake pad and clutch facing problems are similar, while the starter pinion is somewhat different. Normal start-up will produce an impact between the pinion and ring gear. Pushing the start button while the engine is running will produce the same impact with the addition of rotational energy from the ring gear.

Ingestion of Explosive Methane-Air Mixtures

One of the Canadian contributions to the 17th International Conference of Director of Safety in Mines Research being held at Varna, Bulgaria, this October (1977) will be a paper summarizing methane-air ingestion studies on a single cylinder test engine (10). Intermittent or sporadic combustion of methane-air mixtures occurred well within the compression ratio range of modern indirect-injection diesel engines. The determination of whether the ingested mixture was firing in the cylinder was simplified by the fact that at typical diesel engine compression ratios methane-air will detonate violently, producing audible knock.

The violence of the methane-air detonation has made us wonder about the implications in full-sized engines. If ingestion of flammable methane-air mixture results in the destruction of the engine, the failure mode is important because at the time of failure the engine is surrounded by flammable methane-air.

EXHAUST TREATMENT SYSTEMS

Diesel engines which have been flameproofed for use in coal mines are equipped with a bulky, high-maintenance exhaust treatment system to cool the combustion products and prevent exhaust backfires from propagating. Since this system is necessary for flameproof considerations, effective exhaust treatment to reduce objectionable pollutants tends to be neglected. In our minds, diesel exhaust treatment is one of the more cost-effective methods of controlling the exposure of underground workers in dieselized mines.

Water Bath Conditioners

Water-bath conditioners will trap a portion of the unburned and partially oxidized hydrocarbons, sulphur oxides, and nitrogen dioxide. Because the sulphur oxides and nitrogen dioxide form acids, stainless steel construction and buffering chemicals are often recommended to reduce corrosion. CO and NO are not very soluble in water and will not be absorbed in any significant quantities by currently available units.

The lack of definitive information on particulate material retention in water-bath conditioners led to recently-completed federally-funded tests that assessed the particulate material-retention efficiency of two state-of-the-art water-bath conditioners and a monolithic platinum catalytic-purifier water-bath conditioner combination (11). These tests suggest that the two commercially available units will retain 30 percent of the particulate, 20 percent of the hydrocarbons, and 50 to 80 percent of the sulphur oxides.

When the monolithic purifier was positioned ahead of the water-bath conditioner, the particulate retention was increased to 50 percent. The level of retention discovered in this work suggests that more sophisticated water-bath conditioners, equipped with a chiller and de-mister, will be capable of removing the bulk of engine-generated particulate material without creating fogging problems.

Catalytic Purifiers

The purifiers (both pelleted and monolithic) used in Canadian underground mines are platinum catalytic purifiers. The CO and hydrocarbon oxidation capabilities of these units at temperatures above 200C have been well documented. Base metal catalysts and iron ore pellets have also been examined but do not appear to offer enough potential to warrant consideration for underground applications.

Platinum catalytic purifiers do not significantly alter the exhaust concentrations of diesel soot. There is evidence that these devices do convert the bulk of any low-load engine-generated NO_2 to NO, perhaps by a mechanism of the form $CO + NO_2 \rightarrow CO_2 + NO$. Some recent unpublished work suggests that for extremely low CO and hydrocarbon-producing engines, a portion of the engine-generated NO can convert to NO_2 at high exhaust temperatures (11).

Concern in the automotive field about SO_2 to SO_3 conversion in platinum catalytic purifiers has led to recent tests which have demonstrated that this problem exists for diesel platinum oxidation catalysts (11). Tests are currently under way in Canada and the U.S. to determine the severity of this potentially hazardous effect. SO_2 to SO_3 conversion is a serious problem because the threshold limit value of SO_3 is 0.25 ppm.

Exhaust Filters

A federally-funded project has demonstrated that it is feasible to remove engine-generated particulate material by filtration (12). Testing is continuing to assess additional filter media, and a full-scale prototype will be built for evaluation. Agglomeration techniques may also be investigated.

CASE HISTORY: ENVIRONMENTAL CONTROL AT THE ONTARIO DIVISION OF INCO METALS COMPANY

The mining operations of the Ontario division of Inco Metals Company are centered at Sudbury, Ontario, some 200 miles north of Toronto. In 1976, the ore production from the 12 underground mines totalled 16.6 million tons. As the largest single user of diesel-powered underground mining equipment in Canada, Inco Metals Company was approached to provide the following summary of their involvement with diesels.

Underground Diesel Equipment

"The first diesel-powered machine used underground in our mines was a 130 hp scooptram put into service in March 1966. In April 1971, there were 363 diesel units in our Ontario mines. We now have 571 units in use underground; the engines have a total rating of 57,000 brake horsepower. The diesel equipment includes:

255 Load-Haul Dump Machines	13-1.3 cu yd - 52 bhp
	55-2 cy yd - 78 bhp
	90-4 cu yd - 130 bhp
	58-5 cu yd - 175 bhp
	39-8 cu yd - 222 bhp
119 Locomotives for track haulage	mainly 48 to 52 bhp
65 Drill Jumbos	
22 Secondary Drills	
17 Haulage Trucks	
93 Service and Personnel Vehicles	

"In 1976, 74 percent of the ore removed from the stopes was handled by L.H.D. machines. Most of our diesel units are powered by Deutz air-cooled, indirect-injection engines with pre-combustion swirl chambers. These are very clean-burning engines operating at higher temperatures than water-cooled engines and thus better suit the use of catalytic exhaust scrubbers. Only No. 1 diesel fuel is used; at present the fuel has a sulphur content of 0.2 percent by weight.

Catalytic Exhaust Purifiers

"The exhaust gases from all engines are passed through catalytic scrubbers. Originally only the Oxy-Catalytic Dieseler III purifiers with platinum-coated pellets were used; the model 51 unit is used on all of the L.H.D. machines except the 22 hp engines which are equipped with the Model 52 scrubbers. There is one exhaust scrubber on each of the 52 and 78 hp units and two parallel scrubbers on the larger engines, one on each side.

"We are now also using the platinum-coated honeycomb grid type (PTX) scrubbers; these units require less space and thus can be located close to the exhaust manifold. The catalytic scrubbers eliminate most of the toxic gases in the diesel engine exhaust, changing them into non-toxic gases by means of catalytic oxidation at normal exhaust temperatures, from 500 to 900F. Up to 90 percent of the hydrocarbons are removed. One toxic product of diesel combustion, nitric oxide, is not affected appreciably by the oxidation process in the scrubber, but some is converted to nitrogen dioxide. Thus it is necessary to keep in mind that adequate ventilation is required to supply fresh air to the engine and to dilute and remove the oxides of nitrogen along with the carbon dioxide, the carbon particulate, and the remnants of the other toxic gases.

"Using catalytic scrubbers, it is important not to allow the diesel engines to be run at idling speed except for very short periods, as the temperature of the exhaust gases drops quickly to approximately 275F, allowing unburned fuel and carbon particles to be deposited on the catalyst. We permit a normal maximum idling time of five minutes and our experience is that the scrubbers remain clean; fuel or carbon deposited during the brief idling periods is burned off during normal working periods.

"From our experience with catalytic scrubbers and some knowledge of the problems with water scrubbers used on diesels at some of the other mines, it is our opinion that the catalytic scrubbers operate at appreciably higher efficiency, are easier to install on mobile equipment, and require considerably less maintenance; they do not require attention by the operators during the working shift; however they do not capture the carbon particulate or the sulphur dioxide. On the other hand, the water scrubbers should be kept relatively full of water for proper scrubbing during the working shift and should be drained and refilled with clean water each shift to maintain appreciable retention of the carbon particulate and sulphur; these scrubbers have no effect on the carbon monoxide and the nitric oxide and only remove a small percentage of the hydrocarbons; their main advantage is the cooling of the exhaust gases. The high temperature of the exhaust gases from the catalytic scrubbers is not a problem at our mines.

Operator and Mechanic Training

"Thorough operator and mechanic training is essential to the safe and efficient operation of diesel equipment. Prospective miners progress through five weeks of basic induction and drilling training, based on meeting specific performance standards.

"The company provides a three-year garage mechanic apprentice program and also hires certified Class A motor vehicle repairers as garage mechanics who undergo training on diesel mining equipment. An extensive upgrading program is conducted for LHD operators, mechanics and supervisors on the complete scope of trackless equipment operation and maintenance.

Maintenance of Diesel Equipment

"The successful use of diesel-powered equipment in underground mining operations requires strict adherence to a well-planned inspection and maintenance program.

"The first line of maintenance is the vehicle operator. At the beginning and at the end of each shift the operator makes a check of his machine using a checklist that is completed, signed and given to his foreman; these are kept on file for six months. Any faults found are reported immediately and are corrected by a mechanic.

"The Maintenance Department schedules each piece of diesel-powered equipment for inspection and service every two weeks or 200 operating hours. This schedule must be rigidly followed to ensure that the equipment is available for sufficient time on the day scheduled to permit a thorough inspection and the carrying out of the services and any repairs required. Forms are used for the 2-week, 18-week and annual inspections. All inspections, services and repairs are noted by the mechanic in a logbook provided for each machine.

Undiluted Engine Exhaust Tests

"The Mines Branch of the Ontario Ministry of Labour requires a weekly test for carbon monoxide in the undiluted exhaust after the scrubber(s) of each diesel engine. These tests are made by the mine ventilation staff using Drager detector tubes. The readings obtained from the 9600 tests made for carbon monoxide in the diesel exhausts during the first six months of 1975 are summarized as follows:

L.H.D. machines and teletrams - 90 percent are below 200 ppm; 97 percent are below 300 ppm.

Locomotives - 83 percent are below 500 ppm; 98 percent are below 800 ppm.

All other diesels - 93 percent are below 750 ppm; 99 percent are below 1000 ppm.

(Note: The Ontario Diesel Code limit for CO in the diesel exhaust is 1500 ppm.)

Ventilation at Diesel Operations

"The new Ontario Diesel Code increased the volume of ventilation air required at new diesel operations as of February 1, 1977, from 75 to 100 cfm. per maximum brake horsepower. We had been designing our ventilation at diesels on the higher figure for many years. During the last eleven years the total volume of fresh air supplied to our mines has been increased from 3.3 to 6.7 million cubic feet per minute. The volume of air supplied per ton of ore hoisted per mine day has gone from 50 cfm. up to 90 cfm.

"Mechanical ventilation systems are provided for all diesel-powered development operations and supplementary systems are installed at all diesel ore extraction operations except those ventilated directly by the main fans. Electrically-driven fans are used, except in the short headings and at the dead ends of some stopes where it is more feasible to use compressed-air fans for the temporary ventilation installations.

Ambient Gas Tests and Ventilation Measurements

"(A) Weekly Tests - The ventilation staff at each mine makes the weekly gas tests with Drager tubes and the volume survey at each diesel unit as required by the Ontario Mines Branch. The readings obtained from approximately 6900 tests made during the first six months of 1975 are as follows:

(1) Adjacent to the engine (at the operator or just downstream)

- (a) Carbon Monoxide - 87 percent are from trace to 5 ppm; 98 percent are below 10 ppm. (TLV = 50 ppm.)
- (b) Nitrogen Dioxide - 98 percent are from trace to 1 ppm; 99.5 percent are below 2 ppm.
- (c) Aldehydes - 95 percent are from nil to trace; 99 percent are below 1 ppm. (TLV = 2 ppm.) (TLV = 5 ppm.)

(2) In the general atmosphere

(a) Carbon Monoxide - 85 percent are from trace to 2 ppm; 97 percent are below 5 ppm (The Ontario Diesel Code Limit = 20 ppm)

(b) Carbon Dioxide - 96 percent are from 400 to 1000 ppm; 99 percent are below 1500 ppm (TLV = 5000 ppm.) Most of the ventilation volumes measured at the diesels are over the 100 cfm. per rated brake horsepower required. The results of all weekly tests are recorded in a special logbook kept in the foreman's office at the shaft collarhouse. These are inspected by the engineers from the Mines Branch.

"(B) Daily Tests - All mine foremen carry a Drager gas detector and carbon monoxide tubes. In the event of a complaint, or suspected abnormal occurrence on any shift, a test is made at the diesel operator. In addition, each day on the 8:00 AM to 4:00 PM shift the foremen takes one test at operator of each diesel haulage unit during the shift. If any appreciable reading is obtained (over 25 ppm --50 percent of the TLV) the diesel engine is turned off until the ventilation system is checked and the engine is inspected by a mechanic. The supervisors record the results of all of their tests in a separate logbook also kept in the foremen's office.

Gravimetric Dust Sampling

"Personal gravimetric dust sampling on the operators of diesel haulage units at 2 liters per minute over the 8-hour shift using 10 mm. nylon cyclones and 25 mm. silver membrane filters indicate a range in the total respirable dust from 0.5 to 2.0 mg/m3, a carbon particulate from 0.2 to 1.0 mg/m3 (weight loss after heating to 750F in a muffle furnace) leaving a mineral dust from 0.3 to 1.0 mg/m3 with a quartz content of 5 to 15 percent.

Annual Miners Chest X-Ray

"All miners in Ontario are given an annual chest x-ray by the Workmen's Compensation Board of Ontario. There has been no indication among our miners of a health problem resulting from the use of diesel engines underground for the past 11 years.

Conclusion (of INCO Metals Company)

"It is our opinion that the successful use of diesel-powered equipment in underground mining operations depends directly on all of the points outlined in this summary and the co-operative effort of all of the people involved."

CONCLUSIONS

The large scale introduction of diesel equipment will represent a difficult transition period for underground coal miners unless they draw upon the mineral sector experience. While there are unanswered questions in the areas of flameproofness, exhaust emissions, operator exposure and health effects of the mineral experience, operator exposure and health effects of the mineral experience suggest the diesel equipment is both economically attractive and capable of operating safely in the underground mine environment.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to the Provincial mechanical/electrical inspectors of mines for their assistance in preparing the breakdown of diesel equipment used underground in Canada and to the Ontario division of Inco Metals Company for the case history.

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QUESTIONS AND ANSWERS

QUESTION: How do they contend with the high surface temperatures of catalytic converters? Do they use water jackets?

STEWART: Catalytic convertors are not used in coal mines. There are, however, ways to use water jackets to deal with the problem.

QUESTION: Is there any way to distinguish between pollutants from diesel exhaust and from blasting?

STEWART: If monitoring was done simultaneously, one should be able to separate them because the levels of condensation are different.

QUESTION: What studies have been done to find out what effect diesel engines have on the health of workers?

(Mr. Stewart referred the question to Ernest Mastromatteo, Medical Director, Inco, Ltd., Toronto, Canada.)

MASTROMATTEO: Although railroad workers say that diesel emissions cause cancer, researchers have found no association between diesel emissions and lung cancer. The railroad workers are given yearly X-ray exams and questionnaires, and pulmonary function tests are administered.

QUESTION: Was there any increase in respiratory problems?

MASTROMATTEO: No evidence was found.

GERMAN EXPERIENCE

Dr. Dieter A. Kraft
Mercedes-Benz

I appreciate very much the opportunity to give you a very brief presentation of the respective situation in Germany. I apologize for my simple English and I hope you can understand it. I would like also to point out that I am not entitled to speak on behalf of the mining industry nor for any governmental agency concerned with the health implications of the use of diesel engines in underground mines. I am also not familiar in depth with the actual situation in operating diesels underground, but I am a little bit surprised about the over-emphasized reaction about health hazards ascribed to diesel engine emissions. In Germany, these diesel health effects are not a topic in the general air pollution discussion. This does not necessarily mean that a hazard does not exist. Of course, all the substances described in the NIOSH report, "The Health Implications of the Use of Diesel Engines in Underground Coal Mines" (unpublished working paper), really exist.

It might be helpful to bear in mind that we in the automotive industry were encouraged greatly to build diesel engines for passenger cars just because of the clean emissions and the fuel economy advantages. Fuel economy of diesel passenger cars is running now at 20-45 miles per gallon; all other gasoline-fueled cars are ranging approximately 10-15. No gasoline vehicle known to me is meeting even 20 miles per gallon.

Again a good fuel economy also means reduced exhaust emissions. This picture is in principle applicable also to medium and heavy-duty diesels used underground.

Why, we might ask, are the European, American, and Japanese automotive industries manufacturing diesel passenger cars if the emission picture might be really so bad?

Of course, unlike the underground diesel, the car is not restricted to a limited area. But each diesel driver and consequently the persons sitting in the car are breathing the same engine exhaust. I do not understand. If there is any real potential hazard in doing so, why are the environmental agencies showing great interest in increasing the production of diesels worldwide?

At risk of being polemical, I would like again here to cite a British Medical Report authorized by P. F. Lawther, which is concerned with carbon monoxide exposure on human beings. He said that during the so-called Suez Crises, only diesel passenger cars could be operated in London, and the CO level dropped to nearly zero. Under normal driving conditons, that means that if we include all types of vehicles, levels average 20-30 ppm CO with peak concentration of 300 ppm CO. Non-smokers in the London traffic had no more than 3 percent CO - hemoglobin, compared to smokers, who had maximum levels of 9.6 percent COHb. The World Health Organization recommended in 1972 a maximum level of 4 percent COHb. So, I have no further comment on this aspect.

Coming back to the specific situation in Germany, it might be of some interest for you to know that the administrative influence in this question is very complex. The supreme authority in all air pollution matters is the Um Welt Bundesant (i.e., respiratory environmental Federal agency) located at Berlin and founded in 1975. This office is investigating all relevant aspects of air, water, and ground pollution. So far, it also has responsibility for underground mining. But up to now this office has not been involved in any relevant action.

With regard to the historical development of the mining industry in Germany, it should be mentioned that the so-called Oberbergbauamter (Supreme Mining Bureau), located close to the mining areas in Dortmund (Ruhr area), Essen, Bodum, Clausthal, etc., has the responsibility to approve technical equipment for safety considerations. They are assisted by the Rheinisch - Westfalische Technische Uberwachungsverein e.V. Essen, (Technical Control Board) in creating guidelines and performing specific concern of Westfalische Bergwerkschaffkasse Bochum, a union-like organization.

Furthermore, for all kinds of scientific and technical investigation, the Bergbauforsching Essen is a central institution. Unfortunately, it is not finished, all counties in West Germany having their own government with Departments of Economics and Interior Affairs. Last but not least, the Central Federal Government in Bonn has equivalent departments for traffic, health, economic and interior affairs which are concerned in different ways with the question under consideration.

Finally, The Economic Commission for Europe (ECE) has the difficult job of harmonizing all the different national regulations of mining countries in Europe for all types of diesels independent from the operation area. The ECE Regulation No. 24 applies to all relevant aspects in general and in detail.

Up to now, only the emission of particles in terms of soot is ruled out and measured with the Bosch filter method. New measurement techniques such as those used in the Bosch opacimeter are under way.

The German standard for type approval of diesel engines operated underground calls for a maximum concentration of 500 ppm CO. A second diesel standard prescribes 1200 ppm CO for the upper limit concentration of a used engine. If values are exceeded, the engine must not be used underground. These type approval values are considerably lower than those of the United States, which are expressed in terms of grams per brake horsepower per hour (g/bhp/hr) but are approximately equivalent to 1500 ppm CO. It may be of interest to know that in Russia the application of catalyst for diesel engines is under legal pressure if the CO concentration meets 800 ppm CO.

NOx Standard

There is not yet any NOx standard effective in Germany, but a type approval emission standard of 750 ppm is under strong consideration. This value is ranging something between the United States (1500) and Russian (600) values when a conversion from g/bhp is accepted again. It may be worthwhile to add that this German Standard might be expressed in both terms of NO and NO_2. That means the NO_2 content might not exceed a value of about 50 ppm or something like that.

Hydrocarbons

There are no specific hydrocarbon limitations under consideration because studies show that a reduction of CO lowers hydrocarbons automatically. I do not want to discuss the whole area of carcinogenic substances in diesels here because I am told that can be done better in the workshop groups. But I would like to draw your attention to the point that all diesel manufacturers with no exceptions do invest a high engineering and scientific potential in understanding the building process and consequently in approaches of suitable technologies in order to reduce the mass output of these substances. There is no question that these substances exist in diesel engines, but it should not be dramatized. As I understand the situation, long term exposure figures cannot be expected since there are few of these types of engines and they have only been in operation a short time.

This brings up the question of how many engines are operated in Germany. I have no exact figures here with me. From my estimation, looking into sources normally crossing my desk, I would suggest that we are ranging between U.S. and British figures. A further explanation why the operation of diesels, especially in coal mines in Germany, did not increase substantially is that in Germany in the 1960's the activities in stone coal mines were stopped due to economic reasons. You know that the potential coal layers are concentrated in deep levels close to 1000 meters under the ground. That requires very good mechanical equipment, but also high costs. I recall that during this time, in fact, the Volkswagen factory at Wolfsburg in Germany imported large quantities of American coal because it was priced lower than German coal.

In addition, the very inexpensive Near East oil in the beginning of the 1960's dramatically reduced the coal production in Germany.

Today the situation has changed and the coal mines were reactivated, but now the equipment and machinery is outdated and must be changed. So far there has been little interest in questions such as those being raised at this workshop. Now the signs for an increasing diesel market in underground operation are visible, and I agree that the health implications must be considered.

If anyone is interested in having a comprehensive documentation of the air pollution of diesel engines, I would like to recommend the official publication under the authority of Commission des Communautes Europeenne (Economic Commission of Europe). The author is Professor van Laer of Belgique. I am sorry to say that the report is available only in French.

Thank you for your attention and patience in listening to my German-English.

QUESTIONS AND ANSWERS

QUESTION:	Are chemical analyses of emissions available?
KRAFT:	Yes they are published.
QUESTION:	The high levels of pollution in Hamburg approximate the quality of air in mines with operating diesels. Is it due to industry or auto emissions?
KRAFT:	Probably both.

THE USE OF DIESEL ENGINES UNDERGROUND
IN SOUTH AFRICAN MINES

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Johannesburg, 2000

INTRODUCTION

Mining in South Africa is conducted entirely by private enterprise, with the exception of one offshore operation. Employment is provided for more than a half million people, approximately 390,000 of whom work underground.

The main underground operations involve the mining of gold, platinum, diamonds, and coal. Most coal mines are shallower than 200 m, while in gold mines the deepest workings extend to 3,600 m below surface. Uranium is produced as a by-product of gold mining.

The approximate tonnages of rock broken underground in the various mining sectors are shown in Table I.

Gold and platinum mines involve the extraction of very thin reefs which extend laterally for many kilometres and which dip downwards at angles usually between 7 dgr and 40 dgr. The thickness of the reefs varies from 1 to 200 cm, with about 90 percent of reefs being narrower than 50 cm. Stoping widths when mining the narrower reefs are typically 120 cm, although in some mines the stoping width is only 90 cm.

Coal is extracted from relatively thick, near-horizontal seams. Most coal is extracted in bord and pillar operations although a start has been made on the introduction of longwall mining techniques.

There are two bodies that play an extremely important part in mining in South Africa. These are the Chamber of Mines of South Africa, and the Department of Mines of the Central Government.

THE CHAMBER OF MINES OF SOUTH AFRICA

The Chamber of Mines of South Africa is not a government body, but is an association of mining companies. It is a central, cooperative organization which looks after those interests of its members that can best be handled on a cooperative basis.

TABLE I. ESTIMATED ANNUAL ROCK PRODUCTION FROM UNDERGROUND MINES IN SOUTH AFRICA (1977)

(in million tons per year; 1 ton + 1,000 kg)

Gold mines	100
Platinum mines	17
Diamond mines	11
Coal mines	77
Other:	
Copper	4
Iron	3
Chrome	3
Tin	2
Antimony	0.7
Manganese	0.5
Asbestos	0.4

TABLE II. DIESEL LOCOMOTIVES USED UNDERGROUND IN GOLD MINES

Rating, kW	Number
5 - 15	64
16 - 30	1739
31 - 45	1011
46 - 60	227
60 - 75	5

In mid-1977 there were 116 members: 14 financial corporations, 46 gold mining members, 43 coal mining members, and 13 other mining members.

The Chamber carries out many duties on behalf of its members. It acts as the mouthpiece of the employers in representations to the Government and as the spokesman of the mining industry as a whole in matters of common policy. It negotiates all labour matters in gold and coal mining industries with the recognized officials' associations and trade unions. Through its associated companies it handles matters such as the refining and selling of gold and uranium and the recruitment of labour. The Chamber also operates a large research and development organization.

THE DEPARTMENT OF MINES

The mineral and mining laws of the country are administered on behalf of the Central Government by officials of the Department of Mines. The permanent head of the Department is the Government Mining Engineer, who is also the chief technical adviser to the Government on matters relating to mining.

The functions and duties of the Department cover a wide field including:

(a) The control and administration of prospecting and mining rights. (This work is the responsibility of the Mining Commissioners in the various mining districts.)

(b) The supervision of mines and works in the interests of safety and the promotion of health, including the investigation of accidents. (This work is the responsibility of the Inspectors of Mines in the various mining districts.)

Naturally the Department has many other responsibilities, but for the purpose of this introduction these need not be mentioned here.

It should be noted that in South Africa the Provinces are not concerned directly with mining matters, as are the States in the United States of America. Lease considerations, taxation, and safety and health are all the concern of the Central Government.

The Mines and Works Act is the principal legislation under which mining is carried out in South Africa. Reference will be made later to the provisions in this Act that relate to the use of diesel engines underground.

THE USE OF DIESEL ENGINES UNDERGROUND

The use of diesel engines is permitted in coal and other underground mines, subject to approval by the Inspector of Mines and subject to compliance with the Mines and Works Regulations.

Diesel locomotives are used in practically all underground metalliferous and diamond mines, although diesel-driven loaders are seldom used. It is relevant here to mention that about 600 km of tunnels are driven every year in South Africa in connection with underground mining operations.

About 80 percent of all diesel locomotives used underground in South Africa are to be found in gold mines; the utilization in these mines is as given in Table II. It will be noted that the total number in use is about 3,000 and the preferred size about 30 kW. The Mines and Works Act imposes no restriction or requirement on the use of diesels in non-fiery mines other than a limitation on the concentration of CO and NOx in the ventilation air (Regulation 10.25.5).

Vehicles of the LHD type (load-haul-dump) are not used in gold and platinum mines, but are used in several other types of mines, including coal and copper mines. For example, in one mine where the production is 320,000 tons per month the rated capacity of all diesel vehicles in use underground is 8,200 kW. The mine specification requires that 8 m3/s of ventilation air be provided per 100 kW (123 cfm/bhp). The mining layout is such that one collection level serves three derailing levels, with three LHD vehicles on each level. Experience has shown that conditions become decidedly unpleasant if the air available is only 6 m3/s per 100 kW, although the levels of CO and NOx remain well below the maximum permitted levels.

Measurements of fuel consumption on this mine suggest that the average load factor of these diesels during each shift is close to one third.

The diesels used in coal mines are mainly of the tractor type that are used to haul trailers, although several coal mines also operate LHD vehicles. In terms of Regulation 10.25.2 of the Mines and Works Act, permission for the use of diesels in fiery mines must be obtained from the Inspector of Mines. Such diesel engines must be "flame-proof" and they may be used only in places where the ventilation air speed is not less than 0.5 m/s.

HEAT AND OXYGEN DEFICIENCY PROBLEMS

In considering minimum ventilation requirements for diesels it is necessary to bear in mind the temperature rise of the air and the oxygen deficiency, in addition to the gas pollution levels.

Temperature-rise

The overall efficiency of diesel engines is probably not much better than 33 percent, so that the total amount of heat to be dissipated is typically three times the brake power. The rise in temperature of the ventilation air, assuming a ventilation specification of 8 m3/s per 100 kW, would therefore be

$$3 \times 100 / 8 \times 1.2 \times 1.014 = 30C.$$

The corresponding rise in wet-bulb temperature would be about 6C, which could be very serious since it is inadvisable for unacclimatized men to work at wet-bulb temperatures above 28C.

Most diesel engines that are used in mines are fitted with wet scrubbers to cool the exhaust gases and to prevent the emission of sparks. The evaporation rate of water from these scrubbers serves to humidify the air, this humidification tending also to cool the air. The evaporation, however, has no effect on the wet-bulb temperature of the ventilation air; the increase in wet-bulb temperature remains the same as calculated above, regardless of how much water is evaporated in the scrubbers.

It must be remembered that diesels in mines do not operate steadily at maximum power, so the above calculations serve to provide an upper estimate of the temperature-rise of the ventilation air.

Oxygen deficiency

Any depletion in oxygen content of the ventilation air could adversely affect the fuel-air ratios in engines, causing a loss of power and an increase in smoke emission. The effect on people is unlikely to be serious because the human body can tolerate oxygen levels far below the usual 21 percent.

The rate of consumption of oxygen in a combustion process is about **0.07 g/s/kW of heat output, so that the rate of consumption of oxygen in a 100-kW engine at 33 percent overall efficiency is about**

$$0.07 \times 300 = \text{g/s}$$

Air has an oxygen content of about 250 g/m3, and the consumption of oxygen at a rate of 21 g/s from an air quantity of 8 m3/s therefore corresponds to a depletion rate of

$$21/\ (8 \times 250) \cong 1 \text{ percent}$$

This depletion rate is small and is not likely to be a serious problem except perhaps when engines work temporarily in stagnant corners. (It is in long railroad tunnels that oxygen-depletion can become a serious problem.)

INFLUENCE OF ALTITUDE ON ENGINE PERFORMANCE

In deep mines the barometric pressure can change significantly from surface to the deepest workings, with the consequence that the density of the air can affect quite seriously the performance (and emissions) of engines that are adjusted on surface. An increase in air density of 25 percent between surface and underground workings is not uncommon in South African gold mines.

REGULATIONS GOVERNING THE USE OF DIESEL ENGINES UNDERGROUND

The regulations governing the use of diesel engines underground are covered in Chapter 10 of the Mines and Works Act (No. 27 of 1956). **In Tables III and IV the relevant general ventilation specifications are reproduced** along with sections of the regulations that refer specifically to diesel engine emissions.

Several features of these regulations should be noted:

(a) In regard to diesel fumes, the only gases referred to are carbon monoxide, and oxides of nitrogen (Regulation 10.25.5).

(b) There is no mention of a minimum requirement in regard to air quantity in relation to the rated capacity of diesel engines.

(c) The only reference to fiery mines in regard to the use of diesel engines is in Regulation 10.25.2(b). In this Section, the Inspector of Mines requires a minimum air speed of 0.5 m/s in all places where diesel engines are used in fiery mines.

EFFICIENT OPERATION OF DIESEL ENGINES

In order to ensure the least possible pollution from exhaust gas emissions, special attention is given to several details of operation and maintenance of locomotive engines, as follows

(a) The quality of diesel fuel should conform to an accepted specification such as BS 2869 "Oil Fuels," Class A: or ASTM-D975/Grade 2B.

(b) Over-rich fuel-air ratios should be avoided. The procedure that is recommended is to derate the engine by setting the maximum fuel stop on the injectors for a maximum fuel delivery that is 15 percent below the sea-level setting for a fuel of specific gravity 0.83. This procedure ensures smoke-free operation at all altitudes less than about 1,200 m above sea level.

(c) The load should be commensurate with the rating of the engine. Typically this means that the load should not exceed approximately eight four-ton trucks for every 25 **W of power.**

(d) The cooling system of the engine should maintain the circulating water at a temperature of 85C ± 10C (85C = 185F).

(e) Air filters should be replaced regularly, at intervals depending on the prevailing dust load.

(f) Exhaust scrubbers should be checked regularly.

Some mines have experimented with catalytic exhaust cleaners, but this type of cleaner has not found wide acceptance. Of far greater significance seems to be the implementation of good maintenance practices.

GENERAL REMARKS

Most South African mines are so deep that relatively large quantities of ventilation air must be circulated in order to counteract the pollution from heat and humidity and, in general, pollution from diesel locomotives and dust is not a problem. Exceptions occur only in localized places, and these situations, when identified, are usually resolved by simple modifications to the local ventilation arrangements.

In coal mines the requirement that through-flow ventilation air velocities must not be less than 0.5 m/s in places where diesel engines are used is considered to be adequate to ensure sufficient dispersion of the fumes and heat from the point of view of health and safety. Although it is impractical to maintain such high air velocities in advance headings (with the result that conditions in such headings are often unpleasant although not dangerous to safety and health), the mounting of small jet-fans on end-loaders and LHD vehicles, and the proper positioning of the exhaust, can assist materially in sweeping fumes from such advance headings.

In summary, therefore, diesel engines are not considered to constitute a health hazard in the conditions under which they are used in South African mines.

ACKNOWLEDGEMENT

This paper is submitted with the approval of the Chamber of Mines of South Africa.

TABLE III. GENERAL PROVISIONS OF THE MINES AND WORKS ACT THAT RELATE TO HARMFUL GASES

Act No. 27 of 1956 Regulations

MINES AND WORKS

Ventilation of workings

10.6.2 The workings of every part of a mine where persons are required to travel or work shall be properly ventilated to maintain safe and healthy environmental conditions for the workmen and the ventilating air shall be such that it will dilute and render harmless any flammable or noxious gases and dust in the ambient air. No work in harmful air.

10.6.4 No person shall enter or remain in or cause or permit any other person to enter or remain in any part of the workings of a mines if the air contains harmful smoke, gas, fumes or dust perceptible by sight, smell or other senses unless such person is wearing effective apparatus approved for the purpose by the Government Mining Engineer to prevent the inhalation of such smoke, gas, fumes or dust.

Permissible quantities of gas and dust

10.6.6 In the general body of the air at any place where persons are required to work or travel, under normal working conditions:

CO_2 (a) the amount of carbon dioxide shall not exceed 5000 parts per 1000 000 of air by volume,

CO (b) the amount of carbon monoxide shall not exceed 100 parts per 1000 000 of air by volume,

NOx (c) the amount of oxides of nitrogen shall not exceed 5 parts per 1000 000 of air by volume,

H_2S (d) the amount of hydrogen sulphide shall not exceed 20 parts per 1000 000 air by volume,

CH_4 (e) the amount of flammable gas shall be insufficient to show a distinct cap on the reduced flame of a safety lamp, and

Dust (f) the concentration of dust shall not exceed such standard as may from time to time be specified by the Government Mining Engineer.

Quantity and velocity of air - metalliferous and diamond mines.

10.7 In every controlled metalliferous or controlled diamond mine unless exempted in writing by the Inspector of Mines:

10.7.1 the velocity of the air current along the working face of any stope shall average not less than 0.25 metre per second over the working height; and

10.7.2 the quantity of air supplied at the working face of every development end such as a tunnel, drive, crosscut, raise or winze which is being advanced and at the bottom of any shaft in the course of being sunk shall not be less than 150 cubic decimetres per second for each square metre of the average cross-sectional area of the excavation. (0.15 m3/s per m2).

Quantity and velocity of air - coal mines.

10.8 In every coal mine not exempted in writing by the Inspector of Mines:

10.8.1 the quantity of fresh air in cubic decimetres per second supplied throughout the 24 hours to each ventilating district shall be not less than 25 multiplied by the maximum mass in metric tons of coal and rock mines per shift in such district;

10.8.2 no ventilating district shall at any time contain more than 200 persons;

10.8.3 in longwall working the velocity of the air current along any face shall average not less than 0.25 metre per second over the working height;

10.8.4 in bord and pillar working, roadways that carry a unidirectional flow of air over the whole of their cross-sectional area from the main intake to the main return aircourse of any section of the workings for the purpose of ventilating such workings shall be provided and maintained to carry such flow as close as practicable to every working place in such section. The average velocity of the air current through any such roadway as its nearest point from any working place which it serves with air shall not be less than 0.25 metres per second;

10.8.5 the quantity of air supplied at the face of any heading which is being advanced in coal and which has advanced more than 20 metres from its point of communication with the nearest roadway that is carrying a unidirectional flow of air over the whole of its cross-sectional area from the main intake to the main return aircourse of the section of the workings in which such heading is being advanced shall not be less than 150 cubic decimetres per second for each square metre of the average cross-sectional area of the heading;

10.8.6 the quantity of air supplied at the face of any tunnel being advanced in stone or in dyke and at the face of any shaft in the course of being sunk shall not be less than 150 cubic decimetres per second for each square metre of the average cross-sectional area of the excavation and a waterblast shall be installed in accordance with regulation 10.10.5.

TABLE IV. PROVISIONS OF THE MINES AND WORKS ACT THAT RELATE SPECIFICALLY TO DIESEL ENGINES

Act. No. 27 of 1956 Regulations

MINES AND WORKS

Internal combustion engines underground

10.25.1 No internal combustion engine other than a diesel engine shall be used underground in any mine.

10.25.2 No diesel engine shall be used underground

(a) in any mine unless there is sufficient ventilation to render harmless the exhaust gasses produced, and

(b) in any fiery mine or in any other mine in the workings of which there may be a risk of such diesel engine igniting gas or coal dust unless it is of a design and construction approved in writing by the Government Mining Engineer, and then only under such conditions and subject to such restrictions as he may specify.

10.25.3 Every diesel engine used underground shall be provided with means whereby the air entering the engine is cleaned, the exhaust gases before being expelled are cooled and where expelled are diluted, and the emission of flames or sparks is prevented. These means shall be maintained in an effective condition.

10.25.4 Where a diesel engine is used underground samples shall be taken

(a) at intervals not exceeding one month, of the general body of the air at representative places and times laid down by the manager and while the engine is running, and

(b) at intervals not exceeding three months, of gas emitted from the exhaust of the diesel engine when the engine is developing maximum power and when the engine is idling.

The percentage by volume of carbon monoxide or oxides of nitrogen present in each sample shall be determined and a record kept of the results.

10.25.5 The operation of a diesel engine underground shall be discontinued until conditions have been remedied

(a) if the air at any place where it is being used is found to contain more than 100 parts of carbon monoxide or 5 parts of oxides of nitrogen per 1,000,000 by volume; or

(b) if the exhaust gases of the engines are found to contain more than 2 000 parts of carbon monoxide or 1,000 parts of oxides of nitrogen per 1,000,000 by volume; or

(c) if the engine is found to have any defect which may cause danger to persons.

10.25.6 The engine of a diesel powered unit underground shall not be kept running idle except while being tested or during brief halts while in use.

10.25.7 Diesel engine fuel shall be delivered underground in such a manner that no spillage can take place during delivery. When the fuel is piped underground the pipes shall be drained each time after use. The fuel shall be stored underground only in robust closed containers which do not leak. Except with the written permission of the Inspector of Mines, the quantity of diesel fuel stored underground shall not exceed 3 days' estimated consumption.

QUESTIONS AND ANSWERS AND COMMENTS

COMMENT: It seems that they don't know if they have a problem or not. I think there is a problem but the evidence has escaped them.

WHILLIER: I disagree since 10 to 20 percent of the total population are career miners, and they have no health problems attributed to them. X-ray examinations are given each year to all active miners. If anything shows up, they are further examined. Currently, they have no serious problem with any mine pollutants including diesel emissions. The examination will be changed to once every two years since the yearly exam has revealed such a low level of complaints.

QUESTION: How strong are the unions?

WHILLIER: Unions are right-wing. They affect government policy, particularly in mining.

QUESTION: What are the concerns for carbon monoxide and other dangerous gases?

WHILLIER: There is no evidence in the workers of any illness related to gases. The main problem is dust. There is no evidence that diesel emissions or radon is causing problems. There is a limit on radon.

QUESTION: What percentage of the miners are white?

WHILLIER: In coal mining, 90 percent of the miners are black and 10 percent are white.

QUESTION: Black miners usually work six months to one year. Those who return to work are reexamined. Are those who leave and don't return examined later?

WHILLIER: No.

QUESTION: Are the exams applicable as to the length of exposure or overall health of the men?

WHILLIER: Probably not in the pure statistical sense. But they are good as regards the health of the individual miner.

COMMENT: Data from South Africa is not applicable to my country because of social differences.

COMMENT: Inferences cannot be generalized because of the way the miners work.

COMMENT:	One half of the white miners and an equal number of black miners are career miners. Their records provide general health trends.

THE SWEDISH EXPERIENCE WITH DIESEL ENGINES IN UNDERGROUND MINING

Harold S. Jorgensen, D.P.H., D.I.H.
World Health Organization

During the last 15 years the number of diesel engines in Swedish underground mines has steadily increased. The principal reasons for this have been the functional advantages: the possibility of introducing more flexible machines and of mechanizing the heavy work. This has made it possible to increase the production considerably and has been decisive for the survival of these mines. It is uncertain whether other sources of power could have produced equal results and it is not very likely.

The costs directly attributed to the diesels increased over the years far more than initially calculated, mainly because vastly more diesels were eventually introduced underground than originally anticipated.

The gradually acquired knowledge of the possible dangers of diesel exhaust gases to the health of the workers later resulted in a drastic increase in the hygienic requirements. Furthermore, the employees are today far more alert to the possible hygienic risks than 10 to 15 years ago. They consistently exhibit a strong influence toward the continued improvement of the underground environment.

SWEDISH GOVERNMENT REGULATIONS FOR THE USE OF DIESEL POWERED EQUIPMENT IN UNDERGROUND MINING

These regulations are established and enforced by the National Board of Occupational Safety and Health (NBOSH) under the Mining Regulations (No. 67,1974). They aim at the control of the air quality underground and the emissions of diesel engines.

Regulations Pertaining to the Air Quality

The present requirements are shown in Table I.

The permissible limit for NO_2 is lower (2 ppm) than the corresponding TLV outside mines which is 5 ppm NO_2. This is based on the asumption that the biological effect of NO_2 most likely is enhanced by other substances in the air and possibly also by smoking.

TABLE I. AIR QUALITY REQUIREMENTS WHEN DIESELS ARE USED UNDERGROUND

Gas	Estimated average exposition ppm, during:	
	30 minutes counted from the first sample	8 hours, counted from the first sample
Carbon monoxide	50	25
Carbon dioxide	15000	5000
Nitrogen dioxide	3	2
Nitrogen oxides	30	20

The CO and NO_2 content in the air should be determined regularly and at least once every second week. When a new worksite or a new engine is taken into use and the ventilation system is altered, the content of CO, CO_2, and NOx shall be determined. Where a new or technically altered engine is taken into use, O_2, SO_2, and HCOH concentrations should also be determined.

The content of oxygen (O_2) in the air should not fall short of the values shown in Table II.

These limits are intended to prevent lack of oxygen and to ascertain a normal combustion in the diesel engines.

There are at present no regulations for polynuclear aromatic hydrocarbons or for visibility deterioration but it is recommended that levels below 10 nanograms of 3, 4 benz-pyrene and 5 COH be aimed at.

Regulations for the Control of Emissions from Diesel Engines Used Underground

These regulations cover carbon monoxide and smoke and also include some practical recommendations for the use of diesels.

1. All vehicles should be checked every 150 working hours or at least every second month. Sampling should take place with no load on the engine with warmed-up engine at 3/4 - 1/1 of maximum allowable rpm at full effect. The sample should be taken in the exhaust pipe before the scrubber but after the catalytic purifier if these devices are present. If possible, sampling should also be done at full load. The carbon monoxide content should not exceed 600 ppm if tested at no load and 800 ppm if tested at full load. If the carbon monoxide content exceeds by 25 percent the normal value, the engine should be taken out of service for adjustment. Engines 150 kW or more should not exceed Bosch No. 1 when tested at no load and No. 2 if tested at full load.

Fuel

The fuel used should contain less than 0.1 percent sulphur, and the fuel injection pump should be sealed to limit the performance to 90 percent of the maximum effect.

There are no government regulations concerning the use of scrubbers or catalytic purifiers on diesels but only a general recommendation.

Ventilation

The recommendations are as follows:

Air dilutions and airing out of diesel exhaust gases may be approximately calculated as follows:

TABLE II. OXYGEN REQUIREMENTS WHEN DIESELS ARE USED UNDERGROUND

Diesel powered equipment	Concentration of oxygen (O_2) in percentage per volume, estimated average value during	
	30 minutes, counted from the first sample	8 hours, counted from the first sample
not in use	17	19
in use	19	20

$$Qe = \frac{P \times 0.27 \times Qs \times k}{3600}$$

where

Qe = requisite air flow, m^3 per second,
P = Catalogue effect of engine in kW,
0.27 = Specific fuel consumption, kg per kWh,
Qs = Specific requisite air volume m^3/kg fuel consumption
= 5000 at dilution (low rooms),
= 3000 - 4000 at air flow upwards (high rooms),
k = coefficient = 0.15 at hauling,
= 0.30 at loading (and hauling more than 25 m), and
= 0.45 at loading (including hauling maximum 25 m).

ROUTINE CONTROL OF AIR QUALITY AND DIESEL OPERATIONS IN LKAB

About 1500 diesels are in use underground in Swedish mines today. More than 50 percent of these diesels are being operated by the iron ore company LKAB in Northern Sweden.

Until 1959, the LKAB mine in Kiruna was mainly an open pit mine. In the late 1950's, subterranean mining was started and the mine is today supposed the largest such mine in the world. Diesel engines were at the same time introduced for subterranean transportation.

Table III shows the different categories of diesels operating underground in LKAB today.

TABLE III. DISTRIBUTION AND RELATIVE FUEL CONSUMPTION OF DIESELS UNDERGROUND IN LKAB

	No	Ehk-103	m^3 Fuel/day	Percentage
Drilling machines	73	7.7	0.3	0.5 percent
Loading	112	26.5	15	27 percent
Trucks	185	43.2	28	50 percent
Service vehicles	270	24.9	5.1	9 percent
Passenger vehicles including buses	124	11.1	7.5	14 percent

Trucks account for 50 percent of the total fuel consumption, front loaders for 27 percent, buses and passenger cars for 14 percent, and service vehicles for 9 percent.

The number of diesels underground has increased more than expected, partly because of increased production targets but also because productivity has been less than anticipated. The technical development has also had as a consequence that many new types of machines designed for specific purposes have been introduced.

All diesel vehicles are equipped with a cabin for the driver and move around considerably. Air samples are therefore taken at the place with the poorest hygienic conditions, i.e. at the extreme front.

Sampling of the air is carried out by six employees especially trained, divided into two shifts. Each day they are directed to those places of work where the gas concentration may be expected to possibly exceed the TLV's.

The concentrations of carbon monoxide, nitrogen dioxide, nitrogen dioxide plus nitrogen oxide, aldehydes, and dust are measured. (Gravimetric measurements of total dust show a concentration of between 3 and 9 mg/m^3 with about 40 percent of the particles below 5 micrometers.)

The results are protocolled as are the time, place, ventilation type and performance, type of diesel engine, and type of work. All information is eventually computerized. Approximately 20,000 samples are taken each year.

Based on this, it is possible to fairly accurately determine the polluting result of different diesel engines, combination of work processes, ventilation type, etc., and it is possible to optimize these factors as far as the hygienic situation is concerned. For example, it was shown at an early stage that front loaders loading and carrying the ore were obviously much less polluting than the combination of joy loaders and trucks. The trends according to time and places are of course also registered.

The emissions from the unloaded diesel engines are checked with Hartridge smokemeters once a month at a control station underground. The seal of the fuel injection pump is also checked.

Ventilation (LKAB)

A powerful and extensive ventilation system is used to keep air pollution at a low level. Air is pressed down into the mine through 26 fresh air shafts.

The amount of air by weight which is blown down into the mines is greater than the amount of iron ore which is brought up. The total ventilation costs are about 15-20 million dollars per year. This means that each dollar's worth of fuel used underground costs an additional five dollars in ventilation. It also means that each vehicle used in underground operations requires an additional 10,000-20,000 dollars in ventilation costs.

The general aim is an airflow of Q = 3000 m3/kg fuel. Further increases tend to produce complaints of draft. This should be the airflow at the front, where the greatest pollution risks are. Where diesels are not in operation but other work processes are going on (e.g. drilling), an airflow of 10,000 m3/h is recommended. The distance between the air tube and the front should not exceed 30 meters. It is realized that one of the most important efforts should be to make the maximum use of the total ventilation according to where and when it is most needed.

MEDICAL EXPERIENCE

Studies were previously done on mine workers in LKAB (1). They showed a significantly increased prevalence of bronchitis among underground workers exposed to diesels for several years, especially the smokers, as compared to surface workers. Smoking and underground exposure evidently acted synergistically. Lung function studies did not reveal any significant differences between surface and underground workers. However, smokers working underground complained more frequently about smell and irritation by the diesels. It was impossible to distinguish between the effects of the dust and those of the gaseous components, since no control groups not exposed to diesels and working underground were available. It was assumed that both the dust and the gaseous components could have contributed.

The situation has lately been further complicated by the newly acquired knowledge of the presence of radon gas in the Swedish iron ore mines. Recent epidemiological studies (2,3) have shown that the prevalence of lung cancer among mine workers underground is about three times the rate among surface workers. This higher prevalence was significant among workers who had not been exposed to diesels at all or only for a few years. Nearly all of them were smokers (only one exception).

This would not necessarily be an indication of the magnitude of the lung cancer risk the workers are exposed to today, since the hygienic conditions in the mines have improved considerably during the last five to ten years. To be able to evaluate today's risks, we will probably have to wait for the results and do follow-up studies during the next 10-20 years.

A co-carcinogenic effect of exposure to diesel exhaust gas cannot be excluded and may possibly show up in a future study in which workers with long exposure to diesels are included.

Accumulated Exposure Data

When the previously mentioned epidemiological studies on Swedish mine workers were carried out, the main difficulty was to obtain reliable quantitative information concerning the worker's previous exposures to the environmental hygienic factors in the mines.

In an effort to ameliorate this situation, a project was initiated about three years ago for the purpose of creating a continuous registration of important hygienic factors in the mining environment which the individual worker is exposed to during his whole working life. A system is now being developed whereby the accumulated exposure to dust (silica + iron) carbon monoxide, nitrogen dioxide and radon is registered continuously on a monthly basis. All the information will be computerized. The system is planned to eventually be expanded further with other factors and to include all mine workers in Sweden.

The final aim is to create a data bank of detailed information on each individual worker's accumulated exposure which can be utilized in future epidemiological studies. It may also be possible to establish limits for accumulated exposure to specific substances.

The Importance of Smoking in the Occupational Context

One circumstance should be emphasized. Synergistic effects of smoking and other pollutants have repeatedly been reported. The need for smokers exposed to diesel exhaust to quit smoking is probably more important than any other hygienic effort.

FUTURE TRENDS

The general opinion in Sweden today is that diesel use underground is an evil, but also that for the time being it is a necessary evil. At present and probably for many years to come, diesels will continue to be the principal source of energy in Swedish mines.

It is specifically stated in the mining regulations "that engines should be electrically-powered where this is possible." Electricity is undoubtedly the main alternative but other sources of energy are also being looked into.

In LKAB's development plans, it is anticipated that 60-80 percent of the resources will be spent on further improvements of the performance of the diesel engine aiming at the proposed California regulations for 1983. Ten to twenty percent of the resources are expected to be spent on studies for the purpose of adapting electrically-powered engines for selective use in the mines. All three alternatives--cable, trolley, and battery-transmitted electrical power--are at present being studied on a small scale. Most likely, future development will show the utilization of both diesel and electrical power, with the definite emphasis on diesel.

The ventilation system will be further improved. The aim will be greater flexibility and specificity in the ventilation system and an overall coordination of the total ventilation capacity by computer.

The mining research department of the Technical High School for Northern Sweden has a project on the development of the highest possible control of the ventilation system in mines. Another ongoing project is the development of an average duty cycle for diesels under normal operation underground. A third project is the development of exhaust gas purifiers with optimal effect.

The surveillance of underground workers will be radically amended by the computerized registration of accumulated individual exposures.

The basis for carrying out analytical epidemiological studies will thereby be much improved and may enable us in the future to more precisely determine the size of the hygienic risks attached to the use of diesel engines underground.

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QUESTIONS AND ANSWERS:

QUESTION: What was the concentration of oxygen estimated in the samples?

JORGENSEN: When diesels were not in use, the concentration was 17 percent for 30 minutes and 19 percent for eight hours. With diesels in operation, it was 19 percent for 30 minutes and 20 percent for eight hours.

QUESTION: What was the relationship between diesel usage and productivity?

JORGENSEN: Productivity has increased by using diesels, but it has not been what was expected. Production has increased from 15 million tons to 28 million tons.

QUESTION: Are more specifics on exposure histories available?

JORGENSEN: Until 1970 the levels were slightly above what was expected. It is thought that radon causes lung cancer.

JAPANESE EXPERIENCE

Dr. K. Tsujimura
Large Engine Design Section
Isuzu Motors, LTD

My presentation today is divided into two parts. First I will discuss the situation in Japan, the use of diesel engines in our coal mines, and mainly the regulation of the diesels. Second I will present a very rough description of our exhaust emission study.

As you well know, natural resources in Japan are very limited and there are few coal mines. Moreover, several mines have been closed as rising operation costs prevented them from competing with imported coal. In Japan, coal is very deep under the ground and difficult to extract. Another reason for the closing of mines is the decrease of the demand for coal. The cost of operation with coal is higher than that with oil, so many newly-built power stations use oil instead of coal, and steam locomotives were changed to electric or diesel locomotives.

Consequently, I am not able to present extensive information about the actual situations in which diesels are used in coal mines, but I presume that such diesel use in Japan will be quite limited.

I do have, however, information about the regulatory situation. Recently, trucks, Jeeps, and some working equipment with rubber tires are often being used in mines in addition to locomotives. New regulations concerning exhaust emissions of such equipment are being planned.

As you probably know, Japanese regulation of exhaust emissions of passenger cars if very strict. Also, the regulation of emissions from heavy-duty diesels is getting more and more strict. So, it is very natural for the Japanese regulatory officers to consider the revision of emission regulations concerning mine diesels.

At present, Japanese regulations for mine diesels are aimed mainly at preventing explosions and were devised along the lines of German regulations of several decades ago. The exhaust emission part of the regulations seems to be modeled on U.S. regulations. The main points of it are as follows:

1. Temperature of the outside surface of the engine should be below 200C (392F).

2. The exhaust gas temperature should be below 80C (170F).

3. CO and NO2 concentrations should be below 0.12 percent and 30 ppm respectively, measured in six operation modes which are constructed from two different speeds and three different loads. Speeds are lowest operation and highest rated. Loads are 100 percent, 50 percent, and no load.

4. CO concentration at idling multiplied by 1.355 should be below 0.06 percent.

Besides these, there are regulations for anti-explosion characteristics of the engine in environments containing methane and for fire extinguishing equipment or emergency stop devices. Water injection into the exhaust manifold and water scrubbers are the devices formally used in meeting these requirements in the coal mine diesel.

Our company, Isuzu Motors, Ltd., has no experience in manufacturing such coal mine diesels. But as we produce many diesel engines for vehicle use, we have made considerable efforts to decrease exhaust emissions of our engines. Our study is directed mainly to the problem of exhaust smoke, NO, unburned hydrocarbons, and exhaust gases which irritate the eyes and nose.

Exhaust smoke is an old but ever-continuing problem of the diesel, and many investigators of diesel combustion are studying it extensively. We, of course, have studied the problem but I don't want to discuss it here, as it is of interest only to diesel engineers.

Instead, I shall describe some other results. Previously, people disliked diesel smoke as it interfered with visibility in road traffic. Now, however, we must treat it as particulate matter which is thought to have some health effect on human beings. From this point of view, the weight density and particle size distribution of the smoke is more important than its capacity to reduce visibility.

We investigated the correlation between the smoke weight density and Bosch smoke reading, and our result coincided fairly well with other investigations.

Smoke particle size distribution was measured by using Andersen Stack Samplers, and we noticed, as other investigations have indicated, that very fine particles constitute the major part of the smoke.

We then studied the feasibility of eliminating the smoke through collecting it by some means. The most effective way we found is to use a bag filter with special soot-blowing regeneration to prevent clogging of the filter. By using this instrument we could decrease the smoke to Bosch 0, but because of the thermal problem of the bag material and the large size of the instrument, I feel this cannot be practical.

Concerning NO reduction, we think the injection timing retard is the only practical way, but it causes a fuel economy penalty, and hydrocarbon emissions increase. EGR, water injection, and emulsified fuel with water are all effective methods to decrease NO, but again they seem impractical.

Unburned hydrocarbons can be decreased by exhaust catalyst, but as the fuel-air ratio of the diesel varies following the load, exhaust temperature also changes with the load and the efficiency of hydrocarbon oxidation by the catalysts decreases so much at low load. Moreover, if there is a possibility of sulphate emission increase by the catalyst, as in the case of gasoline engines, it may be better not to use it.

Irritating exhaust gas is often emitted from the diesel engine, especially at the cold start of the engine. I don't know whether the coal mine diesel is often started at cold state, but as the prolonged idling of the engine causes some amount of irritating gas emission, this problem should be included to evaluate the diesel exhaust. We studied this also and found an appreciable decrease of the irritancy of the exhaust by applying exhaust back pressure to the engine or by cutting the fuel delivery to half of the cylinders of the engine.

These are the findings of our investigation and I would be very happy if they were to make some contribution to this workshop.

QUESTION:	Are water injections effective but not practical?
TSUJIMURA:	There is a need to cool exhaust gases by some means, but if water is injected there is a noticeable water increase in the oil. This shortens engine life.

Diesel Experience in the United States

Dr. Aurel Goodwin
Mining Enforcement and Safety Administration
Arlington, Virginia

I appreciate the opportunity to contribute to this workshop. The substance of my paper is devoted to in-mine measurements of diesel exhaust contaminants and is primarily a summary of work done at Michigan Technological University by Dr. John Johnson and work done by the MESA Technical Support Center in Denver. Mr. Glen Sutton has been responsible for most of the latter work. I will not cover activities such as approval and testing of diesel engines or other laboratory work done on diesel exhaust characterizations.

The Michigan Tech work I will describe started in 1974 with a MESA contract to Michigan Technological University. This contract work has been subsequently continued by the U. S. Bureau of Mines. The MESA Technical Support work was started early in 1976 and is part of an environmental study done as part of the joint MESA/NIOSH diesel/silica study. NIOSH has conducted the medical examinations while MESA obtained corresponding environmental and exposure data.

In my presentation I may identify equipment by brand name. This does not constitute an endorsement by MESA; rather it is done for completeness.

The objective of the Michigan Tech work included two phases under the MESA contract. The first phase was to apply the latest available portable instrumentation to characterize mine air, and the second phase was to design and construct a portable instrument package for use in underground mines employing well-developed, state-of-the-art, laboratory instrumentation. Phase I turned out to be primarily an evaluation of portable instruments. While some instruments were found suitable in mines, no completely satisfactory instant read-out instruments were found. They all suffered in one or more respects; e.g., calibration drift, temperature drift, interferences, slow response or complete failure in the mine environment. Since the beginning of the contract, there has been improvement in several instruments so that now there are portable instruments that are sufficiently reliable to monitor some exhaust components, such as CO, NO, NO_2 and CO_2 for diesel engines.

In addition to these portable instruments, an NO_2 dosimeter and a machine-mounted CO_2 detector were evaluated. The CO_2 instrument was designed by the U. S. Bureau of Mines Bartlesville Energy Research Center (now a part of ERDA) and was intended to be used as either an alarm or automatic engine shut-off if the CO_2 concentration exceeded some present level. The motivation for developing such an instrument was the incident that resulted in the two fatalities that Mr. Barrett described earlier. CO_2 was chosen because it is relatively easily measured and it provides a valid indication of oxygen depletion if an engine is operating in a confined space and rebreathing its own exhaust. CO_2 was also found by personnel at the White Pine Mine to be well correlated with other exhaust components such as CO, NO, NO_2, etc., and they have a rule of thumb that if the CO_2 concentration is above 0.15 percent then they take CO and NO samples. If levels are above 0.25 percent, then either ventilation is increased or some other action is taken, such as moving to another workplace.

The Michigan Tech group has demonstrated that this is indeed a valid concept when diesel exhaust is the only source of contamination. Figure 1 shows the data on the contaminants CO, NO, and NO_2 combined according to the American Conference of Governmental Industrial Hygienists procedures vs. CO_2 Concentration. They conclude that the concentration represented as a combination will never exceed unity as long as the CO_2 concentration remains below 0.2 percent.

Although these data show good correlation there are sources of each of these gases that are not diesel-related. The most prevalent and obvious of these other sources is blasting. The most persistent of the several gases is carbon monoxide. The oxides of nitrogen are readily absorbed by moisture, or they react chemically, and are removed rapidly from mine atmospheres. Before we look at the individual contaminants, let me illustrate the kind of activity taking place in a mucking operation. Figure 2 schematically depicts a typical heading the White Pine Mine. The scoop tram moves in and out of the heading containing the muck pile, picking up muck and loading the ore car in the loading area. Samples were taken in the heading at the location marked "end of PVC tubing," and samples were taken simultaneously in the cross-cut at the Jeep location. Concentrations of CO, NO, and CO_2 as a function of time are shown in Figure 3. The mucking operation began about 5:00 p.m. As the muck pile is disturbed, the CO concentration increases in the drift initially but drops rapidly within about a half-hour of the start of mucking. The other contaminants slowly increase as the mucking operation proceeds. The CO peak after the start of mucking is mostly due to gas trapped in the muck pile at the time of blasting.

Figure 4 shows the correlation between the CO and CO_2 for the period shortly after mucking activity is started. The correlation coefficient for these data is 0.158, indicating low probability of correlation.

Correlation of CO and CO_2 for later mucking operations is shown in Figure 5. Although there is a good deal of scatter in the data, the correlation coefficient is 0.408. Figure 6 shows the correlation between NO and CO_2 This correlation is much better (correlation coefficient of 0.830) and tends to indicate that NO from blasting is readily absorbed and not released from the muck pile after wetting down.

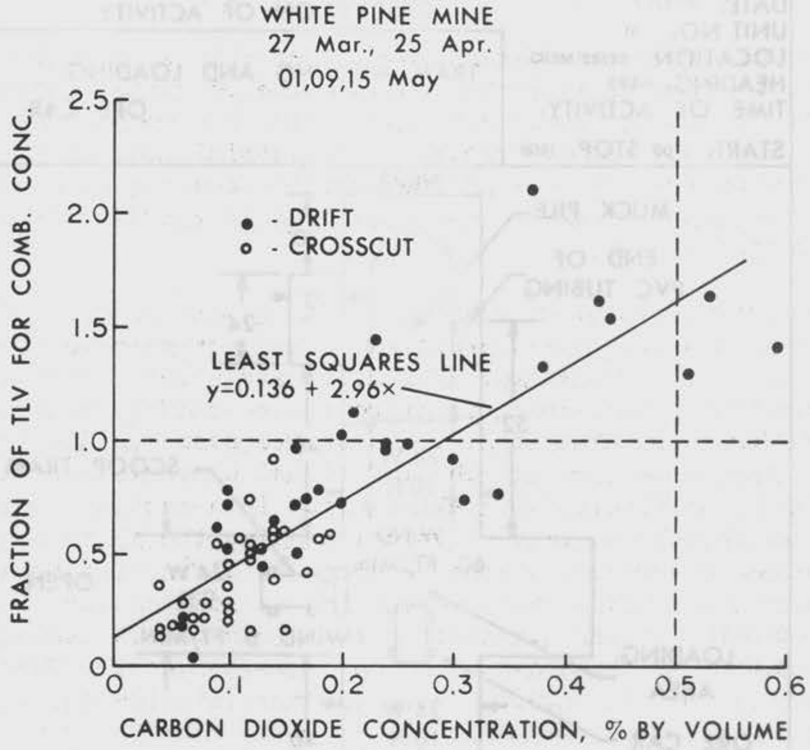


Figure 1 Fraction of TLV for combined concentration of CO, NO, and NO_2 vs. carbon dioxide concentration.

DWG.NO. 5—15—1

AREA DESCRIPTION RECORD

DATE: 5/15/75
UNIT NO: 31
LOCATION: SE182 NE93
HEADING: NE93
TIME OF ACTIVITY:
START: 1700 STOP: 1808

DESCRIPTION OF ACTIVITY

TRAM MUCKING AND LOADING ORE CAR

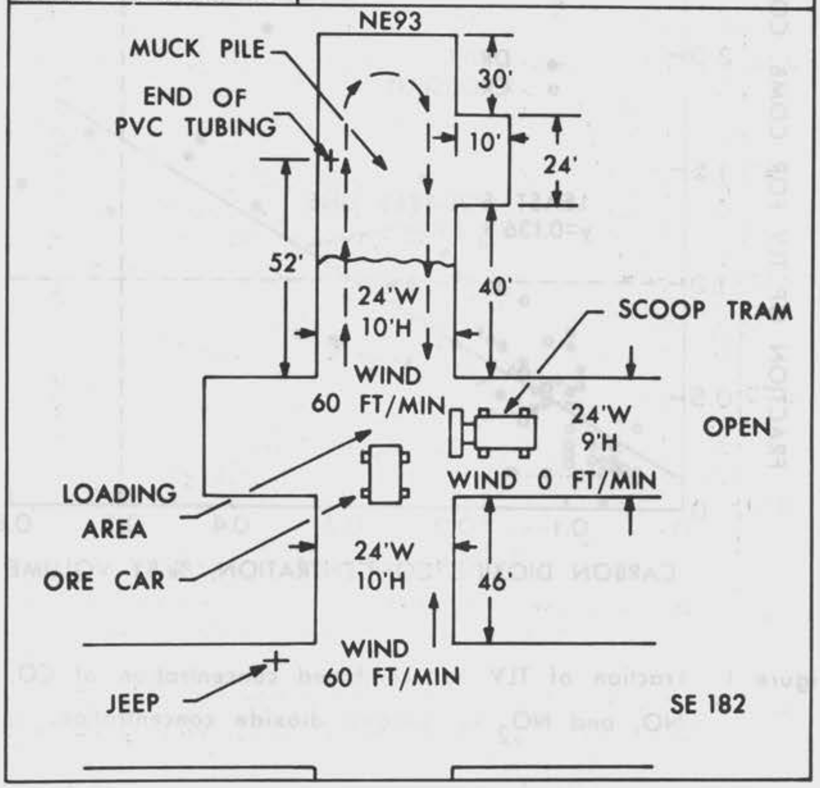


Figure 2 Description Record for area sampled to produce data shown in Figure 32.

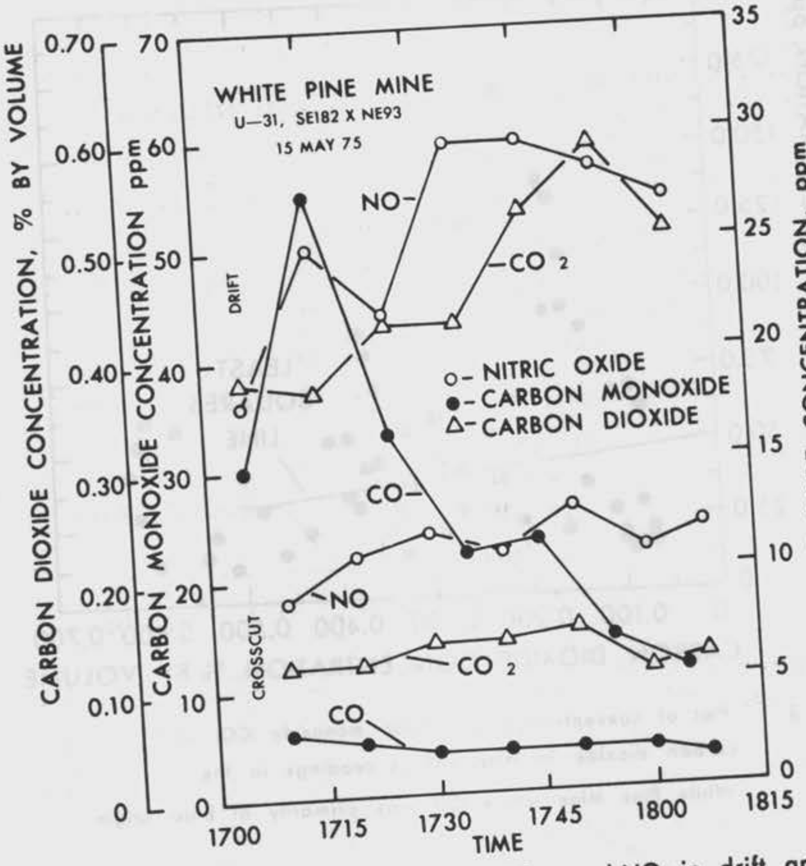


Figure 3 Concentrations of CO, CO 2 and NO in drift and first crosscut at various times during mucking operation.

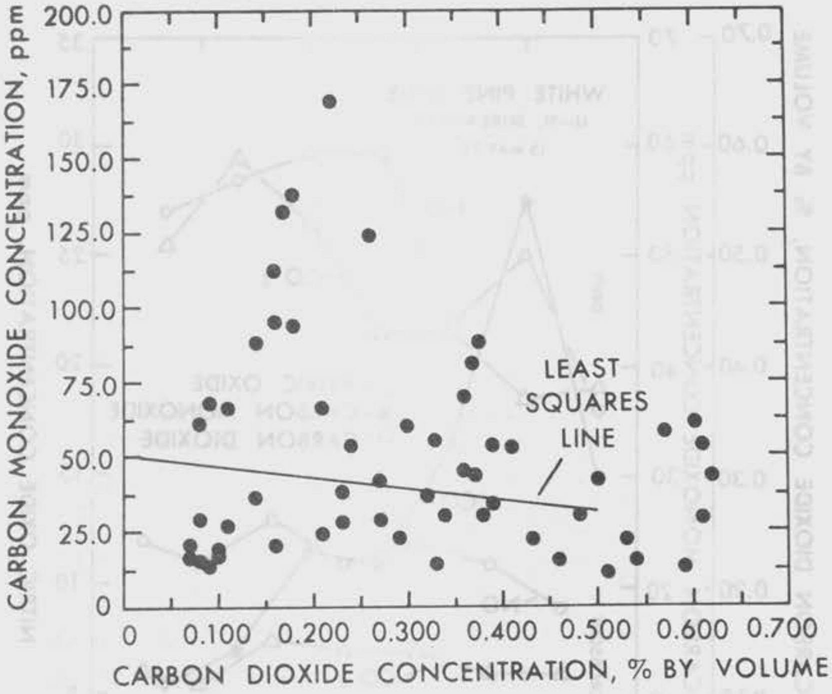


Figure 4 Plot of concentration of carbon monoxide (CO) vs. carbon dioxide for simultaneous readings in the White Pine Mine where CO was primarily of blast origin.

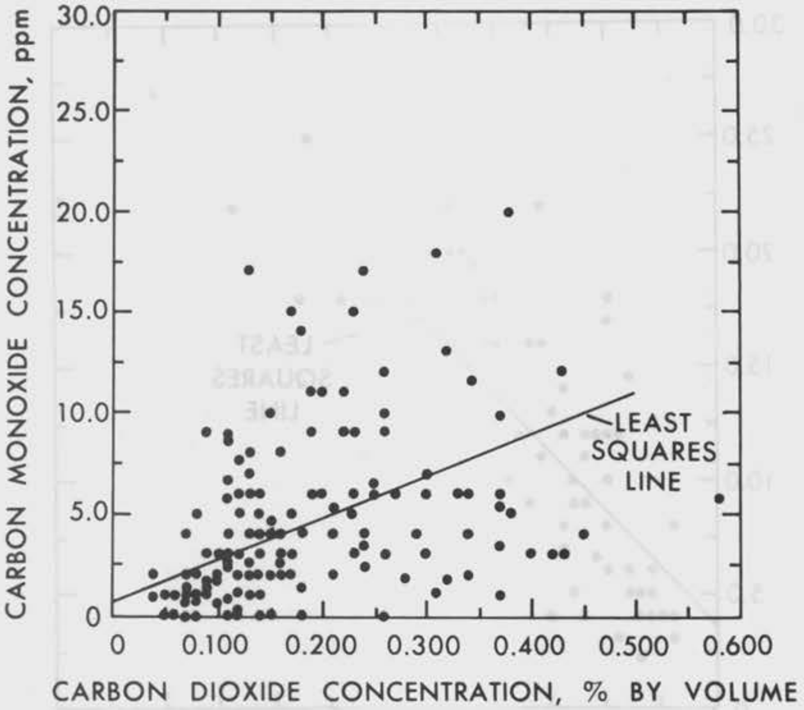


Figure 5 Plot of concentration of carbon monoxide (CO) vs. carbon dioxide for simultaneous readings in the White Pine Mine where CO was primarily of diesel origin.

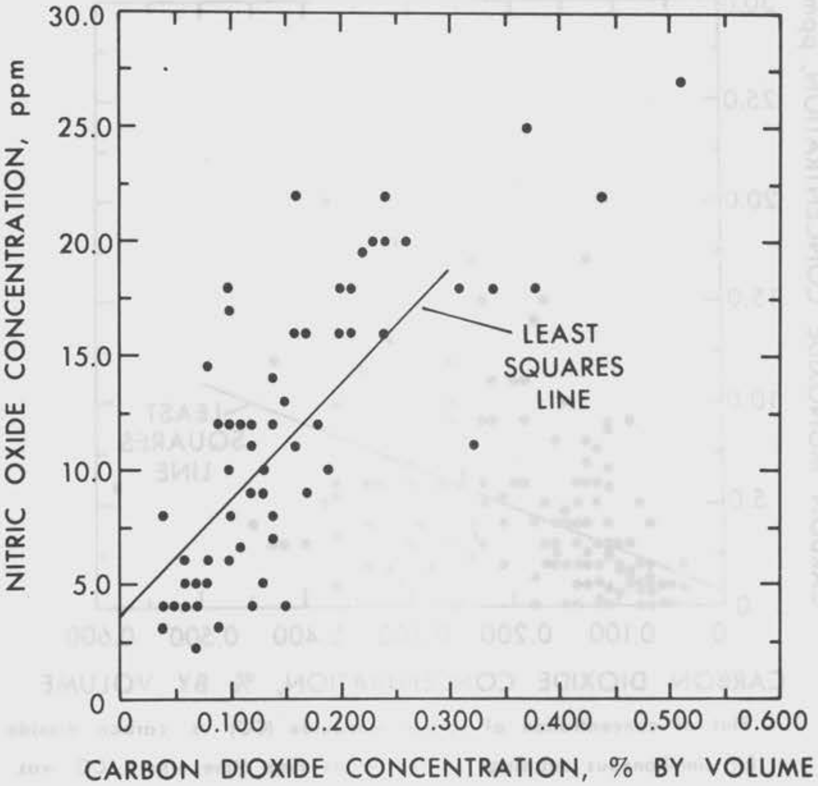


Figure 6 Plot of concentration of nitric oxide vs. carbon dioxide for simultaneous readings in the White Pine Mine.

Another correlation that is interesting is shown in Figure 7. This is a graph showing the correlation of the concentration of airborne particulate matter with CO_2. The excellent correlation (correlation coefficient of 0.943) is rather suprising and might suggest that the origin of most of the particulate matter is diesel exhaust. Of course, increased CO_2 should correlate with increased diesel activity, which also may be a source of increased mineral dust generation. Later measurements resulted in an average carbon-plus-hydrogen fraction in the particulate matter of 0.57. The range of this fraction was 0.18 to 0.99, suggesting that under some circumstances nearly all particulate is from diesel exhaust.

It has been shown that environmental samples often have a lognormal distribution of concentration vs. frequency. Figure 8 is an example of such a lognormal plot for CO_2. Figure 9 is a similar plot for CO. The CO distribution appears to be the sum of two different lognormal distributions. This is thought to be due to two different sources for CO, i.e., blasting and diesel emissions. From such distributions, of course, one can calculate the probability of exceeding a time-weighted average of any specific value.

Figures 10 and 11 show, respectively, the correlation of simultaneous samples taken, grab samples (labeled "bistable samples"), and samples taken with continuous direct-reading instruments. These correlations can be used to determine the confidence of grab samples, assuming the direct reading instruments are correct. The bistables are approximately 12 ml samples which are transported to a laboratory for gas chromatographic analysis. Because the bistable samples are filled by hand, by snapping the sides of the cans apart, it is suspected that the sample could be contaminated by the breath of the person taking the sample. If the person is a smoker, both the CO and CO_2 levels may be elevated. These samples are used by mine inspectors for determining air quality in underground mining operations. However, in addition to the bistable samples, detector tubes are usually used at the same time by the inspectors.

Phase II of the MESA contract with Michigan Tech was to design and construct a "portable" underground monitoring laboratory. This laboratory has the following capabilities:

1. It can alternately monitor up to four pre-selected sample sites at distances from the trailer of up to 300 feet with separate lines for gaseous and particulate airborne contaminants.

2. It can monitor for CO in four ranges including concentrations from 0 to 2500 ppm, for CO_2 in three ranges including concentrations from 0 to 5 percent by volume, for NO and NO_2 in four ranges including concentrations from 0 to 500 ppm, and for particulate matter in number concentration for 10 geometric size increments ranging from 0.0032 to 1 micrometer in particulate matter concentrations less than 1 μm of up to 1 mg/m^3.

3. It is specially equipped for on-site calibration.

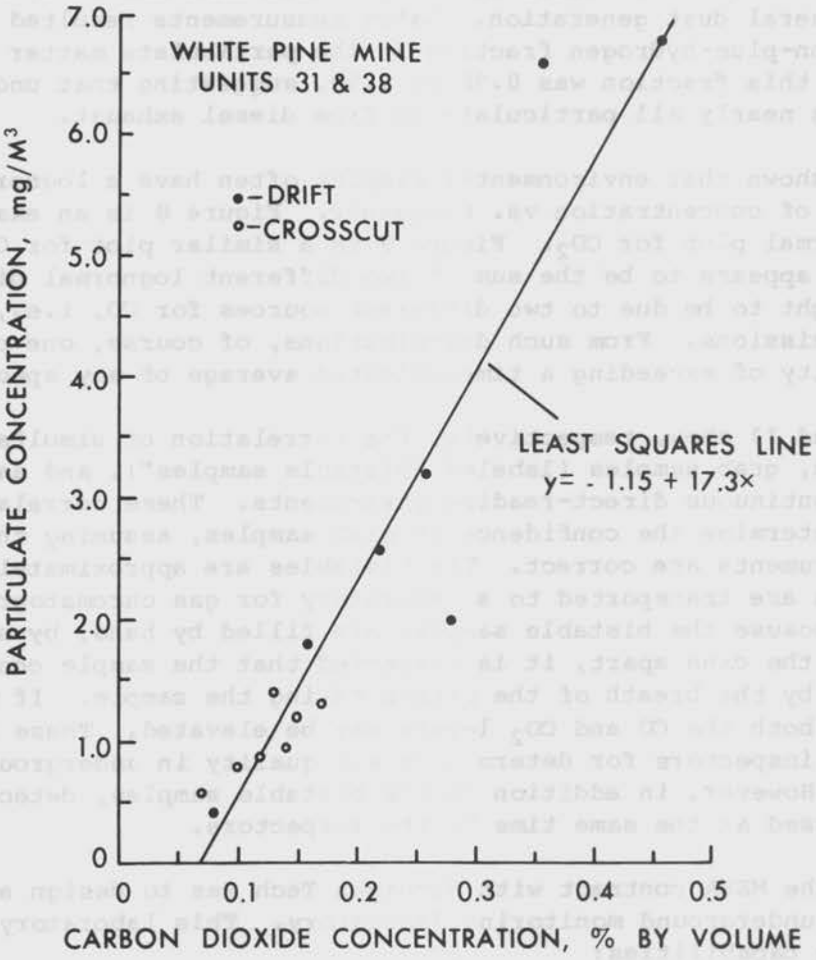


Figure 7 Concentration of respirable particulate matter vs. average concentration of carbon dioxide for simultaneous measurements at White Pine Mine.

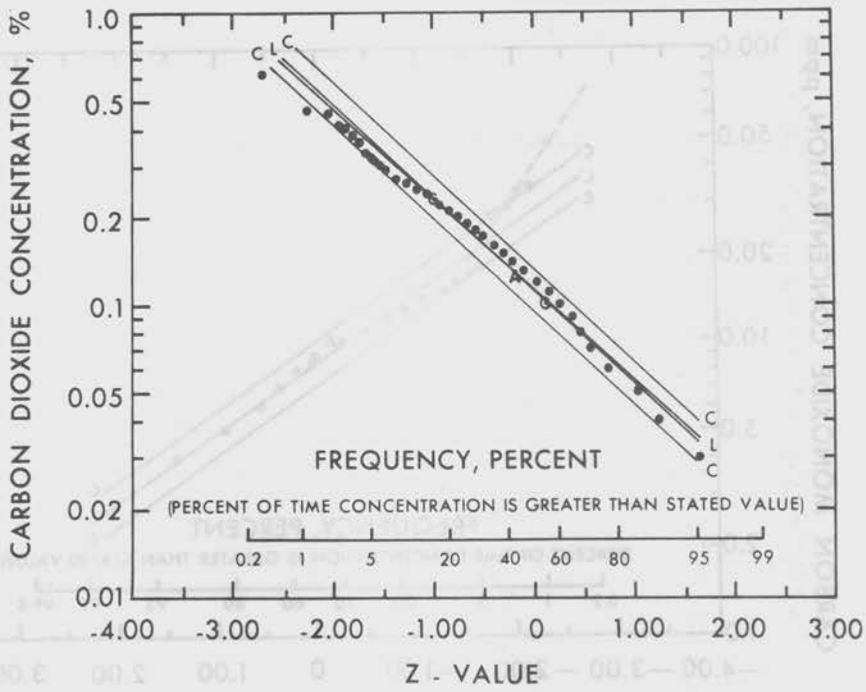


Figure 8 Log normal computer plot of cumulative percentage carbon dioxide one—hour—average readings indicated concentrations by Beckman 868 on Tram 05059 from Feb. 17 - 26, 1975.

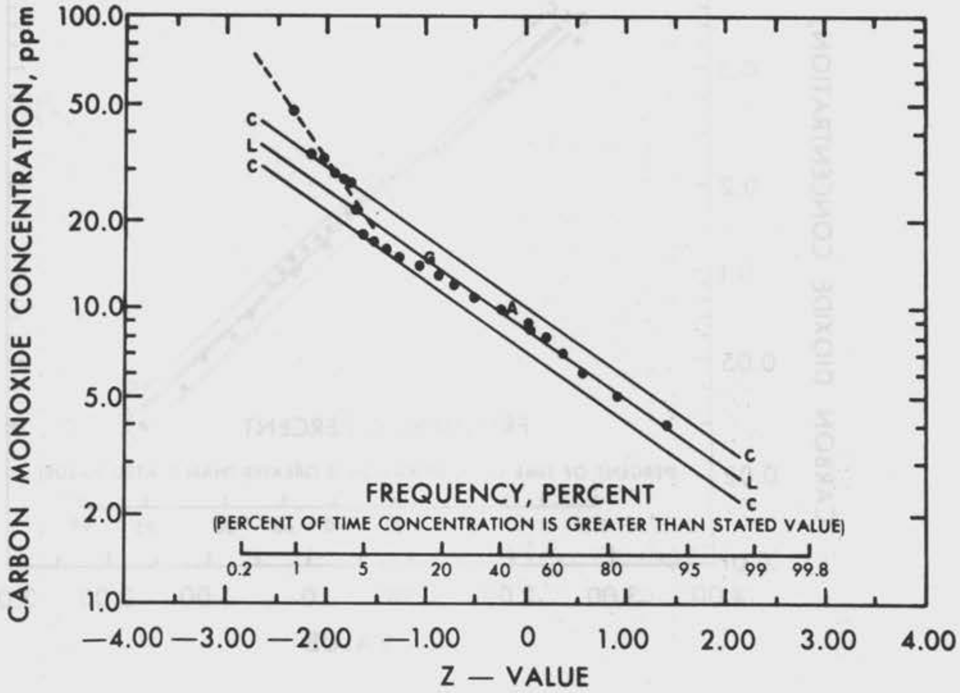


Figure 9 Log normal computer plot for cumulative percentage carbon monoxide 15—minute—average readings above indicated concentrations by Ecolyzer 2600 at U31 lunch area from Jan. 14—16, 1975.

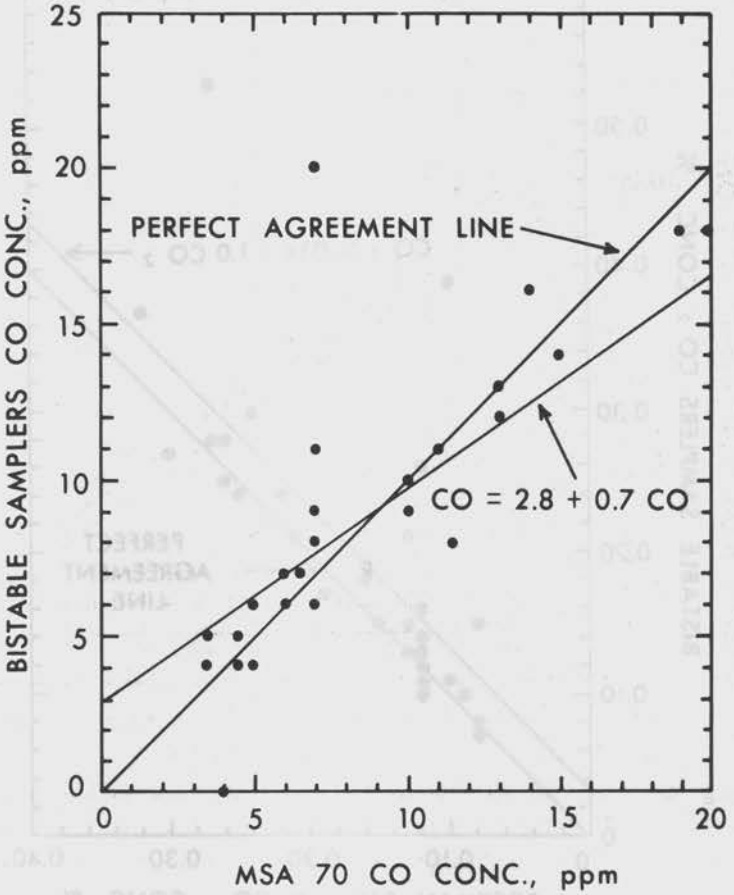


Figure 10 Carbon Monoxide Concentrations measured by collection in Bistable Samplers and analyzed at DTSC vs. MSA 70 readings simultaneous to collection. Data collected during July 1976

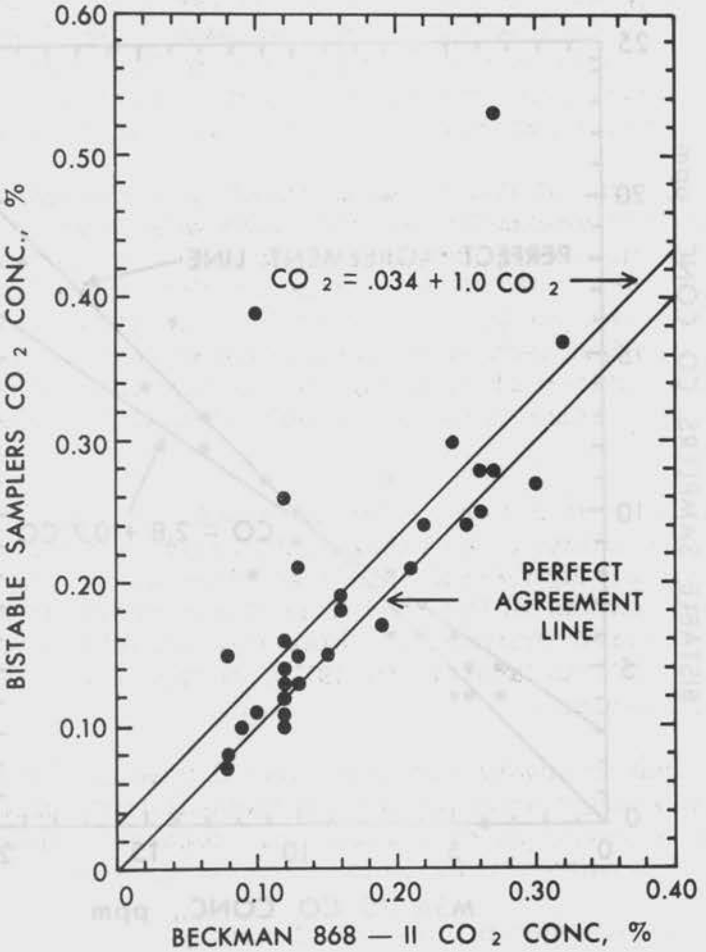


Figure 11 Carbon Dioxide Concentrations measured by collection in Bistable Samplers and analyzed at DTSC vs. Beckman 868 II readings simultaneous to collection. Data collected during July 1976

4. It will operate unattended and supply data both as recorder strip charts and as digital printouts.

Figure 12 shows the kind of data that can be obtained from the trailer operating unattended. The top trace is CO, the second is CO_2 the third is NO, the fourth is NO_2, and the bottom trace is the temperature. The total period over which this data was taken was two days. The figure shows only one day. The sharp increase in the CO followed by "exponential" decay is due to blasting. Other, more gradual variations in levels are related to diesel activity. This is particularly visible in the CO_2 trace.

The spikes on the CO and CO_2 traces were caused by line voltage spikes. Frequency distributions obtained from these data are shown in Figures 13 and 14. The nitric oxide data covering the blasting do not show a lognormal distribution, while the CO concentration during diesel operations follows a lognormal distribution very closely. In concluding my discussion of the Michigan Tech work, I should say that I believe they have demonstrated the feasibility of getting good data on many diesel contaminants in mines. These data can be obtained with a variety of instruments.

The results from this contract are given in detail in a final report which is available from the National Technical Information Service and is identified by the number PB 258-038/AS. The title of the report is "The Development and Application of Advanced Mine Air Monitoring Techniques to Mines Using Diesel-Powered Equipment." Also the Annual Report for the period September 1, 1975 to January 15, 1977, to the Bureau of Mines contains additional results.

The MESA work was done to supply exposure data for an epidemiology study of respiratory disease among miners exposed to mineral dust (silica) and diesel exhaust. As a gross classification for comparing miners' health, the mines were divided into the following four categories:

1. High free silica content/low diesel use,
2. Low free silica content/low diesel use,
3. High free silica content/high diesel use, and
4. Low free silica content/high diesel use.

As a matter of interest, there were 22 mines in the study; Figure 15 shows their distribution in the United States. Not shown on this figure are three salt mines in Kansas that were added to the list late in the study. These three mines had no diesels.

In order to apply the environmental data to employees, we attempted to sample each job classification working underground. Ten full shifts of exposure were taken in most cases to provide an adequate average exposure.

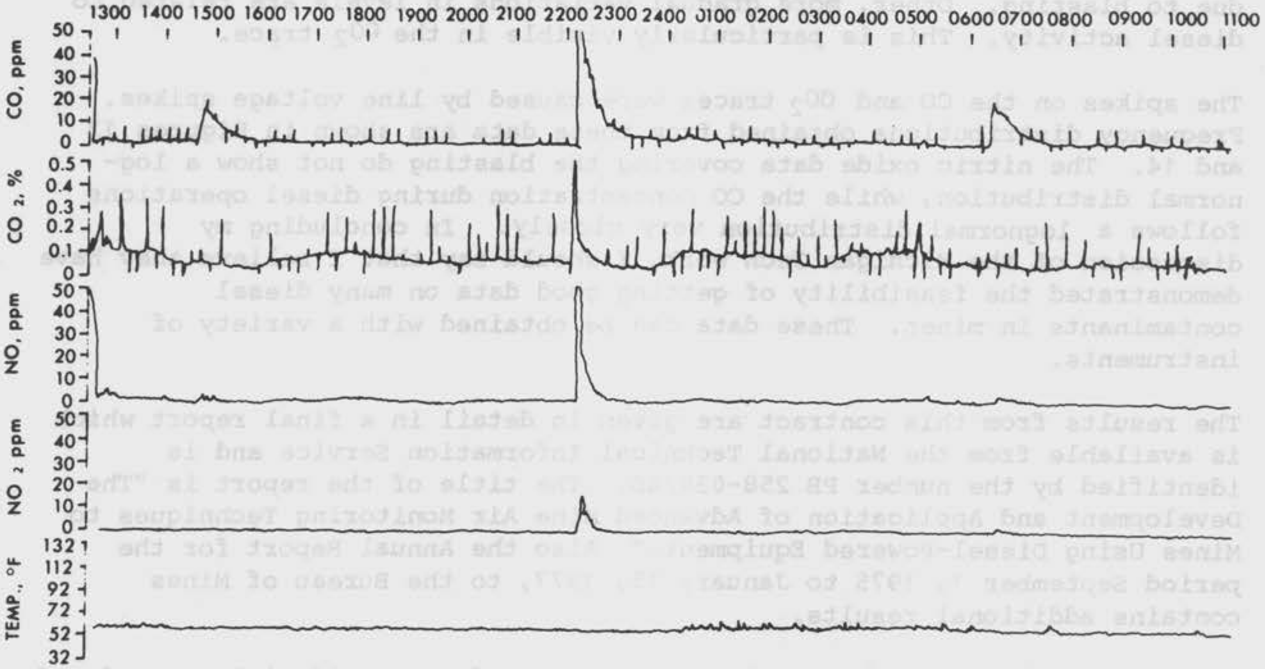


Figure 12 Strip Chart for Experiment 027

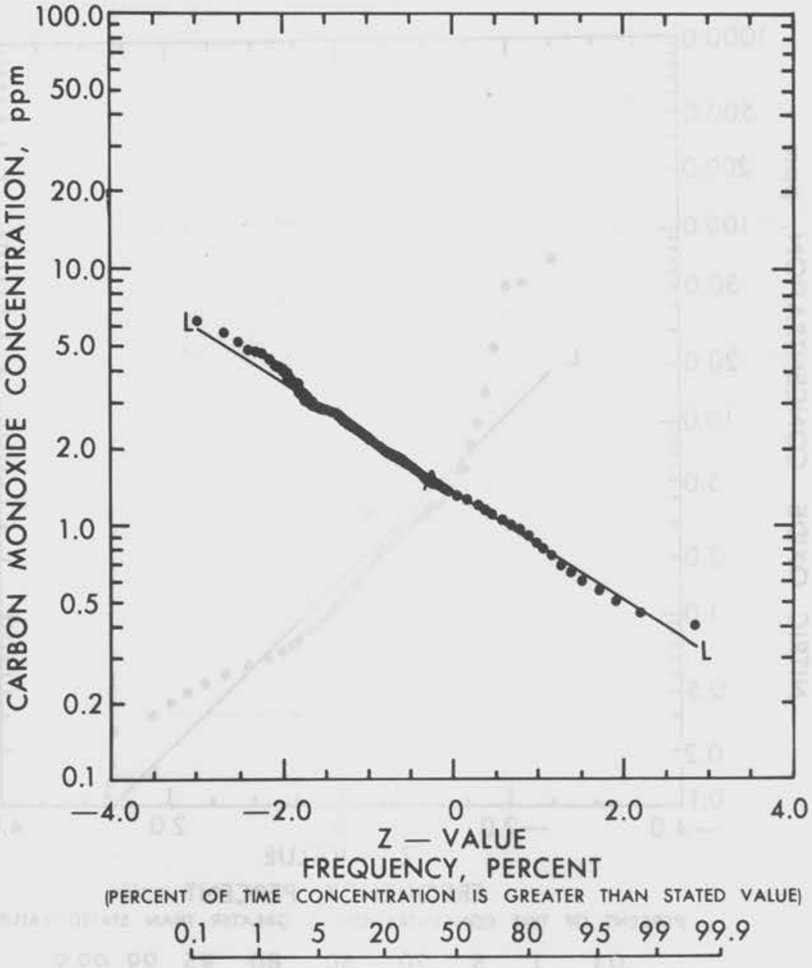


Figure 13 MAML Experiment 027 — Lognormal Frequency Distribution of CO Concentration from Scans made every 5 minutes while mucking in Unit 96 of the White Pine Mine during the period 5/3/76 — 5/5/76

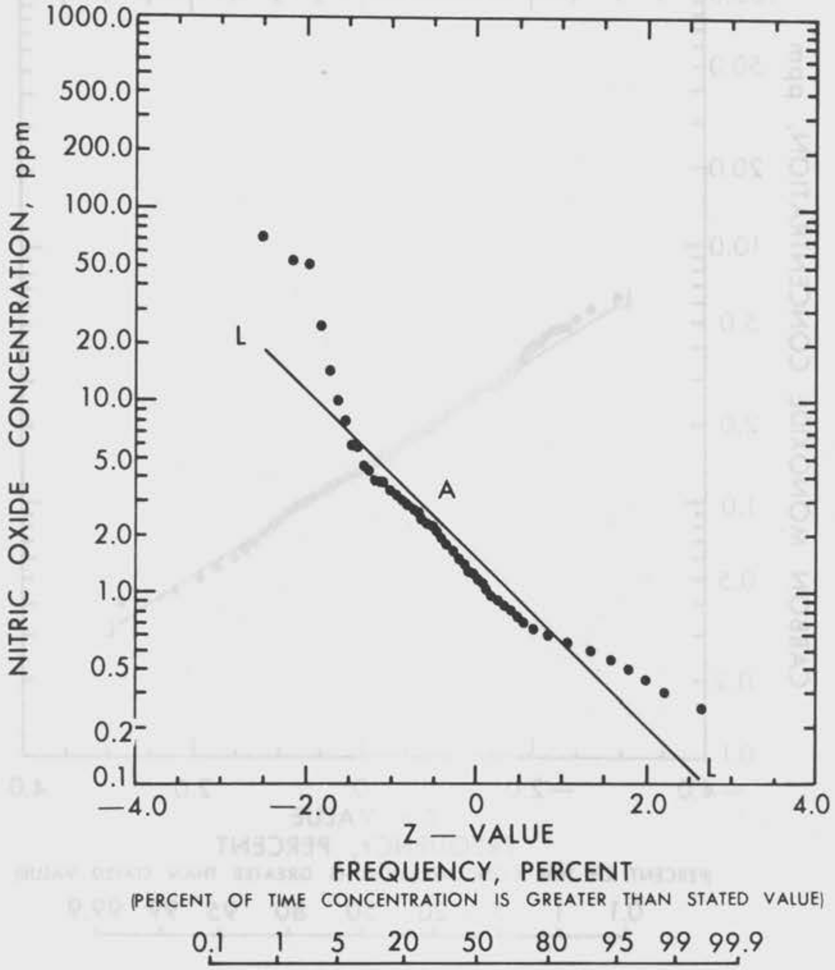


Figure 14 MAML Expriment 027 — Lognormal Frequency Distribution of NO Concentration from Scans made every 5 minutes while Blasting in Unit 96 of the White Pine Mine during the period 5/3/76 — 5/5/76

Figure 15 Distribution of mines in study of mineral dust (silica) and diesel exhaust.

Table I shows the kind of data obtained. This particular example was for the job class designated "loader operation." Particularly, I would like to run down the list of contaminants that were included in the sampling:

1. Dust: Filter samples were collected in both cases. Mine A was a potash mine; therefore, total dust was measured since it will affect the upper.
2. Fibers: If asbestos minerals are present, fibers are sampled.
3. Air quality: The first four contaminants are bistable sample results, i.e., CO, CO_2, O_2, CH_4; the last three contaminants are stain tube results: NO_2, NO-NO_2 and formaldehyde.
4. NO_2 dosimeter: This is the dosimeter developed by Ed Palmes at New York University.
5. Temperature and Relative Humidity.
6. Oil Mist: These are samples taken on filter paper.
7. Total aldehydes: These were bubbler samples early in the program and later we used activated alumina which could be held for laboratory analysis.
8. Instrument, NO, NO_2: This is the Ecolyzer nitrogen oxides analysis.
9. Ventilation (cfm).
10. Diesel Soot BaP: This is a benzo[a]pyrene analysis of diesel soot collected on a filter.

Figure 16 and Table II summarize the measurements pertinent to diesel exhaust contaminants. Figure 16 shows the NO_2 and CO measurements. The high is the average high reading in all mines. The average is the average of all averages, and the low is the average of all low readings. None of the contaminants looked at in this way exceeded or even approached current regulations. It is interesting for NO_2 that the average for the detector tubes and Enolyzer readings were close to the dosimeter.

Table II shows the frequency distribution of the CO and NO_2 concentrations for the several diesel mines in the study. Except for Mine D, most of the levels are well within regulations.

We were unable to detect benzo[a]pyrene in any sample. Insofar as this study has determined, the exposures to those diesel contaminants that we sampled for were generally well below current regulations. We did not specifically try to separate diesel soot from other particulate matter. However, Figure 17 shows the results of dust sampling. Again, the average dust concentrations (where silica was present) were below the current standards in most cases.

Table I. Typical Data From Study of Mineral Dust (Silica) and Diesel Exhaust

Job Class-Loader Operator

SAMPLE DATA		AVERAGE CONCENTRATION	
		Mine "A"	Mine "B"
1.	Dust:		
	Respirable: Mg/m^3	17.54	1.57
2.	Fiber: Fibers/ml	0.3	14
3.	Air Quality:		
	CO: ppm	0	0.1
	CO$_2$: ppm	700	2
	O$_2$: %	20.9	20.9
	CH$_4$: ppm	6	3
	NO$_2$: ppm	0.4	Trace
	NO-NO$_2$: ppm		1
	HCHO: ppm	2	0.2
4.	NO$_2$ Dosimeter: ppm	2	1.2
5.	Temperature & R.H.:	76°F;32%	69°F;90%
6.	Oil Mist: Mg/m^3	N.D.	N.D.
7.	Total Aldehydes: ppm	5.3	0.3
8.	Instrument:		
	NO: ppm	N.D.	0.2
	NO$_2$: ppm	N.D.	0.2
9.	Ventilation: cfm	5,000	8,000
10.	Diesel Soot: BaP	N.D.	N.D.

Figure 16 CARBON MONOXIDE - NITROGEN DIOXIDE MEASUREMENTS ALL MINES

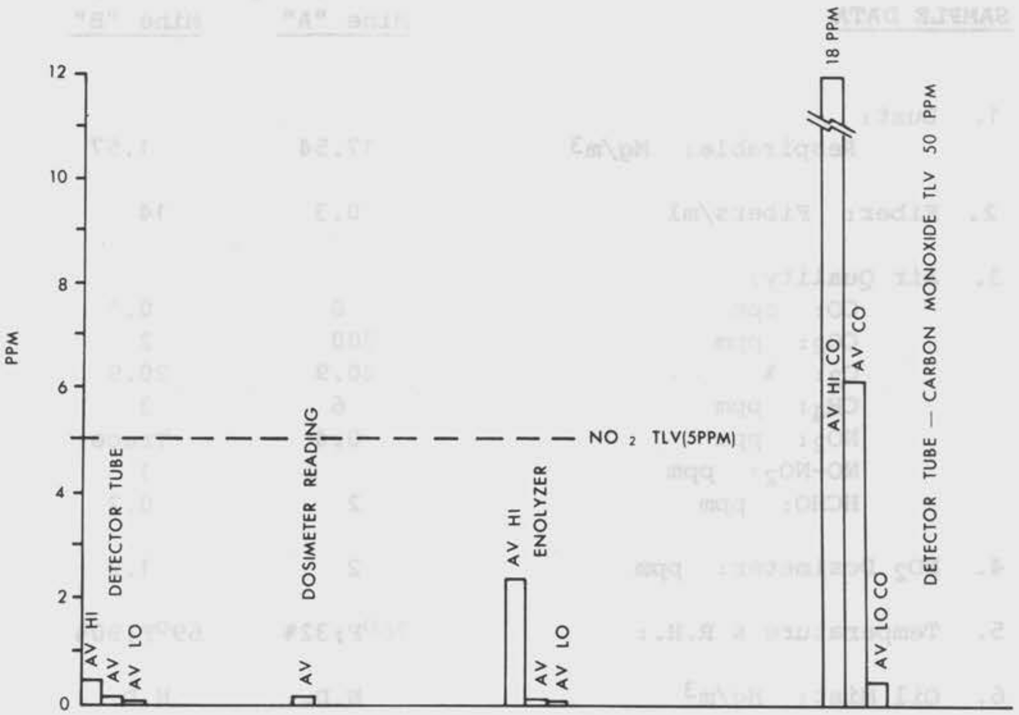
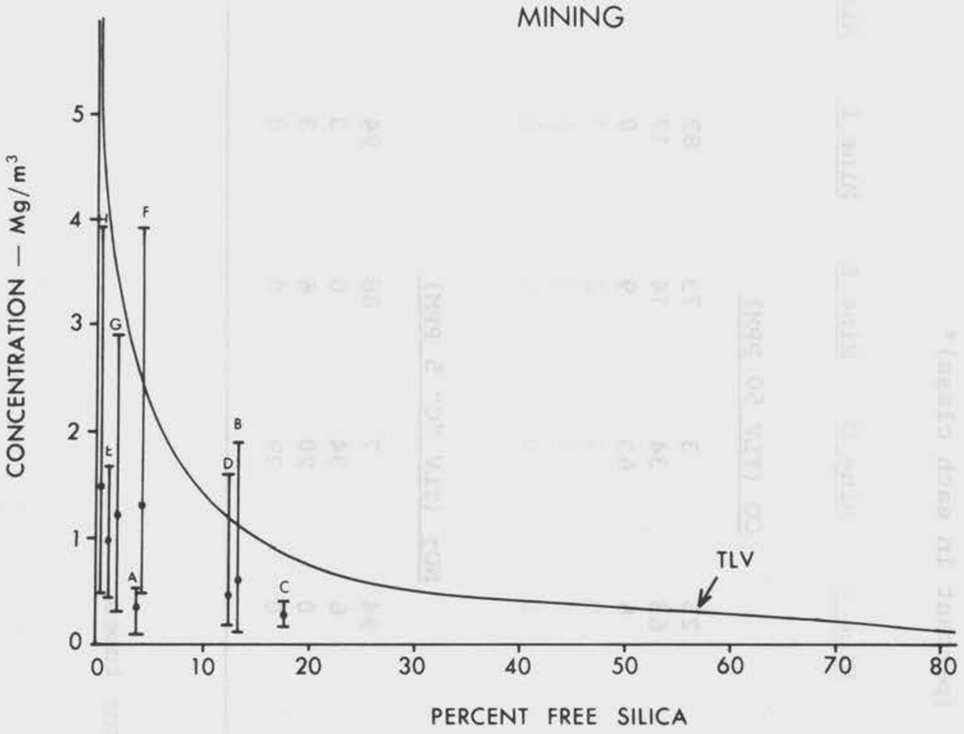


Table II. Frequency Distribution of
845 Measurements
(percent in each class)*

PPM Range	Mine A	Mine B	Mine C	Mine D	Mine E	Mine F	Mine G	Mine H
				CO (TLV 50 PPM)				
0-5	79	79	25	3	73	82	75	92
6-10	15	21	63	34	14	17	16	7
11-20	7	0	6	63	9	0	8	1
21-30	0	0	0	0	2	1	0	0
31-50	0	0	0	0	1	0	2	0
over 51	0	0	6	0	0	0	0	0
				NO_2 (TLV "C" 5 PPM)				
0-1	100	92	94	7	88	94	96	89
2-3	0	0	6	34	6	3	2	11
4-5	0	0	0	20	6	3	2	0
over 5	0	8	0	39	0	0	0	0

*all measurements taken with detector tubes.

Figure 17 RESPIRABLE GRAVIMETRIC DUST ALL METAL MINES



The diesel soot is included in the particulate weight that is compared with the TLV. In this respect, we at least have an upper boundary on the diesel particulate concentrations. Of course, there are many organic compounds in diesel exhaust that we were unable to include in our sampling program. Most of these are contained in the soot material.

We do not know what, if any, effects result from long-term exposures to all of these contaminants, but it is our objective to determine if there are any and to prevent them in the future.

EMISSIONS AND CONTROL TECHNOLOGY WORK GROUP

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INTRODUCTION

The Emissions and Control Technology Work Group recognized that the critical parameter, with regard to emissions of pollutants from diesel engines, is a working-shift, pollutant-specific, emission factor. After consideration of mine air supply, number of diesel units, etc., the emission factor could be used to estimate underground miner exposure to pollutants. From such exposure information health professionals could then address the issue of potential health consequences. The Work Group estimated emission factors on a mass basis for various exhaust untreated and treated engines. These estimates are shown in Table I.

The group took into consideration the often dramatic impact of various engine and engine operating parameters on emission factors. The following parameters were identified for discussion:

a. Engine Type
b. Duty Cycle
c. Fuel Additives
d. Maintenance
e. Engine Size
f. Fuel
g. Emission Control
h. Inlet air (to the engine)
i. Emission Characterization
j. Potential for Future Engines

The following questions were applied in the examination of each parameter:

1. How important are the effects of variables on emission factors?
2. What is the current state-of-the-art?
3. What recommendations can be made with regard to research needed to fill critical gaps, should such gaps exist?

After examining each parameter individually, the Work Group reviewed the issue again, this time from a general perspective, and prepared a "composite review" which included overall suggestions and recommendations. Finally, the group took up the important task of reviewing the draft NIOSH report, "The Health Implications of the Use of Diesel Engines in Underground Coal mines." The group concluded that an adequate review of this document could be accomplished only after emissions and control technology issues had been examined individually and collectively.

DUTY CYCLES

The exposure of the underground mine worker to diesel exhaust products obviously depends on the integrated emission levels produced. The duty cycle (load factor, etc.) of diesel equipment significantly affects the exhaust emissions measured. The definition of duty cycles to establish a base line by which underground emissions may be approximated is therefore very important. In addition, agreed-to standard duty cycles would be considerably useful in comparing engine options for a given machine operation and in providing guidance for research on minimizing emissions, fuel usage, etc. in mining.

TABLE I

EMISSION FACTORS
Preliminary - September 20, 1977

Emissions Workgroup
All Units: Grams/Brake Horsepower/Hour (g/bhp/hr)

Pollutant	Untreated Engine	Catalyst Treated	Water Scrubber	CAT + H2P Scrubber
CO	0.6-2.7	0.6-0.3	0.6-2.7	0.6-0.3
HYDROCARBONS	0.03-0.17	0.003-0.017	0.02-0.12	0.003-0.017
NO	1.25-4.1	1.25-3.5	1.25-4.1	1.25-3.5
NO_2	0.3-0.7	0.15-1.1	0.3-0.7	0.15-1.1
PARTICULATE (CARBON ONLY) (PARTICULATE 80% CARBON)	0.17-0.67	0.17-0.67	0.12-0.47	0.08-0.33
PHENOLS*	Trace	80-90% Reduction	30% Reduction	80-90% Reduction
ALDEHYDES	0.02-0.2	0.005	0.01	0.005
SO_2	0.5	0.25	0.096	0.09
H_2SO_4 (0.2% S FUEL)	----	0.37	---	0.24
TRACE METALS**	---	0.025 MAX	---	---
PNA's*	Trace	80-90% Reduction	30% Reduction	80-90% Reduction
BENZENE	0.5-1% of Hydrocarbons			
ODOR	---	SUBSTANTIAL REDUCTION WITH CATALYST		
IRRITANCY	---	SOME REDUCTION WITH WATER SCRUBBER		

TABLE I

Continued

CO_2	510-600 - ALL SYSTEMS
NOISE	96-104 DBA - ALL SYSTEMS
HEAT	6000 Btu/bhp/hr (in excess of electric motor heat emissions)

*While the group recognizes that PNA's and phenols are, in fact, emitted from diesel engines and associated with the particulate fraction, the current state of analytical technology is such that even qualitative emissions factor estimates are not possible. It has been demonstrated, however, that oxidation catalysts and water scrubbers remove PNA's and phenols from the exhaust stream as noted above. Phenols may also be emitted from brake linings.

**Number shown reflects a maximum additional trace metal emission associated with catalyst attrition products from pelleted systems.

ADDITIONAL NOTES: TABLE I

1. Units provided above are a mass emission rate per rated engine horsepower per hour for the maximum values.
2. These represent our current best estimates for diesel engines in mining.
3. Duty cycle, service-versus-work engine applications, and total rated horsepower in a mine section are factors which the Environmental Characterization and Pollutant Interaction Work Group should address.
4. For information the following represents our current "best guess" as to application of various engines/systems in underground mines:

   0% turbo-charged (underground coal mines only)
   10% without exhaust treatment
   90% with exhaust treatment
      -60% catalyst
      -40% scrubbers

TABLE I

Continued

5. Smoke suppressant additives are <u>not</u> widely used in these diesel fuels. Barium additives are not permitted by MESA under schedules 24 and 31 approvals.

6. The above data represent engines <u>not</u> using smoke suppressant additives.

7. Data are for typical de-rated 75 to 180 hp indirect injection diesels.

A discussion of duty cycle data was presented to the Work Group by Paul Mogan of the Department of Energy, Mines, and Resources, Government of Canada. These cycles were measured, evaluated, and compiled for Load-Haul-Dump (LHD) operations as experienced underground at INCO Metals, Ltd., Sudbury, Ontario, Canada. The Work Group felt that the data represent well the conditions and equipment under discussion.

Integrated emission levels from LHD cycles correlate extremely well with John Johnson's real-time mine sampling results at White Pine Copper Mine.

Cycles also may be partly deduced from exhaust temperature data. It was noted by the Work Group that effects of roadway (e.g., whether it is hard or soft, muddy or dry, level or inclined) and load (coal, ore, etc.) conditions will result in load factor variations during the cycle segments.

In order to avoid creating new cycles, maintain continuity of development, and utilize the existing data base, the Work Group recommended that a cycle composed of modes 3, 6, 9, 10, plus one idle should be used to represent diesel mining equipment operation--unless an in-depth evaluation of the present data or the introduction of new data indicates specifically how diesel engines are operated in underground mining equipment. The recommended duty cycle, with appropriate modal weighting factors yet to be determined, can characterize the emission levels. Development of realistic mining-oriented cycles may well indicate that some of the minor emission components for which there is a considerable health concern are present in different quantities than is the case for normal, non-mining duty cycles.

LOAD CYCLES OF TYPICAL UNDERGROUND VEHICLES

The load cycle for an underground mining vehicle varies enormously depending on the type of vehicle and the underground mining conditions. Obviously, the load cycle of a personnel carrier will differ completely from that of an ore hauling car, and steep gradients or muddy floor conditions can increase power requirements considerably.

Current ventilation regulations for diesel powered vehicles are based on the dilution requirements for the engine on full load. However, it should be remembered that the load factor on many pieces of equipment is so low that this ventilation rate represents a high safety factor. In order to determine the actual ventilation rate required to reduce pollutant levels to safe limits, it is necessary to define a typical load cycle and an average utilization time. This paper tabulates some common equipment used in U.S. underground coal mines and the associated typical load cycles.

Vehicles in U.S. Coal Mines

It is beyond the scope of this paper to consider the load cycle of coal cutting machinery, as it is unlikely that these units will ever become dieselized. The mobile equipment typically used, therefore, comprises the following:

Coal loaders	(front end loader)
Shuttle vehicles	(shuttle car or RAMCAR)
Clean-up scoops	(also used for supply)
Supply tractors	(includes large personnel trucks)
Supply locomotives	(includes large portal cars)
Personnel buggies	(rubber tired)
Personnel jeeps	(rail mounted)

Except for the shuttle vehicle, which may be powered by cable, the above vehicles will all be battery-powered in non-dieselized mines. Both coal loaders and shuttle vehicles will vary greatly in dimensions and installed power depending on the coal seam thickness, but the majority of the supply and clean-up equipment has approximately the same gross weight and power, regardless of seam thickness. For the purpose of this paper, coal seam thicknesses are defined as follows:

(a) Thick Seam--Coal seam over 6' thick, requiring vehicles with a maximum body height of about 54".

(b) Medium Seam--Coal thickness between 4' and 6', requiring transport vehicles with a maximum body height of 36".

(c) Low Seam--Coal thickness 36"-48", requiring vehicles with a body height of approximately 26" maximum.

Although there are many mines operating with coal seams less than 36" thick, it is not expected that it will be economically feasible or practical to operate diesel powered equipment in these mines unless the transport roadways are cut out to give at least 36" clearance.

It is a general rule that when a diesel engine replaces a direct current traction motor in a vehicle, the diesel should have a gross power of about twice the rating of the electric motor for the same performance. Power requirements for mobile equipment under various conditons are given in Table II.

Haulage Distances

In general, loading and shuttle vehicles in U.S. coal mines operate over relatively short haulage distances. Diesel power releases the vehicle from the limitation of the length of a cable or life of a battery, allowing for longer haul distances. However, it is still more productive to keep the haulage distance short, and the following load cycles are based therefore on an average one-way haul distance of 300'.

In most mines, the clean-up scoop will also be used for hauling supplies. Consequently, the load factor and utilization can be considered to be similar to that of a supply tractor.

Supply tractors and rubber-tired personnel buggies are usually limited to distances of less than 1 mile, owing to the short life of the battery.

TABLE II

Comparative Power Requirements of Electric and Diesel Mining Equipment

Vehicle Type	Seam Category	Max. Speed (mph)	Electric Power	Approx. Diesel Power Requirement
Loader (LHD)	High	8	--	150
	Medium	6	50	90-100
	Low	4	30	50-65
Shuttle Vehicle	High	7	100	150
	Medium	5	70	90-100
	Low	4	40	50-65
Scoop	All	5	40	65
Supply Tractor (incl. large personnel cars)	All	5	40	65
Supply Locomotive (10 ton)	All	8	50	90-100
Supply Locomotive (5 ton) & Portal Buses		8	30	65
Personnel Buggies	All	6	10	25

Diesel power will eliminate this problem; therefore, the load factor calculation is based on an average one-way haul of 5,000 ft.

Supply locomotives and rail-mounted portal cars and jeeps are usually used for travel distances of 1-5 miles depending on the size and age of the mine. The duty cycle for these vehicles is based on an average one-way haul distance of 12,000 ft.

Utilization and Productivity

The utilization of underground equipment varies greatly from mine to mine, depending on the time lost in traveling to and from the workplace, the reliability of the equipment, and worker habits. Production from a single work face in an underground coal mine using two loading or shuttle vehicles may average between 100 and 1500 tons per shift, depending on conditions, machinery, and attitudes. However, if the total underground tonnage, about 300 million tons of coal, is divided by the loading and shuttle vehicle population of approximately 7,000 units and each unit operates shuttle 250 days per year and an average of 1.5 shifts per day, the average tonnage is 115 tons per shift. This gives an average production figure of 230 tons per shift per working section. Assume two vehicles per section.

Experience in a limited number of dieselized mines indicates that in similar working conditions, diesel vehicles can be twice as productive as electric vehicles. However, for the purpose of this paper the average production of a working section utilizing two diesel loaders or two diesel shuttle vehicles is taken to be 500 tons (250 tons/vehicle/shift).

It should be noted that several dieselized mines are currently averaging nearly 1000 tons per shift per operating section, but these mines are non-union, high-seam, and some operate 9 hour shifts. If diesels are introduced into normal unionized mines, average production is expected to be less than 500 tons/shift.

Personnel transportation requirements will not vary directly in proportion to production, whereas material supply requirements do vary with production. However, owing to poor maintenance that is usually given to non-essential support equipment, the availability of supply vehicles is usually quite low and as a result overall utilization averages only 50 percent. This percentage is taken for all support vehicles. The availability of loading and shuttle vehicles is already taken into account by averaging the coal tonnage produced.

Effect of Floor Conditions and Grades

Both floor conditions and grades can affect the amount of power required. The rolling resistance of rubber tires on dry concrete is as low as one percent or 20 lbs/ton. The rolling resistance on hard dirt is about 60 lbs/ton, whereas on mud the rolling resistance will vary from 80 lbs/ton to 300 lbs/ton, depending on the consistency. This means that it could take up to five times as much power for a given vehicle to negotiate a muddy bottom as compared to a dry dirt floor. A typical value of roadway rolling resistance in a U.S. coal mine would be between 80 lbs/ton and 150 lbs/ton, and for the purpose of load cycle calculations, a figure of 120 lbs/ton, or slightly worse than average, has been used.

With a rolling resistance of 120 lbs/ton an upgrade of six percent represents a doubling of horsepower requirements, assuming the speed of the vehicle is maintained up the grade. Although slightly less power is required on the downgrade part of the haul cycle, this by no means cancels out the effect in terms of total emissions. In most cases, a fully-loaded, diesel-powered vehicle will require about 60 percent of its installed power to tram at rated speed on level ground. Hence, the doubling of the resistance that results from a six percent grade will cause a reduction in speed, as double the power is not available. The effect of reducing speed is to lengthen the haul cycle, and in this case the total emissions for a given tonnage of production will also be increased. Fortunately, most coal seams in the United States are relatively flat, and grades of over 10 percent are rarely found in coal mines. If a grade is inherent in the seam, the operator will normally mine the coal diagonally across the dip, which has the effect of reducing the grades in the haulage roadways.

For the purpose of load factor and duty cycle calculation the root-mean-square power requirement over the shift has been calculated for a level roadway, and for each vehicle a worst-case figure is estimated to take into account the effect of a steep gradient against the load.

Effect of Acceleration and Deceleration

For four to five seconds after moving from rest, most diesel vehicles will require full power to accelerate to their tramming speed. However, before stopping, the throttle pedal will be released and the vehicle will coast for a few seconds with the engine effectively at idle. Although the total quantity of emissions will be higher under full-load accelerating conditions, the emissions will be much lower than average in the coasting mode. For the purposes of the following calculations, the accelerating mode and decelerating mode are each assumed to require five seconds. The power requirement for accelerating is 100 percent and the power on deceleration is taken as 20 percent.

Most modern diesel-powered vehicles are now fitted with torque converter and multi-ratio power shift transmissions. This type of transmission is very suitable for underground operations, as it remains very efficient over a wide speed range, and the slip in the torque converter allows the engine to operate more closely to its highest efficiency point. Another advantage of this transmission is that the engine does not have to operate permanently in the high rpm range which is necessary for some hydraulic and electric transmissions. The disadvantage of high rpm operation is increased engine wear, high fuel consumption, increased noise pollution, and increased heat emissions. Conversely, with the powershift transmission the engine will return to idle when no power is required. Engine idle rpm is usually only about one-fourth of the full-speed revolutions. Auxiliary equipment, such as air compressors, hydraulic pumps, and cooling fans, have a power consumption approximately proportional to the square of the speed, assuming the hydraulic circuit is fitted with an unloader valve. This means that the power drawn by the auxiliaries at idle rpm is only about one-sixteenth of the power requirement at full load. With an auxiliary power loss of about 15 percent of rated power at full load, this means a power requirement of less than 1 percent of rated load at idle. Therefore, the engine is effectively completely unloaded when the vehicle is left idling. This is important because pollution levels from a heavily loaded engine at idling rpm can be several times worse than those from an engine in an unloaded mode. This argument, however, may not apply to some older mining machinery designs in which the hydraulic system works constantly against a relief valve pressure and, hence, the engine is partially loaded even when idling.

Recent tests on underground LHD (Load-Haul-Dump) vehicles by the Canadian Department of Energy indicate that engine auxiliary and hydraulic pump losses can be as high as 40 percent of the total available power at full engine rpm. If this auxiliary load is added to the horsepower required for tramming (about 60 percent on level ground) the resultant load factor is extremely high.

However, another Canadian study measured exhaust gas temperature throughout the load cycle. A study of this parameter indicates that for a typical 750 ft. haul to a truck loading point on level ground, the overall load factor is only about 50 percent. If the 30 percent time at idle while waiting for the truck is included, with no waiting interval, the load factor approached that observed for the same machine operated on a 300 foot haul with a 5 percent incline, i.e. 70 percent.

Conclusion

It is clear that under all forseeable coal mining conditions, the overall load factor of a diesel-powered production machine will seldom exceed 50 percent. Under normal conditions (300-600 tons/shift), the load factor would be nearer 25 percent. Typically, supply vehicles, supply locomotives, and personnel carriers will have a power utilization of less than 25 percent.

These figures for diesel vehicles can be verified by comparing the theoretical calculations with actual fuel consumption in operating mines. A further check can be made by comparing these calculations with the average peformance of thousands of battery-powered vehicles currently in use in underground coal mines. The fact that a battery-powered shuttle vehicle with only 70/kWh battery capacity can normally last a full production shift clearly indicates the low power and operating factors associated with underground haulage.

DIESEL ENGINE TYPE

Diesel engines are commercially produced in the following types: (1) indirect-injection, four cycle; (2) direct-injection, two cycle; and (3) direct-injection, four cycle. Both air-cooled and water-cooled systems are used. All engine types may be turbocharged or turbocharged and after-cooled. Diesels used in mining machinery are predominantly indirect-injection, naturally-aspirated, four-cycle because of the more favorable emission characteristics, and the resulting lower ventilation requirement.

The following is an attempt to compare the two combustion systems without emission control systems:

Characteristic	Direct Injection	Indirect Injection
Fuel economy	Favorable	Less Favorable
CO	Less favorable	Favorable
HC	Less favorable	Favorable
NO and NO_2	Less favorable	Favorable
Particulates*	--------	--------
Aldehydes	Less favorable	Favorable
SO_2	Approximately same	Approximately same
Other pollutants	?	?

Based on the above comparison it can be concluded that the indirect injection engine has advantages for underground mining use and is likely to retain these advantages for at least the next few years. Certain pollutants are still to be determined when appropriate instrumentation and procedures are available and a suitable duty cycle is defined.

Table III presents a summary of Caterpillar Tractor Company 1976 certified truck engine certification, data results. In addition, data on several engine types in use in Canada can be obtained from Ontario Research Foundation.

EMISSION CHARACTERISTICS - STATE OF THE ANALYSIS

Because of the increase in importance of the constituents of exhaust gases of internal combustion engines, development of suitable analytical instruments and methods is extremely important. Technological advances have been and will continue to be made in instrumentation and methodology based on previous experience, research, and improved state of the art. These we feel should fall into the following two categories:

(1) Continued research in laboratory analysis, and

(2) Further development of portable measuring methods for field use.

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*To be determined with known duty cycle.

TABLE III

1976 EPA CERTIFICATION VALUES FOR CATERPILLAR TRUCK ENGINE FAMILIES

Engine Family	Engine Model	HC g/hp/hr	CO g/hp/hr	NOx g/hp/hr
3	3208 DINA	1.7	4.4	7.3
3	3208 DINA	1.8	5.5	6.6
4	3306 PCT	.2	1.4	5.7
4	3306 PCT	.2	1.4	6.1
6	1693 TPC	.33	1.42	4.96
7	1693 TAPC	.2	1.0	5.1
7	1693 TAPC	.2	1.0	4.8
9	3406 PCT	.18	1.36	6.30
10	3406 PCTA	.10	1.03	5.73
11	3406 DIT	.44	3.10	8.97
12	3408 PCTA	.16	1.37	5.54
14	3306 PCTA	.22	1.76	5.44
15	3408 DIT	.47	2.76	8.22

DI - Direct Injection
PC - Precombustion Chamber (indirect injection)
T - Turbocharged
TA - Turbocharged and after cooled
NA - Naturally Aspirated

Emission components in diesel exhaust are analyzed in the laboratory and in mines. Laboratory analysis is employed for assessment of engine characteristics and is usually conducted by in-line instruments on diluted exhaust. Field sampling and analysis is used for measurement of ambient levels of toxicants in mines.

In the laboratory, CO, NO, and CO_2 are analyzed reliably by non-dispersive infrared (NDIR) analyzers. NOx (NO + NO_2 reported as NO_2) is determined by chemiluminescent, dual detector NDIR, and electrochemical instruments.

Field sampling and analysis in mines is conducted using hand-held gas detectors and dosimeters, chemical tubes, personal monitors, and machine-mounted monitors with meter and/or alarm response. Table IV presents the state of the art of sampling and analysis using field devices.

MAINTENANCE

Both engine and exhaust treatment are very important in emission control and in particular in maintaining the system at emission levels characteristic of the "new" engine. Maintenance can be subdivided into two principal categories: (1) preventive maintenance (PM), and (2) major overhaul (OH). Significant items to be considered under PM are

1. Filters
    a. Fuel (little effect on emissions)
    b. Air
2. Exhaust treatment
    a. Scrubber system
    b. Catalytic Converter ΔP, make-up
3. Cooling
4. After cooler (turbocharger not likely for coal mine application)
5. Timing
6. Injector
7. Flame trap (inlet and exhaust)

Significant items to be considered under OH are

1. Utilization of original manufacturer's parts,

TABLE IV

STATE OF THE ART OF SAMPLING AND ANALYSIS OF DIESEL CONTAMINANTS

Analyte	Sampling Method(s)	Analysis (current)	Reliability*	Analysis on Horizon
CO	----	NDIR	Good	Online scattering piezobalance
Particulate	Membrane filter	Gravimetric	Good	
	Multistage impactor	Gravimetric	Good	
	Air Dilution technique	Gravimetric	Good	
**Polynuclear aromatic	Membrance filter	Gas chromatographic (GLC)	Fair	Better derivatives and stationary phases
		Liquid chromatographic (LC)	Fair	
		U.S. Fluorescence	Fair	
Unburned hydrocarbons	Absorption trap online	GLC, LC	Good	
		hydrocarbon analyzer	Good	
Sulfur dioxide	Evacuated tube (batch)	West Gaeke	Good	
	online	stain length tube	Fair to poor	
		electrochemical	Good	
Sulfur trioxide (H2SO4)	Membrane filter impinger - liquid	Turbidmetric, chloranillate	Fair	Flame photometric
Carbonyls	Impinger, adsorption	General MBTH (spectro.)	Fair	Better reagents and stationary phases
		Acrolein GLC, stain tube	Fair	
		HCHO GLC, stain tube	Fair	

TABLE IV
(continued)

Analyte	Sampling Method(s)	Analysis (current)	Reliability*	Analysis on Horizon
NOx	Impinger	Phenoldisulfonic (NOx)	Good (high conc.)	Newer generation of online instruments
		Saltzman (NO_2)	Good (low conc.)	
		NOx and NOx	Fair to poor	
		Chemiluminescence (NOx, NO_2)	EPA Reference method	
		Electrochemical (NOx, NO_2)	Fair	
NO2	Hot line	NDUV	Fair to good	
Odor components	Absorption tube	LC (A.D. Little)	Fair	
	Online	Odor Panel	Fair	

*Sampling and analysis
**See attached report on PNA analysis

2. Replacement of all critical components with a possible future life, and

3. Engine performance (emissions) under load after overhaul.

Available Data Base:

PM: Literature is available from engine manufacturers on the effect of inadequate PM on emissions, i.e., clogged filter, etc. The data base is adequate, but instrumentation and/or techniques are required to spot check engine exhaust systems. A reliable analyzer for an exhaust species such as CO, CO_2 NOx, and pressure differential across the conditioner is essential.

OH: Literature is available from engine manufacturers on the overhaul procedures. However, limited field experience has shown that overhauled engines have shown some unusual emission characteristics. Theoretically, if an engine is overhauled and adjusted according to the engine manufacturer's specifications, the emissions of the engine, when returned to service, should be no higher than those from a new engine. However, preliminary field experience reveals cases in which emissions are higher than expected. It is obvious that further study is necessary and the influence of used parts, mechanics' training, factory tolerances, etc., needs to be evaluated.

Application:

The above criteria are applicable to all of the five application areas: LHD and FEL, Main-line haulage, man and material transport, shuttle cars, and service vehicles.

Recommendations and Conclusions:

1. Considerable experience has been accumulated by mine oeprators on the maintenance of engines and exhaust treatment systems. Where data have been collected for these units, analysis would be helpful to ascertain field performance.

2. An investigation of the cause and extent of abnormal emissions after engine overhaul is required.

3. Instrumentation and/or techniques are required for in-mine assessment of engine and exhaust treatment performance.

FUEL AND FUEL ADDITIVES

Generally speaking, variations in commercially available diesel fuels do not have significant impact on emissions of CO, HC, and NOx. There is some indication that increased aromatic content results in increased particulate. The effect of changes in fuel specification or other pollutant levels remains to be determined. It is clear that No. 1 type fuel tends to produce less odor and irritation.

Sulfur dioxide and any other resulting sulfur compounds are directly related to the fuel sulfur content, which can be reduced at some cost. Before extensive health effect studies and research of diesel exhaust sulfur compounds are undertaken, it is recommended that the feasibility of reducing the sulfur content of the fuel to the lowest practical level be determined.

While smoke suppressant additives, such as the barium-based additive, are currently available, it is thought that their use may not be extensive. Engine manufacturers generally do not recommend the use of smoke suppressants because of potential reduction of engine life. Other detergent type additives are used in diesel fuel to assist in keeping the injectors clean. Any influence on emissions is still to be determined.

The U.S. Environmental Protection Agency (EPA) presently regulates and registers diesel fuels and fuel additives. Anyone interested in diesel fuel additives should consult EPA. EPA does not allow smoke suppressants in truck diesel engine certification fuel.

Conclusion: Before extensive health effect studies and research on diesel exhaust are undertaken, it is recommended that the feasibility of substantially reducing sulfur from diesel fuel be ascertained and that smoke suppressants be eliminated. Consultation with fuel suppliers concerning reformulation of fuels should be considered as further pollutant reduction is demanded.

EMISSION CONTROLS

The group determined that emission control devices are fitted to approximately 90 percent of all underground diesel-powered equipment (there are an estimated 10,100 diesel engines operating in underground mines in North America), some 60 percent utilizing oxidation catalysts and 40 percent water scrubbing devices. Water scrubbers are used extensively in coal mines to reduce temperatures and arrest sparks and flame.

Presently there are two distinct types of oxidation catalysts, pelletized and monolithic honeycomb. Both are used to oxidize the pollutants of diesel exhaust gas with varying degrees of efficiency. Most efficient oxidation is obtained with a catalyst inlet temperature of 415F or higher; however, oxidation commences at much lower temperatures: e.g. 50 percent oxidation occurs at 350F for some engines. Oxidation values of selected exhaust gas compounds are shown in Table I above.

Water Scrubbers

Water scrubbers cool by passage of exhaust through a water bath containing baffles to aid in heat exchange. The relative effect of water scrubbers on specific exhaust pollutants is reviewed in Table I above.

Other types of scrubbers are being developed which remove significant amounts of particulate matter. Some of these serve also as effective exhaust coolers. These devices depend on Venturi scrubbing on filters of various configurations. The filter media (dry or wetted) act by impaction, sieving, or other mechanisms which are less well defined.

Combination Water Scrubbers and Oxidation Catalysts

As a result of recent observations and tests by the Ontario Research Foundation, it is apparent that the recognized deficiencies of water scrubbers alone on diesel engines are overcome by the addition of a catalyst into the system upstream of the scrubber (see also Table I above).

Other emission controls include exhaust gas recirculation (EGR), water induction, retarded injection timing, and turbocharging with or without aftercooling and inlet air cooling. With EGR, a portion of the engine exhaust is added to the engine inlet air. The advantage of EGR is substantial reduction of NO. In water induction, the water absorbs some heat, reducing combustion temperature and thereby reducing NO. Retarding timing also lowers NO. Retarding timing excessively to lower NO can, however, increase smoke, CO, and HC. Turbocharged engines with or without aftercooling can produce relatively low emissions; however, their use in coal mines is limited by temperature considerations. Finally, the fuel/air ratio (lean-rich) substantially affects emissions.

INLET AIR

The following parameters have a distinct effect on the operational and exhaust characeristics of diesel engines operating in underground mines:

1. Methane atmosphere,
2. Rebreathing (including ingestion of other mine gases such as CO and CO_2 from spontaneous combustion and other diesel units),
3. Changes in atmospheric pressure,
4. Changes in temperature,
5. Changes in humidity, and
6. Cleanliness of air.

The data base appears to be adequate on the effects of these conditions on inlet air and the resulting exhaust emissions as determined in the laboratory. However, more field research under operating conditons and the control of these parameters is required.

Current MESA information includes some data on methane in the intake air and the effect of reduced intake air pressure. Effects of temperature, humidity, and pressure are available from EPA data. The effects of rebreathing have been documented by Bartlesville Energy Research Center and are available from the U.S. Bureau of Mines.

POTENTIAL DIESEL ENGINE EMISSIONS IMPROVEMENTS

The emissions reductions reflected in this section are primarily based upon technical "guesstimates" rather than hard research or in-use data.

Improvements related to the engine intake system:

1. Water emulsions: NOx 50 percent

   HC = 50 percent
   Particulate 30 percent

2. Water injection: NOx 10-20 percent
3. EGR uncooled: 25 percent
4. EGR cooled: NOx 50 percent

   Particulate + ?
   HC + ?

5. Fuel type/quality: SOx reduced pro rata with S content
6. Methanol asperation:

   NOx + 15 percent
   CO + 30 percent
   Particulate/HC 50 percent

7. Methanol emulsification:

   Particulate 80 percent
   HC + 5 percent
   NOx + 50 percent

8. Fuel additives: Small effects only
9. Turbocharging (Comprex system**):

   Particulate 50 percent

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* No sign for reduction; + means increase

** Sulzer-Switzerland

In-cylinder control

1. Control of injection-spray quality and electronic timing control: improvements in all emissions, particularly transients.
2. Thermal isolation of cylinder walls and of prechambers: PNA's hydrocarbons, odors, irritants, and other oxidizable compounds are reduced.
3. Catalytic in-cylinder combustion: reduction for all pollutants other than NOx.

Post cylinder control

1. Standard catalysts (monoliths and Pellets): 90 percent CO, 80 percent HC.
2. Catalysts (thin metal) as integral parts of the cylinder head and exhaust ports: 95 percent CO, 90 percent HC (better performance at light loads).
3. Basic water scrubber optimized using pumped water sprayers: SOx 95 percent, particulates less than 30 percent.
4. Water scrubber with Venturi pressure reduction (mist reduction and water retention): SOx 95 percent, particulates less than 30 percent.
5. Conventional water bath conditioner, but with a pre-catalyst: $S0_2$ 95 percent, CO 90 percent, HC 90 percent, particulate 50 percent, H_2SO_4 30 percent.
6. Same as 4 above, but with water manifold injection for condensation scrubbing: SOx 95 percent, CO 90 percent, HC 90 percent, particulates 80 percent, NOx 20 percent.
7. Particulate control by hot filter (e.g., spiral manifold reactors with or without catalyst loading): CO 95 percent, HC 95 percent, particulates 30 percent.
8. Control by cold filters (fabric or fiber with a form of plug-in-cartridge for one shift use): particualtes 90 percent, HC 50 percent.
9. Same as above, but with continuous water irrigation for self-cleaning, nonreplaceable elements: particulates 90 percent, HC 50 percent.
10. Agglomerations or thermal precipitators with induced soot-breakaway and cyclone collection: particulates 50 percent, HC 30 percent.

11. Emission control by exhaust feedback sensing (e.g., soot by opacity or electronic sensing, CO by infrared sensing or O_2 by zirconia detector): useful for malfunction/warning detection and transients.

12. Catalytic conversion of NO to NO_2 with water scrubbing using alkaline solutions or organic agents, limestone, etc.: NOx 25 percent.

13. Ozone oxidation of NO to NO_2 and scrubbing in 12 above: NOx 50 percent.

14. Electrostatic precipitators and filter composites: unknown efficiency and durability.

APPLICATIONS

The diesel applications and probable power ranges the Work Group considered most likely to occur in underground coal mining are as follows:

Working Place:	Load-Haul-Dump (LHD) vehicles	140-350 hp
	Front-end loaders	
	Clean-up scoop	50-100 hp
Mineral Haulage:	Rail Locomotive (smaller range only)	200-400 hp
	Trucks	200-400 hp
Service Duties:	Personnel transport	50- 80 hp
	Supplies transport	75-200 hp
	Maintenance vehicles	25- 50 hp
	Drills (transport only)	50- 80 hp

It is not considered for coal mines that there is an early possiblity of the use of diesel-powered drills or roof-bolting equipment, continuous miners, longwall equipment, or rail locomotives in the range 400 to 1000 hp.

Diesel function and resulting emissions are thought to be closely related to the particular diesel application in mining. The duty cycle undoubtedly varies widely from one type to another. The term "load factor," introduced in this context, relates to the likelihood that, in addition to the variation of power requirement during a mission, for some applications the engine will be out of use for lengthy intermittent periods during each shift. Also, rapid fluctuation in power demand will occur with some duties such as loading, while rail transport power need is relatively steady. In addition, direct (clutched) drive is employed for some purposes, while for others, hydrostatic transmissions, involving substantial base level loads, are used.

The location of use and the design of vehicle significantly affect engine service conditions. The worst conditions are likely to be found inby, where skilled supervision is likely to be absent and random damage more likely. There is presently an unfilled demand for mobile power units of greater robustness, simplicity, and ease of maintenance for the more exacting applications.

The data base for detailed characterization of applications is not firm at the present time. While some operators may have data, there has been virtually no publication. A study of LHD duty has been carried out by the U.S. Bureau of Mines, but analysis of the data is not yet complete. Information relative to metal mine service is available from the Michigan Technological University, though the emphasis so far has been on instrument development: their in-mine environmental surveys have provided good correlation with the calculated integrated emission levels. In addition, a powerful technique, already in use for optimization of vehicle usage, is that of computer modeling. The U.S. Bureau of Mines has available programs for diesel, cable, and bolting vehicles, as has St. Joe Minerals Corporation. These are based on manufacturers' performance figures and availability percentages based on experience. Floor condition and grade may also be considered. As they become available, these techniques should be very suitable for handling duty cycle data.

CONCLUSIONS AND RECOMMENDATIONS

General

Conclusion: The present data base is inadequate for derivation of diesel engine emission factors on which to base estimates of underground exposures to diesel pollutants.

Recommendation: Before meaningful exposure estimates can be derived, a substantial body of additional data must be obtained. Very recent research is beginning to develop such data. The Work Group recommends that a second workshop be held by NIOSH in one year to further review emissions and control technology issues. The group also recommends that NIOSH consider the conclusions and recommendations outlined below appropriate for research projects.

Emission Characterization

Conclusion: Emission characterization is broadly composed of three essential elements: generation, collection, and analysis. The generation aspect is noted under the Duty Cycles section of this report. Collection and analysis expertise ranges from good to excellent for the more common pollutants, such as CO, HC, NO, and NO_2; to poor for most of the "unregulated" pollutants, such as PNA's and phenols.

Recommendation: Substantial research must be devoted to developing sample collection and analysis capabilities before meaningful additional studies of exposure and health effects can be undertaken.

Engine Type

Conclusion: Diesels used in mining machinery are predominantly indirect injection, naturally aspirated, four-cycle engines. This is because such engines currently have more favorable emission characteristics, thereby resulting in lower ventilation requirements. This type of engine is likely to retain these advantages for the next few years.

Recommendation: Further studies are recommended to characterize and compare engine types and those emissions which are thought to have the most adverse health effects, especially NO_2, particulates, and PNA's.

Duty Cycles

Conclusion: An adequate body of engine emission data is available as a result of the required Federal 13-mode and MESA certifications. However, little specific mining duty cycle information exists to permit prediction of integrated emission levels in mines.

Recommendation: It is recommended that much more mining cycle information be collected to allow the establishment of a relationship to existing emission data (selected segments of the 13-mode Federal cycle may be most appropriate).

Inlet Air

Conclusion: There are a number of environmental parameters which can modify the inlet air of a diesel engine when operated in an underground mine; variations in these parameters could have an adverse impact on environs.

Recommendation: While data appear to exist, they need to be compiled and more field research needs to be done under operating conditions.

Maintenance

Conclusion: It is commonly agreed that poor engine and exhaust system maintenance can have a detrimental effect on engine exhaust emissions. However, data are not available as to the extent of this problem in underground mining.

Recommendation: Considerable experience has been accumulated by mine operators and engine manufacturers on the correct maintenance of diesel engines and exhaust treatment systems. Where data have been kept on these units, compilation of same would be helpful to ascertain field performance. Where the data are not adequate, studies should be made. The cause and extent of abnormal emissions after engine overhaul must be investigated. Instrumentation and/or techniques are required for in-mine assessment of engine and exhaust treatment performance.

Potential Engine Emission Improvement

Conclusion: There are many options available which have high potential for considerably improving diesel engine exhaust emissions. These fall under three headings:

1. Improvements related to the engine intake system,
2. In-cylinder control of the combustion process, and
3. Post-cylinder exhaust emission control.

In the short term, the greatest potential appears to lie in post cylinder exhaust emission control.

Recommendation: It is recommended that research toward the development of a combined emission control system, comprising advanced catalyst, water scrubber, and particulate filtration technology. be initiated. Some potential also lies in the use of water/fuel emulsification and water injection techniques together with EGR for reducing NOx emission.

In the long term, development of alternate low emission engines may prove to be more effective than employment of complex, retrofit, emission control devices. However, the market for such engines is small, and the prospect may be unattractive to major engine manufacturers. Employment of retrofit devices and engine derating therefore appears to be the only solution to minimizing underground diesel emissions in the next decade. Further emission improvement than can be accomplished by such control of diesel engines may result from the development and use of other prime movers such as flame shielded methanol and external combustion engines.

Fuels and Additives

Sulfur

Conclusion: Sulfur compounds in the exhaust are directly related to the sulfur quantity in the fuel and can be controlled by reducing the fuel sulfur.

Recommendation: The feasibility of substantially reducing the fuel sulfur to the lowest practical minimum should be determined.

Smoke Suppressants

Conclusion: Smoke suppressant fuel additives are neither widely used nor essential to diesel operation.

Recommendation: Smoke suppressant additives should be eliminated because of their negative effect on engine life and their influence on exhaust particulate emissions.

Fuel Formulation

Conclusion: Lowering of the fuel aromatic content results in a reduction of exhaust particulates; No. 1 fuel tends to reduce odor and irritancy.

Recommendation: Fuel characteristics should be studied as an aid to minimizing those emissions of greatest health concern.

Emission Controls

Conclusion: Current emission control technology is available to substantially reduce recognized pollutant compounds in a diesel exhaust gas stream using either singular devices or a combination of devices and methods by catalytic oxidation, water application, and engine control with a resultant decrease in exhaust gas temperature at the tailpipe.

Recommendation: Further research should be concentrated on the development of the combination of devices and on engine controls, such as water jacketing for coal mine application. The need to reduce NOx ($NO + NO_2$) and particulate matter should be emphasized. Research is needed on the anlysis and reduction of PNA's and phenols. Sulfur emissions may be controlled at source by drastic reduction in sulfur in diesel fuel.

Application

Conclusion: Anticipated diesel applications and horsepower ranges were identified. Further analysis of specific machines for certain applications and the development of duty cycles will permit detailed assessments of potential emissions.

Recommendation: In-depth analysis of applications and the development of average emissions will permit the design of moving systems and/or emission controls suitable for specific applications.

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POLLUTANT INTERACTION and ENVIRONMENTAL CHARACTERIZATION

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BACKGROUND

The Pollutant Interaction and Environmental Characterization Work Group considered the following topics:

1) Factors relevant to the determination of contaminant concentration profiles in an underground coal mine environment where diesel engines are in use;

2) Interactions of exhaust components in and with mine air, such as dilution, diffusion, transport, deposition, absorption, adsorption, and chemical and other physical transformations;

3) Factors involved in estimating the exposure of miners to pollutants, including consideration of ventilation effects, load cycles, mathematical models, and measurements;

4) Estimations of concentration ranges for mine air components and toxic substances that might be expected in existing U.S. coal mines if diesels are used; and

5) Estimations of exposure to physical agents, such as noise and radon daughter radiations.

The objective was to determine the critical factors, the adequacy of information and techniques relative to these factors, and to identify the high-priority research gaps. The Work Group recognized that many variables had to be considered: engine type and size, fuel type and quality, exhaust control technology, engine loading, duty cycle. and maintenance. Mine related variables, such as mine size, design, mining techniques, and ventilation, also would affect emission and ambient profiles. However, it is not anticipated that most variables would affect significantly the approach and problems involved in investigating the subject topics.

The Work Group limited discussion to considerations of the requirements for health research while recognizing that additional research would also be necessary in order to obtain adequate technology for some aspects of enforcement.

CRITIQUE OF THE NIOSH DRAFT DOCUMENT, "THE HEALTH IMPLICATIONS OF THE USE OF DIESEL ENGINES IN UNDERGROUND COAL MINES"

The statement in the NIOSH draft document that photo-chemical reactions and the resulting reaction products would not occur because of a lack of ultraviolet (UV) radiation must be qualified. The Department of Labor, Mining Enforcement and Safety Administration (MESA), is requiring illumination of the workplace in underground coal mines, which may result in the production of UV radiation from some light systems. No one in the Work Group could estimate the amount of UV radiation which might be generated nor how it would affect the photochemical process. The matter was therefore recognized as a research gap, but was not considered by the group in general as having high priority. UV transmission through the thick glass or plastic lenses required for explosion proofing would probably be negligible. It was considered by most members of the Work Group that ozone-dependent reactions would be of minor importance.

The Work Group agreed that CO, CO_2, and unburned hydrocarbons would be stable in the underground coal mine environment. However, it was estimated that aldehydes potentially could react to form acids. The consensus was that although the chemical composition of emitted particulates might not change, the physical characteristics could change, especially during the initial moments after emission. It was also pointed out that the chemical constituents which might be absorbed or otherwise attached to the particulate could undergo change.

The Work Group restated the appraisal made of the studies of exposure to diesel pollutants as follows:

1. Past studies have not separated diesel-generated pollutants from mine-based pollutants, especially particulates and organic soluble particulate fractions.
2. Specific emission factors for diesel-powered equipment in their respective duty cycles have not been determined.
3. Mine pollutant concentration profiles have not been adequately determined for many substances.
4. Pollutants of critical chronic health concern, PNA's for example, have not been measured using sensitive methodology.

EXPOSURE ESTIMATES

Estimates of worker exposure to diesel-generated substances were made based on the assumption that diesels were in use in existing U.S. underground coal mines. These estimates were made for the sole purpose of providing the Health Effects Work Group with information to aid in discussion of potential health effects. Any other use of these estimates is inappropriate, as there is a great deal of uncertainty in many of them.

The evaluations of exposure shown on Table I (Coal Mine Exposure Concentrations) are based on either measured concentrations in the mine, as reported in the literature (Addendum A), or by using the best available emission values generated by the Emissions and Control Technology Work Group (Addendum C). In the latter case, the median dilution factor for CO_2 was taken as a "best estimate" to estimate the exposure concentrations. It is recommended that when the available data do not agree with the CO_2 median dilution factor, the concentration data and conversion factors should be scrutinized to determine the source of the disagreement.

TABLE I

COAL MINE EXPOSURE CONCENTRATIONS*

(NOTE: Values in this table are approximations subject to change as more accurate data become available.)

Component	Range, Undiluted (1)	Exposure Values			Confidence in exposure values	Calc Dil'n factor (avg.)	Comments
		Units	Median	Range			
CO_2	6.1-7.2%	ppm	700	500-1100	Good	(165)	Dilution factor is baseline for comparison of all values. Exposure values include 300 ppm background CO_2.
CO	114-513 ppm	ppm	10	0.20	Good	10-50(30)	Suggest undiluted values low.
NO	225-735 ppm	ppm	3	1-5	Good	75-245(160)	
NO_2	36-84 ppm	ppm	0.3	0.1-0.5	Good	120-280(200)	
SOx	7.7 ppm	ppm		0.5			No mine data.
SOx(2)	40 ppm	ppm		0.5	Good upper limit	80	No mine data. Base on 0.2 sulfur in fuel.
H_2SO_4		mg/m3		0.2	Unknown		Used 10% of SOx value as basis.

TABLE I
(continued)

Component	Range, Undiluted (1)	Exposure Values			Confidence in exposure values	Calc Dil'n factor (avg.)	Comments
		Units	Median	Range			
Hydrocarbons	(3)	ppm		5-20	Poor		Measured values as methane but unverified. Ref. 8, Addendum A
Benzene	(3)	ppm		0.01			Rough estimates
Aromatics		mg/m3	0.7	0.13-2.1	Unknown		Ref. 2, Addendum A
Oxygenates	(3)	mg/m3	0.04	0.006-0.11	Unknown		Ref. 2 does not contain formaldehyde.
Total Aldehydes	(3)	mg/m3	0.045	0.007-0.19	Unknown		(2)
Formaldehyde	(3)	mg/m3	0.04	0.007-0.06	Unknown		(2)
Diesel Particulate	0.12-9.47 g/bhp/hr	mg/m3		0.1-1	Unknown		
Respirable Coal Particulate		mg/m3	1.3	0.1-10	Good		Compliance values

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*There are insufficient data to estimate exposures to PNA's, organic acids, organo-sulfur compounds, organo-nitrogen compounds, HNO_3, HNO_2, and trace metals.

Footnotes:

1) Emission Work Group data
2) Without scrubber
3) Emission work data questionable or no data

The emission data presented by the Emission and Control Technology Work Group (Addendum C) were converted from mass to concentration values using the factors shown in Addendum B. The exposure values given in Table I all consider the use of a water bath exhaust conditioner. As reliable emission data become available for some of the components, the median CO_2 dilution factor (165) can be used to derive rough estimates of exposure from source (i.e., tailpipe) concentrations unless strong interactions are suspected in the mine environment. The number of gaps in Table I indicate the lack of reliable emission data to permit engineering judgments to estimated exposure values.

THE COMMON GASES

Carbon monoxide

Significant quantities of CO typically result from blasting operations in which the gas is forced out of undisturbed muck piles and released quickly upon wet-down and ore removal. CO is a non-reactive gas, and therefore concentrations are reduced simply by dilution. CO concentrations in work areas can be determined with fair precision using permissible, self-contained continuous direct-reading instruments which are small enough to be hand-carried. Personal CO exposure measurements based upon integration of continuous measurements in the breathing zone are desirable. CO concentrations can be measured using a commercially available, pocket-sized CO dosimeter.

Grab samples can be obtained using vacuum bottles or bistable cans, or with less precision using NIOSH certified detector tubes. TWA sampling can be done using the vacuum-critical orifice sampler or by a detector tube and pump system specifically designed for long term sampling (National Drager, Inc.)

Carbon dioxide

Carbon dioxide (CO_2) is a very stable gas, and therefore concentrations are reduced simply by dilution with ventilation air. CO_2 also naturally occurs in the intake air at a concentration of about 300 ppm. Thus ventilation air used for exhaust dilution contains a background level of CO_2 plus a maximum of 100 ppm CO_2 from other mine sources (e.g. oxidation of coal and wood). CO_2 also results from blasting operations.

There are presently no portable, permissible, continuous area monitors for CO_2, although present U.S. Bureau of Mines research is expected to develop prototype hand-held CO_2 detectors or monitors in late 1978.* However, instantaneous measurements may be obtained using detector tubes, and grab samples for CO_2 may be obtained using vacuum bottles or bistable cans. Personal exposure for CO_2 can be determined using critical orifice personal samplers. Continuous CO_2 monitoring and recording equipment that can be mounted on the diesel vehicle will be commercially available soon. These

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*Editorial Note: Prototypes are now being field tested by U.S. Government agencies.

have been shown to be useful data gathering and ventilation control devices in U.S. metal mines.

CO_2 is a likely candidate for a correlative species to be used as an index of diesel exhaust exposure or levels, since it is directly related to fuel burned and is very stable. Also, the levels of CO_2 resulting from off-shift blasting exist for approximately 15 minutes and are negligible with respect to their shift average contribution.

Nitric oxide

Nitric oxide (NO) is a relatively stable species after dilution by mine ventilation air. The dilution can be assumed to occur rapidly upon exit from exhaust systems. At such low concentration levels, the oxidation of NO to NO_2 is very slow. Ten percent of a concentration of 10 ppm of NO in air is oxidized in about half an hour. At the working face, where the majority of men will be located in a coal mine, NO to NO_2 conversion can be assumed to be small and contribute little to the NO_2 exposure of these workers. Without recirculation, which is not permitted in coal mines, the half-hour old mine air is in the returns where it is further diluted owing to leakage of fresh air into the returns.

A continuous, portable, battery-operated, permissible, direct-reading, recording monitor for NO is commercially available. A personal TWA (Palmes') sampler for monitoring NO was ready for field trials in late 1977. Detector tubes can also be used for grab sampling. Sample storage devices, such as vacuum bottles, cannot be used for grab or TWA sampling. Triethanolamine (TEA) sorbent tube sampling can be used as well.

Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a reactive species. It is readily absorbed by water vapor and solids, such as mine roof, rib, and floor; machinery; and particulates, and could participate in non-organic and organic acid formations as well as with other organic species. These reactions will be discussed in another section of this report. Continuous, portable, direct-reading, battery-operated, recording monitors are available for NO_2. Estimation of personal exposure can be made using the Palmes' sampler or the TEA sorbent tube and pump sampling method.

Surfur dioxide

Sulfur dioxide (SO_2) is reactive in that it is very soluble in water. Thus, in the wet and rock-dusted mine environment gaseous SO_2 quickly dissipates by deposition or reaction to become another species. Studies of the products of SO_2 reactions must be initiated. Possible products are HSO_3 or H_2SO_3, with adsorbtion on soot or coal dust. Detector tube measurements in dieselized metal mines have not shown measurable quantities. Continuous, direct-reading, SO_2 monitors which require short time constants and are convenient to use are not yet available. Vacuum bottle grab sampling may be feasible. Wet chemical methods could be used for long term work-shift area sampling only. These are available, but interferents are unknown.

Research Gaps

Before the above instruments and methods should be used to gather data, they should be scrutinized for response to interferents. Electrochemical instruments for CO, NO,and NO_2 are fairly interferent free. The specificity of the NIOSH SO_2 methods when used in underground mines with diesels was raised and must be resolved. TEA also traps SO_2 but suitable analysis techniques have not yet been perfected.

For monitoring and control of underground diesels, less cumbersome, direct-reading devices should be developed. The Palmes passive samplers for NOx and NO_2 are adequate. However, similar devices for CO, CO_2 and SO_2 do not yet exist. For adequate enforcement and monitoring it may not be necessary to measure all contaminants; research should be continued to find a correlative species in the diesel exhaust which provides an adequate index of pollutant levels and/or individual exposures. From the data now available, the level of CO_2 correlates well with the level of diesel particulates and only fairly well with the other gases in metal mines. Further correlative studies are required in dieselized coal mines. Continuous CO_2 monitors on each diesel vehicle are demonstrating practicability as air quality control tools. They also perform a safety function by shutting off the diesel engine after CO_2 levels are sustained over set point levels. Work area pollutant characterization is an ongoing project and will provide mine/work cycle related to pollutant levels in the working section of a coal mine. Measurement techniques for common gases in diesel exhaust are summarized in Table II.

HETEROATOMIC ORGANICS (Excluding Polynuclear Aromatics)

In the general category of heteroatomic organic compounds, three distinct classes exist:

1) Oxygenated compounds
2) Nitrogen compounds
3) Sulfur compounds

It is likely that the various species in these classes of compounds exist in the coal mine environment whether or not diesels are used. The coal mine environment itself is complex, and the relative contributions of diesel engines and other mine sources in producing heteroatomic compounds are not known. However, the fact that many of the emission products are

TABLE II

SUMMARY OF AVAILABLE MEASUREMENT TECHNIQUES FOR COMMON GASES IN DIESEL EXHAUST

Gas	CO	CO_2	NO	NO_2	SO_2
Stable (S) Reactive (R)	S	S	R	R	R
Continuous; Point	X[1]		X[1]	X[1]	
Whole Shift; Point					X[6]
TWA; Personal, Active	X[2]		X[7]	X[7]	X[6]
TWA; Personal, Passive			X[4]	X[5]	
TWA;COPS3	X	X			
GRAB; Det. Tube	X	X	X	X	X
GRAB; Air Sample	X	X	X	X	X
On Board Vehicle		X			

1. Electrochemical, Energetics Science, Inc., Elmsford, NY., Series 6000, 7000. Portable battery-operated. Suggest underground or daily surface calibration. MSA Model 70 is equivalent.
2. General Electric, "CO dosimeter", Electrochemical pocket-sized, with alarm on high instantaneous level, recorder output.
3. NIOSH-NRL-Critical Orifice Personal Sampler. Collects all gas species, using vacuum sampling over 8 hours, small; specificity and sensitivity depends upon analysis method; stable species, passive.
4. Palmes', NYU. passive personal sampler for NOx; field trials late 1977; analysis same as NO_2 sampler.

TABLE II
(continued)

5. Palmes', NYU. Passive sampler for NO_2, TEA plus colorimetric NDEA; analysis kit available late 1977.

6. Wet chemical, personal impinger, or portable colorimetric, conductrimetric analysis.

7. TEA sorbent. With pump and oxidizer measures both NO and NO_2.

adsorbed onto the surface of the airborne respirable particulate may make them readily accessible to the metabolic process after inhalation. Thus, the health effects may be proportionately greater than emission concentrations might indicate.

Oxygenated compounds include alcohols, aldehydes, ketones, carboxylic acids, ethers, and lactones. Nitrogen compounds include amines and nitroso compounds. Both cyclic and acyclic sulfur compounds are present.

Of the oxygenates, formaldehyde, acetaldehyde, isobutylaldehyde, crotonaldehyde, propionaldehyde, benzaldehyde, and propiolactone have been identified in diesel exhaust. Quantitative environmental information is available only for formaldehyde and total aldehydes. In addition to aldehydes, high resolution mass spectrometry (HRMS) data on raw exhaust indicate the presence of the following classes of oxygenates: aliphatic ketones, lactones, esthers, and alcohols; and aromatic esthers, ketones, anhydrides, phenols and dihydric phenols. With the exception of formaldehyde, none of the compounds in these groups has been specifically measured in the mine environment; however, it is likely that they are present. Infrared analysis has confirmed the presence of the above classes of compounds, as well as carboxylic acids, in diesel emissions. Through further oxidation of alcohols and aldehydes, additional carboxylic acids may be formed.

Of the nitrogen compounds, nitrosamines present the greatest concern, in the Work Group's estimation. Nitrosamines have not been detected in diesel emissions. However. the precursors for the formation of nitrosomines (NO + NO_2 plus secondary amines) are commonly present in both diesel exhaust and coal mine dust. Other nitrogen compounds which have been identified in diesel exhaust are aniline, methylaniline, pyridine, and dinitrocresol. No quantitative environmental data are available.

Among sulfur heterocyclics, trace amounts of benzo and dibenzo thiophenes have been identified in diesel emissions. Both cyclic and acyclic sulfur compounds are found in coal.

Standard analytical methods for heterocompounds of these types have not been applied to the analysis of diesel emissions or the coal mine atmosphere. Significant research gaps remain in the areas of sample collection, elimination of interferences, discrimination between pollutants from coal mine dust and pollutants from diesel emissions, and quantitative removal of hazardous compounds from particulate matter.

MBTH and chromatropic acid colorimetric methods have been used to measure total aldehyde ($C1$ to C6) and formaldehyde, respectively. A large data base for aldehydes in diesel exhaust has been generated using these methods. Recent data show severe interferences by SO_2 (present in diesel exhaust). Techniques presently being examined are infrared characterization (for acrolein) and LC cleanup followed by GC, EC-MS, and HPLC analysis.

Although the Emissions and Control Technology Work Group did not identify all of the compounds mentioned above, it is likely that these compounds will be present. Therefore, research to develop sampling and analytical methods is a critical need for adequate chemical characterization of the coal mine environment, particularly where diesels are used.

PARTICULATE AND PARTICULATE-ASSOCIATED SUBSTANCES

In considering particulates, trace metals, inorganic acids, PNA's, hydrocarbons, and aromatics normally associated with diesel soot or other coal mine dusts, we must emphasize that research on the physical properties and chemical composition of particulates in mines where diesel equipment is used is required so that environmental and health effects data can be correlated. To assess the particulate contribution from diesels, sampling methods must be developed which distinguish diesel sources from other sources. One thought is to consider all particulate smaller than about one micron to be of diesel origin. Until other methods are available to distinguish diesel emissions from other pollutants, inertial classification of different-sized fractions of particulates can adequately separate coal mine dusts into a sufficient number of fractions to determine potential health effects. The fraction less than about one micron in diameter can be attributed to diesel exhaust. Physical characterization data to be obtained should include:

a) shape, by microscopic examination,
b) specific surface,
c) relative mass of diesel to that of coal particulate, and
d) vapor pressure.

Microscopic data will give some idea of the geometry of the particles. Most of this research has been done. Specific surface research will identify the potential ability for adsorption of mine air, gas, and vapor contaminants and allow a comparison of the relative capacities of coal mine dust and diesel particulates for adsorption of gaseous contaminants in the mine.

Vapor pressure of the different chemical species is an important factor since many substances which exist as solids and liquids can coexist as vapors. Nitric acid, PNA's, and hydrocarbons are just a few examples. A knowledge of vapor pressures for some substances may be required for the proper design of sampling systems.

Valid sampling and analytical methods must be developed to characterize and quantitate the particulates. Furthermore, because of the number of substances and the number of samples, rapid, single sample, substance-species analytical methods must be developed for PNA's and trace inorganic substances. These techniques can be applied to personal samples, area samples, and samples from the different stages of inertial separators. Chromatography and emission spectroscopy offer the potential for specific multisubstance analysis. The NIOSH document "The Health Implications of the Use of Diesel Engines in Underground Coal Mines" indicates that a number of polynuclear aromatic hydrocarbons (PNA's), trace metals, and other hydrocarbons can be emitted from diesel engines and are also found in non-dieselized mines. To characterize accurately the mine atmospheres where diesels are used, portable, direct-reading instruments; area monitors; and laboratory instrumentations and methods will have to be developed and tested. Some of this technology is here today and needs only to be adapted to the coal mine environment.

The following are a few examples of instrumentation and methods research techniques which may solve mine monitoring needs:

a. High performance liquid chromatography (HPLC) coupled to rapid scanning spectrometric detectors provide a potential for routine specific quantitations of the number of PNA's in a single sample.

b. Optical emission spectroscopy (OES) is a sensitive and accurate method for quantifying a number of trace metals in collected samples. The inductively-coupled, plasma-OES technique is being developed to characterize mine/diesel samples and can be applied to this analytical problem for routine sample analysis.

c. High-resolution mass-spectroscopy (HRMS) and gas-chromatography mass-spectrometry (GC-MS) methods must be developed to characterize mine/diesel samples as well as assist in the development of routine methods such as those described above.

Portable, direct-reading instruments which can detect hydrocarbon vapors would be useful as survey instruments, personal exposure meters, and area monitors. The development of miniature gas chromatographs and GC detectors should be pursued. The GC concept will add to specificity and therefore aid in exposure interpretations.

Sulfuric acid, nitric acid, sulfates, and nitrates are expected to be present in the mine atmosphere as a result of NO_2 and SO_2 directly emitted from the engine or as a result of the use of emission controls. Ion chromatography applied to these and other cations or anions can be a powerful technique in species indentification and quantitative analysis.

Development of other instrumentation which can be used for in-mine measurements of particulate for enforcement purposes may be needed. Direct-reading instrumentation to give mass concentration of coal mine particulates is already under development by U.S. Bureau of Mines contractors. This instrumentation would also be sensitive to diesel particulate.

It is not certain whether the present coal mine dust personal sampler will measure all diesel particulate which is present in mine air, since some of the particulate may be small enough to pass through the filter. If future tests show that a substantial amount of diesel particulate escapes, the sampler will have to be improved so that it is adequate for coal mines in which diesels are present. If future research shows that vapors (such as nitric acid, PNA's,etc.,) may be a problem, it may be necessary to modify the personal sampler by adding a third stage to capture vapors. It will also be necessary to develop the sampling methodology, including determination of accuracy and precision required to establish compliance with health standards in dieselized coal mines. Again the role of correlative species cannot be ignored.

MATHEMATICAL MODELING

Diesel Emissions Dilutions and Personnel Dosage

Most diesel applications in mines can be modeled mathematically to derive air quantities required to achieve any desired degree of dilution. The following models are available in published literature (1,2):

1. Single engine in stationary mode, such as a diesel-powered generator.
2. Single engine moving in an airway with or against the air current, such as a diesel locomotive or a supply vehicle.
3. Multiple engines moving in a single roadway or a runaround, such as LHD vehicles on a combination of loader and trucks in a panel. Several subcases involving multiple engines in a single roadway have been identified and modeled as follows:
    - a. Multiple engines moving in a cycle in an airway with leakage.
    - b. Multiple engines moving in a cycle in an airway with no leakage.
    - c. Multiple engines moving randomly in an airway with no leakage.

All the above situations were modeled using partial differential equations of turbulent dispersion. Solutions obtained were in closed forms and directly applicable to calculation of diluent air.

4. Multiple units in a network of airways: analytical solutions are not possible for this case. Consequently, numerical methods were used to predict ambient air concentration of diesel exhaust. Emission sources were normalized using California 13-mode city cycle and steady, point (or line) sources. This assumption is considered valid in view of the fact that health effects are related to time-averaged exposures for most species in the diesel exhaust. These models can be used to analyze various dieselization alternatives (different equipment combinations) in any kind of ventilation system to derive technically consistent and quantitative exposure limits.

Suggested Improvements in the Models (Research Gaps)

Some improvements in these models can be made as follows:

1. Analytical models for cases 1, 2, and 3 can be extended to two or three dimensions.
2. Computer simulated models for dispersion can be extended to include the time-dependence of exhaust emissions and dispersion. This may be essential for certain species of exhaust which have a ceiling limit.
3. The network representation of a mine, as used in case 4 above, may not be the most suitable. Alternate representations, e.g., the mine as a structure in a continuum, should be explored.
4. These models can be modified to include a decay term for reactive species and used to derive absorption/adsorption coefficients.
5. As data become available on diesel emissions as a function of duty cycle, it may be possible to generate emissions from production-oriented system simulators to calculate peak and time-averaged emissions (3).

Personnel Dosage

Personnel dosage can be derived in the following three ways:

1. By using personal samples for one (or more) correlative species of diesel exhaust.
2. By statistically deriving personal exposure when only area samples of diesel exhaust are measured using precise and accurate devices. This method is a compromise.
3. By using the above mathematical and computer-simulated models and a time-and-motion study on personnel in mines.

PHYSICAL AGENTS: NOISE, IONIZING RADIATION, AND HEAT

Noise

Only limited data exist on exposure to noise in dieselized coal mines. The data indicate that noise levels greater than those allowed by the Coal Mine Health & Safety Act of 1969 were often exceeded, in one case by as much as 2.7 times the allowable value (by dosimeter) (4). In at least one instance, noise level was above the 115 dBA standard. The data, however, do not include noise levels prior to the introduction of diesel equipment.

It is known that instantaneous face equipment readings are usually over 90 dBA.

Noise exposure is a problem in nearly all mining. As is the case with hard-rock mining noise, coal mine noise is a function of machine design, machine use, and mine characteristics. However, the noise energy absorbing characteristics of coal may differ from those of the various types of hard rock.

The technology for noise measurement is commercially available. The Work Group agreed that noise control research has no serious gaps. There has been considerable research on noise in general industry, tunnels, and metal and non-metal mining, and mandatory requirements for maintaining acceptable noise levels are well established.

Ionizing Radiation

According to Rock and Svilar, et al. (5), only a few underground coal mines in the United States have natural radioactive aerosols present to the extent that they could constitute a health hazard. Only two of 223 mines evaluated using nearly 1600 samples were found to have working level (WL) concentrations greater than 0.2. None of the samples indicated concentrations over 0.3 WL.

Because known WL concentrations have been shown to be low or non-existent in underground U.S. coal mines, major research seems not to be justified. As coal seams at deeper levels become more feasible to mine, some cursory monitoring would certainly be in order whether diesel or alternate systems of mining are used.

Heat

To the Work Group's knowledge, there is no information available in the literature on heat stress caused by the use of diesel equipment in underground coal mines. Information available on heat stress resulting from mine characteristics in some metal mines is not applicable to coal mining.

Coal mines are known generally to be cool, and the Work Group does not anticipate that heat stress would become a problem if diesel engines were to be widely introduced into underground coal mines. No research is recommended on this subject.

ADDENDUM A

SOURCES OF INFORMATION FOR TABLE I

1. Emission factors from Emissions and Control Technology Work Group (Addendum C).
2. Unpublished data, U.S. Bureau of Mines Contract No. J0166009.
3. Participant input on U.S. Bureau of Mines studies on 22 mines in the United States.
4. Michigan Technological University studies, Annual Reports.
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10. U.S. Bureau of Mines. 1975. Information Circular No. 8666. Washington, D. C.
11. Mines resources development conversion factors for g/bhp/hr to ppm. (Addendum B).

ADDENDUM B

CONVERSION OF G/BHP/HR EMISSIONS TO PPM

All gases: 1 g/bhp/hr = 185 ppm by volume

O_2: 1 g/bhp/hr = 190 ppm by volume

NO: 1 g/bhp/hr = 180 ppm by volume

NO_2: 1 g/bhp/hr = 120 ppm by volume

NOx: 1 g/bhp/hr = 174 ppm by volume (10 percent NO_2)

SO_2: 1 g/bhp/hr = 80 ppm by volume

CO_2: 1 g/bhp/hr = 120 ppm by volume

All figures assume exhaust gas emission of 70 1/bhp/min (2 1/2 cfm/bhp)

ADDENDUM C

EMISSION FACTORS
PRELIMINARY - SEPTEMBER 20, 1977
EMISSIONS WORK GROUP
ALL UNITS: GRAMS/BRAKE HORSEPOWER

Pollutant	Untreated Engine	Catalyst Treated	Water Scrubber	CAT + H_2O Scrubber
CO	0.6-2.7	0.6-0.3	0.6-2.7	0.7-0.3
Hydrocarbons	0.03-0.17	0.003-0.017	0.02-0.12	0.003-0.017
NO	1.25-4.1	1.25-3.5	1.25-4.1	1.25-3.5
NO_2	0.3-0.7	0.15-1.1	0.3-0.7	0.15-1.1
Particulate (carbon only) (Particulate 80% Carbon)	0.17-0.67	0.17-0.67	0.12-0.47	0.08-0.33
Phenols*	0-0.1	80-90% Reduction	?	80-90% Reduction
Aldehydes	0.02-0.2	0.005	0.01	0.005
H_2SO_4 (0.2% Fuel)	--	0.37	--	0.24
Trace Metals**	--	0.025 MAX	--	--
PNA's*	--	--	--	--
Benzene	0.5-1% of Hydrocarbons			
Odor	--	Substantial Reduction with Catalyst		
Irritancy	--	Same Reduction with Water Scrubber		

ADDENDUM C
(continued)

Pollutant	Untreated Engine	Catalyst Treated	Water Scrubber	CAT + H_2O Scrubber
CO_2	510-600 - All Systems			
Noise	96-104 dBA - All Systems			
Heat	12000 Btu/bhp/hr			

* Group feels that current analytical technology for phenols and PNA's is inadequate to articulate even a qualitative emission factor.

** Number shown reflects a maximum additional tract metal emission associated with catalyst attraction products.

Emission Factors:

Notes:

1. Units provided in the above table are a mass emission rate per rated engine horsepower per hour.
2. These represent our current best estimate of mining diesel engine emissions.
3. Duty cycle, service-versus-work, engine applications, and total rated horsepower in a mine section are factors which the Emissions and Control Technology Work Group should address.
4. For information, the following represents our current "best guess" as to application of various engines/systems in underground coal mines:

0% turbo-charged
10% without exhaust treatment
90% with exhaust treatment
    -60% catalyst
    -40% scrubbers

5. Smoke suppressant additives are not used in these diesel fuels.

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HEALTH EFFECTS WORK GROUP

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BACKGROUND

It was recognized by the Health Effects Work Group that it is important to appreciate that the underground coal mine is a very special environment and that coal miners already carry a significant burden of occupationally induced disease and dysfunction. In particular, coal miners are exposed to two major health hazards: coal mine dust and noise.

It is now well documented that coal workers pneumoconiosis occurs, by radiographic assessment, in 10-15 percent of U.S. underground coal miners (1). In addition, roughly a third of the miners, as judged by NIOSH's National Study of Coal Workers' Pneumoconiosis, have industrial bronchitis attributable to at least three factors: coal mine dust, cigarette smoking, and aging (2). Also, a significant proportion (2) have been found to have airways obstruction (FEV_1/FVC less than 0.7) again other etiological factors besides coal mine dust, particularly cigarette smoking are important (3). Taken together these conditions affect a substantial proportion of underground coal miners.

Noise is the second major health hazard occurring in underground coal mines. A recently published NIOSH study (4) found 25 percent of a sample of underground coal miners to have hearing impairment. In addition, an unusually high proportion were found to have external otological abnormalities which may or may not be associated with long term exposure to coal mine dust. It was further recognized that adequate hearing is essential to the safety of underground miners in that they must be able to hear "roof talk" during quiet periods of their work.

Much of the concern in regard to diesel emissions in underground mines centers on the question of carcinogenesis. Mortality patterns of underground coal miners were reviewed in the NIOSH draft paper "The Health Implications of the Use of Diesel Engines in Underground Coal Mines" and were further addressed by the Health Effects Work Group. It was agreed that available coal miner mortality studies consistently reveal excess deaths for non-malignant respiratory diseases and accidents, but that death-specific patterns for malignant neoplasms were not as clear. There have been consistent excesses for stomach cancer (5,6,7), but not lung cancer, where some studies show excesses and others deficiencies in SMR's (8,9,10,11). The Work Group felt that it is important to point out that we do not at this time know whether these observed excesses in cancer mortality among underground coal miners are attributable entirely to coal mine dust or other factors, or a combination of these factors. It was agreed, however, that this is an area of major concern, particularly as it relates to potential exposure to known carcinogens contained in diesel emissions.

EPIDEMIOLOGIC INVESTIGATIONS

1. Published Epidemiologic Investigations:

Seven published reports on health effects from diesel exposure were reviewed and are summarized as follows:

a. An early study of lung cancer among London transport workers driving and servicing diesel bus equipment was reviewed (12). The authors found no excess of lung cancer "among any group of London transport staff such as would have been expected if diesel exhaust were a serious contributory factor in producing an excess of lung cancer in urban dwellers."

The previous author referred to a study of diesel exhaust in a London diesel bus garage (13). The concentration of diesel smoke increased during periods of increased vehicle activity in the garage. Analysis of diesel exhaust revealed no BaP in exhaust from properly maintained diesels. The concentration of BaP in the garage "remained very similar to that of outside air."

b. A mortality study was carried out on railroad workers for the years 1953-1958 inclusive (14). The study comprised 235,110 person-years. The workers were divided into three groups: operating personnel exposed to diesel and coal exhausts, e.g. trainmen (73,790 person-years); non-operating personnel exposed to less diesel and coal exhaust than operating personnel, e.g. electricians, car men, and boilermakers (120,470 person-years; and non-operating, non-exposed workers, e.g. office workers (40,850 person-years). There were 6,506 deaths in all with 154 from lung cancer compared with 192 expected on the basis of age-specific rates. There was no increase in lung cancer mortality in any of the three groups studied.

c. Clinical and experimental data on the relation of health to exposure to diesel exhaust were reviewed by the author (15). The author concluded that no health damage was consistently obtained in animals or clearly defined in humans. Additional systematic observations were recommended.

d. Pulmonary function tests and X-ray examinations carried out in 210 railroad workers exposed to diesel exhaust over a period of 15 years (average 10 years) showed no difference from those of a group of 154 railroad workers of similar age, smoking history, and comparable job status but without a history of exposure to diesel exhaust (16). The frequency of complaints of bronchitis also did not differ between the two groups.

e. Small groups of volunteers were exposed by mouth inhalation and eye contact to varying levels of diesel exhaust for short periods up to one hour (17). The substances and concentrations measured in diesel exhaust included NO_2 (0.2-7.0 ppm), SO_2 (0.2-2.8 ppm), CO (less than 20-80 ppm), CO_2 (900-15,000 ppm), O_2 (19.5-20.5 percent), total aldehydes (less than 1-2 ppm), and hydrocarbons (less than 5-6 ppm). No effect was measurable in these volunteers.

f. Mortality in potash workers from eight mines was studied for the period 1940 to 1967 (18). The cohort included 2,743 surface workers and 1,143 underground workers with one year or more of employment exposure. There were 438 deaths in both groups, and in 433 of these the death certificates were found. No significant increase in lung cancer was found in either the surface or underground workers. Observed lung cancer in surface workers was 10 (compared to 9 expected). Two of the other mines used diesel equipment underground, one since 1949 and the other since 1957. No cause of death, including lung cancer and respiratory disease, was reported more frequently than expected among the 31 observed deaths associated with the two dieselized mines. The authors noted that insufficient time may have elapsed to show these effects in this relatively small group.

g. Mortality of a cohort of 15,094 uranium miners who worked one month or more in uranium mines for the period 1955 to 1974 was studied (19). There were 81 lung cancer deaths compared to 45 expected in this cohort. Although these mines are dieselized, the excess of lung cancer was attributed to exposure to radon daughters. Those miners with lung cancer received 0 to 375 WLM (average 75 WLM). The significance of exposure to diesel exhaust in this group of underground miners, if any, is difficult to assess.

Summary:

A number of reports have addressed the question of worker health effects in relation to exposure to diesel emissions. However, because available studies are based on too few cases or an insufficient exposure and/or latency period, it is difficult to determine whether exposure to diesel exhaust presents any increased risk of respiratory disease or cancer in diesel bus workers, diesel railroad workers, and metal and non-metal miners working with diesel equipment underground.

2. Ongoing Epidemiologic Investigations

Six major epidemiologic studies concerning diesel exposure in underground mines are currently under way. Three are cohort mortality studies which address the important question of cancer risk as well as mortality from chronic respiratory diseases. These studies, which are summarized in Table I, are briefly described as follows:

a. NIOSH is studying the mortality experience of 12,600 metal and non-metal miners exposed to varying levels of silica, diesel exhaust, and radon daughters; in question is the extent and definition of diesel exposure among many of these miners. Results are expected in 1978.

b. The second cohort mortality study is being conducted by McMaster University under the sponsorship of INCO and the United Steel Workers of America. This study will examine the entire Ontario nickel operation of INCO since 1950, including active miners, pensioners, and those who have quit. This operation has been heavily dieselized only since 1966. The work environment has been studied for diesel pollutants since 1966 and for respirable particulates for many years prior to that. Results are expected in 1979.

c. The third cohort mortality study, sponsored by the Swedish government, will study more than 16,000 metal miners exposed to diesel exhaust since 1959.

d. The Swedish mortality study will complement a medical surveillance program on these miners, who are given chest X-rays, pulmonary function tests, respiratory questionnaires and audiometry every three years. Results of these two studies are expected in 1981-1982.

e. Two cross-sectional morbidity studies are being conducted by the United States Government. NIOSH and MESA are currently studying more than 5,000 metal and non-metal miners exposed to various levels of silica and diesel exhaust. Thorough environmental sampling has been presented by Dr. Aurel Goodwin at this conference. NIOSH has collected questionnaires, pulmonary function test data, and chest X-rays which are being analyzed for evidence of respiratory symptoms, airways dysfunction, and radiographic abnormalities which may or may not be associated with diesel exposure in some of these mines.

f. The second NIOSH cross-sectional study investigates combined exposure to diesel emissions(for less than 7 years) and coal mine dust. This study of five mines includes 823 coal miners in Kentucky, Wyoming, and Utah and follows closely the protocol used in the NIOSH/MESA study. However, in addition

TABLE I

ONGOING INVESTIGATIONS

Investigators	Population	Type of Study	Observation
1) NIOSH/MESA	5500 metal and non-metal miners exposed to diesel, silica, radon daughters.	Cross-sectional morbidity. Pulmonary function, respiratory symptoms, chest X-rays.	Results in 1978
2) NIOSH	12,600 metal and non-metal miners exposed to silica, diesel, radon daughters.	Cohort Mortality	Results in 1978
3) NIOSH	823 coal miners exposed to diesel exhaust for 6-7 years or less.	Cross-sectional morbidity and acute effects of study. Pulmonary function, respiratory symptoms, chest X-rays.	Results in 1978
4) INCO/Steel Workers-McMaster University Study	INCO total Nickel Ontario Operation (n=95,000) since 1950. Environmental characterization: CO, CO_2 total respirable particulates, organic fraction, NOx, aldehydes, from 1966 when diesels were introduced. Dust exposure characterized from an earlier date.	Cohort Mortality	Results in 1979-80

TABLE I
(continued)

Investigators	Population	Type of Study	Observation
5) Work Environment Fund of Sweden	16,000 Swedish Metal Miners exposed to diesels since 1959.	Medical Surveillance Environmental Surveillance (Reconstructed prior to 1975). Every third year: Chest X-ray, MTD, pulmonary function tests, questionnaire, audiometry.	Results in 1981-82
6) Work Environment Fund of Sweden	16,000 Metal Miners (as above)	Cohort Mortality	Results in 1981

NIOSH has studied changes in pulmonary function over a work shift. Matched controls need to be identified and environmental characterization of the mines is required before any conclusions can be drawn from this study. These results are expected in 1978.

Summary:

All of these studies should help answer questions concerning cancer and chronic respiratory disease risk from diesel exposure in underground mines. Additional research, however, will be required.

It is possible that adequate data bases exist in foreign countries, and studies of these may answer important epidemiologic questions. The Work Group concluded that these data have not yet been adequately studied; it is possible that investigation of Australian, Canadian, German, or British data may be profitable. Other coal producing countries, including Belgium, Japan, France, and India, should also be queried for any data they may have regarding health effects of diesel engines used in underground mines.

IN VITRO AND IN VIVO INVESTIGATIONS

1. Completed In vitro and In vivo Investigations:

There is a paucity of published reports on the toxic effects of diesel exhaust on man. These reports, which are summarized in Table II, can be briefly described as follows:

a. Kotin and Falk (20) applied diesel exhaust condensates to the backs of mice and found nephrotoxicity, papillomas, and epidermoid carcinomas.

b. Battigelli, et al. (21) studied the response of tracheal clearance (mucociliary) activity in rats exposed to diluted diesel exhaust. The tracheas were excised, exposed for various lengths of time (4-100 hr), and the rates of transfer of graphite particles 50 micrometers in diameter were measured. In addition to the time variable of exposure, the investigators used two concentrations of diesel exhaust and a particulate-free exposure group. The results indicated that diesel exhaust at concentrations not effective in modifying airway resistance in humans can elicit a prolonged duration of tracheal clearance as measured by this system. The removal of particulates substantially lowers the inhibitory effect of diesel exhaust on tracheal clearance of graphite particles.

TABLE II

COMPLETED IN VITRO AND IN VIVO STUDIES OF DIESEL EXHAUST EXPOSURES

Reference No. and Author	Species	Condition of Study	Observation
(20) Kotin, et al.	Mice: C57 B1 Male & Female (A strain)	Skin painting 3x/wk. Engine exhaust particulate extracts in acetone solution. Cycled, inefficient operation, with load.	Nephrotoxic, skin papillomas, epidermoid carcinomas.
(21) Battigelli, et al.	Rats: Dawley; Sprague-Dawley; Sprague	Inhalation, 4-100 hrs. Engine exhaust without load or cycling: NO_2, 2-15 ppm; SO_2, 0-3 ppm; particulate, 0.7-17 mg/m.	Filtered exhaust (gaseous components only): no effects. Whole exhaust (gaseous plus particulates): marked inhibition of mocociliary clearance.
(22) Battigelli et al.	Rats: Sprague-Dawley Mice: Albino Swiss	Inhalation 15 hr. Engine Exhaust without load or cycling: NO_2 5-10 ppm; particulate, up to 17 mg/m3.	Increase in DNA labeling index of alveolar epithelium.
(23) Stuart, et al.	Male Syrian Golden Hampsters	Inhalation, 5 hrs/day, 5 days/wk, for up to 20 months; engine exhaust from inefficient operation, with load and rpm cycling: CO, 50 + 2 ppm; NO_2, 4-6 ppm; SO_2, 1 ppm; particulate, 6-10 mg/m3 respirable.	Marked particulate aggregation in alveoli or in macrophages, pulmonary consolidation, vesicular emphysema, interstitial fibrosis, cuboidal metaplasia.

c. Battigelli, et al. (22) exposed Sprague-Dawley rats and albino Swiss mice to diesel engine exhaust without load or cycling for more than 15 hours. Exposures to NO_2 ranged from 5-10 ppm, and particulate exposures were as high as 17 mg/m3. Increased DNA labeling index of alveolar epithelium was observed.

d. Stuart and colleagues (23) have conducted the only experimental animal exposure study of diesel exhaust. Syrian golden male hamsters were exposed 5 hours daily, 5 days per week, for up to 20 months to engine exhaust from an inefficiently operating engine with load and rpm cycling. Exposures to NO_2 ranged from 4-6 ppm, and respirable particulates from 6-10 mg/m3. Pathological examination following exposure revealed marked particulate aggregation in alveoli or macrophages, pulmonary consolidation, vesicular emphysema, interstitial fibrosis, and cuboidal metaplasia.

Summary:

Clearly there has been little work in the experimental area. Work now available does show potential for carcinogenic effects by skin painting. Extensive pathological changes have also been found in experimental animals exposed to an inefficient diesel engine that produces levels of NO_2, SO_2, and particulates which may be found in some underground metal and non-metal mines.

2. Ongoing In vitro and In vivo Investigations:

Although NIOSH is currently planning a chronic inhalation study of experimental animals exposed to diesel exhaust and coal mine dust, only a single study is currently under way in this area. This project (see Table III) was designed to study the development of pneumoconiosis, pulmonary fibrosis, and emphysema in an experimental protocol in order to clarify the mechanisms of induction of these diseases and the levels of in-mine contaminants that are necessary to induce them. SPF male Wistar rats are used; daily exposures as outlined below were started in fiscal year 1977, with the animals at 18 weeks of age.

The diesel exhaust utilized in these studies is that from an inefficiently-operated diesel engine to simulate poorer engine maintenance situations in order to determine the risk associated with worst-case conditions. The coal dust aerosols consisted of bituminous coal from Cambria County, Pennsylvania, a coal associated with a high prevalence of CWP.

At the time of the workshop, after 10 months of exposures, the average weights of the animals in each group were increasing at the same rate. Sacrifices of six-animal groups were scheduled at 4, 8, and 12 months after the start of exposures. At those

TABLE III

ONGOING INVESTIGAIONS - IN VIVO STUDY OF DIESEL EXHAUST EXPOSURES

Reference No. and Author	Species	Condition of Study	Observations
(23) Stuart, B.O.	Rats: SFP Male Wistar	Inhalation of diesel exhaust, 6 hrs/day, 5 days/wk for 24 months or longer. Engine exhaust from inefficient operation with load and rpm cycling. CO, 50 + 2 ppm NO_2, 0.5 - 1.5 ppm; SO_2, 1 ppm; particulate, 8-10 mg/m^3 respirable. These exposures with and without bituminous coal mine dust (respirable) at 6 mg/m^3 simultaneous exposures, same regimen.	At 4 and 8 months: particulate aggregation in alveoli, in macrophages. Slight vesicular emphysema, interstitial fibrosis, hyperplasia and cuboidal metaplasia.

times, samples are obtained for detailed histopathologic, biochemical, and hematologic examinations.

Pulmonary alterations after 4 and 8 months of daily exposures include marked accumulation of diesel soot and/or coal dust particulates in alveoli or phagocytized by pulmonary macrophages. This appears to be associated with early pulmonary lesions, including vesicular emphysema, interstitial fibrosis, and hyperplasia and cuboidal metaplasia of the bronchial epithelium.

INVENTORY OF DIESEL EMISSIONS AND RESULTING COAL MINER HEALTH EFFECTS

During the workshop, emission factors were defined by the Emissions and Control Technology Work Group and within certain limits quantified. In turn, the Pollutant Interaction and Environmental Characterization Work Group developed exposure estimates of working ranges of emission components found, or likely to be found, in underground mines. Using this information, the Health Effects Work Group developed an inventory of exposures and ranked each exposure on a severity scale of one (low severity) to three (high severity). We also attempted to determine which exposures were likely to result in potentially harmful interactions between two or more individual exposures or emission products. There was not always unanimous agreement as to the severity score and, therefore, minority opinions were also recorded.

It was, however, unanimously agreed that diesel particulate, other components, and especially PNA's, pose potentially serious problems. It was also recognized that coal mine dust must always be considered a serious hazard. This inventory is reviewed in Table IV.

RESEARCH GAPS

1. Epidemiologic Investigations:

    a. No morbidity or mortality studies considering the use of diesels in coal mines are now available. Both foreign and domestic studies should be undertaken.

    b. The latency periods characteristic of available morbidity and mortality studies on diesel emission exposure are too short to allow adequate confidence that negative results accurately portray the disease picture. Domestic populations of railroad or other diesel mechanics may provide an important cohort exposed to diesels since the early 1950's.

    c. Ergonomic studies considering noise, vibration, heat, accidents, and musculoskeletal effects in similar equipment powered by diesel and electric units are needed.

TABLE IV

INVENTORY OF DIESEL EMISSIONS - COAL MINE HEALTH EFFECTS+

Diesel Component	Health Severity Score
CO	1 (2)
CO_2	1
Hydrocarbons	1*
NO	1
NO_2	3 (2) (1)
SO_2	1 (2)
Diesel Particulate	3*
Oxygenates	1 (2) (3)*
Formaldehydes	1
Aldehydes	1
H_2SO_4	1
Noise	2 (3)
Phenols	1
PNA's	3*
Odorants & Irritants	2
Heat	1
Ergonomic hazards (vibration)	1

Mine Components	
Coal Mine Dust	3
Radiation	3 (2) (1)

Potential Interaction

Noise + Stress → ↑ Accidents
NO_x or SO_2 + BaP (or other carcinogens) → ↑ Carcinogensis
Particulates + BaP → ↑ Carcinogenesis
NO_x + amines → Nitrosamines → ↑ Carcinogenesis
NO_2 + coal mine dust or diesel particulates → ↑ airway effects

*Carcinogenic potential
+Minority opinions on health severity are given in parentheses.

d. Epidemiologic studies of acute and chronic infections together with assessment of immunologic components may well be useful.

e. Assessment of sputum cytology of uranium miners who have had varying diesel exposure may be instructive. These data may now be available.

f. The effects of odor and mucous membrane irritation on miners exposed to diesel emissions must be studied and compared to effects on unexposed miners.

2. In vitro and In vivo Investigations:

There are two broad areas of concern in identifying critical research gaps:

a. Identification of variables and their resultant potential biological effects in the operation and design of diesel engines; and

b. Identification of specific potential health effects on miners, most notably with regard to such diseases as lung cancer, chronic obstructive lung disease such as emphysema, and genetic damage including mutagenesis or reproductive aberration including teratogenic effects. The first area of concern can be approached by using relatively inexpensive, simple and rapid in vitro and some in vivo mammalian techniques to answer questions such as the following:

   (i) How do in situ mine samples compare to diluted engine exhausts in the laboratory?

   (ii) How do such factors as engine design, fuel type, and duty cycle influence the biological activity of fractions or components of diesel exhaust?

The second area of concern in health hazard assessment involves long term studies, which are generally quite expensive. Even though some research gaps, such as the effects of diesel exhausts on lung clearance mechanisms, may be addressed by short term studies, the majority of the biological response questions remaining to be answered require assessment of chronic effects, such as carcinogenesis.

a. In vitro test recommendations

   (i) "Potential Carcinogenesis" Screens

      a) Bacterial mutagenesis assays correlated with carcinogenesis; e.g., Ames assay, repair deficient strains assays.

b) Chemical transformation assays; e.g., Syrian hamster embryo cells (Petra, 1977), (BHK-21, 10T 1/2, Balb C/3T3).

(ii) Mutagenesis Screens (data base must be defined) as recommended in DHEW and EPA guidelines. These should encompass point mutations, DNA repair and breakage, chromosomal breakage and rearrangement, and reactivity to DNA.

(iii) In vitro cellular toxicity tests

a) Biochemical, e.g. alterations proteins and DNA synthesis

b) Functional, e.g. macrophage assays

c) Replication of cultured cells

(iv) <u>In vitro</u> teratology methods are not available.

(v) Experimental animal urine and blood samples for mutagenesis screening are being developed.

b. In vivo test recommendations

(i) Screening system for mutagenesis

a) Drosophilia melanogaster

b) Tier II mammalian screens, e.g. dominant lethal, host mediated assay, etc.

(ii) Animal acute inhalation exposure including design variables such as:

a) Dose response

b) Concomitant effects of coal dust

c) Immunological effects

d) Microbiological effects

e) Reproductive effects, including teratology, dominant lethal, sperm abnormalities, embryotoxicity

f) Biochemical function

    g) Behaviorial effects, including combined exposure to appropriate physical agents, i.e., noise, heat, vibration, radiation, etc.

(iii) Other routes of administration for chronic exposure

    a) Skin painting and feeding of diesel condensates

    b) Neonatal administration of diesel condensates, e.g., subcutaneous, oral, etc.

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PRODUCTIVITY AND SAFETY WORK GROUP

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The Safety and Productivity Work Group recognized that its primary purpose was to decide whether either safety hazards or rate of productivity associated with the use of diesel-powered equipment in U.S. underground coal mines are such that the rapid expenditure of NIOSH resources in a joint NIOSH/MESA environmental and health study relating to diesel engines in U.S. underground mining, especially coal mining, should be pursued less vigorously or even discontinued in favor of other important studies. A secondary task was to consider how additional information on these topics could be assembled and presented in a manner which could assist underground coal mine operators and employees in deciding whether to accept intensified dieselization in U.S. underground coal mining.

The modus operandi was for the Chairman to preside in an informal manner. With few exceptions, the Work Group concensus on the topics discussed and reported herein was sufficiently evident to make voting unnecessary. Any members who wished to be recorded as being opposed to the group action are identified in this report. A quorum was present during all meetings.

The group considered various types of coal mining equipment and concluded that continuous miners and coal cutters do not lend themselves to diesel power. It was felt that Load-Haul-Dump (LHD) and shuttle vehicles, locomotives for hauling equipment and supplies, and utility vehicles or "jeeps" for transporting men and materials would probably be the first equipment in which diesel power would replace present cable reel, battery-powered, or trolley units. Other units which may follow, without regard to order, are main line haulage locomotives, roof bolting machines, loaders, face drills, scoops, and rock dusters.

It was noted that there are now approximately 160 diesel-powered units of various kinds in U.S. underground coal mines and that large numbers are being used in other countries. We learned that MESA inspects these diesel units in the course of regular mine inspection to determine their operating conditions. MESA also examines the company's coal mine ventilation plan before approval for use of diesel equipment is granted. The MESA member confirmed that coal mine operators are showing increased interest in using diesel-powered equipment.

The group decided not to address State laws concerning the use of diesel engines in underground coal mines. The professional experience of the Work Group members and known data show that if diesel-powered equipment should be substituted for electric-powered equipment, there would be a reduction in fires and ignitions from electricity, electric shock, and burns, including those from battery liquids (1).

On the basis of British, Australian, and South African experience, papers in the U.S. Bureau of Mines Information Circular 8666 (2,3), a study by Ramani and Kenzy (4), and the verbally-reported, up-to-date experience record of Martin County Coal Corporation (5), transportation, storage, and transfer of diesel fuel for mining equipment underground can be controlled so as not to present a hazard. A study by Ketron, Inc., (6), was cited as evidence that the versatility and less restricted mobility of rubber-tired, diesel-powered equipment add potential for increased production.

Reports by Stefanko, et al. (7,8), Hews and Rutherford (2), and Bradbury (9) indicate that the introduction of diesel-powered equipment may call for modified or additional ventilation. Higginson (3), in a study of British experience, recognizes that disel engines require greater maintenance and specially trained personnel. However, he states that maintenance costs for diesel equipment are comparable to those for battery units. The group suggested that any underground maintenance or repair shops would have to be designed to accommodate diesel equipment. The group also concluded that underground traffic control may require modification if diesel-powered equipment is introduced into U.S. coal mines. Also, the operating speed of diesel vehicles should be determined by the conditions of the floor and the width of the roadway. The present standards for metal and non-metallic mines (Title 30, Code of Federal Regulations), may serve as the basis for these determinations.

A reference in U.S. Bureau of Mines Information Circular 8666 points out that noise from diesels tends to obscure conversation or warning device signals. Mr. Clark reported that large Australian LHD diesel equipment produces from 92-106 dBA; small front-end loaders from 86-92 dBA; and shuttle cars, both diesel and electric, from 80-93 dBA. High noise level is presently a common problem in mining systems worldwide.

Data on productivity in hard rock mines show that the combination of modified mining systems and the change from electric to diesel equipment has resulted in productivity increases (International Nickel Company, Canada). In French iron ore mines, diesel equipment has replaced electric over a period of 25 years. During this period there was a 600 percent increase in productivity (J. Leandri-AMC). Current experiences in U.S. coal mines, although limited, indicate that higher productivity is being achieved from diesel equipment. Published theoretical models indicate increased productivity of 15 percent to 60 percent can be expected to result from conversion from trailing cable to diesel haulage in existing mines (5,6,10,11).

It is difficult to assess the productivity advantage of dieselizing material supply. Man-transit time can be reduced using diesel portal cars, thereby providing a corresponding increase in available production time (T. Clark, Australia). R. L. Sundeen maintained that U.S. experience indicates that heavy face equipment is more easily moved with diesel support vehicles than with conventional vehicles, thus resulting in potentially higher productivity (12).

The Work Group recommended that safety and productivity of diesel equipment in underground coal mining be promptly investigated through comparative studies. Studies of existing Government, company, and other records may be sufficient. However, if experimental work is necessary, it must be done with due regard to safety and health. Findings of these studies, which include the impact of seam height, maintenance and repair procedures, vehicle speed, and ventilation requirements for diesel engines, should be published.

The Work Group Chairman proposed that the Work Group call attention to the desirability of obtaining a national policy statement, probably from the U.S. Department of Energy, on making U.S. mineral extraction industries more dependent on petroleum fuels or synthetically-produced petroleum fuels. Although the Chairman felt the matter to be important, the group did not concur.

Mr. Vestich vigorously objected to any discussion of productivity in this workshop. Although he acknowledged that conversion of equipment from electric and battery power to diesel power may be more economical and hence increase productivity, he stated this is not the responsibility of NIOSH to decide. He contended that the statutory responsibility of NIOSH is limited to research in safety and health problems with emphasis on health; therefore workshop topics should exclude economic problems for which the Institute has neither budget nor expertise.

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June 7, 1976

Dr. Robert E. Barrett
Administrator
Mining Enforcement and
  Safety Administration
4015 Wilson Blvd.
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Dear Mr. Barrett:

We appreciated the opportunity to meet with you and your staff to discuss the issue of diesel usage in underground coal mines. The purpose of this letter is to confirm the National Institute for Occupational Safety and Health (NIOSH) position on the possible health implications of exposure to diesel exhausts.

We recognize that the Mining Enforcement and Safety Administration (MESA) is currently enforcing existing standards for coal mine dust, nitrogen dioxide, and carbon monoxide. Further, we understand you are drafting more stringent diesel control regulations limiting the emissions of engines to be used in mining and setting requirements for ventilation and workplace sampling. NIOSH certainly supports these actions based on the present knowledge of the effects of diesel exhaust contamination. However, we remain concerned about the possible enhanced health effects of long-term exposure to a combination of coal dust, a known pneumoconiotic agent, and the gases and vapors of diesel exhaust which are also known to be pulmonary irritants, e.g., nitrogen dioxide and certain organic compounds. Although standards exist for coal dust and nitrogen dioxide, these are based upon controlling health effects of single exposures. We cannot, with any confidence, state that exposures occur. To the contrary, we have scientific evidence that they potentiate their effect upon the lung tissues. The possibility that such synergism exists between respirable coal dust particles and the known respiratory irritants found in diesel exhaust must be seriously considered. Until further studies prove or disapprove this possibility, we cannot, in our professional judgment, offer any assurances that long-term exposure to coal dust and diesel exhaust at levels maintained within existing standards will protect a coal miner from adverse health effects. In addition, we know very little about the possible carcinogenic potential of chemicals which may be formed by the interaction of gases and vapors from diesel exhaust and organic substances which may be present in the coal mine atmosphere.

Although we are concerned about the possible health effects, we do not now have adequate human or animal studies to justify a recommendation at this time that existing diesel usage in underground coal mines be prohibited.

NIOSH and MESA have underway a joint study of the health status of underground miners who have been exposed to diesel exhaust over a period of years. While this study involves "hard rock" mines, it should provide us with valuable information on the possible long-term effects of diesel exposure. In addition, NIOSH will conduct a cross-sectional study of miners working in coal mines where diesels have been used for long periods of time. The health status of these men when compared with coal miners not exposed to diesel exhaust should provide additional valuable information. NIOSH also intends to recommend to MESA for promulgation as a standard, a requirement that all coal miners exposed to diesel exhausts be placed under strict medical surveillance, including periodic pulmonary function testing and appropriate blood testing. This should permit early detection of any adverse trends in pulmonary function.

These studies will be completed by 1979 and should provide us with the evidence necessary to make a rational decision on whether or not diesel as used in underground coal mines poses a significant health problem.

We feel it prudent to inform all concerned in the coal mining industry that further introduction of diesel equipment into underground coal mines pending completion of these studies might result in future economic disruption should their use pose an unacceptable health risk.

Sincerely yours,

/s/John F. Finklea, M.D.

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Director

Prepared by: JButler:agm:6/4/76

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—559-093/604

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