DIESEL PARTICULATE MATTER
SAMPLING METHODS STATISTICAL COMPARISON

By

Winthrop F. Watts, Jr., Ph.D., and David B. Kittelson, Ph.D.
University of Minnesota
Department of Mechanical Engineering
Center For Diesel Research

And

Jon Kogut, M.S.
U. S. Department of Labor
Mine Safety and Health Administration

A Proposal Submitted to the Diesel Emission Evaluation Program

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EXECUTIVE SUMMARY

An objective of the Diesel Emission Evaluation Program is the evaluation of diesel exhaust and oil mist aerosol measurement methodologies. *The analysis described in this proposal compares the three diesel particulate matter (DPM) sampling methods to determine the limitations and potential applications of each method.*

T*he objectives of the proposed study are:*

- *to review existing information on interferences, sampling and analytical biases, limits of detection, and other limitations of the existing methods for measuring DPM concentrations;*
- *to assemble available data and compare the methods with respect to their specificity, sensitivity and detection limits, and accuracy;*
- *to recommend appropriate conditions for and uses of each method; and to identify needs for further research.*

A literature search will identify existing information on interferences, sampling and analytical biases, limits of detection, and other limitations of the three methods. Previously estimated interferences will be validated by analysis of covariance and comparison with calibration intercepts obtained directly from published and unpublished field data. Published detection limits will also be compared with those estimated from the available data.

Field data will be assembled in a format conducive to statistical analyses. Statistical analyses will be performed to compare the methods with respect to their specificity, sensitivity and detection limits, and accuracy. In essence, this will constitute a meta-analysis of the available data and provide information over a broader range of mining conditions and DPM concentrations than any of the individual studies.

The analyses described above will quantitatively determine the accuracy and sensitivity of each method and will identify known interferences. Based upon the evaluation of this information it will be possible to recommend specific conditions and uses for each method. Finally, based on the results of this project, further research needs will be identified and prioritized.

The University of Minnesota (UMN) and the U.S. Mine Safety and Health Administration (MSHA) are co-authoring this proposal and will collaborate throughout the project. The estimated cost of the proposal is $32,660 (U.S.), which includes a reduced UMN indirect cost rate and no cost for MSHA participation in the study.

PURPOSE AND OBJECTIVES

Diesel exhaust is a complex mixture of noxious gases and diesel particulate matter (DPM). DPM consists of nonvolatile, elemental carbon (EC), adsorbed or condensed hydrocarbons, sulfates, and trace quantities of metallic compounds. It is of special concern because it is entirely respirable in size, with 90% of the particles, by mass, having an equivalent aerodynamic diameter of less than 1.0 μm (HEI, 1995).

Attention has focused on the potential carcinogenicity of DPM and the potential health impact on miners. In 1988, the National Institute for Occupational Safety and Health (NIOSH) recommended that whole diesel exhaust be regarded as a "potential occupational carcinogen", and stated that reductions in workplace exposure would reduce cancer risks (NIOSH, 1988). In 1989, the International Agency for Research on Cancer declared that "diesel engine exhaust is probably carcinogenic to humans" (IARC, 1989).

There is a considerable difference in recommended or established allowable concentrations for DPM in the workplace. In 1995, the American Conference of Governmental Industrial Hygienists (ACGIH) added DPM to the Notice of Intended Changes for 1995-96 with a threshold limit value (TLV^{TM}) recommendation of 0.15 mg/m^3 (ACGIH, 1995). DPM < 1.0 μm in size remains on the ACGIH Notice of Intended Changes in 1998 (ACGIH, 1998). DPM limits are already in place in Canada and Europe. British Columbia, New Brunswick and Ontario have adopted a 1.5 mg/m^3 level for respirable combustible dust (RCD) and the Federal Republic of Germany has adopted technical exposure limits (TRK) of 0.3 mg/m^3 for EC in mines, 0.1 mg/m^3 EC in other workplaces such as tunneling, and 0.15 mg/m^3 total carbon (TC) in other workplaces where more than 50% of the total carbon is organic in nature.

With the low DPM recommended in Europe and the proposed ACGIH TLV for DPM there is a need to ensure accurate sampling methods are available to determine DPM concentrations at these low recommended levels. An objective of the Diesel Emission Evaluation Program is the evaluation of diesel exhaust and oil mist aerosol measurement methodologies. *The analysis described in this proposal compares the three DPM sampling methods to determine the limitations and potential applications of each method.*

Replicated simultaneous samples of DPM aerosols, using different sampling and analytical methods, have been gathered as part of research projects conducted for various purposes. Although these data were not always obtained explicitly to compare methods, (as was the case in the DEEP biodiesel and high sulfide ore studies) the body of available data makes such comparison possible over a broad range of DPM concentrations and under a variety of different mining conditions.

T*he objectives of the proposed study are:*

- *to review existing information on interferences, sampling and analytical biases, limits of detection, and other limitations of the existing methods for measuring DPM concentrations;*
- *to assemble available data and compare the methods with respect to their specificity, sensitivity and detection limits, and accuracy;*
- *to recommend appropriate conditions for and uses of each method; and to identify needs for further research.*

BACKGROUND

Measuring exposure to diesel exhaust aerosol is challenging due to the physical characteristics and chemical complexity of diesel particulate matter (DPM). DPM has a mass median diameter of 0.2 μm, and is composed primarily of organic and elemental carbon, adsorbed and condensed hydrocarbons, and sulfate (IARC, 1989). The proportion of organic to inorganic carbon varies depending upon a number of factors, which include fuel, engine type, duty cycle, engine maintenance, operator habits, use of emission control devices, and lube oil consumption. In general, non-extractable elemental carbon accounts for a greater fraction of DPM mass than extractable organics (Perez and Williams, 1989)

Two sampling methods are routinely used in underground mines to collect DPM samples for analysis; these are respirable dust sampling and size selective sampling. Three analytical methods are used to quantify DPM in collected samples; these are gravimetric analysis, respirable combustible dust analysis and elemental carbon analysis[1] . Combining the sampling and analytical methods yields three methods to quantify DPM, which are referred to as 1) respirable dust sampling with respirable dust analysis, 2) size selective sampling with gravimetric or elemental carbon analysis, and 3) respirable dust sampling with elemental carbon analysis (Watts, 1995; Cantrell and Watts, 1996). Each of these methods has advantages and disadvantages, and is described below.

Respirable Combustible Dust (RCD): The RCD method was developed in Canada to estimate diesel particulate matter (DPM) concentrations in non-coal mines (Gangal *et al*., 1990; Gangal and Dainty, 1993). RCD is composed of all combustible materials collected on a filter including; drill oil mist, the soluble organic fraction of DPM, elemental carbon and other combustible material collected on the filter. Thus, only a portion of RCD is attributable to diesel exhaust aerosol.

In the RCD method, respirable dust is collected a on 25 or 37 mm, 0.8 μm silver membrane or pre-combusted, glass fiber filter after passing air through a 10 mm Dorr-Oliver cyclone at flow rate of 1.7 l/min. Flow is controlled using a personal sampling pump. The cyclone is a respirable dust preclassifier with a 50% cut point of 4.0 μm. Respirable dust is determined gravimetrically by weighing the silver membrane or glass fiber filter before and after the sample is collected. RCD is determined gravimetrically from the amount of material removed from the silver membrane by controlled combustion at 400 ^{o}C (500 ^{o}C for the glass fiber filter) for one to two hours. A correction is made for the loss of mass of the silver membrane due to combustion.

Size Selective Sampling (SS): The SS method is based on a body of literature developed by the University of Minnesota, and the U.S. Bureau of Mines (Marple, *et al*., 1986; Rubow, *et al*., 1990a,b; McCartney and Cantrell, 1992 and Cantrell, *et al.*, 1987, 1990a,b, 1992) which showed that submicron aerosols found in coal mines were primarily diesel in origin. The difference in the aerodynamic diameter particle size between combustion and mechanically generated aerosols

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[1] The elemental carbon analysis referred to here is NIOSH method 5040. This method provides information on EC, organic carbon (OC) and TC. EC is considered a specific marker or surrogate for DPM exposure. However, EC is not a measure of total DPM exposure because the OC portion is excluded. TC has also been used as a measure of DPM exposure (DFG, 1993). The NIOSH method allows the identification of some non-diesel sources of OC, thus allowing the TC estimate to be corrected for these contributions. Data collected during the three Canadian studies and the MSHA studies allow the statistical comparison of SS, RCD, EC and TC.

is used to separate diesel aerosol from noncombustion aerosols in the collecting process. Respirable aerosol sampling has a 50 pct cutpoint at 4.0 µm and collects a fraction of particles up to 10 µm in size. Diesel aerosol has a mass median aerodynamic diameter of 0.2 µm, and 90 % of the particles are less than 1.0 µm in size. Thus, respirable aerosol sampling collects all diesel and nondiesel aerosol particles falling in the respirable size range. The respirable and diesel fractions may be separated using inertial impaction on greased, aluminum foil substrates. Inertial impaction removes nearly all (> 90 %) nondiesel particles and a small percentage (< 15 %) of large diesel particles. The submicrometer diesel aerosol is collected on a filter downstream of the impaction substrate. Gravimetric analyses determine the mass fraction in each size range. Another advantage this method has over traditional respirable dust sampling is that it separates large particles which, are predominately nondiesel in origin, but still allows the respirable fraction to be calculated.

The SS sampler was originally designed for use in coal mines, which use diesel haulage vehicles equipped with water scrubbers. Scrubbers effectively remove diesel aerosol larger than 0.8 µm, thus tailoring the remaining aerosol size distribution and minimizing the amount of diesel aerosol not captured on the filter. The SS sampling method is also used in metal and nonmetal mines where scrubbers are seldom used. In this situation, approximately 10 - 15 % of the total diesel aerosol is not accounted for (Cantrell *et al.*, 1990b), because it is larger than 0.8 µm in size and is removed on the aluminum foil substrate.

The SS sampler can be used in conjunction with the EC method because the filter containing the submicrometer material can be analyzed for elemental and organic carbon. This is an advantage over other aerosol measurement techniques, which either do not collect a submicrometer sample or destroy the sample during analysis.

SS diesel aerosol samplers have been designed by the University of Minnesota, U.S. Bureau of Mines, Mine Safety and Health Administration and the National Institute for Occupational Safety and Health. The most frequently used sampler is a modification of a sampler designed by the University of Minnesota (Rubow, *et al.*, 1990b) and redesigned by the Bureau of Mines (McCartney *et al.*, 1992). The first stage of this sampler is a 10 mm Dorr-Oliver cyclone. This is followed by a four-nozzle inertial impactor with a 0.8 µm cut point. The impaction surface consists of a 37-mm oiled, aluminum substrate which is used to collect respirable dust larger than 0.8 µm. Air is drawn through the sampler at 1.7 l/m using a personal sampling pump. DPM, which is primarily smaller than 0.8 µm, passes through the central exit of the impaction surface and is collected on a polyvinyl chloride filter mounted within an MSA filter cassette. The amount of DPM is determined gravimetrically from the MSA filter. The mass of respirable dust is determined gravimetrically from the combined mass of material collected on the MSA filter and the aluminum substrate.

Elemental Carbon: DPM is a chemically complex. It is composed of soluble organic hydrocarbons, sulfate, EC and traces of other compounds. In general, EC accounts for about 50% of the mass of DPM, but this percentage varies depending upon engine duty cycle, fuel quality, aftertreatment device and other factors. The analytical method used to differentiate EC from OC was originally developed for atmospheric aerosols (Johnson, *et al.*, 1981; Cadel and

Groblicki, 1982; Hering, *et al*, 1990). NIOSH has refined the method and adopted it as method 5040 (Birch and Carey, 1996; NIOSH, 1996). This technique is a sensitive measure of the elemental carbon portion of diesel exhaust aerosol with a working range of 4.4 - 312 $\mu g/m^3$ with a limit of detection of about 1.3 $\mu g/m^3$ for a 960 L air sample collected on a 37 mm filter with a 1.54 cm^2 punch from the filter. The method also determines the presence of organic carbon (OC) and total carbon[2] is determined by summation (EC + OC). Since EC is a product of combustion and is composed of inert graphitic carbon it is a specific marker of diesel exhaust aerosol in many occupational settings where other combustion aerosols are not present. However, the OC portion of the collected aerosol is subject to interferences from other organic aerosols not associated with diesel exhaust, such as drill oil mist, hydraulic fluids, coal dust and other organic material also contribute OC aerosol. This is similar to the situation observed for RCD analysis with the exception that in some cases the NIOSH method can identify the interfering compounds and a correction factor can be applied to improve the TC estimate.

Samples for EC are collected with or without an inertial preselector to remove particles > 0.8 μm that may interfere with analysis. The simplest sampling train consists of a 10 mm Dorr-Oliver cyclone followed by a 37 mm precombusted Pallflex, ultra pure quartz fiber filter mounted in a 37 mm plastic cassette. Alternatively, the Dorr-Oliver cyclone is followed by the 0.8 μm size selective impactor described above. In this situation, DPM, which is primarily smaller than 0.8 μm, passes through the central exit of the impaction surface and is collected on the Pallflex filter. This is advantageous because, large mechanically generated aerosol such as coal dust is not collected on the Pallflex filter and cannot interfere with EC analysis.

<u>Sampling and Analytical Limitations</u>: Recent published and unpublished studies conducted by the U. S. Bureau of Mines, U. S. Mine Safety and Health Administration (MSHA), the University of Minnesota (Watts, et al., 1997, 1998), and CANMET (Grenier, *et al*., 1998) have compared the RCD, SS, and EC methods[3] either directly or indirectly to determine advantages, disadvantages and limitations. Table 1, for example, provides estimates of the interferences to which RCD, SS, and EC are susceptible. Data shown in the table are from remarks by Cantrell summarizing in-mine data collected by the Bureau of Mines and from publications describing these sampling and analytical methods (Watts, 1996). Such interferences pertain to both the specificity and accuracy of the methods, but the data and methods used to obtain these estimates have not been published in detail.

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[2] The Federal Republic of Germany uses the coulometric method to determine EC and TC. The method is described by Dahmann, *et al*., (1996) and is different from NIOSH method 5040.

[3] A very small number of samples were also collected for coulometric EC, TC determination by Dr. Dirk Dahmann.

Table 1. - Comparison of method interferences.

Analytical Method	Interferences Source	Range, µg/m^3
Size*	Atmosphere	1 - 30
	Coal/Ore	3 - 80
RCD*	Oil Mist	0 - 50
	Ore	0 - 10
EC	Atmosphere	0.5 - 2
	Coal/Ore	5 - 15

By gravimetric analysis.
Size = size selective sampling; RCD = respirable combustible dust; EC = elemental carbon.
Source: Remarks by B. K. Cantrell as summarized by W. F. Watts, 1996.

Similarly, using a specially designed chamber, MSHA has collected multiple, simultaneous samples of the same aerosol using the three methods at 18 different mines. These data can be used to estimate detection limits, as well as sampling and analytical precision over a range of DPM concentrations, but MSHA has not yet published these data or any comparison of the methods accuracy.

Published Comparisons: In 1996, UMN, Inco and NIOSH collaborated to evaluate the three sampling methods (Watts, *et al.* 1997). The study was carried out in a non-producing section of Inco's Creighton mine, Sudbury, Canada. Sampling was performed on a mucking operation employing two diesel scoops. Only one vehicle was operated, while the other served as a backup in case of malfunction. The scoop moved muck between two drifts where ventilation airflow was carefully regulated. Samples were collected in triplicate at three locations upwind and downwind of scoop activity and on the scoop.

The major findings of this study were:

- There was no significant difference between the respirable combustible dust and size selective sampling methods.
- Respirable combustible dust measurements made using 0.8 μm silver membrane (SM) filters were more closely correlated with the size selective method than were measurements made using 5.0 μm SM filters.
- Total carbonaceous aerosol determined by the elemental carbon method was strongly correlated with results from the respirable combustible dust and size selective sampling measurement methods.
- Approximately 50% of the carbonaceous aerosol was composed of elemental carbon.

In 1997, DEEP funded a project to evaluate a blended biodiesel fuel in an underground metal mine (Watts, *et al.*, 1998). The study was carried out in the same non-producing section of

Inco's Creighton mine with a similar sampling protocol. The objective of the evaluation was to determine changes in exhaust emissions and to estimate operating costs of a test vehicle fueled with blended biodiesel compared to the same vehicle operated on low sulfur diesel fuel. Data were collected in such a way as to allow comparison of the three sampling methods, but the comparison was not part of the original scope of work and has not been completed.

In 1997, DEEP funded a project to determine the impact of high sulfide ore dust on the three sampling methods (Grenier, *et al*., 1998). Preliminary results from this study appear to confirm the results from the Inco study, but the final analysis is not complete at this time.

DESCRIPTION OF WORK

(1) The first objective of the proposed study will be to review existing information on interferences, sampling and analytical biases, limits of detection, and other limitations of the three methods. A thorough literature search will be conducted to identify all potential interferences and to confirm or modify the estimates presented in Table 1. In addition to the review of existing information from both laboratory and field studies, an attempt will be made to validate estimated interferences by analysis of covariance and comparison with calibration intercepts obtained directly from published and unpublished field data. Published detection limits will also be compared with those estimated from the available data, as described below under the second objective. Any other limitations of the methods identified in the literature review will be documented and explained.

(2) The second objective will be to assemble the available field data in a format conducive to appropriate statistical analyses, perform these analyses in so consistent a manner as the various data sets permit, and use the results to compare the methods (SS, RCD, EC and TC) with respect to their specificity, sensitivity and detection limits, and accuracy. In essence, this will constitute a meta-analysis of the available data and provide information over a broader range of mining conditions and DPM concentrations than any of the individual studies.

Specificity, or selectivity, refers to the extent to which DPM can be measured by a particular method without interference due to the presence of other substances. Since interferences are best identified and quantified under controlled laboratory conditions, primary consideration will be given to estimates obtained from the review of laboratory studies under the first objective. However, these estimates will be evaluated for consistency with the field data in two ways: (a) each suspected interferant will be modeled as an effect of interaction between a covariate (such as coal dust filter load or the presence of a known oil spill) and a measurement method; and (b) in the presence of interferant thought to affect one measurement method but not another, the average effect of the interferants will be modeled as the intercept of the calibration curve relating the two measurement methods.

Sensitivity refers to the smallest change in DPM concentration that can be measured by a particular method at a specified confidence level. As in the case of specificity, sensitivity is best quantified under controlled laboratory conditions, but estimates obtained from the review of laboratory studies can be compared with results from the field data (specifically, slopes of the calibration curves relating measurement methods, along with their associated standard errors) for purposes of validation. The limit of detection for the method is derived by multiplying a confidence coefficient (reflecting the level of confidence desired for establishing that a minimum level of DPM is actually present) by the ratio of the method s imprecision (as expressed by the standard deviation of repeated measurements of the same aerosol) to its sensitivity.

A comprehensive statistical analysis, utilizing multivariate repeated measures models (Cole and Grizzle (1966); Dempster, *et al*., (1984); Jennrich and Schluchter, (1986); Winer (1971)), will be carried out on the available field data to compare the methods with respect to the magnitude and precision of simultaneous measurements. To maximize the power of the statistical tests and estimation procedures to detect important differences between measurement methods, multiple factors will be incorporated into the statistical models. This will prevent having to divide the analysis into a large number of small data sets and will strengthen any conclusions. Systematic differences in DPM measurements will be used to evaluate relative biases in the methods, including those attributable to known interferences. These systematic differences will then be combined with the variability of replicated measurements to assess the accuracy of each method under various conditions. For each method, the relationship between DPM loading and measurement precision will also be investigated. Confidence intervals will be calculated for all differences observed between methods, and any such differences will be tested for statistical significance.

(3) The third objective is to recommend appropriate conditions for and uses of each method, including the range of DPM concentrations. Each method has strengths and weaknesses. For instance, the SS method is being commercialized in the U.S. using a disposable sampling train to allow the determination of the < 0.8 μm fraction, the respirable dust fraction or both. Within the next year the hardware should be available. The RCD method is already widely used and accepted in Canada. The EC method is more costly than either the SS or RCD method but is far more sensitive and specific than either of the other methods. Depending upon the questions being asked, each method may have one or more suitable applications. The analyses described above will quantitatively determine the accuracy and sensitivity of each method and will identify known interferences. Based upon the evaluation of this information it will be possible to recommend specific conditions and uses for each method.

(4) Finally, based on the results of this project, further research needs will be identified and prioritized. During the course of the project deficiencies in the available data will be noted and recommendations made to collect additional data to fill in the gaps. For example, an obvious weakness in previous studies is the lack of laboratory studies. A laboratory study allows comparison under very controlled conditions. Such studies are normally carried out in a special chamber, such as a Marple chamber, which allow samplers to be exposed simultaneously to a well characterized [known concentration with defined chemical and physical composition] aerosol. These studies are also helpful in determining the impact of interfering substances such as drill oil mist, cigarette smoke and other substances on the measurement methods.

COSTS, TIMETABLE AND REPORTING

Table 2 outlines the estimated costs of the project in U. S. dollars. It assumes that the project will be conducted as a purchase order as opposed to a research contract. The indirect cost overhead rate for purchase orders is 16% compared to 47% for a research contract. The cost savings to DEEP is more than $8700 U.S.

Table 2. - Project costs

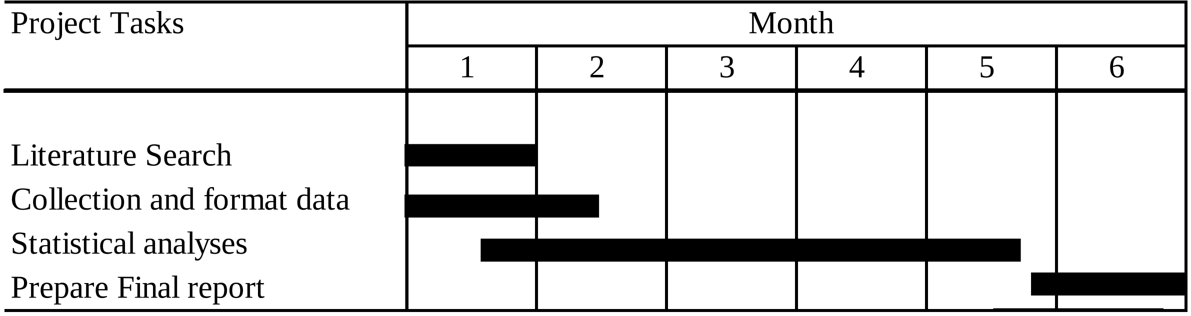
	Personnel	Hours	Total
Direct Charges			
	Administrative	40	1860
	Professional	520	20200
	Faculty	40	3600
	Total	600	25660
Travel			2000
Long Distance Calls			500
Total Direct			28160
Indirect @16 %			4500
Grand Total U.S. $			**32660**

In addition to the costs outlined in table 2, MSHA has agreed to allow Jon Kogut, MSHA's principal inferential statistician, to participate in the project at no cost to DEEP. The project costs include two trips: 1) a project planning and organizational meeting between UMN project personnel and MSHA to be held in Denver; and 2) a trip to Toronto or other Canadian city to present results at the Canadian 1999 Diesel Conference.

Results from the analysis will be submitted in a draft contract final report. A contract final report will be submitted after DEEP review. Results will be reported at the 1999 Canadian Diesel Conference.

Half of the contract payment ($16,298 U.S.) will be payable upon award of the contract with the other half due upon completion of the draft final report.

Figure 1. - Project timeline



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PERSONNEL

DAVID B. KITTELSON

Professor of Mechanical Engineering
Head, Power and Propulsion Division
Director, Center for Diesel Research

EDUCATION

University of Minnesota	B.S.	1964	Mechanical Engineering
University of Minnesota	M.S.	1966	Mechanical Engineering
University of Cambridge, England	Ph.D.	1972	Chemical Engineering

PROFESSIONAL EXPERIENCE

1970-76: Assistant Professor, Department of Mechanical Engineering, University of Minnesota
1976-80: Associate Professor, Department of Mechanical Engineering, University of Minnesota
1980-present: Professor, Department of Mechanical Engineering, University of Minnesota
1996-present: Director, Center for Diesel Research, University of Minnesota

RECENT PUBLICATIONS

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WINTHROP F. WATTS, JR.

Research Associate
Center for Diesel Research

EDUCATION

Salem State College	B.A.	1972	Biology
University of Massachusetts	M.S.	1974	Public Health
University of Minnesota	Ph.D.	1981	Environmental Health

PROFESSIONAL EXPERIENCE

1970 - 1994: Environmental Science Officer, U.S. Army Reserve (retired veteran)
1978 - 1996: Industrial Hygienist, U. S. Bureau of Mines, Minneapolis, MN
1996 - present: Research Associate, University of Minnesota, Center for Diesel Research, Minneapolis, MN

RECENT PUBLICATIONS

Watts, W. F. Practical Ways To Control Diesel Emissions In Mining - A Toolbox. Prepared for the U. S. Mine Safety and Health Administration, 47 pp., March, 1997. (Published electronically at *www.msha.gov* and hardcopy).

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JON KOGUT

jkogut@msha.gov P P.O. Box 25367 P Denver, CO 80225 P (303)231-5593

EDUCATION

CARNEGIE-MELLON UNIVERSITY *M.S., Statistics, 1974*

UNIVERSITY OF PITTSBURGH *National Woodrow Wilson Fellow, Philosophy of Science/Symbolic Logic, 1968-9*

REED COLLEGE *B.A.,Philosophy/Mathematics, 1968*

PROFESSIONAL EXPERIENCE

MINE SAFETY AND HEALTH ADMINISTRATION, U.S. DEPT. OF LABOR, *Mathematical Statistician, 1974 to present*

- MSHA's principal inferential statistician - providing leadership, consultation, analysis, and technical advice to engineers, program analysts, and industrial hygienists throughout MSHA on a broad range of statistical and probabilistic issues.
- Member of various MSHA rulemaking committees - providing expertise on risk assessment, measurement accuracy, enforcement sampling strategies, and confidence levels for noncompliance determinations.
- Recipient of Secretary of Labor's Distinguished Career Service Award (1996), Exceptional Achievement Award (1997), and twelve other performance awards.

RECENT PUBLICATIONS

Technical appendices, MSHA/NIOSH joint notice on accuracy of respirable dust samples. *Federal Register* 63:5678-5684 (1998).

Technical appendices, MSHA notice on respirable coal mine dust noncompliance determinations. *Federal Register* 63:5695-5712 (1998).

Measurement Precision with the Coal Mine Dust Personal Sampler. *Applied Occupational and Environmental Hygiene* 12:999-1006 (1997).

SPECIAL INTERESTS AND SKILLS

Repeated Measures Model
Empirical Bayes Estimation
Multiple Time Series Analysis
Statistical Decision Theory
Environmental Risk Assessment
Statistical Computation and Graphics
    (Gauss, FORTRAN, Basic, Forth, Assembly, Systat, BMDP)
Member, American Statistical Association

GENERAL TERMS AND CONDITIONS

The Client will promptly provide any samples, material, equipment, information and instructions required to be supplied, as defined in the detailed price quote or reasonably requested by University of Minnesota Center for Diesel Research. If anything is not so provided, the University may adjust the price to reflect changes in labor and material costs.

Contract Cost Estimate: Because of the nature and uncertainties of technology and research, it is recognized that the proposed services stated in the estimate may not achieve the desired results, and that in view of the limit or price stated in the estimate, the services to be rendered may not be sufficient to complete the proposed services.

Prices set forth in the Proposal shall be in effect for a period of 30 days. For any order received 30 days or more after the date of the Proposal, prices shall be according to the current fee schedule in effect on the date of such order. Prices are subject to change without notice.

Any samples, materials, supplies or equipment provided by the Client will be disposed of or sent to the Client at the conclusion of the services. The Client, in addition to the quoted price, will reimburse CDR for any costs involved.