CRITERIA FOR A RECOMMENDED STANDARD

Occupational Exposure to Respirable Coal Mine Dust

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FOREWORD

In the Federal Mine Safety and Health Act of 1977 (Public Law 95-164) and the Occupational Safety and Health Act of 1970 (Public Law 91-596), Congress declared that its purpose was to assure, insofar as possible, safe and healthful working conditions for every working man and woman and to preserve our human resources. In these Acts, the National Institute for Occupational Safety and Health (NIOSH) is charged with recommending occupational safety and health standards and describing exposure levels that are safe for various periods of employment, including but not limited to the exposures at which no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience. By means of criteria documents, NIOSH communicates these recommended standards to regulatory agencies (including the Occupational Safety and Health Administration [OSHA] and the Mine Safety and Health Administration [MSHA]) and to others in the community of occupational safety and health.

Criteria documents provide the scientific basis for new occupational safety and health standards. These documents generally contain a critical review of the scientific and technical information available on the prevalence of hazards, the existence of safety and health risks, and the adequacy of control methods. In addition to transmitting these documents to the Department of Labor, NIOSH also distributes them to health professionals in academic institutions, industry, organized labor, public interest groups, and other government agencies.

This criteria document reviews available information about the adverse health effects associated with exposure to respirable coal mine dust. Epidemiological studies have clearly demonstrated that miners have an elevated risk of developing occupational respiratory diseases when they are exposed to respirable coal mine dust over a working lifetime at the current MSHA permissible exposure limit (PEL) of 2 mg/m^3. The exposure limit of 1 mg/m^3 recommended in this document is based on an evaluation of health effects data, sampling and analytical feasibility, and technological feasibility. However, this recommended exposure limit (REL) does not ensure that miners exposed at this concentration over a working lifetime will have a zero risk of developing occupational respiratory diseases. Therefore, NIOSH recommends additional measures to protect miners' health: (1) keeping worker exposures as far below the REL as feasible through the use of engineering controls and work practices, (2) frequent monitoring of worker exposures, and (3) participation of miners in the recommended medical screening and surveillance program.

Future research may provide new and more effective methods for minimizing occupational health risks among coal miners, including new methods for controlling exposures to respirable coal mine dust, more accurate and reliable measures of worker exposures, improved methods for earlier detection of disease, and new medical interventions to halt or reverse disease progression.

If future developments permit a lower exposure limit that is both technologically feasible and prudent for the public health, NIOSH will revise its recommended standard. Until then, adherence to the REL of 1 mg/m^3 will minimize the risk of developing occupational respiratory diseases.

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ABSTRACT

This document examines the occupational health risks associated with exposures to respirable coal mine dust over a working lifetime. Such exposures are associated with the development of occupational respiratory diseases, including simple coal workers' pneumoconiosis (CWP), progressive massive fibrosis (PMF), and chronic obstructive pulmonary disease (COPD). Epidemiological studies have clearly demonstrated that miners have an elevated risk of developing simple CWP, PMF, or deficits in lung function when they are exposed to respirable coal mine dust over a working lifetime at the current Mine Safety and Health Administration (MSHA) permissible exposure limit (PEL) of 2 mg/m^3. Coal miners who are exposed to respirable crystalline silica are also at risk of developing silicosis or mixed-dust pneumoconiosis.

The National Institute for Occupational Safety and Health (NIOSH) recommends that exposures to respirable coal mine dust be limited to 1 mg/m^3 as a time-weighted average (TWA) concentration for up to 10 hr/day during a 40-hr workweek, measured according to current MSHA methods. NIOSH recommends that sampling be conducted with a device that operates in accordance with the NIOSH accuracy criteria and the international definition of respirable dust. The 1-mg/m^3 REL is equivalent to 0.9 mg/m^3 when measured according to these NIOSH recommended sampling criteria. The NIOSH REL represents the upper limit of exposure for each worker during each work shift and shall not be adjusted upward to account for measurement uncertainty. To minimize the risk of adverse health effects, exposures shall be kept as far below the REL as feasible using engineering controls and work practices.

Recommendations are made for minimizing the occupational health risks encountered by underground and surface coal miners. These recommendations pertain to respirable coal mine dust sampling to monitor worker exposures, use of personal protective equipment (including training and fit-testing for the use of respirators), and medical screening and surveillance examinations (including preplacement and periodic chest X-rays and spirometry).

CONTENTS

APPENDICES

ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AEC	U.S. Atomic Energy Commission
ANOVA	Analysis of variance
ATS	American Thoracic Society
BAL	Bronchoalveolar lavage
BMRC	British Medical Research Council
BOM	U.S. Bureau of Mines
Btu	British thermal unit
CEN	Comité Européen de Normalisation
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
CI	Confidence interval
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
CPSU	Coal mine dust personal sampler unit
CWP	Coal workers' pneumoconiosis
DLCO	Diffusing capacity of the lung for carbon monoxide
Fed. Reg.	Federal Register
FEV_1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
gh	Gram hour(s)
gh/m^3	Gram hour(s) per cubic meter
GSD	Geometric standard deviation
HHE	Health hazard evaluation
hr	Hour(s)
ILO	International Labour Office
ISO	International Standards Organization
L	Liter(s)
L/min	Liter(s) per minute
LLN	Lower limit of normal

LOD	Limit of detection
LOQ	Limit of quantitation
MAQ	Minimum accurately quantifiable concentration
MCE	Mixed cellulose ester
mg/m^3	Milligram(s) per cubic meter
$mg\text{-}yr/m^3$	Milligram year(s) per cubic meter
min	Minute(s)
ml	Milliliter(s)
MMD	Mass median diameter
MMU	Mechanized mining unit
MRE	Mining Research Establishment of the National Coal Board, London, England
MSHA	Mine Safety and Health Administration
MVV	Maximum voluntary ventilation
NIOSH	National Institute for Occupational Safety and Health
n	Nanoliter(s)
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
psi	Pounds per square inch
PMF	Progressive massive fibrosis
PMNs	Polymorphonuclear leukocytes
PVC	Polyvinyl chloride
REL	Recommended exposure limit
RV	Residual volume
SAR	Supplied-air respirator
SCBA	Self-contained breathing apparatus
SCSR	Self-contained self rescuer
SD	Arithmetic standard deviation
SIP	Spot inspection program
SMR	Standardized mortality ratio
TLC	Total lung capacity
TLV	Threshold limit value
TNF	Tumor necrosis factor
TWA	Time-weighted average
UCL	Upper confidence limit
UK	United Kingdom
USC	United States Code
VC	Vital capacity

GLOSSARY

Active workings: Any place in a coal mine where miners are normally required to work or travel [30 CFR 70.2].

Aerodynamic diameter: The diameter of a sphere with a density 1 g/cm^3 and with the same stopping time as the particle. Particles of a given aerodynamic diameter move within the air spaces of the respiratory system identically, regardless of density or shape.

Black lung: A common term used to refer to occupational respiratory disease in miners [Weeks and Wagner 1986].

Chronic obstructive pulmonary disease (COPD): Includes chronic bronchitis, impaired lung function, and emphysema. COPD is characterized by the irreversible (although sometimes variable) obstruction of lung airways.

Clearance: The translocation, transformation, and removal of deposited particles from the respiratory tract [Lioy et al. 1984].

Coal face: The exposed area of a coalbed from which coal is extracted [EIA 1989].

Coal fines: Coal with a maximum particle size that is usually less than one-sixteenth of an inch and rarely above one-eighth of an inch [EIA 1989].

Coal rank: A classification of coal based on the fixed carbon, volatile matter, and heating value of the coal. Coal rank indicates the progressive geological alteration (coalification) from lignite to anthracite [EIA 1989].

Coal type: A classification of coal based on physical characteristics or microscopic constituents [EIA 1989].

Coal workers' pneumoconiosis (CWP): A chronic dust disease of the lung arising from employment in an underground coal mine [30 USC 902]. In workers who are or have been exposed to coal mine dust, diagnosis is based on the radiographic classification of the size, shape, profusion, and extent of opacities in the lungs.

Coefficient of variation (CV): The CV is a measure of relative dispersion; it is also known as relative standard deviation and defined as the standard deviation/mean [Leidel et al. 1977].

Concentration: The amount of a substance contained per unit volume of air [30 CFR 70.2].

Confidence interval (CI), confidence limits (CLs): A range of values (determined by the degree of presumed random variability in the data) within which a parameter (e.g., a mean) is believed to lie with the specified level of confidence. The boundaries of a CI are the CLs [Last 1983]. These include the lower confidence limit (LCL) and the upper confidence limit (UCL).

Continuous mining: A mining method used in room-and-pillar mining in which the coal is removed from the coal face in one operation using a continuous mining machine.

Conventional mining: A mining method used in room-and-pillar mining in which the coal face is cut so that it breaks easily when blasted (with either explosives or high-pressure air). The broken coal is then loaded onto conveyors or into shuttle carts for removal to the surface.

Crystalline silica (or free silica): Silicon dioxide (SiO_2). "Crystalline" refers to the orientation of SiO_2 molecules in a fixed pattern as opposed to a nonperiodic, random molecular arrangement defined as amorphous. The three most common crystalline forms of free silica encountered in general industry are quartz, tridymite, and cristobalite [NIOSH 1974]. In coal mines, the predominant form is quartz.

Culm: Fine anthracite.

Culm bank: The hillside where waste from anthracite mines is dumped.

Deposition: The collection of inhaled airborne particles by the respiratory tract and the initial regional patterns of these deposited particles [Lioy et al. 1984].

District manager: The manager of the Coal Mine Safety and Health District in which the mine is located [30 CFR 70.2].

Geometric mean (GM): The GM is a measure of central tendency for a log-normal distribution [Leidel et al. 1977].

Geometric standard deviation (GSD): The GSD is a measure of relative dispersion (variability) of a lognormal distribution.

Gob area: The area of subsidence that occurs when roof supports are removed during longwall mining and the area caves in. The gob area then supports the overlying strata.

Engineering controls: Hazard controls designed into equipment and workplaces.

Highwall: The unexcavated face of exposed overburden or coal in a strip pit.

Inby: Toward the workings of a mine.

Incidence: The frequency of occurrence of new cases of a disease for a given period.

Incidence rate: The rate at which new events occur in a population. The number of new events (e.g., new cases of a disease diagnosed or reported during a defined period) is divided by the number of persons in the population in which the cases occurred [Last 1983].

Inhalable dust: The particulate mass fraction of dust in the mine environment that is hazardous when deposited anywhere in the respiratory tract [ACGIH 1994].

Longwall mining: A system of mining in which long sections of coal (also called panels) up to 1,000 ft are removed by a cutting machine without leaving pillars of coal for support. A movable, powered roof support system is used to support the roof in the working area; when these supports are moved, the area (gob area) caves in and supports the overlying strata.

Mechanized mining unit (MMU): A unit of mining equipment (including hand-loading equipment) used for the production of material [30 CFR 70.2].

MRE instrument: The gravimetric dust sampler with a four-channel horizontal elutriator developed by the Mining Research Establishment of the National Coal Board, London, England [30 CFR 70.2].

Normal production shift: A production shift during which the amount of material produced in an MMU is at least 50% of the average production reported for the last set of five valid samples; or, the amount of material produced by a new MMU before five valid samples are taken [30 CFR 70.2].

Outby: Toward the shaft or entry of a mine.

Overburden: Any material, consolidated or unconsolidated, that overlies a coal deposit. Overburden ratio refers to the amount of overburden that must be removed to excavate a given quantity of coal [EIA 1989].

Prevalence: The frequency of all current cases of a disease (old and new) occurring within specific populations at a particular time.

Prevalence rate (ratio): The total number of all individuals who have an attribute or disease at a given time or during a given period divided by the population at risk of having the attribute or disease at this point in time or midway through the period [Last 1983].

Progressive massive fibrosis (PMF): Coal workers' complicated pneumoconiosis. Diagnosis is based on radiographic determination of the presence of large opacities of 1 cm or larger.

Quartz: Crystalline silicon dioxide (SiO_2) not chemically combined with other substances and having a distinctive physical structure [30 CFR 70.2].

Regression analysis: Given data on a dependent variable Y and an independent variable X, regression analysis involves finding the best mathematical model (within some restricted form) to describe Y as a function of X or to predict Y from X. Most commonly, the model is linear. The logistic model is also common in epidemiology. Multiple regression analysis considers Y as a function of more than one independent variable [Last 1983].

Respirable coal mine dust: That portion of airborne dust in coal mines that is capable of entering the gas-exchange regions of the lungs if inhaled; by convention, a particle-size-selective fraction of the total airborne dust; includes particles with aerodynamic diameters less than approximately 10 μm.

Respirable convention (E_R): The target sampling curve for instruments approximating the respirable fraction. E_R is defined at aerodynamic diameter D by ISO [1993], CEN [1993], and ACGIH [1994] in terms of the cumulative normal function Φ as:

$$E_R = E_I \bullet \Phi[\ln[D_R/D]/\sigma_R]$$

where the indicated constants are $D_R = 4.25$ μm and $\sigma_R = \ln[1.5]$, and the *inhalable* convention E_I is defined by

$$E_I = 0.50\,(1 + \exp[-0.06\,D]),\ D < 100\ \mu m$$

Retention: The temporal distribution of uncleared particles in the respiratory tract [Lioy et al. 1984].

Room-and-pillar mining: A system of mining in which the mine roof is supported primarily by coal pillars that are left at regular intervals [EIA 1989].

Spoil: Overburden removed in gaining access to the coal during surface coal mining.

Thoracic dust: The particulate mass fraction of dust in the mine environment that is hazardous when deposited anywhere within the lung airways and the gas-exchange region [ACGIH 1994].

Time-weighted average (TWA): Exposure of a worker over an 8-hr work shift as defined in 29 CFR 1910.1000(d)(1).

Work practices: Procedures followed by employers and workers to control hazards.

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1 RECOMMENDATIONS FOR A COAL MINE DUST STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that occupational exposures to respirable coal mine dust and respirable crystalline silica* be controlled by complying with the provisions presented in this document. These recommendations are designed to protect the health and provide for the safety of workers exposed to respirable coal mine dust and respirable crystalline silica for up to 10 hr/day during a 40-hr workweek over a working lifetime. The information presented in this document demonstrates that underground and surface coal miners are at risk of developing simple coal workers' pneumoconiosis (CWP), progressive massive fibrosis (PMF), silicosis, and chronic obstructive pulmonary disease (COPD). Adherence to the recommendations in this document should prevent or greatly reduce the risk of adverse health effects in workers exposed to respirable coal mine dust and respirable crystalline silica. NIOSH recommends that preventive efforts be focused primarily on reducing worker exposures. Effective health and hazard surveillance and medical screening are also useful components of a comprehensive prevention effort.

1.1 DEFINITIONS

1.1.1 Miner or Coal Miner

"Miner" or "coal miner" refers to any individual working in a surface or underground coal mine (including any worker employed by a contractor) who is (1) engaged in the extraction and production process, or (2) regularly exposed to mine hazards, or (3) employed as a construction, maintenance, or service worker.

1.1.2 Ex-Miner

"Ex-miner" refers to any individual who was previously employed as a coal miner but who left coal mining for reasons including retirement, disability, lay-off, or other employment.

1.1.3 Coal Mine

"Coal mine" refers to "an area of land and all structures, facilities, machinery, tools, equipment, shafts, slopes, tunnels, excavations, and other property, real or personal, placed upon, under, or above the surface of such land by any person, used in, or to be used in, or resulting from, the work of extracting in such area bituminous coal, lignite, or anthracite from its natural deposits in the earth

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*This document provides the current NIOSH REL for respirable crystalline silica because this substance is an important component of respirable coal mine dust [NIOSH 1974; NIOSH 1988b]. Evaluation of the health effects of respirable crystalline silica is beyond the scope of this document.

by any means or method, and the work of preparing the coal so extracted, and includes custom coal preparation facilities" [30 USC[†] 802(h)(2)].

1.1.4 Mine Operator

Except where otherwise indicated, a "mine operator" is any owner, lessee, or other person who operates, controls, or supervises a surface or underground coal mine, or any independent contractor performing services or construction at such a mine [30 USC 802(d)].

1.1.5 Surface Coal Mine

"Surface coal mine" refers to "a surface area of land and all structures, facilities, machinery, tools, equipment, excavations, and other property, real or personal, placed upon or above the surface of such land by any person, used in, or to be used in, or resulting from, the work of extracting in such area bituminous coal, lignite, or anthracite from its natural deposits in the earth by any means or method, and the work of preparing the coal so extracted, including custom coal preparation facilities" [30 CFR[‡] 71.2(n)].

1.1.6 Surface Work Area of an Underground Coal Mine

"Surface work area of an underground coal mine" refers to "the surface areas of land and all structures, facilities, machinery, tools, equipment, shafts, slopes, excavations, and other property, real or personal, placed in, upon or above the surface of such land by any person, used in, or to be used in, or resulting from, the work of extracting bituminous coal, lignite, or anthracite from its natural deposits underground by any means or method, and the work of preparing the coal so extracted, including custom coal preparation facilities" [30 CFR 71.2(p)].

1.2 RECOMMENDED EXPOSURE LIMITS (RELS) FOR RESPIRABLE COAL MINE DUST AND RESPIRABLE CRYSTALLINE SILICA

1.2.1 RELs

NIOSH recommends that exposures to respirable coal mine dust be limited to 1 mg/m^3 as a time-weighted average (TWA) concentration for up to 10 hr/day during a 40-hr workweek[§], measured according to current MSHA methods (see Section 5.1 and Appendix J). NIOSH recommends that sampling be conducted with a device that operates in accordance with the NIOSH accuracy criteria [Busch 1977; Busch and Taylor 1981] and the international definition of respirable dust [ACGIH 1994; CEN 1993; ISO 1993; Soderholm 1991a,b; 1989].[**]

The recommended exposure limit (REL) of 1 mg/m^3 represents the upper limit of exposure for each worker during each work shift. For single, full-shift samples used to determine noncompliance,

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[†] *United States Code.*

[‡] *Code of Federal Regulations.* See CFR in references.

[§] A method for estimating an exposure limit "reduction factor" for extended work shifts is described by Brief and Scala [1975].

[**] The recommended exposure limit (REL) of 1 mg/m^3 is equivalent to 0.9 mg/m^3 when measured according to these NIOSH recommended sampling criteria (see Sections 5.2 and 5.4).

NIOSH recommends that MSHA make no upward adjustment of the REL to account for measurement uncertainties [NIOSH 1994c] (see also Section 5.6.2).

Occupational exposures to respirable crystalline silica shall not exceed 0.05 mg/m^3 as a TWA concentration for up to 10 hr/day during a 40-hr workweek [NIOSH 1974; NIOSH 1988b].

1.2.2 Sampling and Analysis

The concentration of respirable coal mine dust shall be determined gravimetrically (see Appendices I and J). The concentration of respirable crystalline silica shall be determined by NIOSH Method 7500, 7602, or a demonstrated equivalent [NIOSH 1994b] (see also Section 5.7).

1.3 EXPOSURE MONITORING

1.3.1 Initial Exposure Monitoring Survey

When a new mechanized mining unit (MMU) is established, the mine operator shall conduct an initial monitoring survey to determine the exposure of miners to respirable coal mine dust and respirable crystalline silica. The production level during sampling shall be typical of the normal production for that MMU (see Sections 5.5.3 and 5.6.1.4). Whenever changes in operational conditions might result in exposure concentrations above the REL, air sampling shall be conducted by the mine operator as if it were an initial monitoring survey.

1.3.2 Periodic Exposure Monitoring

Personal exposures to respirable coal mine dust and respirable crystalline silica shall be monitored periodically at intervals that depend on the concentrations determined in the initial and subsequent monitoring surveys. For occupations in which worker exposures are found to exceed the REL for respirable coal mine dust or the REL for respirable crystalline silica (see Section 1.2.1), exposures shall be monitored as frequently as necessary to demonstrate that exposures have been controlled. See Section 5.6 for further discussion and recommendations for exposure monitoring.

1.3.3 Sampler Performance Criteria

Worker exposures shall be compared with the RELs for respirable coal mine dust and respirable crystalline silica using single, full-shift samples collected with a sampling device that operates in accordance with the NIOSH accuracy criteria [Busch 1977; Busch and Taylor 1981] and the international definition of respirable dust [ACGIH 1994; CEN 1993; ISO 1993; Soderholm 1991a,b; 1989] (see Section 5.2).

1.3.4 Worker Notification

A worker exposed to respirable coal mine dust or respirable crystalline silica at concentrations above the REL shall be notified of the exposure and of the control measures being implemented to reduce exposures.

1.3.5 Intake Air Concentrations

Intake air concentrations of respirable coal mine dust and respirable crystalline silica shall be kept sufficiently below the RELs to provide effective dilution of respirable dust concentrations and to keep worker exposures below the RELs.

1.4 MEDICAL SCREENING AND SURVEILLANCE PROGRAM FOR UNDERGROUND AND SURFACE COAL MINERS

1.4.1 General

All medical examinations and procedures shall be performed by or under the direction of a licensed physician or other qualified health care provider at NIOSH-approved facilities. The mine operator shall ensure that miners can participate in the medical screening and surveillance program at a reasonable time and place without loss of pay or other cost to the miner.

1.4.2 Preplacement and Periodic Medical Examinations

The Coal Workers' X-Ray Surveillance Program is administered by NIOSH and was established under the Federal Coal Mine Health and Safety Act of 1969 [Public Law 91-73].[††] Under this program, underground coal mine operators are required to provide periodic chest X-rays to underground coal miners and workers at surface work areas of underground coal mines. The specifications for giving, interpreting, classifying, and submitting the chest X-rays[‡‡] required for this program are contained in 42 CFR 37. See Section 6.2.1 for a more detailed description of this program. NIOSH recommends that surface coal miners be included in the Coal Workers' X-Ray Surveillance Program with the same provisions established for underground coal miners.

In addition to the periodic chest X-ray, NIOSH recommends that the Coal Workers' X-Ray Surveillance Program be extended to include spirometric examination both at the initial (preplacement) medical examination and at the intervals specified below. The purpose of spirometric examination is to detect unusual decrements in lung function and to permit timely intervention in the development of COPD.

The recommended components of the revised medical screening and surveillance program for underground and surface coal miners include the following:

- An initial (preplacement) spirometric examination and chest X-ray as soon as possible after beginning employment (within 3 months for a spirometric examination and within 3 to 6 months for a chest X-ray)

- A spirometric examination each year for the first 3 years after beginning employment and every 2 to 3 years thereafter if the miner is still engaged in coal mining

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[††] The 1969 Act was later amended by the Federal Mine Safety and Health Act of 1977 [30 USC 843].

[‡‡] Also called radiographs or roentgenograms.

- A chest X-ray every 4 to 5 years for the first 15 years of employment and every 3 years thereafter if the miner is still engaged in coal mining
- A chest X-ray and spirometric examination when employment ends if more than 6 months have passed since the last examination
- A standardized respiratory symptom questionnaire, such as the American Thoracic Society (ATS) respiratory questionnaire [Ferris 1978 (or the most current equivalent)], to be administered at the preplacement examination and updated at each periodic examination
- A standardized occupational history questionnaire (including a listing of all jobs held up to and including present employment, a description of all duties and potential exposures, and a description of all protective equipment the miner has used or may be required to use) to be administered at the preplacement examination and updated at each periodic examination

Information about the interpretation of chest X-rays and spirometric examinations and about medical intervention procedures is provided in Section 6.4.

1.5 POSTING

All warning signs shall be printed in both English and the predominant language of non-English-reading workers. Workers unable to read the posted signs shall be informed verbally about the hazardous areas of the mine and the instructions printed on the signs.

If respiratory protection is required, the following statement shall be posted:

RESPIRATORY PROTECTION REQUIRED IN THIS AREA

1.6 ENGINEERING CONTROLS AND WORK PRACTICES

The mine operator shall use engineering controls and work practices to keep worker exposures at or below the RELs for respirable coal mine dust and respirable crystalline silica. Chapter 8 and Appendices C and D describe available engineering controls and work practices.

1.7 RESPIRATORY PROTECTION

1.7.1 General Considerations

Respirators shall be used when engineering controls and work practices are not effective in maintaining worker exposures at or below the RELs for respirable coal mine dust and respirable crystalline silica. Respirators may be used as an interim[§§] control measure, but they shall not be used in lieu of

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[§§] Interim use periods shall meet one or more of the three conditions listed in Section 8.6.2.1.

feasible engineering controls and work practices. Whenever respirators are used, the mine operator shall institute a respiratory protection program conforming to the recommendations in Chapter 8.

1.7.2 Respiratory Protection Program

This program shall include, at a minimum, the following elements:

- A designated individual responsible for the administration of the program
- A written program for respiratory protection that contains standard operating procedures governing the selection and use of respirators
- Initial and annual training of workers in the proper use and limitations of respirators as required in 30 CFR 48.28 and 48.31
- Annual training of persons whose jobs require them to be certified at underground coal mines in the use of self-contained, self-rescue devices as required in 30 CFR 75.161
- Evaluation of working conditions in the mines (including periodic air monitoring of worker exposures) to identify situations that require respiratory protection
- Routine inspection, cleaning, maintenance, and proper storage of respirators according to the *NIOSH Guide to Industrial Respiratory Protection* [NIOSH 1987a]
- Initial quantitative fit testing by a trained and qualified person to determine the level of protection provided by each respirator worn (for a description of qualitative fit testing, see the *NIOSH Guide to Industrial Respiratory Protection* [NIOSH 1987a])
- Additional daily fit checks conducted by the worker to ensure proper assembly, function, and face-seal integrity of the respirator
- Medical evaluation of the worker's physical ability to perform work continuously while breathing through a respirator [Appendix H of NIOSH 1991b; NIOSH 1994d]
- Periodic evaluation of program effectiveness through the monitoring of respirator use patterns, quarterly inspection of the respirator maintenance program, and testing of supervisors and workers for awareness of respirator use requirements

1.7.3 Respirator Selection

Respirators shall be selected by a qualified person according to the guidelines in Section 8.5.2.2 of this criteria document and the most recent edition of the *NIOSH Respirator Decision Logic* [NIOSH 1987b]. Only respirators approved by NIOSH and the Mine Safety and Health Administration (MSHA) shall be used.

1.8 INFORMING WORKERS OF THE HAZARDS

1.8.1 Notification of Hazards

The mine operator shall provide all miners with information about workplace hazards before job assignment and at least annually thereafter.

1.8.2 Training

The mine operator shall institute a continuing education program conforming to the requirements in 30 CFR 48. The purpose of this program is to ensure that all miners have a current knowledge of workplace hazards (e.g., respirable coal mine dust and respirable crystalline silica), effective work practices, engineering controls, and the proper use of respirators and other personal protective equipment. The continuing education program shall also include a description of the exposure monitoring and medical surveillance programs and the advantages of participating in them. This information shall be kept on file and shall be readily available to miners for examination and copying. The mine operator shall maintain a written plan of these training programs and a written record of the miners' attendance at such programs (including dates).

Miners shall be instructed about their responsibilities for following proper work practices and sanitation procedures necessary to protect their health and safety.

1.9 SANITATION AND HYGIENE

1.9.1 Smoking

Smoking shall be prohibited in all underground and surface coal mines and all other work areas associated with coal mining. MSHA currently prohibits smoking in all underground mines and in surface coal mines where fire or explosion may result [30 CFR 75.1072 and 77.1711]. In addition, NIOSH recommends that smoking be prohibited to prevent exposure to environmental tobacco smoke, a potential occupational carcinogen [NIOSH 1991a].

1.9.2 Drinking Water

An adequate supply of potable water shall be provided for workers at each underground worksite [30 CFR 75.1718] and each surface worksite [30 CFR 71.600–71.603].

1.9.3 Showering, Changing, and Toilet Facilities

The mine operator shall provide workers with clean facilities for showering and changing clothes at the end of each work shift. Mine operators shall provide an adequate number of toilet facilities. The mine operator shall also provide storage facilities such as lockers to permit workers to store street clothing and personal items. Regulations for bath, toilet, and changing facilities are provided in 30 CFR 71.400–71.501 for surface worksites, and in 30 CFR 75.1712 for underground worksites.

1.10 RECORDKEEPING

1.10.1 Records of Exposure Monitoring

Records related to the exposure monitoring required in Section 1.3 shall be retained by the mine operator or by MSHA, as applicable, for at least 40 years after termination of employment.

1.10.2 Medical Records

NIOSH-held records related to the medical screening and surveillance program in Section 1.4 shall be maintained by NIOSH in accordance with 42 CFR 37.80. Any medical records that the mine operator may have as part of a medical program for coal miners shall be retained by the mine operator for at least 40 years after termination of employment.

1.10.3 Availability of Records

The miner shall have access to his medical records and be permitted to obtain copies. Records shall also be made available to former miners or their representatives and to the designated representatives of the Secretary of Labor and the Secretary of Health and Human Services.

1.10.4 Transfer of Records

Exposure monitoring and medical records shall be transferred as follows:

- Upon termination of employment, the mine operator shall provide the miner with a copy of his records related to exposure monitoring and medical screening and surveillance.

- Whenever the mine operator transfers ownership of the mine, all records described in this section shall be transferred to the new operator, who shall maintain them as required by this standard.

- Whenever a mine operator ceases to do business and there is no successor, the mine operator shall notify the miners of their rights of access to those records at least 3 months before cessation of business.

- Before a mine operator disposes of records or ceases to do business without a successor to maintain records, the mine operator shall notify the Director of NIOSH in writing. No records shall be destroyed until the Director of NIOSH responds in writing to the mine operator.

- After informing the Director of NIOSH of impending disposal or lack of successor to maintain records, the mine operator shall transfer custody of records to NIOSH if the Director of NIOSH or a designee requests it.

2 INTRODUCTION

2.1 PURPOSE

This document presents the criteria and recommended standards necessary to reduce or eliminate health impairment from exposure to respirable coal mine dust. The document was developed in accordance with the Federal Mine Safety and Health Act of 1977 [30 USC 811 and 842(d)]* and the Occupational Safety and Health Act of 1970 [29 USC 20(a)(3) and 22(c)(1)]. In these Acts, NIOSH is charged with recommending occupational safety and health standards and developing criteria for toxic materials and harmful physical agents. These criteria are to describe exposures that are safe for various periods of employment—including (but not limited to) the exposures at which no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience.

NIOSH has formalized a system for developing criteria on which to base standards for ensuring the health and safety of workers exposed to hazardous chemical and physical agents. Simple compliance with these standards is not the only goal. The criteria and recommended standards are also intended to help management and labor develop better engineering controls and more healthful work practices.

Recommended standards for respirable coal mine dust apply to workplace exposures arising from the extraction, processing, and use of coal. The recommended standards are intended to protect workers from the chronic effects of exposure to respirable coal mine dust. Exposures are measurable by techniques that are valid, reproducible, and available to industry and government agencies. Recommendations in this document pertain to existing regulations in 30 CFR 48, 70, 71, 74, 75, 77, and 90, and in 42 CFR 37.

2.2 SCOPE

The information in this document is used to assess the hazards associated with occupational exposure to respirable coal mine dust. Epidemiological studies from the United States and abroad have shown that underground and surface coal miners are at risk of developing simple CWP, PMF, silicosis, and COPD. PMF and advanced stages of silicosis and COPD are associated with respiratory impairment, disability, and premature death.

Chapter 1 presents the recommended standards and describes their requirements. Chapter 3 contains information about the chemical and physical properties of respirable coal mine dust, production

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*This act amended the Federal Coal Mine Health and Safety Act of 1969 [Public Law 91-173].

methods, uses, and the extent of worker exposure. Chapter 4 discusses the health effects of exposures to respirable coal mine dust. Chapter 5 addresses environmental monitoring, and Chapter 6 describes the recommended medical screening and surveillance program for underground and surface coal miners. Chapter 7 discusses the basis for the recommended standard for respirable coal mine dust. Chapter 8 describes methods for worker protection, and Chapter 9 lists research needs. The appendices include tables of exposures to respirable coal mine dust by occupation; methods for controlling respirable dust in underground and surface coal mines; technical aspects of spirometric examinations, spirometry reference values, and the occupational history questionnaire; and technical analyses of sampling criteria, exposure variability, and validation of risk estimates.

2.3 NIOSH ACTIVITIES AND PROGRAMS FOR COAL MINERS

In addition to recommending occupational safety and health standards under the Federal Mine Safety and Health Act of 1977 [30 USC 811], NIOSH is responsible for several activities related to coal miners:

- Conducting epidemiological research to
    - identify and define factors involved in occupational diseases of miners,
    - provide information about the incidence and prevalence of pneumoconiosis and other respiratory ailments of miners, and
    - improve mandatory health standards [30 USC 951(a)(5)]
- Prescribing the specifications for giving, reading, and classifying chest X-rays and any other medical tests NIOSH deems necessary [30 USC 843(a)]
- Providing for the autopsy of miners with the consent of the surviving spouse or the next of kin [30 USC 843(d)]
- Approving respiratory equipment [30 USC 842(h)]
- Certifying coal mine dust sampling units [30 USC 842(e)]

Under the Black Lung Benefits Act of 1981 [30 USC 901-945], NIOSH is to provide criteria for medical tests that accurately reflect total disability in coal miners [30 USC 902(f)]. A discussion of the Black Lung Benefits Program is provided in Appendix H.

2.4 HEALTH EFFECTS STUDIES

Numerous U.S. and foreign studies show that miners exposed to respirable dust in underground coal mines over a working lifetime are at risk of developing simple CWP and PMF [Attfield and Seixas 1995; Attfield and Morring 1992b; Maclaren et al. 1989; Hurley et al. 1987; Hurley et al. 1982; Shennan et al. 1981]. Miners who show evidence of the higher radiographic categories of simple

CWP are at increased risk of developing PMF. The current U.S. standard of 2 mg/m^3 for respirable coal mine dust [30 USC 801-962; 30 CFR 70 and 71] is based primarily on estimates of early studies of coal miners in the United Kingdom [Jacobsen et al. 1971; McLintock et al. 1971; Cochrane 1962]. The intent of the standard of 2 mg/m^3 is to prevent the development of PMF by preventing progression of simple CWP to category 2 or greater.

More recent studies from the United States and the United Kingdom indicate that the risk of PMF is higher than estimated in the studies used as the basis for the current U.S. coal dust standard [Attfield and Seixas 1995; Attfield and Morring 1992b; Hurley and Maclaren 1987; Hurley et al. 1987]. These U.S. and U.K. studies have shown that the prevalence of simple CWP and PMF has been declining since the 1960s [British Coal Corporation 1993; Attfield and Castellan 1992; Attfield and Althouse 1992]. However, simple CWP and PMF have not been eliminated under the current standard. Estimates indicate that at age 58, an average of 7/1,000 U.S. workers (exposed to low-rank coal) and 89/1,000 U.K. workers (exposed to high-rank coal) will have developed PMF during 40 years of exposure to respirable dust at a mean concentration of 2 mg/m^3 [Attfield and Seixas 1995; Attfield and Morring 1992b; Hurley and Maclaren 1987]. Within this range, the higher disease prevalences are predicted for U.S. miners and for U.S. and U.K. miners exposed to the dust of higher-ranked coal.

Studies from the United States and abroad have also shown that coal miners are at increased risk of developing COPD, whether or not simple CWP or PMF is present [Seixas et al. 1993, 1992; Attfield and Hodous 1992; Soutar et al. 1988; Marine et al. 1988; Soutar and Hurley 1986; Rogan et al. 1973]. Studies of surface coal miners have shown that they are also at risk of developing simple CWP [Love et al. 1992; Amandus et al. 1989, 1984].

2.5 OTHER STANDARDS AND RECOMMENDATIONS

2.5.1 MSHA

The current Federal standard of 2 mg/m^3 for respirable dust in the mine atmosphere was established by the Federal Coal Mine Health and Safety Act of 1969 [P.L. 91-173], which was amended by the Federal Mine Safety and Health Act of 1977 [30 USC 801-962]. An interim standard of 3 mg/m^3 was in effect from 1969 to 1972 [30 USC 842 (b)], when the current standard became effective. MSHA of the U.S. Department of Labor was established under the Federal Mine Safety and Health Act of 1977 [30 USC 801-962]. MSHA is responsible for enforcing the provisions of the Act, including the establishment of safety and health regulations [30 CFR 70 and 71]. Two Federal agencies preceded MSHA: the Mine Enforcement and Safety Administration (MESA) of the U.S. Department of the Interior (from 1972 to 1977) and the U.S. Bureau of Mines Inspection Division (before 1972).

MSHA has adopted a permissible exposure limit (PEL) of 2 mg/m^3 for respirable coal mine dust, which is measured gravimetrically as an 8-hour TWA concentration of the respirable coal mine dust. The applicable standard for respirable coal mine dust is reduced when the respirable quartz content exceeds 5% (a formula of 10 divided by the percentage of respirable quartz is used to determine the reduced PEL for respirable coal mine dust) [30 CFR 70.101 and 71.101]. Thus, the

MSHA PEL for respirable quartz (0.1 mg/m^3) corresponds to a respirable coal mine dust concentration of 2 mg/m^3 and a quartz content of 5%.

Coal mine operators are required to take bimonthly samples of airborne respirable dust in the active workings of a coal mine with a device approved by the Secretary of the U.S. Department of Labor and the Secretary of the U.S. Department of Health and Human Services [30 CFR 70.206, 71.206, and 74]. The measured concentration is multiplied by a conversion factor of 1.38 to adjust for differences in sampling devices used in the United States (a 10-mm nylon cyclone) and the United Kingdom (a horizontal elutriator developed by the British Mining Research Establishment [MRE]) [Tomb et al. 1973]. The respirable particulate size fraction is defined by the British Medical Research Council criterion for particle-size selective dust samplers as "100% efficiency at 1 micron or below, 50% at 5 microns, and zero efficiency for particles of 7 microns and upwards" [ATC 1970; Orenstein 1960].

2.5.2 OSHA

OSHA has adopted a PEL of 2 mg/m^3 for the respirable dust fraction containing less than 5% quartz and a PEL of 0.1 mg/m^3 for the respirable quartz fraction of coal dust containing 5% or more quartz. Both OSHA PELs are 8-hr TWAs.

2.5.3 ACGIH TLV

The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for respirable coal mine dust is 2 mg/m^3 as a TWA.

2.5.4 WHO Exposure Limit

The World Health Organization (WHO) [WHO 1986] has recommended a "tentative health-based exposure limit" for respirable coal mine dust (with <7% respirable quartz) ranging from 0.5 to 4.0 mg/m^3. WHO recommended that this limit be based on (1) the risk factors (i.e., coal rank or carbon content, proportion of respirable quartz and other minerals, and particle size distribution of the coal dust) for CWP category 1 that are determined at each mine, and (2) the assumption that the risk of PMF over a working lifetime (56,000 hr) will not exceed 2/1,000. Based on the WHO approach, the risk of disease would be determined separately for each individual mine or group of mines, and the exposure limit would vary from mine to mine.

2.5.5 Limits in Other Countries

Table 2-1 lists occupational exposure limits for respirable coal mine dust and respirable crystalline silica in various countries. Exposure limits cannot be directly compared from country to country because of differences in measurement strategies. Prinz and Stolz [1990] describe differences in the sampling locations within the mines and differences in the number of samples and the frequency of sampling in various countries. Measurements in the United States have been compared with those in the United Kingdom by applying the MRE conversion factor (Section 2.5.1).

Table 2-1. Occupational exposure limits for respirable coal mine dust and respirable crystalline silica in various countries

Country	Recommended value (gravimetric)	Comment
Australia[*]	$3\ \text{mg/m}^3$	Coal dust with ≤5% respirable free silica
Belgium	$\frac{10\ \text{mg/m}^3}{\%\ \text{respirable quartz} + 2}$	
Brazil	$\frac{8\ \text{mg/m}^3}{\%\ \text{respirable quartz} + 2}$	
Finland	$2.0\ \text{mg/m}^3$ $0.2\ \text{mg/m}^3$ $0.1\ \text{mg/m}^3$	Coal dust Quartz (fine dust <5 μm) Silica: cristobalite, tridymite
Federal Republic of Germany[†]	$0.15\ \text{mg/m}^3$ $4.0\ \text{mg/m}^3$	Quartz (including cristobalite and tridymite) Fine dust containing quartz (1% or greater quartz by weight)
Italy	$3.33\ \text{mg/m}^3$	Coal dust with <1% quartz
	$\frac{10\ \text{mg/m}^3}{q + 3}$ where q = % of quartz (mass)	Coal dust with >1% quartz
Netherlands	$2\ \text{mg/m}^3$[‡] $0.075\ \text{mg/m}^3$	Coal dust (less than 5% respirable quartz) Silica: cristobalite, tridymite
Sweden	$0.05\ \text{mg/m}^3$	Silica: cristobalite, tridymite
United Kingdom[§]	$3.8\ \text{mg/m}^3$	Coal mine dust (average concentration at the coal face)
United States (MSHA)	$2.0\ \text{mg/m}^3$	Coal dust with <5% silica
	$\frac{10\ \text{mg/m}^3}{\%\ SiO_2}$	Coal dust with >5% silica
	$\frac{10\ \text{mg/m}^3}{\%\ \text{respirable quartz} + 2}$	Silica: quartz
	Half of the value for quartz	Silica: cristobalite, tridymite
Yugoslavia	$4\ \text{mg/m}^3$	Fine dust with <2% free crystalline silica
	$\frac{0.07 \times 100\ \text{mg/m}^3}{\%\ \text{FCS}}$	Fine dust with >2% free crystalline silica
	$0.07\ \text{mg/m}^3$	Pure quartz (fine dust)

Source: WHO [1986] (except as otherwise noted).

[*] Source: Coal Mines Regulation Act 1982 (New South Wales); Coal Mines Regulation, Respirable Dust 1978 (Queensland).

[†] Source: German Research Institute [1992].

[‡] Source: Cook [1987].

[§] Source: Jacobsen [1984]. Recommended value is based on maximum allowable concentration of $7\ \text{mg/m}^3$ in the return airway during the working shift.

3 PROPERTIES, PRODUCTION, AND POTENTIAL FOR EXPOSURE

3.1 CHEMICAL AND PHYSICAL PROPERTIES OF COAL MINE DUST

3.1.1 Coal and Its Characteristics

Coal is a combustible, carbonaceous, sedimentary rock that is formed by the accumulation, compaction, and physical and chemical alteration of vegetation [Simon and Hopkins 1981; Bates and Jackson 1987]. Coal is classified according to its type, grade, and rank. The *type* of coal relates to the plant materials from which the coal originated. The *grade* of coal refers to the purity of the coal—or the amount of inorganic material (including ash and sulfur) left after the coal is burned [Bates and Jackson 1987; Stefanko 1983]. The *rank* of coal indicates its degree of metamorphosis and roughly correlates to the geological age of the coal or the geological environment from which it has been mined [Bates and Jackson 1987]. Rank also indicates the percentage of carbon in dry, mineral-free coal [Whitten and Brooks 1973] and the degree to which the coalification process has progressed [Larsen 1981]. The geological process of coalification begins with organic materials (e.g., celluloses, lignins, and other plant compounds that are deoxygenated and then dehydrogenated) and ends with coal of various geological ages, from lignite to anthracite [Larsen 1981]. Table 3-1 presents the American Society for Testing and Materials (ASTM) classification of coals by rank. According to Parkes [1982], high-rank coal includes anthracite and semianthracite coal ("hard coal," with 91% to 95% carbon); intermediate-rank coal includes low-, medium-, and high-volatile bituminous and sub-bituminous coal ("soft coal," with 76% to 90% carbon); and low-rank coal includes lignite (with 65% to 75% carbon or less). The rank of coal tends to increase from the western to the eastern United States, with anthracite occurring primarily in eastern Pennsylvania [Schlick and Fannick 1971]. Most of the coal currently mined in the United States is bituminous [Given 1984]. A classification of the coal in the United States is provided in Table 3-2.

3.1.2 Composition of Coal Mine Dust

Coal mine dust is a complex and heterogeneous mixture containing more than 50 different elements and their oxides [Coates 1981; Larsen 1981]. The mineral content varies with the particle size of the dust and with the coal seam [Stobbe et al. 1990]. Common minerals associated with coal mine dust include kaolinite, illite, calcite, pyrite, and quartz [Stobbe et al. 1990]. The sulfur content varies from 0.5% (by weight) to more than 10%, with coal from the western United States generally having lower sulfur content [Coates 1981].

Airborne respirable dust in underground coal mines has been estimated to be 40% to 95% coal; the remaining portion consists of a variable mixed dust that is generated from fractured rock on the mine roof or floor, or that is encountered within the coal seam [Kim 1989]. The coal component of respirable dust at surface coal mines can be even more variable, depending on the stage of the mining operation.

Table 3–1. ASTM classification of coals by rank

Coal rank and group	Basis of classification		Agglomerating character
	% fixed carbon (range)[*]	Heat content in Btu/lb (range)[†]	
Anthracitic:			
Meta-anthracite	98	——	Nonagglomerating
Anthracite	92–<98	——	Nonagglomerating
Semianthracite[‡]	86–<92	——	Nonagglomerating
Bituminous:			
Low-volatile bituminous	78–<86	——	Commonly agglomerating[§]
Medium-volatile bituminous	69–<78[**]	——	Commonly agglomerating[§]
High-volatile A bituminous	<69[**]	——	Commonly agglomerating[§]
High-volatile B bituminous	——	13,000–<14,000	Commonly agglomerating[§]
High-volatile C bituminous	——	11,500–<13,000	Commonly agglomerating[§]
High-volatile C bituminous	——	10,500–<11,500	Agglomerating
Sub-bituminous:			
Sub-bituminous A	——	10,500–<11,500	Nonagglomerating
Sub-bituminous B	——	9,500–<10,500	Nonagglomerating
Sub-bituminous C	——	8,300–<9,500	Nonagglomerating
Lignitic:			
Lignite A	——	6,300–<8,300	Nonagglomerating
Lignite B	——	<6,300	Nonagglomerating

Sources: ASTM [1993]; EIA [1993].

[*] Percentages are based on dry, mineral-matter-free coal. Volatile matter (not shown) is the complement of fixed carbon; that is, the % fixed carbon and % volatile matter is 100%. As % fixed carbon decreases, % volatile matter increases by the same amount.

[†] Calorific values in Btu/lb are based on moist, mineral-matter-free coal.

[‡] If agglomerating, classify in the low-volatile group of the bituminous class.

[§] Nonagglomerating varieties may exist in the bituminous class, most notably in the high-volatile C bituminous group.

[**] Coals having ≥69% fixed carbon are classified according to fixed carbon, regardless of Btu value. Coals with <69% fixed carbon but with ≥14,000 Btu/lb are classified as high-volatile A bituminous.

Huggins et al. [1985] compared the size distributions of respirable quartz at surface and underground coal mines and found that the distributions of particle sizes less than 4.2 µm were similar. The distribution of particles at surface coal mines included more quartz particles in the size range of 4.2 to 9.6 µm (2.7% versus 6.4%). The distribution of particles in both surface and underground coal mines contained <0.25% of respirable quartz larger than 9.6 µm.

Dust of high-rank coal contains a greater proportion of silica particles with uncontaminated surfaces than does dust of lower-rank coal [Kriegseis and Scharmann 1985]. Dust of high-rank coal also

Table 3-2. Coal classification: source and analyses of U.S. coal*

Classification by rank	State and county	Bed	Type of sample†	Proximate %		Ultimate %					Calorific		Value (Btu/lb)
				Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	
Meta-anthracite	Rhode Island (Newport)	Middle	1	13.2	2.6	65.3	18.9	0.3	1.9	64.2	0.2	14.5	9,310
			2	——	2.9	75.3	21.8	0.3	0.5	74.1	0.2	3.1	10,740
			3	——	3.8	96.2	——	0.4	0.6	94.7	0.3	4.0	13,720
Anthracite	Pennsylvania (Lackawana)	Clark	1	4.3	5.1	81.0	9.6	0.8	2.9	79.7	0.9	6.1	12,880
			2	——	5.3	84.6	10.1	0.8	2.5	83.3	0.9	2.4	13,470
			3	——	5.9	94.1	——	0.9	2.8	92.5	1.0	2.8	14,980
Semianthracite	Arkansas (Johnson)	Lower Hartshorne	1	2.6	10.6	79.3	7.5	1.7	3.8	81.4	1.6	4.0	13,880
			2	——	10.8	81.5	7.7	1.8	3.6	83.6	1.6	1.7	14,240
			3	——	11.7	88.3	——	1.9	3.9	90.6	1.8	1.8	15,430
Low-volatile bituminous coal	West Virginia (Wyoming)	Pocahontas No. 3	1	2.9	17.7	74.0	5.4	0.8	4.6	83.2	1.3	4.7	14,400
			2	——	18.2	76.3	5.5	0.8	4.4	85.7	1.3	2.3	14,830
			3	——	19.3	80.7	——	0.8	4.6	90.7	1.4	2.5	15,690
Medium-volatile bituminous coal	Pennsylvania (Clearfield)	Upper Kittanning	1	2.1	24.4	67.4	6.1	1.0	5.0	81.6	1.4	4.9	14,310
			2	——	24.9	68.8	6.3	1.1	4.8	83.3	1.5	3.0	14,610
			3	——	26.5	73.5	——	1.1	5.2	88.9	1.6	3.2	15,590
High-volatile A bituminous coal	West Virginia (Marion)	Pittsburgh	1	2.3	36.5	56.0	5.2	0.8	5.5	78.4	1.6	8.5	14,040
			2	——	37.4	57.2	5.4	0.8	5.4	80.2	1.6	6.6	14,370
			3	——	39.5	60.5	——	0.8	5.7	84.8	1.7	7.0	15,180
High-volatile B bituminous coal	Kentucky Western field (Muhlenburg)	No. 9	1	8.5	36.4	44.3	10.8	2.8	5.4	65.1	1.3	14.6	11,680
			2	——	39.8	48.5	11.7	3.0	4.9	71.2	1.5	7.7	12,760
			3	——	45.0	55.0	——	3.4	5.5	80.6	1.7	8.8	14,460

See footnotes at end of table.

(Continued)

Table 3-2 (Continued). Coal classification: source and analyses of U.S. coal*

			Type	Proximate %			Ultimate %					Calorific		
Classification by rank	State and county	Bed	of sample†	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Value (Btu/lb)
High-volatile C bituminous coal	Illinois (Sangamon)	No. 5	1	14.4	35.4	40.6	9.6	3.8	5.8	59.7	1.0	20.1	10,810
			2	——	41.4	47.4	11.2	4.4	4.9	69.8	1.2	8.5	12,630
			3	——	46.6	53.4	——	5.0	5.6	78.6	1.3	9.5	14,230
Sub-bituminous A coal	Wyoming (Sweetwater)	No. 3	1	16.9	34.8	44.7	3.6	1.4	6.0	60.4	1.2	27.4	10,650
			2	——	41.8	53.8	4.4	1.7	4.9	72.7	1.5	14.8	12,810
			3	——	43.7	56.3	——	1.8	5.2	76.0	1.5	15.5	13,390
Sub-bituminous B coal	Wyoming (Shedian)	Monarch	1	22.2	33.2	40.3	4.3	0.5	6.9	53.9	1.0	33.4	9,610
			2	——	42.7	51.7	5.6	0.6	5.6	69.3	1.2	17.7	12,350
			3	——	45.2	54.8	——	0.6	6.0	73.4	1.3	18.7	13,080
Sub-bituminous C coal	Colorado (El Paso)	Fox Hill	1	25.1	30.4	37.7	6.8	0.3	6.2	50.5	0.7	35.5	8,560
			2	——	40.6	50.3	9.1	0.4	4.6	67.4	1.0	17.5	11,430
			3	——	44.6	55.4	——	0.5	5.0	74.1	1.1	19.3	12,560
Lignite	North Dakota (McLean)	Unnamed	1	36.8	27.8	29.5	5.9	0.9	6.9	40.6	0.6	45.1	7,000
			2	——	43.9	46.7	9.4	1.4	4.5	64.3	1.0	19.4	11,080
			3	——	48.4	51.6	——	1.6	5.0	70.9	1.1	21.4	12,230

Source: EIA [1989].

*Note: Source and analysis of coal was selected to represent the various ranks of the specifications for classification of coals by rank adopted by the American Society for Testing and Materials.

†1 = Sample as received; 2 = moisture-free; 3 = moisture- and ash-free.

contains a greater concentration of oxygen radicals when the coal is freshly crushed [Dalal et al. 1989a,b; Dalal et al. 1988; Vallyathan et al. 1988] and a greater concentration of respirable particles that have large surface areas relative to other particles in the same aerodynamic size range (i.e., plate-shaped particles) [Addison and Dodgson 1990]. Dust of anthracite coal may contain a greater concentration of respirable crystalline silica than dust of lower-rank coal because the anthracite seams are dominated by quartzite in the roof and floor [Mutmansky and Lee 1984].

The particle size distribution of dust in the mine environment includes the respirable, thoracic, and inhalable particulate mass fractions. These fractions are defined as those that are hazardous when deposited in the following regions of the human respiratory tract: in the gas-exchange region (respirable dust), anywhere within the lung airways and gas-exchange region (thoracic dust), and anywhere in the respiratory tract (inhalable dust) [ACGIH 1994]. The source of the dust generated in longwall mines influences the particle size distributions measured at various locations in the mines [Potts et al. 1990]. The proportion of thoracic dust is up to seven times greater than that of respirable dust [Potts et al. 1990]. Furthermore, the thoracic dust concentration is higher in mines using longwall methods than in mines using continuous methods.

Coal miners may be exposed to diesel emission particulates in mines where diesel-powered equipment is used. These diesel particulates are of respirable size and contribute to the total concentration of respirable dust in an occupational environment [NIOSH 1988a]. The concentration of respirable coal mine dust is determined gravimetrically, and this method does not distinguish between coal dust particulates and diesel particulates. In a study of five underground coal mines using diesel equipment, Cantrell et al. [1993] found that 27% to 62% of the measured respirable dust concentration was diesel exhaust particulates (depending on the sampling location).

3.2 COAL PRODUCTION AND MINING METHODS

As mechanization was introduced into the mines, the total number of U.S. coal miners decreased from more than 400,000 in 1950 to approximately 130,000 in 1990, and coal production increased fivefold (Table 3-3) [EIA 1989; Morgan 1975]. Table 3-3 lists coal mine production and number of miners employed from 1900 through 1990. In 1992, approximately 120,000 U.S. coal miners produced 997.5 million short tons of coal (1 short ton = 2,000 lb); 41% of the total production was from underground mines, and 59% was from surface mines [EIA 1993]. Figure 3-1 shows U.S. coal production from both surface and underground coal mines. Figure 3-2 illustrates U.S. coal production by rank (as described in Section 3.1.1).

Whether coal is mined by underground or surface methods depends on the depth of the coalbed from the surface and the character of the terrain. Underground methods are usually used to mine coalbeds deeper than about 200 feet, and surface methods are used to mine shallower coalbeds [EIA 1989].

3.2.1 Underground Coal Mining Methods

Underground mines are classified by their openings to the surface of the earth and by the coal mining method. A "shaft mine" is driven vertically into the coal deposit, while a "slope mine" is driven at

Table 3-3. Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990[*]

Year	Production (in thousands of short tons)			Number of miners employed[†]	Average tons per miner per day[‡]
	Underground	Surface	Total		
1900	212,316	NA[§]	NA	304,375	2.98
1901	225,828	NA	NA	340,235	2.94
1902	260,217	NA	NA	370,056	3.06
1903	282,749	NA	NA	415,777	3.02
1904	278,660	NA	NA	437,832	3.15
1905	315,063	NA	NA	460,629	3.24
1906	342,875	NA	NA	478,425	3.36
1907	394,759	NA	NA	516,258	3.29
1908	332,574	NA	NA	516,264	3.34
1909	379,744	NA	NA	543,152	3.34
1910	417,111	NA	NA	555,533	3.46
1911	405,907	NA	NA	549,775	3.50
1912	450,105	NA	NA	548,632	3.68
1913	478,435	NA	NA	571,882	3.61
1914	421,436	1,268	422,704	583,506	3.71
1915	439,792	2,832	442,624	557,456	3.91
1916	498,500	4,020	502,520	561,102	3.90
1917	546,273	5,518	551,791	603,143	3.77
1918	571,275	8,111	579,386	615,305	3.78
1919	460,270	5,590	465,860	621,998	3.84
1920	559,807	8,860	568,667	639,547	4.00
1921	410,865	5,057	415,922	663,754	4.20
1922	412,059	10,209	422,268	687,958	4.28
1923	552,625	11,940	564,565	704,793	4.47
1924	470,080	13,607	483,687	619,604	4.56
1925	503,182	16,871	520,053	588,493	4.52
1926	556,444	16,923	573,367	593,647	4.50
1927	499,385	18,378	517,763	593,918	4.55
1928	480,956	19,789	500,745	522,150	4.73
1929	514,721	20,268	534,989	502,993	4.85
1930	447,684	19,842	467,526	493,202	5.06
1931	363,157	18,932	382,089	450,213	5.30
1932	290,069	19,641	309,710	406,380	5.22
1933	315,360	18,270	333,630	418,703	4.78
1934	338,578	20,790	359,368	458,011	4.40
1935	348,726	23,647	372,373	462,403	4.50
1936	410,962	28,126	439,088	477,204	4.62
1937	413,780	31,751	445,531	491,864	4.69
1938	318,138	30,407	348,545	441,333	4.89
1939	357,133	37,722	394,855	421,788	5.25

See footnotes at end of table.

(Continued)

Table 3-3 (Continued). Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990[*]

Year	Production (in thousands of short tons) Underground	Surface	Total	Number of miners employed[†]	Average tons per miner per day[‡]
1940	417,604	43,167	460,771	439,075	5.19
1941	459,078	55,071	514,149	456,981	5.20
1942	515,490	67,203	582,693	461,991	5.12
1943	510,492	79,685	590,177	416,007	5.38
1944	518,678	100,896	619,576	393,347	5.67
1945	467,630	109,987	577,617	383,100	5.78
1946	420,958	112,962	533,922	396,434	6.30
1947	491,229	139,395	630,624	419,182	6.42
1948	460,012	139,506	599,518	441,631	6.26
1949	331,823	106,045	437,868	433,698	6.43
1950	392,844	123,467	516,311	415,582	6.77
1951	415,842	117,823	533,665	372,897	7.04
1952	356,425	110,416	466,841	335,217	7.47
1953	349,551	107,739	457,290	293,106	8.17
1954	289,112	102,594	391,706	227,397	9.47
1955	343,465	121,168	464,633	225,093	9.84
1956	365,774	135,100	500,874	228,163	10.28
1957	360,649	132,055	492,704	228,635	10.59
1958	286,884	123,562	410,446	197,402	11.33
1959	283,434	128,594	412,028	179,636	12.22
1960	284,888	130,624	415,512	169,400	12.83
1961	272,766	130,211	402,977	150,474	13.87
1962	281,266	140,883	422,149	143,822	14.72
1963	302,256	156,672	458,928	141,646	15.83
1964	321,808	165,190	486,998	128,698	16.84
1965	332,661	179,427	512,088	133,732	17.52
1966	338,524	195,357	533,881	131,752	18.52
1967	349,133	203,494	552,626	131,523	19.17
1968	344,142	201,103	545,245	127,894	19.37
1969	347,132	213,373	560,505	124,532	19.90
1970	338,788	264,144	602,930	140,140	18.84
1971	275,888	276,304	552,192	145,664	18.02
1972	304,103	291,284	595,386	149,265	17.74
1973	299,353	292,384	591,738	148,121	17.58
1974	277,309	326,098	603,406	166,701	17.58
1975	292-826	355,612	648,438	189,880	14.74
1976	294,880	383,805	678,685	202,280	14.46
1977	265,950	425,394	691,344	221,428	14.84
1978	242,177	422,950	665,127	242,295	14.68
1979	320,321	455,978	776,299	224,203	15.33

See footnotes at end of table.

(Continued)

Table 3–3 (Continued). Miners employed and U.S. production trends of bituminous coal and lignite in surface and underground mines, 1900 through 1990[*]

Year	Production (in thousands of short tons) Underground	Surface	Total	Number of miners employed[†]	Average tons per miner per day[‡]
1980	336,925	486,719	823,644	224,938	16.32
1981	315,875	502,477	818,352	226,250	18.08
1982	338,572	494,951	833,523	214,400	18.13
1983	299,892	478,111	778,003	173,543	21.19
1984	351,474	540,285	891,759	175,746	22.26
1985	350,073	528,856	878,930	167,009	23.13
1986	359,800	526,223	886,023	152,668	25.69
1987	372,238	542,963	915,202	141,065	28.19
1988	381,546	565,164	946,710	133,913	30.57
1989	393,322	584,058	977,381	130,103	32.05
1990	424,119	601,449	1,025,570	129,619	33.25

Source: EIA [1991].

[*] Note: Sub-bituminous coal is included with bituminous coal. Totals may not equal sum of components because of independent rounding. Sources: 1900–1976: U.S. Department of Interior, Bureau of Mines, *Minerals Yearbooks*; 1977–1978: Energy Information Administration, *Bituminous Coal & Lignite Production and Mine Operations*; 1979–1990: *Coal Production*, various issues.

[†] Note: The number of "miners employed" is lower than that listed in MSHA [1991] because mines producing less than 10,000 tons are excluded here.

[‡] After 1978, excludes miners employed at mines that produced less than 10,000 tons.

[§] NA = Not available; relatively small amounts included with underground.

an angle to reach the coal. A "drift mine" is driven horizontally into coal that is exposed or accessible in a hillside. A "punch mine" is a small drift mine used to recover coal from strip-mine highwalls or from small coal deposits [EIA 1989]. Room-and-pillar mining and longwall mining are the two predominant methods.

3.2.1.1 Room-and-Pillar Mining

The most common underground coal mining method is the room-and-pillar mining system, in which the mine roof is supported primarily by coal pillars that are left at regular intervals [EIA 1989]. The rooms are the areas where the coal is mined. Either a conventional or a continuous mining method is used to extract the coal in the room-and-pillar method. Conventional mining consists of a series of operations in which the coal face is cut so that it breaks easily when blasted (with either explosives or high-pressure air). The broken coal is then loaded onto conveyers or into shuttle cars for removal to the surface. In continuous mining, the coal is extracted and removed from the coal face in one operation, using a continuous mining machine. Room-and-pillar retreat mining occurs after coal has been extracted from the rooms in a mine section; additional coal is extracted by mining the supportive pillars [EIA 1989].

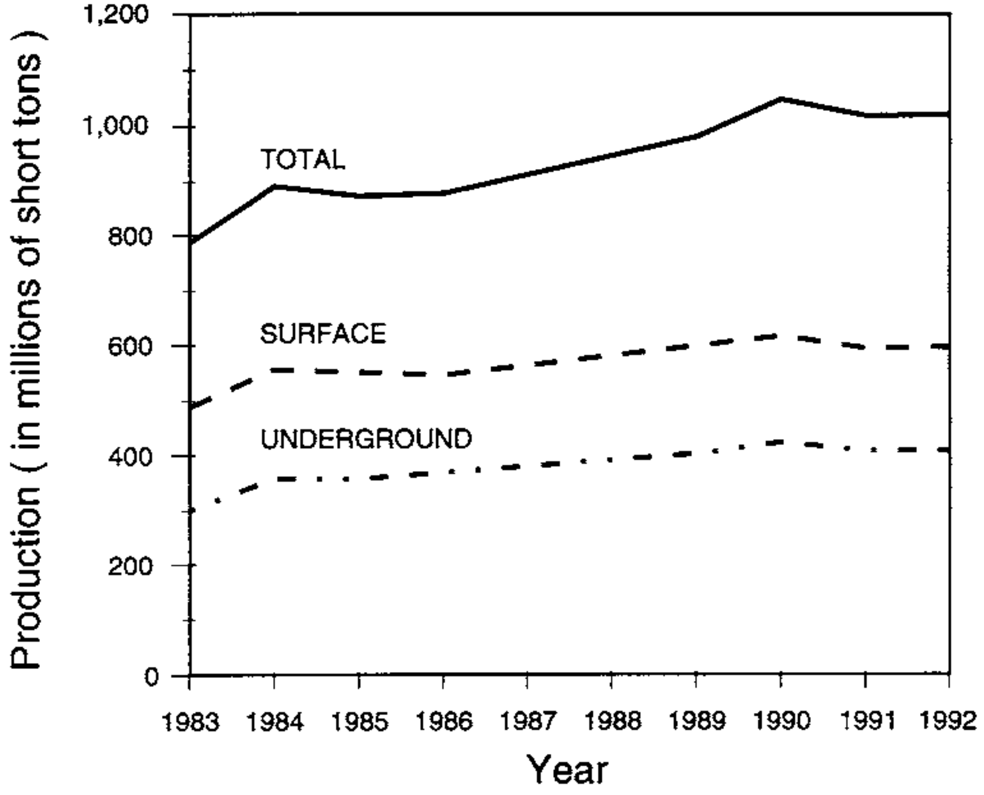

Figure 3–1. U.S. coal production in surface and underground mines, 1983–92. (Source: EIA [1993]).

3.2.1.2 Longwall Mining

Another common underground coal mining method is the longwall mining system, in which long sections of coal (also called panels) up to about 1,000 ft are removed by a cutting machine without leaving pillars of coal for support. Instead, a movable, powered roof-support system is used to support the roof in the working area. When the roof supports are moved, the area caves in and is called the gob area. After subsidence occurs, the gob area supports the overlying strata. Longwall mining is used where the coalbed is thick and generally flat, and where surface subsidence is acceptable [EIA 1989]. In 1992, mines using longwall methods accounted for 31% of the coal produced in underground coal mines [EIA 1993].

3.2.1.3 Additional Underground Coal Mining Methods

A shortwall mining system is a room-and-pillar, continuous mining system in which movable roof supports are used with a continuous miner operator. The working face is wider than in conventional or continuous sections (up to 150 ft) but smaller than in longwall mining [EIA 1989].

Hydraulic mines use high-pressure water jets to break coal from a steeply inclined, thick coalbed. The coal is transported to the surface by a system of flumes or a pipeline [EIA 1989].

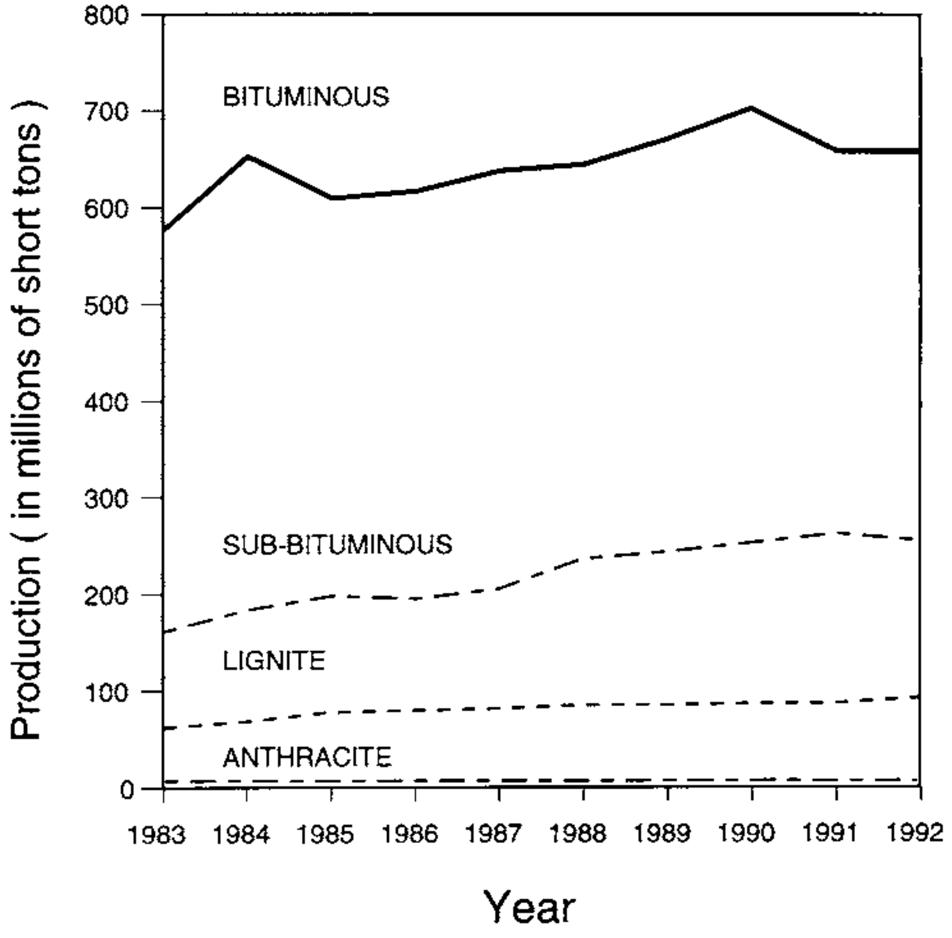

Figure 3-2. U.S. coal production by coal rank, 1983–92. (Source: EIA [1993].)

3.2.1.4 Roof Supports

The principal method of supporting the mine roof in room-and-pillar mining is through roof bolting, a process in which bolts are drilled into the mine roof to strengthen it by pulling together rock strata or by fastening weak strata to strong strata. The bolts are 2 to 10 ft long and have an expansion shell or resin grouting [EIA 1989].

3.2.1.5 Control of Gases and Airborne Dust

The principal method of controlling noxious gases and airborne respirable dust in coal mines is through mine ventilation, in which fans are used to supply fresh air and remove gases and dust from the mine. To reduce the possibility of a coal dust explosion, rock dust is sprayed in underground coal mines. Rock dust is a very fine, noncombustible material—usually pulverized limestone [EIA 1989]. Table 3-4 describes mining equipment used in underground coal mines.

3.2.2 Surface Coal Mining Methods

Strip mining, the most common type of surface coal mining, produced 99% of the coal from U.S. surface coal mines in 1992 (Table 3-5). Auger mining, coal dredging, and culm bank reclamation

Table 3-4. Glossary of underground coal mining equipment

Equipment name	Description
Coal cutting	Equipment used in conventional mining to undercut, topcut, or machine shear the coal face so that coal can be fractured easily when blasted. This equipment can cut 9–13 ft into the coal face.
Continuous auger	Augers used in mining coalbeds less than 3 ft thick. The auger machine cutting depth is about 5 ft. It usually uses a continuous conveyer belt to haul coal to the surface.
Continuous mining	Equipment used during continuous mining to cut or rip the coal from the coal face and load it into shuttle cars or conveyors. Continuous mining equipment eliminates the use of blasting and performs the functions of other machines (e.g., drills, cutting machines, and loaders). It has a turning drum with sharp bits and extracts 16–22 ft of coal before roof bolting is required. Coal is extracted at 8–15 tons/min.
Conveyer systems	Systems to carry coal. The mainline conveyer is permanently installed and carries coal to the surface. The section conveyer connects the working face to the mainline conveyer.
Face drill	Drill used in conventional mining to drill shotholes in the coalbed for explosive charges.
Loading machine	Machines used in conventional mining to scoop broken coal from the working area and load it into the shuttle car.
Longwall mining	A machine that shears coal from a long, straight coal face (up to about 600 ft) by working back and forth across the face under a movable, hydraulic-jack, roof-support system. Broken coal is transported by conveyor. Coal is extracted at 1,000 tons per shift.
Mine locomotive	A locomotive that operates on tracks and is used to haul mine cars containing coal and other material or to move personnel in mantrip cars; some can haul 20 tons at 10 mph. The locomotive is electric or battery-powered.
Ram car/scoop car	A rubber-tired haulage vehicle that is unloaded by means of a movable steel plate at rear of haulage bed.
Roof-bolting machine (roof bolter)	A machine used to drill holes and place bolts to support the mine roof. This machine can be installed on a continuous mining machine.
Scoop	A rubber-tired haulage vehicle used in thin coalbeds.
Shortwall mining machine	Usually a continuous mining machine used with a powered, self-advancing roof support system. It shears coal from a short coal face (up to 150 ft long). Broken coal is hauled by shuttle cars to a conveyer belt.
Shuttle car	A rubber-tired haulage vehicle that hauls coal to mine cars or conveyers for delivery to the surface. The car is unloaded by a built-in conveyer.

Source: EIA [1989].

Table 3-5. U.S. coal production by work location and type of coal in 1987 (operator data)
[In short tons]

Work location	Type of coal: Anthracite	Type of coal: Bituminous*	All coal
Underground mines	369,958	403,233,450	403,603,408
Surface mines:			
Strip mines	1,813,376	575,398,356	577,211,732
Auger mines	——	3,464,461	3,464,461
Culm bank	1,462,002	697,984	2,159,986
Dredge	3,466	258,438	261,904
Total (surface)	3,278,844	579,819,239	583,098,083
Total (underground and surface)	3,648,802	983,052,689	986,701,491

Adapted from MSHA [1993].
*Includes sub-bituminous and lignite.

account for the remainder. At an auger mine, coal is recovered with a large-diameter, screw-type drill that is driven up to 200 feet into a coal seam that outcrops on a hillside [EIA 1993]. Although auger mining is inefficient (only 35% of the coal is recovered), it produces coal at a lower cost in seams that are thin, dirty, isolated, or not economically recovered by other surface methods. In addition, labor costs are minimal because only the auger operators and truck drivers are needed [Porterfield and Phelps 1981]. Silty coal fines are recovered from bodies of water with coal dredges. Culm banks, the hillside where waste from anthracite mines is dumped, have been reclaimed for the fine anthracite (culm) [EIA 1993].

Strip mining is a large-scale, earth-moving process during which the overburden (or material overlying a bed of coal) is excavated and the underlying coal is removed. The working area of the strip mine is known as the pit. Overburden material excavated from the strip being mined typically is side-cast into the strip pit previously mined. The process is repeated over and over until some limit is reached (e.g., a geological limit; a property-line limit; or some economic or equipment limit) [Stefanko 1983]. The average thickness of the overburden to be removed at surface coal mines typically ranges between 30 and 60 ft. The nature of the overburden at surface coal mines is variable but is generally some combination of sandstone, shale, limestone and loose soils. The unexcavated face of exposed overburden or coal in a strip pit is referred to as the "highwall." Highwalls up to 180 ft in height have been mined [Stefanko 1983].

The process of extracting coal from a surface-coal strip mine and delivering it to consumers typically involves the following operations: (1) drilling, (2) blasting, (3) overburden excavation (stripping), (4) coal loading, (5) coal haulage, (6) reclamation, (7) coal preparation, and (8) transportation to the consumer [Stefanko 1983]. Coal preparation and transportation to the consumer are common processes to all coal mining ventures.

3.2.2.1 Drilling

Topsoil is first removed and stored for reclamation of the area to be mined. In most cases, holes are drilled in the overburden material where explosives can be placed for blasting. Drilling and blasting the overburden layer creates fragments that are easier to excavate and results in fewer problems with the operation and maintenance of excavating equipment (and thus a more rapid and economical stripping process) [Stefanko 1983].

If the overburden is greater than 50 ft thick, vertical holes for blasting are drilled in the highwall. The advantage of drilling vertical holes rather than placing explosives in a horizontal hole above the coal seam is that thicker and harder layers of overburden may be fractured without damaging the underlying coal seam. In some mines, vertical holes for blasting are also routinely drilled when the overburden is less than 50 ft thick [Stefanko 1983].

The spacing of the vertical holes in the highwall depends on factors such as the strength of the overburden material to be blasted and the type of explosive that will be used. A larger hole allows a greater amount of explosives and permits greater spacing between holes. Thus, 15-in.-diameter holes might be placed about 35 ft apart, whereas 7-in.-diameter holes might be spaced about 15 ft apart.

A stream of compressed air (referred to as "bail air") is typically injected into the drill stem and forced out through orifices in the drill bit. This air cools the drill bit's cutting points and bearings and keeps the hole being drilled free of cuttings. The injected air bails the drill cuttings up and out of the drill hole. The bail air exiting from the drill hole forms a dust cloud that may contain relatively large amounts of crystalline silica. The amount of dust from the drill hole and the amount of respirable crystalline silica in the dust cloud may fluctuate considerably, depending on factors such as geology, drilling methods, weather conditions, and water content [BOM 1986]. These factors must be considered when selecting a dust collection method for the drilling machinery.

When the overburden is less than 50 ft thick and consists of soft shale materials, an auger-type drill may be used to place long horizontal holes for blasting about 1 to 2 ft above the coal seam. This horizontal hole approach allows a large area of overburden to be blasted with a small number of holes [Stefanko 1983].

3.2.2.2 Blasting

The next step in the work process is to place explosives in the holes that have been drilled in the overburden. Ammonium nitrate (94%) with fuel oil (6%) (generically referred to as ANFO) is the most commonly used explosive in surface coal mining. This explosive is detonated by using special cast primers that are in turn ignited by blasting caps. A detonating fuse is typically used with a highly explosive core of pentaerythritol tetranitrate (PETN). Millisecond-delay elements permit delays between detonation of individual holes to improve fragmentation [Stefanko 1983].

3.2.2.3 Overburden Excavation (Stripping)

The blast causes some of the overburden to fall into the pit. However, most of the overburden is retained in the highwall area as fragmented material. Several different types of equipment may be used to remove the fragmented overburden material. Descriptions of this equipment are provided in Table 3-6. When there are small amounts of overburden, bulldozers, scrapers, and front-end loaders may be used. When there are large amounts of overburden, power shovels may be operated in the pit, or draglines may be operated from on top of the overburden beside the pit. In addition, bucket-wheel excavators are used at a few surface coal mines in the United States [Stefanko 1983].

The overburden removed in gaining access to the coal is called the spoil. The excavated overburden from the pit and the highwall are typically discharged (spoiled) at the side of the pit opposite the highwall. The process builds up mounds of loose material that are collectively called the spoil bank [Stefanko 1983].

3.2.2.4 Coal Loading

Following overburden removal, the exposed coal seam is excavated and loaded onto trucks by power shovels or by front-end loaders, either rubber-tired or track-mounted. In some mines, coal excavation may include drilling and blasting (so that the coal can be excavated with relative ease) or using a ripper to loosen it [Stefanko 1983].

3.2.2.5 Coal Haulage

In the United States, large, off-highway diesel or electric trucks are typically used in surface coal mines to transport coal from the pit to the coal preparation plant or a railroad loading siding. Eastern and midwestern strip mines tend to employ rear-dump units (35- to 85-ton capacity) because this type of truck maneuvers well in compact pit operations, has good traction capabilities, and can cope with the steep ramps and sharp haul road turns. Westernstrip mines tend to use drop-bottom tractor-trailer units (100- to 200-ton capacity) because the pits are larger, the haul distances are longer, the ramps have gentler grades, and traction is not a problem [Stefanko 1983].

3.2.2.6 Reclamation

The Surface Mining Control and Reclamation Act of 1977 [30 USC 1201 et seq.] and State laws require reclamation of a surface mine work area after coal has been extracted. Reclamation enables the land to be used in the future for some other purpose; it also minimizes wind and water erosion, and it is more aesthetically acceptable. The reclamation process includes putting the overburden back in the same stratigraphic layer in which it originally existed, providing drainage, replacing topsoil, recontouring, and reestablishing permanent vegetation [Stefanko 1983].

3.2.2.7 Coal Preparation

Most of the coal produced in the United States undergoes some degree of processing or preparation before it is used. The amount of preparation depends on the specifications of the customer. About two-thirds of the coal shipped to electric power plants from eastern mines is cleaned, whereas most of the coal shipped to electric utilities from western mines is only crushed and screened to facilitate handling and to remove any extraneous material [EIA 1989].

Table 3-6. Glossary of surface coal mining equipment

Equipment name	Description
Auger	A large-diameter (16- to 48- in.) screw drill that cuts, transports, and loads overburden or coal onto vehicles or conveyors.
Bucket wheel	A boom-mounted, rotating, vertical wheel with buckets on its periphery used to load an internal conveyor network that discharges away from the digging area.
Bulldozer	A tractor with a vertically curved steel blade mounted on the front end. The blade is held at a fixed distance by arms secured on a pivot or shaft near the horizontal center of the tractor.
Dragline	Excavating equipment that can cast a cable-hung bucket a considerable distance. The dragline can collect material by pulling the bucket toward itself on the ground with a second cable, elevate the bucket, and dump the material in a pile.
Front-end loader	A tractor-loader with a digging bucket mounted and operated on the front end.
Power shovel	An excavating and loading machine with a digging bucket at the end of an arm suspended from a boom that extends crane-like from the part of the machine that houses the power plant.
Ripper	A steel accessory (tooth-shaped) that is mounted or towed by a bulldozer and is used in place of blasting for loosening compacted materials.
Scraper	A steel tractor that can dig, haul, and grade. A scraper has a cutting edge, a carrying bowl, a movable front wall, and a dumping or ejecting mechanism.

Sources: EIA [1989]; Skelly and Loy [1979].

Cleaning upgrades the quality and heating value of coal by (1) removing or reducing the amount of pyrite, rock, clay, or other ash-producing material, and (2) removing any materials mixed with the coal during mining, such as wire and wood. Coal cleaning is based on the principle that coal is lighter than rock and other impurities mixed or embedded in it. The impurities are separated by various mechanical devices using pulsating water current, rapidly spinning water, and liquids of different densities (dense media). Finely sized coal is cleaned by froth flotation. In this process, the coal adheres to air bubbles in a reagent and floats to the top of the washing device, whereas the refuse sinks to the bottom [EIA 1989]. Exposure to respirable dust at preparation plants may occur (1) during loading, unloading, and moving coal, (2) when processing equipment is cleaned, (3) when heavy media (e.g., magnetite) are added to liquid slurry to achieve a desired specific gravity in a cyclone, and (4) when refuse is transported [Llewellyn et al. 1981].

3.2.2.8 Transportation to Consumers

Coal may be delivered to consumers by several different modes of transportation, including railroads, barges, ships, trucks, conveyors, and slurry pipelines. Railroads deliver nearly 70% of the coal distributed to domestic customers and export terminals. More than half of all railroad coal shipments are made by unit trains (a train that is dedicated to coal transportation and that carries coal from a specified loading facility directly to a specified customer) [EIA 1989].

3.3 NUMBER OF MINERS POTENTIALLY EXPOSED IN U.S. COAL MINES

In 1992, an estimated 118,733 miners were employed in U.S. underground and surface coal mines, including 1,991 miners at anthracite coal mines and 116,742 miners at bituminous coal mines [MSHA 1993]. Of the 118,733 miners, 54% (64,481) were employed at underground coal mines, 34% (39,882) were employed at surface coal mines, and 12% (14,370) were employed at coal preparation plants or other operations [MSHA 1993].

3.3.1 Occupational Exposures in U.S. Coal Mines

MSHA requires that respirable dust samples be collected by mine operators to determine compliance with the PELs for respirable coal mine dust and respirable crystalline silica [30 CFR 70.201-70.220; 71.201-71.220]. MSHA also conducts periodic mine inspections and respirable dust sampling [MSHA 1989a]. From 1988 through 1992, approximately 350,000 respirable coal mine dust samples were collected in underground mines by both MSHA inspectors and coal mine operators, and approximately 19,700 samples were analyzed for respirable crystalline silica. In surface coal mines, approximately 60,600 respirable coal mine dust samples were collected, and approximately 4,100 samples were analyzed for respirable crystalline silica. Tables A-1 through A-3 in Appendix A provide the number of respirable coal mine dust samples collected by MSHA inspectors and mine operators and the number of samples analyzed for respirable crystalline silica each year from 1988 through 1992. Also listed for each year is the number of producing mines.

3.3.1.1 Exposures to Respirable Coal Mine Dust

Tables A-4 through A-7 list the concentrations of respirable coal mine dust in underground and surface coal mines. These concentrations are based on samples collected by MSHA inspectors and coal mine operators from 1988 to 1992. Samples for underground occupations (Tables A-4 and A-5) show that average concentrations of respirable coal mine dust from 1988 to 1992 were below 2.0 mg/m^{3}* for most occupations. However, even occupations with average concentrations below 2.0 mg/m^{3} had up to 42% of individual samples exceeding 2.0 mg/m^{3}. It should be noted that compliance with the MSHA PEL is currently determined by an arithmetic average of five samples collected during a normal production shift or work shift [30 CFR 70.207(a), 70.2(k)]. Thus, the occurrence of individual samples that exceed the MSHA PEL is not an indication that a mine is out of compliance. Another current regulation is that sampling devices are operated for a full shift or for 8 hr, whichever is less [30 CFR 70.201(b), 71.201(b)]. Thus, if actual work shifts exceed 8 to 10 hr/day and 40 hr/week, the measured concentrations would underestimate actual exposures. Area sampling results for respirable coal mine dust in underground mines from 1988 to 1992 are summarized in Table A-12.

Samples for surface coal mine and preparation plant occupations (Tables A-6 and A-7) show that the average concentrations of respirable coal mine dust from 1988 to 1992 were below 2.0 mg/m^{3} for all occupations. In general, less than about 16% of individual samples exceeded 2.0 mg/m^{3}.

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*Based on the current MSHA sampling method (Section 5.1), including use of the MRE conversion factor of 1.38 and a sampling flow rate of 2.0 L/min.

3.3.1.2 Exposures to Respirable Crystalline Silica

The average concentration of respirable crystalline silica from 1988 to 1992 was greater than the MSHA PEL of 0.1 mg/m^3 for up to 7 underground occupations and greater than the NIOSH REL of 0.05 mg/m^{3†} for more than 20 underground occupations (Tables A-8 and A-9). Among those occupations with *average* exposures to respirable crystalline silica less than or equal to the MSHA PEL of 0.1 mg/m^3, approximately one-third of all individual samples exceeded 0.1 mg/m^3. Area sampling results for respirable crystalline silica in underground coal mines from 1988 to 1992 are summarized in Table A-13.

In surface operations, the average concentration of respirable crystalline silica was greater than the MSHA PEL of 0.1 mg/m^3 for all occupations combined (see MSHA code 999, summary for valid occupations, in Tables A-10 and A-11). The average concentration of respirable crystalline silica exceeded the NIOSH REL of 0.05 mg/m^3 for up to 13 surface occupations. Exposures of drillers and driller helpers to respirable crystalline silica are of particular concern, with average concentrations from 1988 to 1992 ranging from 0.15 to 0.51 mg/m^3, and with up to 70% of all samples exceeding the MSHA PEL and up to 82% exceeding the NIOSH REL. Methods for controlling exposures during overburden drilling at surface coal mines are provided in Appendix D.

Only those samples with at least 0.5 mg of respirable coal mine dust are currently analyzed for respirable crystalline silica [Niewiadomski et al. 1990]. Therefore, the estimated values listed in Tables A-8 through A-11 for both the mean concentration of respirable crystalline silica and the percentage of samples exceeding specified concentrations may be biased toward higher concentrations and higher percentages.

Miners who show radiographic evidence of simple CWP category 1 or greater have the option to transfer to another position in the mine where the concentration of respirable dust is either <1.0 mg/m^3 (if attainable) or the lowest attainable concentration below 2 mg/m^3 [30 USC 843(b); 30 CFR 90]. Appendix B provides the respirable coal mine dust and respirable crystalline silica exposures of miners who elected to transfer under the provisions of 30 CFR 90. Tables B-1 through B-4 show that the average respirable coal mine dust concentrations for some occupations exceeded 1 mg/m^3. Among surface occupations, all of the average concentrations of respirable coal mine dust and most of the individual samples were below 1 mg/m^3. Exposure to respirable crystalline silica remains a concern for miners who elect to transfer [30 CFR 90]; Tables B-5 and B-6 show that exposures for some occupations (particularly roof bolters) exceeded the MSHA PEL of 0.1 mg/m^3. Furthermore, the average concentration of respirable crystalline silica for all underground occupations combined (Part 90 miners) exceeded the NIOSH REL of 0.05 mg/m^3 (Table B-5).

3.3.2 Occupational Exposures in Small Mines

Nearly 3,000 small coal mines are in operation in the United States, and more than 40,000 miners are employed at these small mines [MSHA 1994]. A small mine is one with fewer than 50 employees. Small mines are often operated by contract production operators and are part of a larger economic entity. Most small mines are located in the Appalachian regions of eastern Kentucky,

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[†] Based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion.

southern West Virginia, and southwestern Virginia. Sixty-five percent of the small mines are surface mines.

The incidence rates of fatalities and serious injuries have been higher in small mines than in larger mines [MSHA 1994]. The prevalence of simple CWP has also been found to be higher in small mines [Linch 1994]. Exposures to respirable coal mine dust in small coal mines do not exceed those in larger coal mines [Linch 1994], but there is concern that sampling procedures and inspections may be inadequate and that extended work schedules may result in exposures that exceed those reported [MSHA 1994]. In April 1994, MSHA convened a conference to focus on ways to improve safety and health in small mines [MSHA 1994].

4 HEALTH EFFECTS OF EXPOSURE TO RESPIRABLE COAL MINE DUST

This chapter describes the adverse health effects associated with exposure to respirable coal mine dust. Epidemiological studies of underground and surface coal miners in the United States and other countries are discussed. Also discussed are animal studies that add to our understanding of particle deposition and retention in the lungs and associated disease responses. This chapter emphasizes studies that (1) were performed since the passage of the Federal Coal Mine Health and Safety Act of 1969 [P.L. 91-173], (2) used standardized methods of exposure monitoring and disease classification, and (3) investigated exposure-response relationships between respirable coal mine dust exposure and disease. Several published review articles contain further discussion of health effects studies of coal miners [Attfield and Wagner 1992b; Petsonk and Attfield 1994; Cotes and Steel 1987; Merchant et al. 1986; Morgan and Lapp 1976; Morgan 1975].

4.1 DESCRIPTION OF OCCUPATIONAL RESPIRATORY DISEASES IN COAL MINERS

4.1.1 Historical Perspective

"Black lung" was recognized as a disease of British coal miners in the mid-17th century [Davis 1980]. The term "pneumonokoniosis" was introduced in 1866 and was shortened to "pneumoconiosis" in 1874 [Meiklejohn 1951]. The term means "dusty lung." The term "silicosis" was introduced in 1870 to describe pneumoconiosis resulting from silica [NIOSH 1974]. Investigations into the etiology of black lung disease began in the 1900s. By 1907, chest X-rays were used to study lung disease in coal miners, but their quality permitted detection of only gross pathological changes until about 1930 [Meiklejohn 1952 a,b].

The causative agent of pneumoconiosis in coal miners was thought to be silica until studies in the United Kingdom provided evidence that exposure to coal dust containing minimal silica could also cause pneumoconiosis [Collis and Gilchrist 1928; Gough 1940]. These investigators found pneumoconiosis among coal trimmers, who were responsible for the loading and distribution of coal (previously washed and separated from rock) into the holds of ships. King et al. [1956] later reported that the severity of pneumoconiosis (based on both radiographic and pathologic data) was related to the total dust in the lungs of U.K. coal miners but not to the silica content of the coal.

In the United States, few studies of pneumoconiosis in coal miners were performed before the 1960s [Dressen and Jones 1936; Flinn et al. 1941]. In the early 1960s, studies of pneumoconiosis were conducted among coal miners in central and western Pennsylvania [Lieben et al. 1961; McBride et al. 1963] and in seven states in the Appalachian region [Lainhart et al. 1968] (Section 4.2.1.1). By the early 1970s, investigators suggested that CWP was not a single disease but a composite of disorders, each varying in incidence and severity depending on geographic area, occupational exposure, and individual susceptibility [Naeye and Dellinger 1972].

In the Federal Coal Mine Health and Safety Act of 1969, CWP was defined as "a chronic dust disease of the lung arising out of employment in an underground coal mine" [30 USC 902]. The definition of pneumoconiosis was amended in the Black Lung Benefits Reform Act of 1977 as "a chronic dust disease of the lung and its sequelae, including respiratory and pulmonary impairments, arising out of coal mine employment" [30 USC 901(a) and 902(b)]. CWP has been medically defined as a parenchymal lung disease produced by deposits of coal dust in the lung and the response of the host to the retained dust [Weeks and Wagner 1986; Wyngaarden and Smith 1982].

4.1.2 Simple CWP and PMF

Diagnosis of CWP is generally based on chest X-ray findings and a history of working in coal mines (usually for 10 or more years) [Attfield and Wagner 1992b; Balaan et al. 1993]. The radiographic patterns are often the same for CWP and silicosis; thus, these diseases are distinguishable only by work history or pathological examination [Attfield and Wagner 1992b; Wagner et al. 1993b]. The radiographic appearance of simple CWP is not necessarily associated with impaired lung function [Parkes 1982; Morgan et al. 1974] or increased mortality [Cochrane et al. 1979; Jacobsen 1976]. However, miners with simple CWP are at increased risk of developing complicated CWP or PMF [Balaan et al. 1993; McLintock et al. 1971; Cochrane 1962].

PMF is associated with significant decreases in lung function, oxygen-diffusing capacity, and arterial blood gas tension (PaO_2) [Attfield and Wagner 1992b; Rasmussen et al. 1968]. PMF is also associated with breathlessness (at rest or with exercise), chronic bronchitis and recurrent chest illness, right ventricular hypertrophy, and episodes of right heart failure [Cotes and Steel 1987]. Coal miners with silicotic lesions or PMF have an increased risk of tuberculosis and other mycobacterial infections [Petsonk and Attfield 1994]. PMF may progress, even in the absence of further dust exposure [Stewart 1948; Parkes 1982; Merchant et al. 1986]. This disease is also associated with increased mortality [Atuhaire et al. 1985; Miller and Jacobsen 1985].

4.1.2.1 Radiographic Classification of Simple CWP and PMF

The opacities on the chest X-ray are classified according to their size, shape, profusion, and extent [ILO 1980] (Table 4-1). These classifications are used in the diagnosis of simple CWP and PMF.

4.1.2.1.1 Simple CWP

Simple CWP is characterized by the presence of small opacities <10 mm in diameter on the chest X-ray. These opacities are usually seen first in the upper lung zones, but the middle and lower zones may become involved as the disease progresses [Balaan et al. 1993]. The profusion of small opacities is classified as major category 1, 2, or 3. Category 0 is defined as the absence of small opacities, or as small opacities that are less profuse than the lower limit of category 1 [ILO 1980]. Within the 12-point profusion scale, each major category may be followed by a subcategory if an adjacent main category was seriously considered during the classification process (e.g., 1/2 was

Table 4-1. Summary of ILO classification of radiographs pertaining to simple CWP and PMF

Features	Codes	Definitions
Technical quality of radiographs	1	Good
	2	Acceptable (with no technical defect likely to impair classification of the radiograph for pneumoconiosis)
	3	Poor (with some technical defect but still acceptable for classification purposes)
	4	Unacceptable
Parenchymal abnormalities:		
Small opacities:		
Profusion		The category of profusion is based on assessment of the concentration of opacities by comparison with the standard radiographs.
	0/- 0/0 0/1 1/0 1/1 1/2	Category 0: Small opacities are absent or are less profuse than the lower limit of category 1.
	2/1 2/2 2/3 3/2 3/3 3/+	Categories 1, 2 and 3: These represent increasing profusion of small opacities as defined by the corresponding standard radiographs.
Extent	RU RM RL LU LM LL	The zones in which the opacities are seen are recorded. The right (R) and left (L) thorax are both divided into three zones—upper (U), middle (M), and lower (L).
		The category of profusion is determined by considering the profusion as a whole over the affected zones of the lung and by comparing this with the standard radiographs.
Shape and size:		
Round	p/p q/q r/r	The letters p, q, and r denote the presence of small, rounded opacities. Three sizes are defined by the appearance on standard radiographs: p = diameter up to about 1.5 mm q = diameter exceeding about 1.5 mm and up to about 3 mm r = diameter exceeding about 3 mm and up to about 10 mm
Irregular	s/s t/t u/u	The letters s, t, and u denote the presence of small, irregular opacities. Three sizes are defined by the appearances on standard radiographs: s = width up to about 1.5 mm t = width exceeding about 1.5 mm and up to about 3 mm u = width exceeding 3 mm and up to about 10 mm
Mixed	p/s p/t p/u p/q p/r q/s q/t q/u q/p q/r r/s r/t r/u r/p r/q s/p s/q s/r s/t s/u t/p t/q t/r t/s t/u u/p u/q u/r u/s u/t	For mixed shapes (or sizes) of small opacities, the predominant shape and size is recorded first; the presence of a significant number of another shape and size is recorded after the oblique stroke.

(Continued)

Table 4-1 (Continued). Summary of ILO classification of radiographs pertaining to simple CWP and PMF

Features	Codes	Definitions
Parenchymal abnormalities (continued):		
Large opacities		The categories are defined in terms of the dimensions of the opacities.
	A	Category A: An opacity having a greatest diameter exceeding about 10 mm and up to and including 50 mm, or several opacities each greater than about 10 mm, the sum of whose greatest diameters does not exceed about 50 mm.
	B	Category B: One or more opacities larger or more numerous than those in category A whose combined area does not exceed the equivalent of the right upper zone.
	C	Category C: One or more opacities whose combined area exceeds the equivalent of the right upper zone.
Symbols*	ax	Coalescence of small pneumoconiotic opacities
	bu	Bulla(e)
	ca	Cancer of lung or pleura
	cn	Calcification in small pneumoconiotic opacities
	co	Abnormality of cardiac size or shape
	cp	Cor pulmonale
	cv	Cavity
	di	Marked distortion of the intrathoracic organs
	ef	Effusion
	em	Definite emphysema
	es	Eggshell calcification of hilar or mediastinal lymph nodes
	fr	Fractured rib(s)
	hi	Enlargement of hilar or mediastinal lymph nodes
	ho	Honeycomb lung
	id	Ill-defined diaphragm
	ih	Ill-defined heart outline
	kl	Septal (Kerley) lines
	od	Other significant abnormality
	pi	Pleural thickening in the interlobar fissure or mediastinum
	px	Pneumothorax
	rp	Rheumatoid pneumoconiosis
	tb	Tuberculosis
Comments:		
Presence	Y N	Comments about the classification should be recorded—especially if some cause other than pneumoconiosis is thought to be responsible for a shadow that could be interpreted by others as pneumoconiosis; comments should also be recorded to identify radiographs whose technical quality may materially affect the reading.

Adapted from ILO [1980].

*The definition of each of the symbols is preceded by an appropriate word or phrase such as "suspect," "changes suggestive of," or "opacities suggestive of," etc.

judged as category 1, but category 2 was seriously considered; 2/1 was judged as category 2, but category 1 was seriously considered). The shape of the small opacities is recorded as rounded (p, q, r) or irregular (s, t, u). The diameters of these opacities are ≤1.5 (p or s), 1.5 to 3 mm (q or t), or 3 to 10 mm (r or u).

4.1.2.1.2 PMF (complicated CWP)

PMF (or complicated CWP) is classified radiographically as category A, B, or C when large opacities with a combined area of 1 cm or larger are found on the chest X-ray. PMF usually develops in miners already affected by simple CWP, but it may also develop in miners with no previous radiographic evidence of simple CWP [Hodous and Attfield 1990; Hurley et al. 1987].

An unusual presentation of PMF or Caplan's nodule(s) may be difficult to distinguish from a primary or metastatic neoplasm [Lapp and Parker 1992]. When large opacities occur bilaterally on a background of simple CWP, a diagnosis of PMF is reasonably certain; however, when the radiographic background of simple CWP is sparse or absent, or when there are multiple crops of peripherally situated nodules (Caplan's syndrome), it may be difficult to differentiate between PMF and neoplasm [Lapp and Parker 1992].

4.1.2.1.3 Pleural abnormalities

Pleural abnormalities on the chest X-ray (including pleural thickening of the chest wall or diaphragm, obliteration of the costophrenic angle, and pleural calcification) should also be recorded according to the International Labour Office (ILO) classification [ILO 1980].

4.1.2.1.4 Interpretation of chest X-rays

Individuals who interpret chest X-rays under the Federal Mine Safety and Health Act of 1977 [30 USC 843] must be either an A or B reader [42 CFR Part 37]. A person can become an A reader by attending a NIOSH-approved course on interpretation of chest X-rays for pneumoconioses. Certification as a B reader requires passing an examination that tests proficiency in interpretation of chest X-rays for pneumoconioses [Wagner et al. 1992; Morgan 1979]. B readers are therefore considered to have more expertise than A readers in interpreting chest X-rays. Several studies have examined the variability between readers in interpreting radiographic appearances of pneumoconioses [Collins and Soutar 1988; Attfield et al. 1986; Felson et al. 1973; Fletcher and Oldham 1949]. Attfield and Wagner [1992a] discuss training, certification, and quality assurance.

4.1.2.2 Pathological Classification of CWP and PMF

The primary histopathological lesion of CWP is the coal macule [Cotes and Steel 1987]. The macular lesion of CWP has been defined as "a focal collection of coal-dust-laden macrophages at the division of respiratory bronchioles that may exist within alveoli and extend into the peribronchiolar interstitium with associated reticulin deposits and focal emphysema" [Kleinerman et al. 1979]. The primary lesion of CWP is focal, like that of silicosis; but it differs in the amount and nature of dust, the quantity and disposition of fibrous tissue, and the presence of focal emphysema [Heppleston 1992]. Coal macules range in size from 1 to 5 mm and may be rounded, irregular, or stellate [Attfield and Wagner 1992b]. Macular lesions are usually symmetrically distributed in both lungs, with a greater concentration in the upper lobes [Merchant et al. 1986]. Dust-laden macules occur in the region of the first-, second-, and third-order respiratory bronchioles [Attfield and Wagner 1992b]. Macrophages found in both the air spaces and the connective tissue around the respiratory bronchioles may contain dust [Merchant et al. 1986]. The proportion of dust, cellular material, or collagen varies depending on the rank of coal dust inhaled [Cotes and Steel 1987].

Focal emphysema has been defined as the emphysematous changes that are focal in nature and consist of dilation and destruction of alveoli adjacent to the respiratory bronchioles where dust has aggregated [Kleinerman et al. 1979]. Focal emphysema usually involves a region of 1 to 2 mm around the dust-laden macule [Merchant et al. 1986; Attfield and Wagner 1992b].

The macule is a discrete lesion of connective tissue and dust, but it is not necessarily palpable [Kleinerman et al. 1979]. In addition to macules, a variety of nodular lesions are found in coal miners' lungs; these may or may not be related to occupational exposures [Kleinerman et al. 1979]. These nodules are classified according to size and etiology and include the following categories: micronodular CWP (up to 7-mm diameter), macronodular CWP (7- to 20-mm diameter), silicotic nodule, PMF, Caplan's lesion, and infective granuloma (histoplasmosis, tuberculosis) [Kleinerman et al. 1979]. The nodular lesions of simple CWP are palpable because they contain collagen and are sometimes calcified [Merchant et al. 1986].

The National Coal Workers' Autopsy Study [30 CFR 37 Subpart—Autopsies] uses lesions ≥1 cm as the anatomical definition of PMF—a definition consistent with the radiographic definition of opacities ≥1 cm [ILO 1980]. The American College of Pathologists has recommended using lesions ≥2 cm as a more appropriate anatomical definition of PMF for pathological studies [Kleinerman et al. 1979]. The lesions of PMF are solid, heavily pigmented, and rubbery to hard; a PMF lesion may also contain a cavity containing opaque black liquid [Kleinerman et al. 1979; Merchant et al. 1986]. PMF lesions usually occur in the apical posterior portions of the upper lobes or the superior segments of the lower lobes [Kleinerman et al. 1979]. Histologically, the periphery is composed of irregular reticulin and collagen interspersed with black pigment [Merchant et al. 1986]. Blood vessels and airways transversing the lesion are destroyed [Merchant et al. 1986]. PMF generally occurs on a background of simple CWP, and lesions of simple CWP in this case are usually nodular rather than macular [Merchant et al. 1986]. PMF is asymmetrical, in that one lung may be more severely affected than the other [Kleinerman et al. 1979].

4.1.2.3 Relationship Between Chest X-rays, Pathology, and Lung Dust Content

Rossiter [1972a,b] reported a correlation between the radiographic category of simple CWP and the weight of the dust in the lungs of coal miners. Later studies provided information about the types of radiographic opacities and particles in the lungs. Ruckley et al. [1984] reported that the size (radiographic type) of opacity was related to the lung dust weights (see Section 4.1.2.1 for a discussion of radiographic opacities). Miners with the smallest opacities (p) had greater lung dust weights than miners with the largest opacities (r) [Ruckley et al. 1984]. The relationship between the profusion of r-type opacities and lung dust weight was poor, although few cases were examined [Fernie and Ruckley 1987]. Among miners with predominantly p-type opacities, total lung dust provided the best correlation with radiographic profusion; of the pathologic lesions, the number of pinhead nodules (<1-mm diameter) correlated with radiographic profusion [Fernie and Ruckley 1987].

Several investigators have reported a relationship between increasing severity of pathological lesions and increasing mean weight of lung dust [King et al. 1956; Nagelschmidt 1965; Douglas et al. 1986]. However, the percentage of quartz in the total dust was similar (about 6%) for most lesions [King et al. 1956; Nagelschmidt 1965]. These findings suggest that coal dust is more closely associated than silica with the development of simple CWP and PMF. An exception to the above pattern—a decreased amount of total dust and increased amount of silica found in the most severe pathological lesion [King et al. 1956]—might have been related to the additional factor of tuberculosis infection [King et al. 1956]. Douglas et al. [1986] found that miners with PMF had retained more dust in their lungs per unit of dust exposure (during life) than miners without PMF. This finding suggests greater deposition and/or less clearance of dust in the lungs of miners who developed PMF. Among miners of high-rank coal (88.8% to 94% carbon), the composition of lung dust was similar for different pathological lesions [Douglas et al. 1986; 1988]. But among miners of low-rank coal (81.1% to 87% carbon), the proportion of ash* in retained dust was higher than that in the airborne dust to which they had been exposed—and this proportion increased with increasing severity of pathological lesions.

Gough et al. [1950] reported that chest X-rays did not always detect slight pathological grades of pneumoconiosis (see Sections 4.1.2.1. and 4.1.2.2 for discussions about radiographic opacities and pathological lesions). More recently, Attfield et al. [1994] reported that increasing pathological grade of coal macules was associated with a greater likelihood of detecting an abnormality on the chest X-ray (predominant types of opacities were m [mixed], p, and q) [Attfield et al. 1994]. However, there was also a probability (up to 33%) that the chest X-ray would indicate no abnormality (category 0), even when moderate and severe grades of macules were present [Attfield et al. 1994]. Caplan [1962] reported that radiographic appearances were more closely associated with the profusion of nodules than with other types of dust foci. Similarly, Attfield et al. [1994] found better association between the presence of micro- and macro-nodules and the detection of radiographic abnormality: only 0% to 9% of the cases with moderate and severe grades of micro- and macro-nodules had a normal chest X-ray (category 0). Micro- and macro-nodules tended to be associated with the appearance of q- and r-type opacities on the chest X-ray [Ruckley et al. 1984; Attfield et al. 1994]. Douglas et al. [1988] found that three types of PMF lesions were equally associated with the radiographic appearance of large opacities.

4.1.3 Silicosis

Silicosis may develop when inhaled respirable crystalline silica is deposited in the lungs. The disease may be chronic, complicated, accelerated, or acute. The clinical diagnosis of silicosis is based on (1) recognition by the physician that the silica exposure is adequate to cause the disease, (2) the presence of chest radiographic abnormalities consistent with silicosis, and (3) the absence of other illnesses (e.g., tuberculosis or pulmonary fungal infection) that may mimic silicosis [Balaan and Banks 1992].

4.1.3.1 Chronic Silicosis

Chronic silicosis commonly involves 15 or more years of exposure to silica [Parker 1994]. The characteristic microscopic feature is the silicotic nodule, which can be divided into three zones [Silicosis and Silicate Disease Committee 1988]. The central zone is composed of whorls of dense, hyalinized fibrous tissue. The midzone is made up of concentrically arranged collagen fibers that often exhibit a feature known as onion skinning. The peripheral zone consists of more randomly oriented collagen fibers mixed with dust-laden macrophages and lymphoid cells. Chronic silicosis

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*Ash is the solid residue remaining after coal is burned; quartz, kaolin, and mica are common constituents of ash.

is often asymptomatic and may manifest itself as a radiographic abnormality with small, rounded opacities of less than 10 mm in diameter, predominantly in the upper lobes [Parker 1994]. Lung function may be normal or show mild restriction [Parker 1994]. Chronic silicosis is associated with a predisposition to tuberculosis and other mycobacterial infections and with progression to complicated silicosis [Balaan and Banks 1992].

4.1.3.2 Complicated Silicosis

Complicated silicosis, or PMF, occurs when the nodules coalesce and form large conglomerate lesions [Weber and Banks 1994]. Complicated silicosis is characterized radiographically by the presence of nodular opacities >1 cm in diameter on the chest X-ray [Parker 1994]. Complicated silicosis typically causes respiratory impairment that may first manifest itself as exertional dyspnea; this disease commonly involves reduced carbon monoxide diffusing capacity, reduced arterial oxygen tension at rest or with exercise, and marked restriction on spirometry or lung volume measurement [Parker 1994; Balaan and Banks 1992]. Recurrent bacterial infection may occur, and tuberculosis is a concern. Distortion of the bronchial tree may lead to airway obstruction and productive cough. Pneumothorax, a life-threatening complication, may occur because the fibrotic lungs may be difficult to re-expand [Parker 1994; Balaan and Banks 1992]. Hypoxemic respiratory failure with cor pulmonale is a common terminal event [Parker 1994].

4.1.3.3 Accelerated Silicosis

In accelerated silicosis, the duration of exposure is usually 5 to 10 years [Parker 1994]. The lung nodules seen are at an earlier stage of development than those in chronic silicosis [Silicosis and Silicate Disease Committee 1988]; but otherwise, the lung nodules in accelerated silicosis have no specific distinguishing morphologic feature. Symptoms, radiographic findings, and physiologic measurements are similar to those seen in the chronic form [Parker 1994]. Disease progression is likely even if the worker is removed from the workplace [Balaan and Banks 1992]. Autoimmune diseases, including scleroderma and rheumatoid arthritis, are commonly associated with accelerated silicosis [Parker 1994; Balaan and Banks 1992].

4.1.3.4 Acute Silicosis

Acute silicosis may develop within 6 months to 2 years of intensive exposure to fine particles of nearly pure silica—such as those present during sandblasting or drilling. Because acute silicosis is characterized by the filling of lung alveoli with lipoproteinaceous material, it is also known as silicotic alveolar proteinosis [Silicosis and Silicate Disease Committee 1988]. Microscopically, the material in the alveolar air spaces consists of an amorphous, finely granular eosinophilic substance that stains by the periodic acid-Schiff reaction but is resistant to diastase digestion and nonreactive to traditional mucin stains [Silicosis and Silicate Disease Committee 1988]. The risk of tuberculosis or other mycobacterial infection is greater in acute silicosis than in the chronic or accelerated forms [Parker 1994; Weber and Banks 1994].

4.1.4 Mixed-Dust Pneumoconiosis

In coal mining, particularly surface coal mining, the typical worker is exposed to a mixture of dusts over a working lifetime rather than to silica alone or to carbonaceous dust alone. The term "mixed-dust lesion" has been used to describe pulmonary lesions where crystalline silica is deposited

Table 4-2. Terms and diagnostic criteria for describing airways disease*

Disease	Diagnostic criteria	Definition
Asthma	Clinical features	Acute, episodic airflow limitation reversible spontaneously or on treatment† [Fletcher and Pride 1984; ATS 1987b; Tecelescu 1990]
Chronic bronchitis	Symptoms	Chronic or recurrent bronchial hypersecretion‡ (i.e., almost daily sputum for 3 months of the year for at least 3 years) [Fletcher and Pride 1984; ATS 1987b; Tecelescu 1990]
Emphysema	Pathologic features	Dilatation of air spaces distal to the terminal bronchiole with destructive changes in the alveolar walls [Fletcher and Pride 1984; ATS 1987b]
COPD	Lung function deficit with or without other clinical features	Main feature is chronic airflow limitation (largely irreversible) that may, in certain circumstances, be primarily in peripheral airways [Fletcher and Pride 1984; ATS 1987b; Snider 1989; Tecelescu 1990]

Adapted from Becklake [1992].

*Based on definitions proposed by the 1959 Ciba Guest Symposium [Ciba 1959; Fletcher and Pride 1984], the American Thoracic Society [ATS 1987b], and other commentators [Snider 1989; Tecelescu 1990].

†Some definitions included the feature of airway hyperresponsiveness [ATS 1987b].

‡Assessed by clinical history or respiratory symptoms questionnaire.

deposited in combination with less fibrogenic dusts such as iron oxides, kaolin, mica, and coal. Typically, the mixed-dust lesion has a stellate "medusa head" configuration. This lesion has a central zone of collagen that is often hyalinized and surrounded by linearly and radially arranged collagen and reticulin fiber strands mixed with dust-containing macrophages [Silicosis and Silicate Disease Committee 1988].

The knowledge that mixed-dust lesions may occur in coal miners is important in the context of screening for adverse respiratory health effects. Except in the case of acute silicosis (which has a distinctive radiologic presentation similar to pulmonary edema and other diseases that fill air space with fluids and cells), the chest X-ray alone cannot indicate whether changes consistent with pneumoconiosis have resulted from carbonaceous dust or silica dust. That is, in the absence of lung tissue examination or knowledge of the exposure history, a chest X-ray showing pneumoconiosis in a coal miner may represent CWP, silicosis, or mixed-dust pneumoconiosis [Cotes and Steel 1987].

4.1.5 COPD

COPD refers to three disease processes—chronic bronchitis, emphysema, and asthma—that are all characterized by airway dysfunction [Barnhart 1994; Becklake 1992]. Airflow limitation (of varying degree and reversibility) and shortness of breath (nonspecific symptom) are underlying features of COPD [Becklake 1992]. Asthma is characterized by reversible airflow obstruction; chronic bronchitis and emphysema may have partially reversible airflow limitation [Barnhart 1994]. Lung function tests are used to establish the presence of COPD [Becklake 1992]. Table 4-2 lists definitions and diagnostic criteria for COPD and other airways diseases. A major cause of COPD is cigarette smoking; but air pollution and occupational exposure to dust, particularly among smokers, can also cause COPD [Samet 1989; Fletcher et al. 1976]. Chronic bronchitis is characterized by symptoms of chronic mucus hyper-secretion [Becklake 1992]. Chronic bronchitis can also be associated with airflow obstruction and abnormalities in gas exchange [Barnhart 1994]. Pathologically, chronic bronchitis involves hypertrophy and hyperplasia of bronchial mucous glands and the lack of cartilaginous support of the airways [Kilburn 1986]. Occupational or industrial bronchitis is chronic bronchitis that is caused or aggravated by occupational exposure to dust [Morgan and Lapp 1976].

Emphysema is defined as the abnormal, permanent enlargement of air spaces [Barnhart 1994] distal to the terminal bronchiole, accompanied by destruction of their walls [ATS 1962]. Either pathological features or computed tomography can be used to determine the presence of emphysema [Becklake 1992]. The several types of emphysema are classified in terms of lung structure [Thurlbeck 1976].

4.2 EPIDEMIOLOGICAL STUDIES

4.2.1 Studies of Simple CWP, PMF, and Silicosis

4.2.1.1 U.S. Studies from the 1960s

Before 1970, the average concentration of respirable dust for most job categories in underground coal mines exceeded 2 mg/m^3, and the average concentration for some jobs at the working face (where the coal is extracted) exceeded 6 mg/m^3 [Attfield and Wagner 1992b] (Figure 4-1).

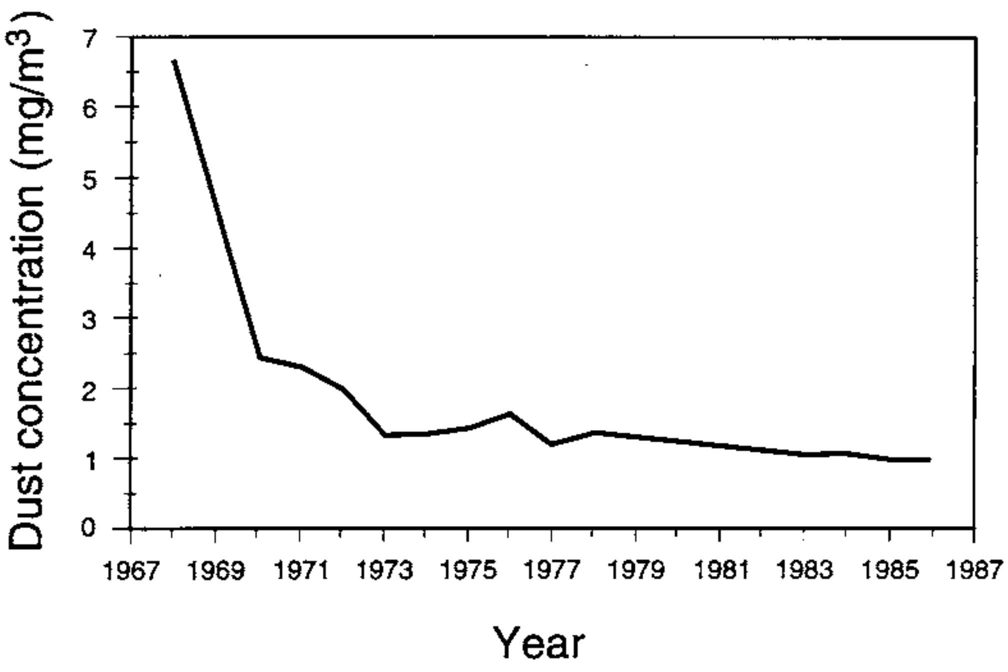

Figure 4–1. Reported trends in dust concentrations for continuous miner operators, 1968–87. (Source: Attfield and Wagner [1992b].)

U.S. studies from the 1960s have reported prevalences of simple CWP category 1 or greater ranging from 4% to 46% (Table 4-3). In these studies, the factors associated with the higher prevalences of simple CWP and PMF were (1) exposure to dust of higher-rank coal, (2) greater number of years worked in mining (especially years worked underground), and (3) increasing age of the miner. Because the mean number of years worked in mining and the mean ages were similar across the various studies (Table 4-3), these factors probably do not account for the different prevalences observed among miners in different regions of the United States. Instead, these differences have generally been attributed to the various ranks of coal mined in these regions.

Lainhart [1969] observed that the prevalence of pneumoconiosis[†,‡] increased as coal rank increased. He reported the following prevalences of pneumoconiosis among miners in the following regions of increasing coal rank: Utah, 4.8%; Illinois and Indiana, 7.5%; and Appalachia, 11.1%. Miners in each region had no significant differences in mean age or mean number of years worked underground. The overall rate of participation in the study was also similar for each region, ranging from 91.7% to 97.5%.

McBride et al. [1963, 1966] observed that the prevalence of pneumoconiosis[†,§] increased with increasing number of years worked. Among working bituminous coal miners in western Pennsylvania, the prevalence of pneumoconiosis was 3%, 8%, 14%, 18%, and 26%, respectively, for groups with <20, 20-24, 25-29, 30-39, and ≥40 years of experience [McBride et al. 1963]. Among working anthracite coal miners in Pennsylvania, the prevalence of pneumoconiosis was 10%, 21%, 39%, 56%, and 50%, respectively, for the same years of experience.

The prevalence of pneumoconiosis was higher among retired coal miners than among working coal miners with a similar number of years of experience. Among retired bituminous coal miners, the prevalence of pneumoconiosis was 24%, 22%, and 32%, respectively, among those with <30, 30-39, and ≥40 years of experience. Among retired anthracite coal miners, the prevalence of pneumoconiosis was 52%, 80%, and 80%, respectively, for the same years of experience. McBride et al. [1963, 1966] also observed increasing prevalence of pneumoconiosis with increasing age.

4.2.1.2 U.S. Studies from 1970 to Present

The National Study of Coal Workers' Pneumoconiosis and the Coal Workers' X-Ray Surveillance Program were established in response to the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-73).[**] The National Study of Coal Workers' Pneumoconiosis is an epidemiological research study [Attfield et al. 1984a,b], and the Coal Workers' X-Ray Surveillance Program is a medical screening and surveillance program [Althouse et al. 1986, 1992]. NIOSH administers these ongoing programs, both of which began about 1970. Results from successive cross-sectional surveys (or rounds) of these studies have shown general downward trends in the prevalence rates of simple CWP among U.S. underground coal miners (Table 4-4 and Figure 4-2).

[†] Pneumoconiosis is defined here as simple CWP (category 1 or greater) or complicated CWP (PMF).

[‡] The 1959 International Radiological Classification of Chest Films was used [ILO 1959].

[§] The U.S. Public Health Service modification of the International Radiological Classification of Chest Films was used [Ashford and Enterline 1966].

[**] This Act was later amended by the Federal Mine Safety and Health Act of 1977 [30 USC 801-962].

Table 4-3. Prevalence of CWP (category 1 or greater) and PMF for some U.S. studies undertaken between 1961 and 1970, in order of coal rank

Study (by coal rank)	Prevalence: CWP (category 1 or greater)	Prevalence: PMF	Mean age (years)	Mean tenure (years): All work in coal mining	Mean tenure (years): Work underground	Comments
High rank:						
Eastern Pennsylvania [McBride et al. 1966]	22	9.6	55	26	——	*
Eastern Pennsylvania [Tokuhata et al. 1970]	34	——	45	——	22	*,†
Medium-high rank:						
Central Pennsylvania [Lieben et al. 1961]	25	8.3	47	27	——	*
Southern West Virginia [Hyatt et al. 1964]	46	7.2	52	——	25	*,‡
Southern West Virginia [Enterline 1967]	14	5.4	44	——	——	§
Medium rank:						
Appalachia [Lainhart 1969]	10	3.0	47	——	22	**
Eastern West Virginia [Enterline 1967]	6	1.1	43	——	——	§
Northern West Virginia [Higgins et al. 1968]	7	0.9	48	——	19	*,‡
Western Pennsylvania [McBride et al. 1963]	9	3.7	47	26	——	*
Medium/low rank:						
Illinois/Indiana [Lainhart 1969]	6	1.5	48	——	20	**
Utah [Lainhart 1969]	4	0.7	51	——	20	**

Adapted from Attfield and Castellan [1992].

[*] The 1959 ILO classification was used.

[†] Exact figure for average age is not given; figure given here has been estimated from age distribution data.

[‡] Group contains both current miners and ex-miners and could not be subdivided [ILO 1959].

[§] Radiographic classification is not stated but is probably the ILO 1959 scheme, given that the study was undertaken from 1963 to 1964.

[**] The classification used is not stated explicitly. The reading sheet shown in the report looks very similar to that of the ILO 1968 classification [ILO 1970], but Morgan [1968] states that the ILO 1959 classification system was used.

Table 4–4. Adjusted summary prevalence estimates for combined small opacities from the Coal Workers' X-ray Surveillance Program and the National Study of Coal Workers' Pneumoconiosis

Category	Study[*]	Reader	Adjusted summary prevalences (%)[†]			
			Round 1	Round 2	Round 3	Round 4
CWP category 1 or greater:						
All participants	CWXSP[‡]	First	22.4	7.1	6.0	5.5
		Second	13.8	5.9	5.7	3.0
Tenure >4 years	CWXSP[§]	First	35.0	20.3	11.4	7.8
		Second	22.1	18.2	9.2	4.0
Common tenure distribution	CWXSP[**]	First	19.5	11.7	8.7	7.2
		Second	10.7	9.9	7.3	3.6
Epidemiological data, common tenure distribution[**]	NSCWP		6.6	5.1	3.6	2.3
CWP category 2 or greater:						
All participants	CWXSP[‡]	First	6.5	1.8	1.1	0.8
		Second	4.5	1.2	0.6	0.3
Tenure >4 years	CWXSP[§]	First	10.8	5.7	2.2	1.2
		Second	7.5	3.8	1.3	0.5
Common tenure distribution	CWXSP[**]	First	4.0	2.0	1.2	1.0
		Second	2.4	1.2	0.7	0.4
Epidemiological data, common tenure distribution[**]	NSCWP		1.5	1.2	0.5	0.3

Source: Attfield and Althouse [1992].

[*] Abbreviations: CWXSP: Coal Workers' X-ray Surveillance Program; NSCWP: National Study of Coal Workers' Pneumoconiosis.

[†] Dates for various rounds of the CWXSP are as follows: round 1, 1970-73; round 2, 1973-78; round 3, 1978-81; round 4, 1981-86.

Dates for various rounds of the NSCWP are as follows: round 1, 1969-71; round 2, 1972-75; round 3, 1977-81; round 4, 1985-88.

[‡] All participants = summary rates based on all mandatory and voluntary X-rays.

[§] Tenure >4 years = summary rates based on all miners with more than 4 years of tenure in mining.

[**] Common tenure distribution = summary rates standardized to date in the far-right column of Table 2 of Attfield and Althouse [1992].

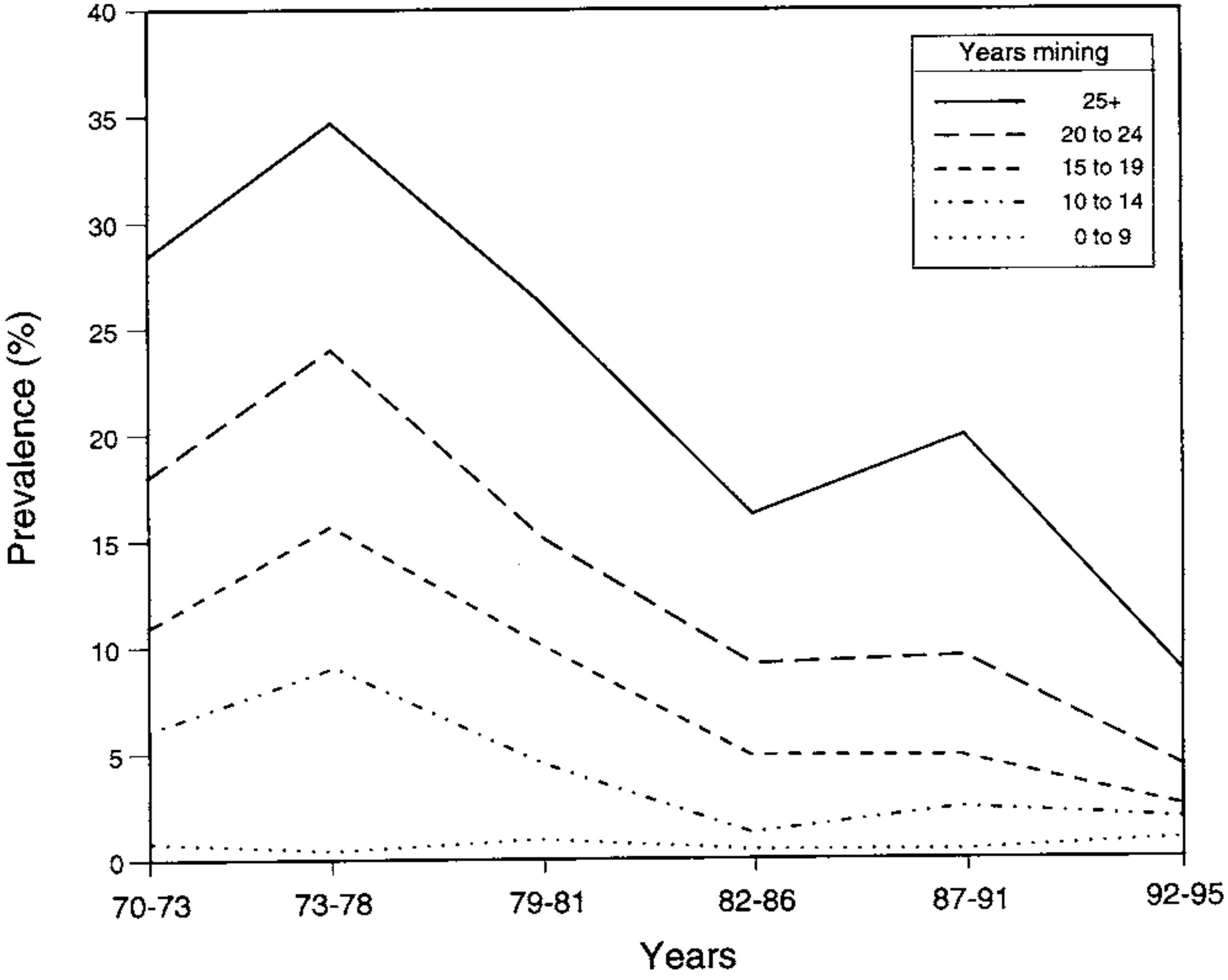

Figure 4–2. Prevalence of CWP category 1 or higher identified in the Coal Workers' X-ray Surveillance Program from 1970 to the present, by tenure in coal mining. The number of miners examined during each round is 71,446 (1970–73), 115,386 (1973–78), 58,294 (1979–81), 25,154 (1982–86), 13,920 (1987–91), and 11,678 (1992–95). (Source: Althouse, unpublished data.)

Thirty-one mines were originally selected for inclusion in the National Study of Coal Workers' Pneumoconiosis from the different mining regions across the continental United States, but many of those mines are no longer in production. The original criteria for selecting mines in round 1 included an expected mine life of 10 years, a workforce of at least 100 miners, geographical and geological spread, and accessibility to a field examination trailer [Attfield and Castellan 1992]. Rounds 1, 2, and 3 were conducted at nearly the same group of mines, but round 4 was organized differently from the previous rounds. The objective of round 4 was a followup study of miners and ex-miners who had participated in earlier rounds. Round 4 examinations were given at three of the original mine sites and in 22 mining communities. Participation rates for the National Study of Coal Workers' Pneumoconiosis were 90%, 75%, 52%, and 70% for rounds 1, 2, 3, and 4, respectively. Participation rates for the Coal Workers' X-ray Surveillance Program were 50%, 44%, 32%, and 30% for rounds 1, 2, 3, and 4, respectively. Recent improvements in the Coal Workers' X-ray

Surveillance Program have resulted in increased participation [Wagner et al. 1993a]. Because both programs consisted of successive cross-sectional studies (rounds), disease prevalences for the corresponding rounds of each study may not be strictly comparable because of differences in X-ray standards, X-ray readers, groups of miners studied, and tenure distributions that occurred in the successive rounds. The UICC[††]/Cincinnati classification of radiographs for pneumoconioses [Bohlig et al. 1970] was used for round 1 of the National Study of Coal Workers' Pneumoconiosis. The 1971 ILO U/C classification [ILO 1970] was used for rounds 2 and 3, and the 1980 ILO classification [ILO 1980] was used for round 4. The 1980 classification is also currently used for the ongoing Coal Workers' X-Ray Surveillance Program. Although the UICC/Cincinnati [Bohlig et al. 1970] classification included small rounded opacities (and excluded small irregular opacities), the 1980 ILO classification [ILO 1980] recommends classification of the profusion of all small opacities.

Morgan et al. [1973b] reported prevalences of simple CWP and PMF among 9,076 U.S. coal miners examined during round 1 of the National Study of Coal Workers' Pneumoconiosis (1969-71). For all regions combined, the prevalence of simple CWP category 1 or greater was 21.2%, and the prevalence of PMF was 2.5%. Prevalences were higher among miners of high-rank coal. The highest prevalence of PMF observed was 14% among miners of anthracite coal [Morgan et al. 1973a,b].

Analyses of round 4 of the National Study of Coal Workers' Pneumoconiosis (1985-88) included determining the prevalence of simple CWP and PMF among 3,194 underground miners and ex-miners who had been previously examined in round 1 (1970-75) [Attfield and Seixas 1995; Attfield 1992]. The prevalence of simple CWP category 1/0 or greater was 6.8% for the whole cohort and less than 5% among miners with 0 to 19 years of experience working underground. Among miners with 20 or more years of experience, the prevalence of category 1/0 increased steadily, reaching about 25% among miners who hadworked 30 or more years (Figure 4-3). The prevalence of simple CWP category 2 or greater increased gradually, reaching 2% among miners with 25 to 29 years of experience, then rising to 10% among miners with 30 or more years of experience (Figure 4-3). The prevalence of PMF was about 0.8%. Prevalences were higher among miners of high-rank coal and among ex-miners who had left work for health reasons.

About one-third (1,206) of the miners who participated in round 4 had started mining after 1969, thus having worked under the conditions mandated by the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173). A respirable coal mine dust standard of 3.0 mg/m^3 was in effect until 1972, when it was reduced to 2.0 mg/m^3. Of these miners, 2% (21/1,206) had chest X-rays indicating simple CWP category 1 or greater (including 3 miners with category 2 or greater) at round 4 (1985-88). In the logistic regression model used to investigate exposure-response, separate coefficients were included for exposure both before 1970 and after. These coefficients were similar in magnitude and statistically significant, indicating that the influence on the development of simple CWP was similar per unit of dust exposure, whether that exposure occurred before 1970 or after.

[††] International Union Against Cancer.

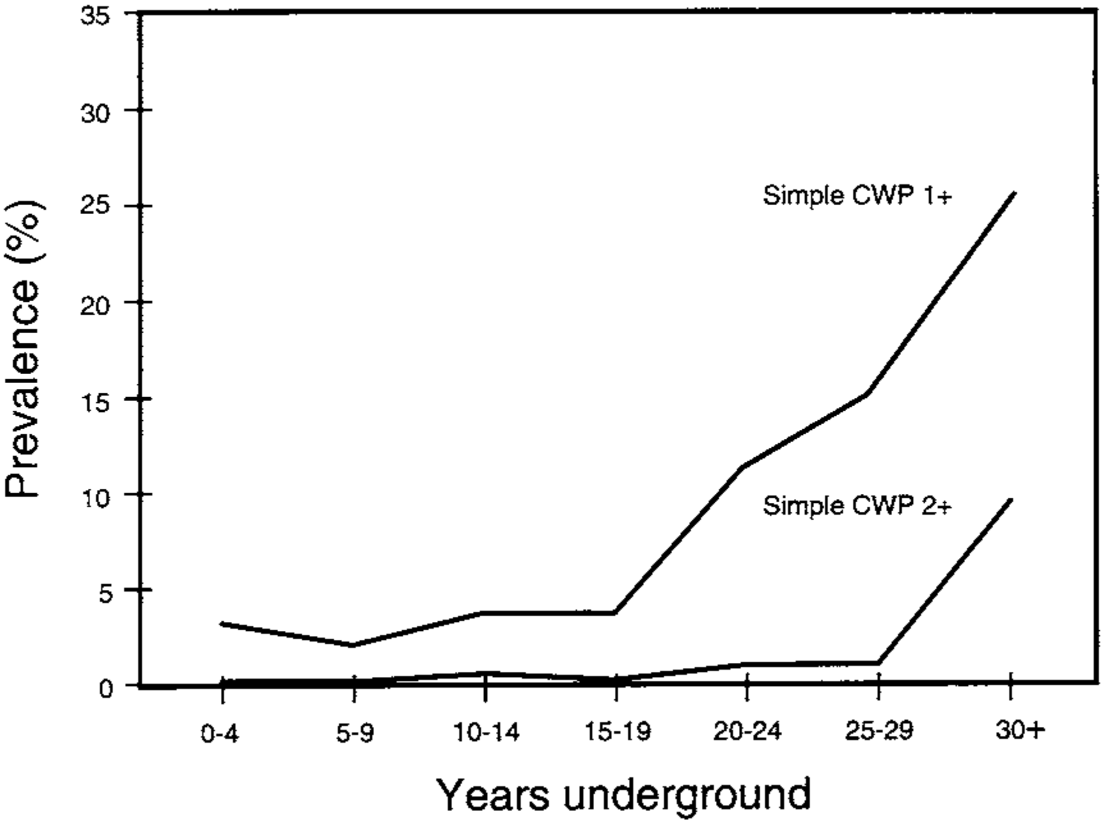

Figure 4–3. Prevalences of simple CWP category 1 or greater (1+) and category 2 or greater (2+) as detected by the median reading of chest X-rays for miners who worked in underground mines for various periods. (Adapted from Attfield and Seixas [1995].)

4.2.1.3 Studies Outside the United States

4.2.1.3.1 U.K. studies

Several important factors in the development of PMF have been determined from studies of coal miners in the United Kingdom. These factors include (1) cumulative dust exposure [Hurley et al. 1984, 1987]; (2) coal rank [Hurley and Maclaren 1987; Bennett et al. 1979; McLintock et al. 1971]; (3) residence time of dust in the lungs [Hurley et al. 1982; Maclaren et al. 1989]; and (4) radiographic category of simple CWP at the beginning of the study interval [Hurley et al. 1987; Hurley and Jacobsen 1986; Shennan et al. 1981; McLintock et al. 1971; Cochrane 1962]. The risk of PMF among miners with initial simple CWP category 2 or 3 is three to four times that of miners with initial simple CWP category 1 (Figure 4–4) [Hurley and Jacobsen 1986; Cochrane 1962].

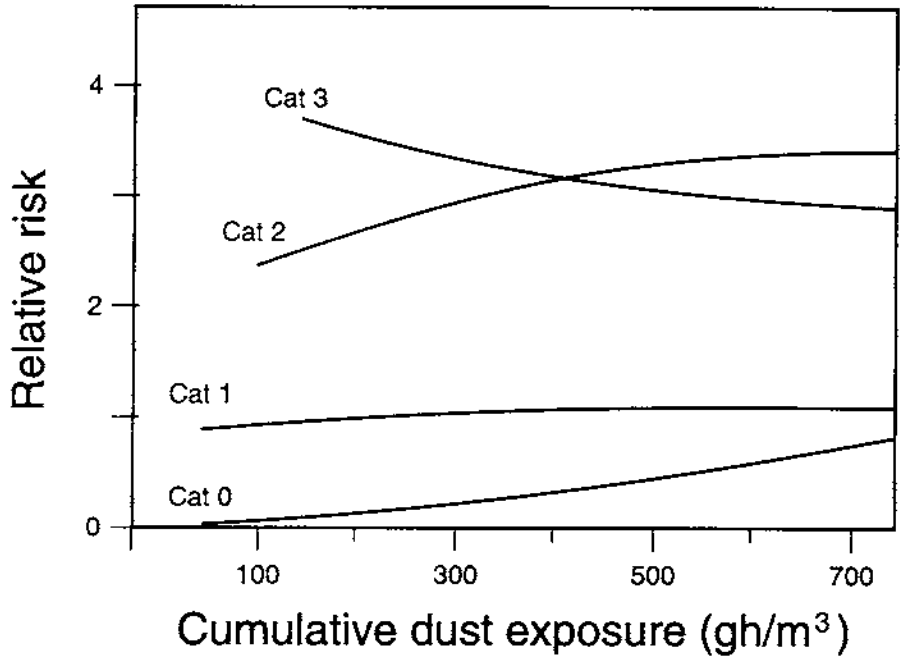

Figure 4–4. Relative risks of PMF over a 5-year period in miners with various cumulative exposures to respirable coal mine dust and various radiographic categories of CWP at the beginning of the period (relative to a miner with CWP category 1 and cumulative exposure to 200 gram hours per cubic meter [gh/m^3]). (Source: Hurley et al. [1987].)

The incidence of PMF among ex-miners in the United Kingdom was about 2.5 times that of working miners of similar ages [Maclaren and Soutar 1985]. However, miners and ex-miners had similar incidences of either simple CWP or PMF when differences in the distributions of age, dust exposure, simple CWP (at the beginning of the study), and mine (where employed) were considered [Soutar et al. 1986; Hurley and Maclaren 1988]. Among 1,902 ex-miners who had not developed PMF within 4 years of leaving mining, 172 (9%) developed PMF after leaving mining [Maclaren and Soutar 1985]. Of those 172 miners with PMF, 32% had no evidence of simple CWP (category 0) when they left mining.

Hurley and Maclaren [1987] investigated the risk of PMF among more than 30,000 U.K. coal miners during 5-year intervals (representing 52,264 risk intervals). The probability of radiographic change (developing simple CWP or PMF, or progressing to a higher category) was determined using a logistic regression model with covariates of age, cumulative exposure to respirable coal mine dust, and initial CWP category (at the beginning of the study interval). The 5-year exposure intervals occurred during the calendar years of 1953 through 1977, with a range of cumulative coal mine dust exposure from 12 to >519 gh/m^3.

The 5-year incidences of PMF among working British coal miners (during the period 1952–77) were 0.2%, 4.4%, 12.5%, and 13.9% for miners with CWP category 0, 1, 2, or 3, respectively, at the beginning of a 5-year interval [Hurley et al. 1987]. The 4.4% incidence of PMF among miners with initial CWP category 1 is three to four times higher than previous estimates [Maclaren and Soutar 1985; Shennan et al. 1981; McLintock et al. 1971]. At the beginning of the 5-year study intervals, most miners (47,087 of 52,264) were classified with CWP category 0 (i.e., no radiographic evidence of CWP or PMF). Thus, although the incidence of PMF is reported to increase with increasing category of CWP, the 0.2% incidence of PMF among miners with CWP category 0 constitutes 20% of the total cases of PMF in the study (94 of 462 cases) [Hurley et al. 1987].

4.2.1.3.2 German studies

In a study of German coal miners, Reisner [1971] reported a relationship between increasing residence time of dust in the lungs and the development of pneumoconiosis (based on the 1930 Johannesburg radiographic classification). In this 10-year study (beginning in 1954) at 10 mines in the Ruhr region, Reisner [1971] also reported an exposure-response relationship between cumulative dust exposure (computed as the summation of the monthly products of average workplace tyndallometric fine dust concentration and number of shifts worked) and the development of pneumoconiosis. In a study of German miners who had worked at least 5 years underground and had left mining in 1980 or 1985, Vautrin et al. [1990] reported a relationship between years worked underground and increasing prevalence or incidence of simple CWP (radiographic classification based on ILO [1980]). Among miners who worked 28 to 30 years, the cumulative incidence of simple CWP category 1/1 or greater was 16.6%, and that of simple CWP category 2/2 was 2.7% [Vautrin et al. 1990].

4.2.1.4 Studies of the Rapid Development of PMF

Researchers have known since the 1960s that the risk of PMF increases as the category of simple CWP increases [Cochrane 1962]. The risk of developing PMF was shown to rise steeply among miners with simple CWP category 2 [Cochrane 1962]. Therefore, a logical occupational health strategy for the prevention of PMF (which was included in the Federal Coal Mine Health and Safety Act of 1969 [Public Law 91–173]) was to identify miners who had sufficient dust exposure to develop simple CWP category 1. These miners were then offered the option of working in a low-dust environment (≤ 1 mg/m^3) with increased frequency of environmental monitoring in the expectation that further disease progression would be prevented.

Studies from the 1970s and 1980s have confirmed that the risk of developing PMF increases as the category of simple CWP increases [McLintock et al. 1971; Hurley and Jacobsen 1986; Hurley et al. 1987; Hurley and Maclaren 1987; Hodous and Attfield 1990]. These studies have also shown that even miners with minimal simple CWP (radiographic evidence of simple CWP category 1 at the beginning of a 5-year interval) or without simple CWP (category 0) have a measurable risk of having PMF detected on their chest X-rays by the end of the 5-year period. The risk of PMF among miners without evidence of simple CWP (category 0) increased with increasing cumulative exposure to respirable coal mine dust. Thus, reducing exposures to respirable coal mine dust is the key factor in preventing PMF in all miners.

Hurley et al. [1987] found that the cumulative exposure to respirable coal mine dust in U.K. coal miners was the "most important single factor determining PMF risks" for two reasons. First, miners with simple CWP (category 1 or greater) are at higher risk of developing PMF than those without it, and the risk of developing simple CWP increases as exposure to respirable coal mine dust increases. Second, miners without radiographic evidence of simple CWP (category 0) have a higher risk of developing PMF with increased cumulative exposures to respirable coal mine dust [Hurley et al. 1987].

Hodous and Attfield [1990] studied 5-year film pairs representing chest X-rays of U.S. coal miners taken from 1969 through 1988 in the National Study of Coal Workers' Pneumoconiosis or the Coal Workers' X-ray Surveillance Program. The objective was to identify X-rays that showed PMF on the later but not the earlier film and to determine the category of simple CWP on the earlier film. Although there were more than 1,300 films showing PMF, most had only one X-ray on file. Of the 69 confirmed PMF cases with two or more films on file, 14% (10 cases) had no evidence of simple CWP (category 0) on the previous film, and 43% (30 cases) showed simple CWP category 1. Also, the earlier films showed 33% (23 cases) of simple CWP category 2 and 9% (6 cases) of simple CWP category 3. These findings in U.S. miners are consistent with the findings of the U.K. studies [Hurley and Maclaren 1987; Hurley et al. 1987].

Pathology studies of coal miners have shown that chest X-rays do not always detect early stages of pneumoconiosis, particularly when the lesions are macular [Gough et al. 1950; Ruckley et al. 1984; Attfield et al. 1994]. Thus, it is possible that early stages of simple CWP may not have been detected on the initial chest X-rays.

4.2.1.5 Studies of the Role of Silica

The composition and the amount of dust retained in the lungs influence the development of fibrotic lung diseases such as pneumoconiosis and silicosis. Noncoal minerals (especially silica) are associated with more severe lesions (i.e., examination of lesions in miners' lungs at autopsy indicate that coal particles were associated with soft macules, and quartz was associated more with PMF lesions [Davis et al. 1977]). Among workers who had equal amounts of retained silica per 100 g of dry tissue, those who had been exposed to coal mine dust with 4% to 5% crystalline (free) silica had less severe silicosis than mixed-metal miners and tunnel and quarry workers who had been exposed to 20% to 25% crystalline (free) silica [Dobreva et al. 1977]. Possible explanations for the differing severity of silicosis with equal amounts of retained silica include (1) the mitigating effects of other coal mine dust components that might coat the silica particles and reduce their toxicity to the alveolar macrophages, and (2) a greater rate of deposition (i.e., higher doses in shorter periods) in the workers exposed to dust with higher percentages of crystalline (free) silica.

Silica exposure may be a factor in the rapid development of PMF. In several U.K. studies, the rapid progression of simple CWP (i.e., an increase of two or more CWP categories over an approximately 5-year period) was reported among miners who had been exposed to respirable coal mine dust with a relatively high respirable silica content [Seaton et al. 1981; Jacobsen and Maclaren 1982; Hurley et al. 1982; Robertson et al. 1987]. On 65% of the X-rays showing PMF in U.S. coal miners [Hodous and Attfield 1990], the r-type small opacities were predominant—a condition that may indicate silicosis [Ruckley et al. 1984].

In a study conducted under the National Coal Workers' Autopsy Study [initiated under 30 USC 843 (d) (1970)], Green et al. [1989] reported that among the 3,365 underground coal miners autopsied,‡‡ the prevalence of silicosis was 12.5% for underground coal face workers and 6.4% for surface workers at underground coal mines. The National Coal Workers' Autopsy Study is a voluntary program, and the cases are submitted by next-of-kin to determine eligibility for black lung benefits.

4.2.1.6 Radiographic Small Opacities Among Nonminers

In a study of 1,422 U.S. workers in nondusty jobs, Castellan et al. [1985] found a low prevalence of radiographic small opacities, which is compatible with radiographic appearances of simple CWP. Among workers with fewer than 5 years of experience in jobs with possible respiratory hazards, 3 of 1,422 workers (0.21%) showed radiographic evidence of category 1/0 or 1/1. The study population consisted of 50.6% men and 49.4% women; 52.5% were whites, and 44.2% were blacks. The mean age of the whole group was 33.8 years (range 16 to 70 years). The mean age of persons with radiographic opacities was 47.5 years [Castellan et al. 1985]. By comparison, the mean age of the coal miners who participated in round 1 of the National Study of Coal Workers' Pneumoconiosis was 44 years [Attfield and Morring 1992b], and the mean age of those who participated in round 4 was 31 years [Attfield and Seixas 1995].

In a study of 200 hospitalized patients, Epstein et al. [1984] reported that 36 patients (18%) had small opacities of profusion category 1/0 or greater by ILO standards [ILO 1980]. Of these 36 patients with positive X-rays, 22 patients had no known dust exposure or medical condition that would explain the X-ray findings. The study population consisted of 64.5% males and 35.5% females, with a mean age of 44.2 years (range, 15 to 84). The mean age of the 22 patients with radiographic small opacities and without known dust exposure or medical conditions was 55.7 years (compared with 41.5 years among patients with negative X-rays).

Because the Castellan et al. [1985] study was based on a worker population, the findings from that study are probably more applicable to coal miners than the findings of the Epstein et al. [1984] study. That is, the prevalence of small opacities expected among workers *without* exposures to respirable dust is probably closer to those reported by Castellan et al. [1985]. A study population of hospitalized patients (such as the one used in the Epstein et al. [1984] study) is likely to be a poor representation of a current worker population (especially those working in strenuous jobs such as coal mining). The study population in Castellan et al. [1985] was also larger (1,422 workers) than in Epstein et al. [1984] (200 hospitalized patients).

4.2.2 Studies of COPD in Coal Miners

Occupational exposure to respirable dust has been shown to be associated with decrements in lung function among coal miners [Attfield and Hodous 1992; Soutar and Hurley 1986; Attfield 1985; Love and Miller 1982], grain dust handlers [Kauffmann et al. 1982], gold miners [Cowie and Mabena 1991; Irwig and Rocks 1978], and other workers exposed to organic and inorganic particles

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‡‡Ten percent of all coal miners who died during the period 1971-80.

[Kilburn 1980, 1984]. Nonoccupational factors that affect lung function include age, race, gender, height, weight, physical activity, and altitude. Decrements in FEV_1 have been associated with reduced life expectancy in studies of coal miners [Ortmeyer et al. 1974, 1973] and other populations [Strachan 1992; Foxman et al. 1986; Peto et al. 1983; Fletcher and Peto 1977; Higgins and Keller 1970].

4.2.2.1 Chronic Bronchitis

Several cross-sectional studies from the United States and the United Kingdom have found that respiratory symptoms (including cough, phlegm, wheezing, and breathlessness) are related to either duration of exposure [Rom et al. 1981; Hankinson et al. 1977a; Kibelstis et al. 1973; Hyatt et al. 1964] or cumulative exposure to respirable coal mine dust [Seixas et al. 1992; Marine et al. 1988; Rae et al. 1971]. Dust exposure and cigarette smoking each contribute to the development of respiratory symptoms and decrements in lung function. Increasing severity of bronchitic symptoms has been associated with loss in FEV_1 after accounting for dust exposure, smoking, age, height, and weight [Rogan et al. 1973]. Rogan et al. [1973] suggest that once early bronchitic symptoms develop, the disease may progress and ventilatory capacity may deteriorate independently of factors initiating the disease process.

Rae et al. [1971] found a statistically significant association between increasing exposure to respirable coal mine dust and increasing prevalence of bronchitis (based on symptoms of cough and phlegm) among U.K. coal miners; a twofold greater prevalence of bronchitis was found among smokers than nonsmokers. A relationship between chronic bronchitis and dust exposure, smoking, and alcohol consumption was reported in a cross-sectional study [Leigh et al. 1986] and a longitudinal study [Leigh 1990] of Australian coal miners.

In an autopsy study of U.S. miners, Naeye and Dellinger [1972] found that the miners had more bronchiolar goblet cells than the comparison group; yet the number of these cells did not correlate with the miners' radiographic category. Similarly, emphysema, dyspnea, and cor pulmonale did not correlate with the radiographic category. In an autopsy study of U.K. coal miners, Douglas et al. [1982] reported that the maximum mucous gland-wall ratio correlated with lifetime occupational exposure to coal mine dust.

4.2.2.2 Emphysema

Autopsy studies of U.K. coal miners have shown a significant increase in emphysema among coal miners compared with nonmining comparison populations [Ryder et al. 1970; Cockcroft et al. 1982b]. Ryder et al. [1970] found that emphysema was more frequent among coal miners with either simple CWP or PMF. Cockcroft et al. [1982b] found that the severity of centrilobular emphysema (the predominant type observed) was related to the amount of dust in the simple foci in the lungs. Cockcroft et al. [1982b] attempted to overcome bias in case selection by using similar methods to select coal miners and nonminers aged 50 to 70 who had died of ischemic heart disease; furthermore, these investigators accounted for age and smoking habits by stratification. Irregular opacities on chest X-rays have been associated with the pathological signs of emphysema and interstitial fibrosis, and with reduced gas transfer factor and reduced total lung capacity [Cockcroft et al. 1982a,b; Cockcroft and Andersson 1987].

In a pathological study of 450 British coal miners, Ruckley et al. [1984] found a direct relationship between exposure to respirable coal mine dust during life and the presence of centriacinar emphysema at autopsy among miners with pathologically determined fibrotic lesions. The prevalence of any emphysema among miners studied was 47% in those with no fibrotic lesions, 65% in those with simple CWP, and 83% in those with PMF. Both panacinar and centriacinar emphysema occurred more frequently in smokers than in nonsmokers, but the relationship with dust exposures was only apparent among those with centriacinar emphysema. The amount of dust in the lungs was also associated significantly with the presence of centriacinar emphysema ($P<0.05$), regardless of the composition of the retained dust.

In a pathology study of 886 Australian coal miners, Leigh et al. [1982, 1983] determined that emphysema is related to coal dust exposure (using years of coal face work as a surrogate for exposure). A recent study of Australian coal miners provides further evidence of an association between emphysema and coal dust in the lungs of both smokers and lifelong nonsmokers [Leigh et al. 1994]. The extent of emphysema in smokers was significantly related to both coal dust content of the lungs and to smoking. In nonsmokers, the extent of emphysema was significantly related to both the coal dust content of the lungs and age. There was no evidence of a relationship between the silica content of the lungs and emphysema, though the silica content of the lungs was significantly related to the degree of lung fibrosis.

4.2.2.3 Decreased Lung Function

Several studies have shown that coal miners reported more respiratory symptoms and had poorer lung function than control groups [Enterline and Lainhart 1967; Higgins and Cochrane 1961; Higgins et al. 1968; Higgins 1972; Higgins et al. 1981]. Exposure to respirable coal mine dust has been associated with deficits in ventilatory function (including FEV_1 and vital capacity, VC) whether or not simple CWP was present [Hankinson et al. 1977a; Morgan 1978]. The presence of small, irregular radiographic opacities has been associated with deficits in FEV_1 and FVC among U.K. coal miners—in addition to those deficits attributable to age, height, weight, smoking habits, and dust exposure [Collins et al. 1988]. Complicated CWP (PMF) has been associated with ventilatory impairment [Morgan et al. 1974] and with decreased resting arterial blood gas tension (Pa_{O2}) [Rasmussen et al. 1968]. Maclaren et al. [1989] reported that miners with dyspnea had a greater risk of developing PMF.

Other measures of lung function (i.e., residual volume [RV] and total lung capacity [TLC]) have been shown to be elevated in miners with simple CWP [Morgan et al. 1971, 1974]. Cigarette smoking and bronchitis were also found to be associated with increased TLC and RV, regardless of the category of simple CWP [Hankinson et al. 1977b]. More recently, FEV_1 and maximum expiratory flow rates were shown to be significantly lower, and RV was significantly higher among nonsmoking coal miners than among nonsmoking steelworkers [Nemery et al. 1987]. These lung function indices were similar among the coal miners, whether or not simple CWP was present [Nemery et al. 1987].

Diffusing capacity has been shown to be either normal or slightly decreased among miners with simple CWP [Cotes et al. 1971; Cotes and Field 1972; Ulmer and Reichel 1972]. Diffusing capacity was reduced among coal miners who smoked, regardless of their duration of exposure to coal mine dust [Kibelstis 1973]. Diffusing capacity was reduced among nonsmoking miners with simple CWP and p-type opacities [Seaton et al. 1972].

4.2.2.3.1 Quantitative estimates of dust-related loss of lung function

4.2.2.3.1.1 Cross-sectional studies

Decrements in FEV_1 and FVC have been shown to be related to coal mine dust exposure (independent of the effects of smoking) in cross-sectional epidemiological studies [Attfield and Hodous 1992; Seixas et al. 1992; Marine et al. 1988; Soutar et al. 1988; Rogan et al. 1973]. The average decrement in FEV_1 from exposure to respirable coal mine dust has been estimated in cross-sectional studies to be 0.6 to 0.76 ml per gh/m^3 [Attfield and Hodous 1992; Soutar and Hurley 1986; Rogan et al. 1973]. A re-analysis of the Rogan et al. [1973] data by Marine et al. [1988] showed a 36% greater loss for nonsmokers and a 56% greater loss for cigarette smokers than originally estimated. Table 4-5 lists the estimated average losses of FEV_1 from coal mine dust exposure reported in several studies.

Two studies of 4,059 British coal miners followed for 22 years indicated that exposure to coal mine dust on pulmonary function can be clinically significant [Hurley and Soutar 1986; Soutar and Hurley 1986]. An "excess effect" of exposure to coal mine dust was observed in a subgroup of 199 miners who had left the coal industry before normal retirement age, taken other jobs, and reported symptoms of chronic bronchitis at the 22-year followup survey. The average loss of FEV_1 among the 199 miners was 600 ml, and the average cumulative exposure to respirable coal mine dust was 300 gh/m^3. The 35 ex-smokers in the subgroup had the greatest loss in FEV_1—an average of 942 ml.

Soutar et al. [1988] found that miners with the first level of breathlessness (troubled by shortness of breath when hurrying on level ground or walking up a slight hill) had lower lung function than predicted normal values in that region. Average decrements in FEV_1 among miners with the first level of breathlessness were 422, 343, and 215 ml, respectively, for miners in South Wales, Yorkshire, and Tyne and Wear. The second level of breathlessness (shortness of breath walking with other people of the same age on level ground) was associated with average FEV_1 decrements of 592, 491, and 386 ml, respectively, for the same regions. The third level of breathlessness (needing to stop for breath when walking at one's own pace on level ground) was associated with average losses of 942, 812, and 800 ml, respectively.

Soutar et al. [1993] examined clinically important dust-related deficits in lung function of U.K. coal miners analyzed previously [Soutar et al. 1988; Soutar and Hurley 1986]. Clinically important deficits of FEV_1 were defined as the average deficit associated with a severe grade of exertional dyspnea (having to stop for breath when walking at one's own pace on level ground). In two of the areas studied (Yorkshire and North East), no exposure-related deficits were demonstrated; however, age and cumulative dust exposure were highly correlated. In the third area (South Wales), significant exposure-related deficits were observed. The mean FEV_1 of miners in South Wales with severe exertional dyspnea was 942 ml less than that predicted for nonsmokers of the same age and stature. This deficit is close to the value of <65% of predicted normal FEV_1 used by Marine et al. [1988] to indicate a clinically important deficit.

Table 4–5. Estimated average loss of lung function (FEV_1) associated with exposure to respirable coal mine dust

References	Loss of FEV_1 per exposure unit (ml per gh/m^3)	Total loss of FEV_1 (ml per 180 gh/m^3)*
Attfield and Hodous [1992]†	0.69	124
Seixas et al. [1992]‡	3.39	610
Soutar and Hurley [1986]§	0.76	137
Marine et al. [1988]**	0.94 (smokers)	169
	1.02 (nonsmokers)	184

*Note: Cumulative exposure of 180 gh/m^3 corresponds to 45 years (2,000 hr/year) at a mean concentration of 2 mg/m^3 of respirable coal mine dust.

†U.S. miners working before 1970; average of 18 years underground.

‡U.S. miners new to mining since 1970; average of 13 years underground.

§British miners working during the 1950s; 22 years of followup.

**British miners working during the 1950s; 10 years of followup.

4.2.2.3.1.2 Longitudinal studies

Longitudinal studies have demonstrated an association between cumulative exposure to respirable coal mine dust and the rate of decline in FEV_1 [Seixas et al. 1993; Leigh 1990; Attfield 1985; Love and Miller 1982]. In a study of 1,677 British coal miners, Love and Miller [1982] found that the loss of FEV_1 in 11 years increased with increasing previous cumulative dust exposure (i.e., exposure occurring before the period of study). Miners with the average previous cumulative exposure of 117 gh/m^3 had an FEV_1 loss of 42 ml in 11 years, with an additional FEV_1 loss of 122 ml among smokers. In a study of 1,470 U.S. coal miners, Attfield [1985] found that the dust-related FEV_1 loss was 36 to 84 ml over 11 years, with an additional FEV_1 loss of 100 ml among smokers.

In a longitudinal study of new coal miners (those who began working in mining since 1970), the average loss related to dust exposure was 13.8 ml per gh/m^3 during the first 3 to 4 years of mining (at round 2 of the National Study of Coal Workers' Pneumoconiosis), with no additional exposure-related loss over approximately the next 13 years (between rounds 2 and 4 of the National Study of Coal Workers' Pneumoconiosis) [Seixas et al. 1993]. Thus, the average exposure-related loss was 3.39 ml per gh/m^3 over the 15- to 17-year period. Another U.S. study reported an average FEV_1 loss of 67 ml per year for the first 2 years of mining, with an average FEV_1 loss of 14.4 ml per year for the next 5 years [Hodous and Hankinson 1990]. However, dust exposure estimates were not provided. The results of the latter two studies suggest (1) a nonlinear relationship between the rate of decline in FEV_1 and coal mine dust exposure, with the greatest rate of decline in FEV_1 occurring during the first few years of mining, and (2) a reduction in the rate of decline associated with subsequent coal mine dust exposures.

In a longitudinal study of lung function in 384 coal miners from France, the average rates of decline for FEV_1 and FVC ranged from 47 ml/year for living nonsmokers to 78 ml/year (measured during life) for deceased smokers [Dimich-Ward and Bates 1994]. The rate of decline in FEV_1 after retirement decreased among coal miners who had never smoked but increased among smokers [Dimich-Ward and Bates 1994].

Such factors as past dust exposure, smoking, and alcohol consumption were associated with decreased FEV_1 and chronic bronchitis in a longitudinal study of Australian coal miners [Leigh 1990]. The mean loss of FEV_1 in 15 years was 0.81 L [Leigh 1990].

4.2.2.3.2 Smoking

The roles of dust exposure and smoking in the development of COPD among coal miners has been the subject of much debate [Attfield and Hodous 1992; Morgan 1986, 1983, 1980; Cochrane 1983; Seaton 1983]. Morgan [1986] has suggested that the effects of smoking and dust exposure are different in that smoking causes severe losses in lung function in a small percentage of individuals and dust exposure causes small losses in lung function in the majority of individuals. Findings from two exposure-response studies of lung function in U.S. miners [Attfield and Hodous 1992; Attfield and Hodous 1989] did not support that suggestion.

Attfield and Hodous [1992] found that both dust exposure and smoking caused shifts in the distribution of FEV_1 values. Loss of FVC was also related to cumulative dust exposure, although the magnitude of the FVC loss was slightly smaller than that for FEV_1. In an earlier analysis of lung function in the same coal miner population reported by Attfield and Hodous [1992] (but without dust exposure data), Morgan et al. [1974] found that the number of years underground was associated with similar losses in both FEV_1 and FVC. Thus, the number of years worked was not associated with a reduction in the FEV_1/FVC ratio [Morgan et al. 1974]. Attfield and Hodous [1992] found an exposure-related loss of the FEV_1/FVC ratio that was statistically significant but small in magnitude.

Among U.K. coal miners, Soutar and Hurley [1986] found that cumulative dust exposure was related to losses in both FEV_1 and FVC. Smoking was associated with a reduction in the ratio of FEV_1/FVC (i.e., FEV_1 was reduced more than FVC), but dust exposure was not related to this ratio (i.e., FVC was reduced at least as much as FEV_1) [Soutar 1987; Soutar and Hurley 1986].

4.2.2.3.3 Dust characteristics

Some studies have shown that the coal rank of the dust to which miners are exposed may affect lung function. Morgan et al. [1974] reported greater decrements of FEV_1 and FVC and greater RV among miners exposed to higher-rank coal (an effect observed in smokers, ex-smokers, and those who never smoked). Because the study did not include dust exposure data, the results could reflect differences in the extent of dust exposure. In a study that did include exposure data [Attfield and Hodous 1992], miners exposed to higher-rank eastern coal had greater decrements in FEV_1 than those with the same cumulative exposure to lower-rank western coal.

Some evidence suggests that exposure to coal mine dust of larger particle size than the respirable fraction may affect the development of COPD. Potts et al. [1990] suggested that thoracic dust, which is deposited primarily in the bronchial airways, may be important in the development of bronchitis and loss of lung function. Thoracic dust concentrations can vary by location in underground coal mines, and thoracic dust concentrations may be five to seven times higher than respirable dust levels [Potts et al. 1990; Burkhart et al. 1987]. Two U.K. studies investigated the correlation between "total" or "inspirable" dust and respiratory disease [Cowie et al. 1981; Mark et al. 1988]. Both studies found that estimated concentrations of the coarse fractions of dust provide no better correlations with disease than concentrations of the respirable fraction.

4.2.3 Predicted Prevalence of Simple CWP, PMF, and Decreased Lung Function Among U.S. and U.K. Coal Miners

In several epidemiological studies of U.S. and U.K. coal miners, statistical models (primarily linear or logistic regression) have been used to estimate the prevalence of simple CWP, PMF, or specific decrements in lung function. The models for simple CWP and PMF have generally included covariates for age and coal rank, and the models for decreased lung function have generally included covariates for age, height, and smoking.

4.2.3.1 Predicted Prevalence of Simple CWP and PMF

Both U.S. and U.K. studies indicate that the risk of developing PMF is greater than the previous risk estimates that were used as a basis for the current U.S. standard for coal mine U.S. and U.K. estimates indicate that 7/1,000 (0.7%) to 89/1,000[§§] (8.9%) miners who were exposed to respirable coal mine dust for 40 years at the current MSHA PEL of 2 mg/m^3 will develop PMF by the age of 58 (Table 4-6); 65 to 316 miners/1,000[§§] will develop simple CWP category 1 or greater. The range of estimates quoted reflect the higher risks predicted for exposure to dust of higher-rank coal as well as possible variations in exposure conditions and differences between the populations of coal miners studied. The risk estimates from the U.S. studies are consistently higher than those from the U.K. studies, even though the various studies are similar in magnitude. However, the estimated reductions in simple CWP or PMF are comparable in the U.S. and U.K. studies. Up to threefold reductions in the prevalence of simple CWP and PMF are predicted if exposures are reduced from a mean concentration of 2 to 1 mg/m^3[***] over a 40-year working lifetime (Table 4-6).

4.2.3.2 Predicted Prevalence of Decreased Lung Function

In addition to the risk of simple CWP and PMF, epidemiological studies have shown that coal miners have an increased risk of developing COPD. COPD may be detected from decrements in certain measures of lung function, especially FEV_1 and the ratio of FEV_1/FVC. Decrements in lung function associated with exposure to coal mine dust are severe enough to be disabling in some miners, whether or not pneumoconiosis is also present [Hurley and Soutar 1986; Soutar and Hurley 1986]. A severe or disabling decrement in lung function is defined here as an FEV_1 <65% of expected normal values; an impairment in lung function is defined as an FEV_1 <80% of predicted

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[§§] Range of mean prevalences.

[***] Measured using the current MSHA sampling method (Section 5.1 and Appendix J); 1 mg/m^3 is equivalent to 0.9 mg/m^3 when measured using the NIOSH recommended sample criteria (Sections 5.2 and 5.4).

Table 4-6. Predicted prevalence of simple CWP and PMF among U.S. or U.K. coal miners at age 58 following exposure to respirable coal mine dust over a 40-year working lifetime

Study and coal rank	Mean concentration of respirable coal mine dust (mg/m^3)	Predicted prevalence (cases/1,000)		
		CWP≥1*	CWP≥2	PMF
Attfield and Seixas [1995]:[†]				
High-rank bituminous	2.0	253 (204-308)[‡]	89 (60-130)	51 (30-85)
	1.0	116 (88-150)	29 (16-51)	16 (7-36)
Medium/low-rank bituminous	2.0	144 (117-176)	31 (20-49)	14 (7-27)
	1.0	84 (64-110)	17 (9-30)	9 (4-19)
Attfield and Morring [1992b]:[§]				
Anthracite	2.0	316 (278-356)	142 (118-172)	89 (69-113)
	1.0	128 (108-152)	46 (35-60)	34 (24-48)
High-rank bituminous (89% carbon)	2.0	282 (250-317)	115 (94-141)	65 (49-85)
	1.0	119 (100-142)	41 (31-54)	29 (20-41)
Medium/low-rank bituminous (83% carbon)	2.0	121 (108-136)	40 (33-49)	22 (17-29)
	1.0	74 (62-89)	24 (18-31)	17 (12-24)
Medium/low-rank bituminous (Midwest)	2.0	89 (73-108)	28 (20-39)	15** (9-26)
	1.0	63 (52-77)	20 (14-27)	14** (9-21)
Medium/low-rank bituminous (West)	2.0	67 (52-86)	15** (8-26)	13** (7-24)
	1.0	55 (44-68)	14** (10-21)	12** (8-20)
Hurley and Maclaren [1987]:				
High-rank bituminous (89% carbon)	2.0	89	29	18
	1.0	40	12	7

See footnotes at end of table.

(Continued)

Table 4-6 (Continued). Predicted prevalence of simple CWP and PMF among U.S. or U.K. coal miners at age 58 following exposure to respirable coal mine dust over a 40-year working lifetime

Study and coal rank	Mean concentration of respirable coal mine dust (mg/m^3)	Predicted prevalence (cases/1,000)		
		CWP≥1[*]	CWP≥2	PMF
Medium/low-rank bituminous (83% carbon)	2.0	65	16	7
	1.0	28	7	3

[*] Abbreviations: CWP≥1 = simple pneumoconiosis category 1 or greater; CWP≥2 = simple pneumoconiosis category 2 or greater; PMF = progressive massive fibrosis.

[†] Attfield and Seixas [1995] define the coal rank groups as follows:

1. High-rank bituminous (89%-90% carbon): central Pennsylvania and southeastern West Virginia
2. Medium/low-rank bituminous (80%-87% carbon): medium-rank—western Pennsylvania, northern and southwestern West Virginia, eastern Ohio, eastern Kentucky, western Virginia, and Alabama
3. Low-rank: western Kentucky, Illinois, Utah, and Colorado

[‡] The 95% confidence intervals, where available, are given in parentheses under the point estimates for prevalence (cases/1,000).

[§] In Attfield and Morring [1992b], the predicted prevalences for CWP category 1 or CWP category 2 did not include high categories.

[**] Attfield and Morring [1992b] define the coal rank groups as follows:

1. Anthracite: two mines in eastern Pennsylvania (about 93% carbon)
2. Medium/low-volatile bituminous (89%-90% carbon): three mines in central Pennsylvania and three mines in southeastern West Virginia
3. High-volatile "A" bituminous (80%-87% carbon): 16 mines in western Pennsylvania, north and southwestern West Virginia, eastern Ohio, eastern Kentucky, western Virginia, and Alabama
4. High-volatile Midwest: four mines in western Kentucky and Illinois

normal values [Boehlecke 1986; Marine et al. 1988; ATS 1991; Soutar et al. 1993]. An exposure-response relationship between respirable coal mine dust exposure and decrements in lung function has been observed in cross-sectional studies [Attfield and Hodous 1992; Seixas et al. 1992; Marine et al. 1988; Rogan et al. 1973] and confirmed in longitudinal studies [Seixas et al. 1993; Attfield 1985; Love and Miller 1982].

Table 4-7 presents the predicted prevalence of decreased lung function among miners at age 58 who have worked 40 years at a mean concentration of 2 or 1 mg/m^3 of respirable coal mine dust. The predicted prevalences are based on studies of U.S. miners [Attfield and Hodous 1992] and U.K. miners [Marine et al. 1988] and are reasonably consistent. These studies show that among miners who never smoked and who were exposed for 40 years at the current MSHA PEL of 2 mg/m^3 for respirable coal mine dust, an estimated 16 to 63/1,000[†††] will have FEV_1 <65% of predicted normal values at age 58. Among smokers with the same exposures, an estimated 80 to 173/1,000 will have FEV_1 <65% of predicted values at age 58. These predicted prevalences include the background prevalence (predicted from the model at zero exposure). See Section 7.3.2.1 for further discussion on background prevalence. Excess (i.e., exposure-attributable) risk estimates computed from these studies are provided in Section 7.3.2.2.

[†††] Range of mean prevalences (range of point estimates).

Table 4-7. Predicted prevalences of decreased lung function* among U.S. or U.K. coal miners at age 58 following exposure to respirable coal mine dust over a 40-year working lifetime

Study and region†	Mean concentration of respirable coal mine dust (mg/m^3)	Lung function decrement (% FEV_1)	Predicted prevalence (cases/1,000)	
			Miners who never smoked	Smokers
Attfield and Hodous 1992:				
East	2.0	<80	141	369
		<65	22	102
	1.0	<80	123	336
		<65	18	87
West	2.0	<80	125	340
		<65	16	80
	1.0	<80	108	309
		<65	13	68
Marine et al. 1988‡	2.0	<80	153	372
		<65	63	173
	1.0	<80	125	314
		<65	52	159

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*Decreased lung function is defined as FEV_1 <80% of predicted normal values. Clinically important deficits are FEV_1 <80% (which approximately equals the lower limit of normal [LLN], or the 5th percentile) [Boehlecke 1986; ATS 1991] and FEV_1 <65% (which has been associated with severe exertional dyspnea) [Soutar et al. 1993; Marine et al. 1988].

†Attfield and Hodous [1992] define the following coal ranks and regions:

East: Anthracite (eastern Pennsylvania) and bituminous (central Pennsylvania, northern Appalachia [Ohio, northern West Virginia, western Pennsylvania], southern Appalachia [southern West Virginia, eastern Kentucky, western Virginia]), Midwest [Illinois, western Kentucky], and South [Alabama].

West: Colorado and Utah.

‡Conversion from gh/year to mg-yr/m^3; assumed 1,920 hr/year for U.S. miners.

4.2.4 Surface Coal Miners

4.2.4.1 Health Hazard Evaluations Among Drillers at U.S. Surface Coal Mines

In 1980, NIOSH performed a health hazard evaluation (HHE) of a surface coal mine that had been in operation in West Virginia since 1972 [Banks et al. 1983]. This HHE was initiated in 1979 when a driller who had worked at this mine for 5 years was hospitalized and diagnosed as having silico-proteinosis, a type of silicosis. Among the other nine miners evaluated in the HHE, two cases of CWP category 1 were identified; both involved surface coal miners who had worked as drillers—one for 4 years and the other for 6 years.

In 1982, MSHA requested that NIOSH conduct an HHE at three surface coal mines to evaluate the respiratory status of surface coal miners who were drillers and driller helpers [Cornwell and Hanke 1983]. The study group of drillers included active miners who were current or former drillers and/or driller helpers. The comparison group consisted of workers who had never worked as drillers or driller helpers. The study found one case of simple CWP category 2 in the driller group and one case of simple CWP category 1 in the nondriller group. The mean length of employment on drill crews for the driller group was 3.8 years, a period that may not have been sufficient to detect exposure-related disease.

4.2.4.2 Medical Evaluations of Miners at U.S. Bituminous Surface Coal Mines, 1972–73

During 1972–73, NIOSH studied U.S. surface coal miners at seven bituminous mines and one anthracite mine [Fairman et al. 1977]. A total of 1,438 miners were examined; the participation rate was 95.5%. Table 4-8 shows the prevalence of simple CWP among bituminous surface coal miners. Miners who had previously worked in underground coal mines or who had worked on drill crews at surface coal mines had higher prevalences of simple CWP than miners who had never worked underground or on drill crews.

4.2.4.3 Medical Evaluations of Miners at U.S. Anthracite Surface Coal Mines, 1984–85

During 1984-85, NIOSH offered medical examinations to 1,348 miners employed at 31 surface coal mines in the anthracite coal region of northeastern Pennsylvania [Amandus et al. 1989]; the participation rate was 80% (1,073/1,348). Miners were grouped according to previous employment in other jobs involving exposure to dust—including jobs in underground coal mining, noncoal mining, construction, welding, sandblasting, manufacturing, steel mills, foundries, and shipbuilding. Table 4-9 shows the prevalence of simple CWP among anthracite surface coal miners. The results indicate a higher risk of developing simple CWP among miners who worked on drill crews of anthracite surface coal mines. The results also suggest that surface coal miners at anthracite coal mines are at greater risk of developing simple CWP than miners at bituminous surface coal mines. These findings are consistent with studies of underground coal miners, which have shown higher prevalences of pneumoconioses among anthracite coal miners than among bituminous coal miners (see Sections 4.2.1.1 and 4.2.1.2). The results of the Amandus et al. [1989] study are consistent with those of the Amandus et al. [1984] study. Both found an excess prevalence (relative to "background" [Castellan et al. 1985]) of simple CWP among surface coal miners who never worked in underground coal mines or on surface coal mine drill crews. Both studies also found that surface coal miners who never worked underground coal but did work on surface drill crews were at risk of developing CWP category 2 or higher.

4.2.4.4 Study of U.K. Surface Coal Miners

A recent study of surface ("opencast") coal miners in the United Kingdom was performed to determine miners' exposures to respirable dust and quartz and to assess their respiratory health [Love et al. 1992]. Concentrations of respirable coal mine dust and respirable quartz were reported to be generally below 1 and 0.1 mg/m^3, respectively. The investigators found that the duration of employment in the dustiest opencast jobs was significantly related to the probability of having radiographic category 0/1 or greater. Age and smoking were controlled in the analyses. The relative risk of category 0/1 doubled for every 10 years worked in those jobs compared with workers of the

Table 4-8. Prevalence of simple CWP among bituminous surface coal miners

Group	Number of workers	Prevalence CWP 1 %	Prevalence CWP 1 Number	Prevalence CWP ≥2 %	Prevalence CWP ≥2 Number
Blue-collar workers with no previous occupational dust exposure [Castellan et al. 1985]	1,422	0.2	3	0.0	0
Surface coal miners:					
Never worked underground or on drill crew; ≤10 years on surface coal mine jobs	516	0.8	4	0.0	0
Never worked underground or on drill crew; >10 years on surface coal mine jobs	486	3.5	17	0.4	2
Drill crew members for 1–10 years; never worked in an underground coal mine	82	3.7	3	0	0
Drill crew member for >10 years; never worked in an underground coal mine	49	14.3	6	2.3	1
Worked 1 year or more in an underground coal mine	215	12.1	26	2.3	5
Total surface coal miners	1,348*	4.2	56	0.6	8

Adapted from Amandus et al. [1984].

*Of the original 1,438 X-rays, two or more readers determined that 90 were unreadable.

same age who were not exposed to dusty work. The relationship between years worked and category 0/1 or 1/0 remained after excluding 198 men with previous underground work experience. Duration of employment was not associated with chronic bronchitis or measures of lung function (FEV_1, FVC, or FEV_1/FVC). The relationship between years worked and small opacities on the chest X-ray was similar for both rounded and irregular opacities.

4.2.5 Studies of Mortality Among Coal Miners

Studies from the United States [Attfield et al. 1985; Ortmeyer et al. 1973, 1974], the United Kingdom [Miller and Jacobsen 1985; Atuhaire et al. 1985; Cochrane et al. 1979], and the Netherlands [Meijers et al. 1991] indicate that mortality from occupational respiratory diseases (PMF, chronic bronchitis, or emphysema) and accidents is elevated among coal miners relative to the general population. Miners with radiographic evidence of PMF had higher mortality rates than miners with or without simple CWP [Atuhaire et al. 1985; Cochrane et al. 1979; Ortmeyer et al. 1974; Cochrane 1973].

Table 4-9. Prevalence of simple CWP among anthracite surface coal miners

		Prevalence			
		CWP 1		CWP ≥2	
Group	Number of workers*	%	Number	%	Number
Surface miners with previous dust exposure	537	7.1	38	1.1	6
Surface miners with no previous dust exposure	516	3.5	18	1.0	5
Never worked on surface coal mine drill crew	448	2.7	12	0	0
Worked 1-9 years on surface coal mine drill crew	46	4.3	2	2.2	1
Worked >10 years on surface coal mine drill crew	22	18.2	4	18.2	4

Adapted from Amandus et al. [1989].

*Of the 1,073 workers who originally participated, 20 were not included in the analyses.

Regional or coal rank differences have also been reported, with higher standardized mortality ratios (SMRs) for all-cause mortality among miners in the anthracite coal regions of the United States [Ortmeyer et al. 1974]. Miners with decreased lung function ($FEV_1/FVC < 70\%$ of predicted normal values) had elevated mortality [Ortmeyer et al. 1974]. Mortality rates for ischemic heart disease were lower in coal miners than in the general population [Costello et al. 1975].

4.2.5.1 Mortality Related to Exposure to Respirable Coal Mine Dust

Most studies of mortality in U.S. coal miners did not include exposure information [Rockette 1977; Costello et al. 1974; Enterline 1972]. Attfield et al. [1985] and Ortmeyer et al. [1974] included surrogate indices of coal mine dust exposure by comparing SMRs for miners with more than or less than 30 years of experience. Amandus [1983] used years of underground mining experience as a surrogate for dust exposure in a regression model; however, it was not statistically significant and was removed from the final model.

Mortality attributed to pneumoconiosis, chronic bronchitis, or emphysema has been related to cumulative exposure to respirable coal mine dust in both U.S. and U.K. coal miners [Miller and Jacobsen 1985; Kuempel et al. 1995]. In the U.K. study [Miller and Jacobsen 1985], 22-year survival rates were determined for 19,500 coal miners who were medically examined between 1953 and 1958. Within 10-year age categories, significant relationships were observed between increasing cumulative exposure category and increasing mortality from all nonviolent causes, pneumoconiosis, chronic bronchitis, or emphysema as the underlying cause of death. Mortality from all nonviolent causes was significantly elevated among miners with PMF compared to miners without radiographic evidence of pneumoconiosis. Survival was also slightly decreased (2% to 3%) among miners with simple CWP category 1 compared to those without pneumoconiosis.

In the U.S. study [Kuempel et al. 1995], significant exposure-response relationships were observed between cumulative exposure to respirable coal mine dust and mortality from pneumoconiosis, chronic bronchitis, or emphysema as an underlying or contributing cause of death. The study included 8,878 miners who were medically examined during the period 1969-71 and followed through 1979. SMRs for pneumoconiosis mortality increased with increasing cumulative exposure category. The effects of age and smoking were controlled by inclusion of these factors as covariates in the proportional hazards models. Pneumoconiosis mortality was significantly elevated among miners with either simple CWP or PMF and among miners exposed to dust of higher-rank coals. On the basis of these analyses, miners with working lifetime exposures to respirable coal mine dust at a mean concentration of 2 mg/m^3 have an increased risk of dying from pneumoconiosis, chronic bronchitis, or emphysema.

4.2.5.2 Studies of Lung Cancer and Stomach Cancer Among Coal Miners

Most studies have reported that mortality from lung cancer is lower than expected among coal miners when compared with general population rates [Liddell 1973; Costello et al. 1974; Armstrong et al. 1979; Rooke et al. 1979; Ames and Gamble 1983; Atuhaire et al. 1985; Miller and Jacobsen 1985; Kuempel et al. 1995], although some studies have reported elevated lung cancer mortality among coal miners [Enterline 1972; Rockette 1977]. Mortality from lung cancer was not associated with cumulative exposure to respirable coal mine dust in the two studies that evaluated this relationship [Miller and Jacobsen 1985; Kuempel et al. 1995]. In a study of lung cancer by histologic type, Vallyathan et al. [1985] found little difference in the pathologic features of lung cancer in coal miners and in men from the general population who smoke cigarettes. Vallyathan et al. [1985] also found no relationship between lung cancer and years in coal mining.

Some studies have reported that mortality from stomach cancer is elevated among U.S. coal miners when compared with general population rates [Stocks 1962; Enterline 1964; Matalo et al. 1972; Rockette 1977]. Miller and Jacobsen [1985] found a marginally significant relationship between cumulative exposure to respirable coal mine dust and mortality from cancers of the digestive system among U.K. coal miners.

Factors including diet, cigarette smoking, chewing tobacco, and coal dust exposure may play a role in the development of stomach cancer [Wu 1990; Ames and Gamble 1983; Ong et al. 1983; Whong et al. 1983; Ames 1982]. Coal dust cleared from the lungs via mucociliary clearance may enter the stomach, where it undergoes nitrosation or other chemical interactions and forms carcinogenic compounds [Ong et al. 1983; Meyer et al. 1980]. The nitrites and nitrates may enter the stomach from diets containing preserved meats or vegetables, or from the use of tobacco. Laboratory studies have shown that nitrosated extracts of coal dusts and tobacco are mutagenic in the Ames assay [Stamm et al. 1994], induce sister-chromatid exchanges in human peripheral lymphocytes [Tucker et al. 1984; Tucker and Ong 1985], and cause transformation of mouse fibroblasts [Wu et al. 1990]. Reduction in exposures to respirable coal mine dust, tobacco, and foods containing nitrites and nitrates may help reduce the risk of gastric cancer among coal miners.

SMRs for lung cancer [Liddell 1973; Costello et al. 1974; Armstrong et al. 1979; Rooke et al. 1979; Meijers et al. 1991] and heart disease [Costello et al. 1975] have generally been lower than expected among coal miners. Stomach cancer mortality rates were elevated among coal miners in some studies in the United States [Stocks 1962; Enterline 1964; Matalo et al. 1972; Rockette 1977]. Miller and Jacobsen [1985] found an association between cancers of the digestive organs and coal mine dust exposure in U.K. coal miners, but the effect was not observed independently of pneumoconiosis.

4.3 ANIMAL AND HUMAN STUDIES OF LUNG DUST BURDEN AND CELLULAR MECHANISMS

Although researchers have conducted extensive epidemiological studies of coal miners (including determination of exposure-response relationships), animal and cellular studies have provided additional useful information on the toxicity of respirable coal mine dust and components of that dust (e.g., silica or diesel exhaust). The animal studies of particle deposition and lung clearance have provided information on dose-response relationships. These studies have enhanced our understanding of disease mechanisms. Further research may provide the methods for earlier identification of disease and more effective medical intervention and treatment.

4.3.1 Alveolar Clearance Mechanisms

Both a sequestration and an overload hypothesis have been proposed to model the accumulation of dust in lungs following continuous exposure to particulates. The sequestration hypothesis was first proposed by Soderholm [Soderholm 1981; Vostal et al. 1982]. Later studies by Vincent et al. [1985, 1987] provided support for this model. The sequestration model predicts that some fraction of dust is sequestered or retained in the lungs even at low exposures. This sequestered dust is unaffected by clearance mechanisms and may be trapped in lymphatic tissue, in the interstitial spaces of alveolar walls, or within macules. Sequestration of dust does not necessarily render it nontoxic. Indeed, some proposed models assume that once particulates have entered the alveolar wall, they exhibit greater fibrogenicity than dust in the alveolar spaces.

The normal clearance of particles from the alveolar or pulmonary region of the lungs by alveolar macrophages is regarded as a first-order process [Task Group on Lung Dynamics 1966; Vincent et al. 1985; Morrow 1992]. However, first-order clearance models do not adequately represent the clearance kinetics under the following conditions: (1) when clearance is by dissolution, (2) when the lung is overloaded with particles, or (3) when cytotoxic dust is cleared [Morrow 1992]. At initial dust exposure, deposition exceeds clearance and the lung burden rises. As clearance increases in response to the added burden, the model from the Task Group on Lung Dynamics [1966] predicts that the lung burden begins to level off to a constant, steady-state value, and eventually clearance equals deposition. Recent studies have shown that the pulmonary clearance of retained particles by alveolar macrophages becomes progressively reduced until it essentially ceases; then the lung burden increases linearly at a rate approximately equal to the rate of deposition [Morrow 1988].

The phenomenon of overloading of lung clearance is consistent with overloading or saturation in other biological systems [Witschi 1990]. The overloading of lung clearance has been observed in studies of several animal species (including rats, mice, and hamsters) exposed to various insoluble, respirable particles, including diesel exhaust [Strom et al. 1988; Wolff et al. 1987], carbon black [Strom et al. 1989; Muhle et al. 1990a,b], test toner (polymer pigmented with carbon black) [Bellmann et al. 1991; Muhle et al. 1990c, 1991], titanium dioxide [Muhle et al. 1990a,b], mineral dusts [Vincent et al. 1985], and amosite fibers [Bolton et al. 1983]. The exposure-dose-response relationships for inhaled respirable particles have been investigated through the development of physiologically based toxicokinetic models to describe the retention and clearance kinetics in the alveolar region of the lungs of rats [Stober et al. 1990; Yu et al. 1988].

As the lung burden increases, alveolar macrophages become activated and release reactive oxygen species and cellular factors that stimulate pathogenic events [Driscoll et al. 1990a]. Activated or overloaded alveolar macrophages may release the following cellular factors: arachidonic acid metabolites [Demers et al. 1988], superoxide anion (O_2-) [Wallaert et al. 1990], platelet- activating factor [Kang et al. 1991], interleukins [Lapp and Castranova 1993], fibronectin, and tumor necrosis factor (TNF) [Vilcek et al. 1986; Driscoll et al. 1990b]. Coal dust-exposed alveolar macrophages from coal miners released significantly increased concentrations of TNF and interleukin-6 after 24-hr culture [Gosset et al. 1991].

Leukotriene B_4, interleukin-8, platelet-activating factor, and platelet-derived growth factor all enhance chemotaxis. In addition, platelet-activating factor and platelet-derived growth factor enhance the production of reactive oxygen species and increase the release of lysosomal enzymes from pulmonary phagocytes [Lapp and Castranova 1993]. Thus, these mediators may play an important role in dust-related inflammation and pathogenesis.

TNF has been the subject of much research. Its functions include (1) stimulating adhesion of polymorphonuclear leukocytes (PMNs) to endothelial cell surfaces (which induces chemotaxis and direct activation of PMNs), (2) indirectly activating fibroblast growth, and (3) inducing mononuclear phagocytes to produce and release cytokine interleukin-1 (IL-1) (which has been suggested to cause fibroblast proliferation and collagen synthesis) and induce the production of reactive oxygen species that cause lung tissue damage [Borm et al. 1988]. Individuals with greater TNF release in response to coal mine dust may be more susceptible to fibrogenesis, and such differences in the release of TNF and/or other indicators could be acquired or genetically controlled [Borm et al. 1988; Schraufnagel et al. 1987].

Overloading of alveolar clearance has been observed in animal studies to be characterized by the following responses, which may also be relevant in the pathogenesis of dust-related lung diseases: accumulation of dust-laden macrophages, increased lung weight, persistent inflammation, increased epithelial permeability, elevated infiltration of neutrophils, septal thickening, lipoproteinosis, increased transfer of material to lymph nodes, decreased or obliterated alveolar clearance, changes in pulmonary mechanics, impaired pulmonary function, and the onset of fibrosis after a critical dose (time-integrated concentration) and a sufficient time interval [Morrow et al. 1991; Muhle et al. 1991; Bowden 1987; Campbell and Senior 1981].

The composition of the dust and the surface properties of the particles influence the cellular response. Kuhn and Demers [1991] reported that rat alveolar macrophages exposed to freshly fractured coal dust[‡‡‡] produced markedly increased levels of prostaglandin E_2 and thromboxane B_2, whereas those

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[‡‡‡] Freshly-fractured silica particles in the coal mine dust produce increased levels of silicon-based radicals [Dalal et al. 1988, 1989b].

exposed to aged coal dust did not. The harmfulness of the coal dust has been attributed to the proportion of clean silica surface area [Kriegseis and Scharmann 1982; Le Bouffant et al. 1988, 1982]. The cytotoxicity (as assayed by erythrocyte hemolysis) of the silica has been shown to decrease after the particles are incubated in dipalmitoyl lecithin, which is a major component of lung surfactant coating alveoli surfaces [Wallace et al. 1988; Cilento and Georgellis 1991].

Relatively innocuous dusts can stimulate chronic inflammation and fibrosis when pulmonary dust burdens are high enough to overload the normal particle clearance mechanisms [Morrow 1988]. For example, in a chronic inhalation study of respirable test toner (a dust with low solubility and low acute toxicity that is used in photographic processes) in rats, retardation of particle clearance progressively increased with lung burdens of toner above approximately 1.0 mg/g of lung [Muhle et al. 1991; Mermelstein and Kilpper 1990]. A mild to moderate degree of lung fibrosis was observed in all of the rats exposed at 5.6 mg/m^3 respirable dust (16 mg/m^3 total dust), and a very slight degree of fibrosis was seen in 25% of the rats exposed at 1.4 mg/m^3 respirable dust (4 mg/m^3 total dust) (Table 4-10). Signs of lung overloading persisted 15 months after cessation of exposure [Muhle et al. 1990b].

4.3.2 Studies of Alveolar Clearance in Animals and Relevance to Dust-Exposed Workers

The finding from animal studies that alveolar-macrophage-mediated clearance can become saturated following long-term exposure to insoluble particles may be relevant to working lifetime exposures of coal miners. Coal miners may accumulate lung dust burdens of more than 10 mg/g of lung over a working lifetime under the current MSHA PEL of 2 mg/m^3 for respirable coal mine dust [Pritchard 1989]. Table 4-11 shows that 5 to 15 mg of dust/g of lung was retained in the lungs of British coal miners with cumulative exposures similar to those of U.S. miners exposed for 40 to 45 years at about 2 mg/m^3 of respirable coal mine dust. At 15 mg of retained dust/g of lung, slight to moderate fibrosis occurred in all animals in the chronic inhalation study (Table 4-10). With 15 mg of retained dust/g of lung, coal miners had developed PMF; and with 5 mg/g, coal miners had developed minimal fibrosis (Table 4-11).

A comparison of the lung dust burdens that caused overloading of alveolar clearance in animal studies and the lung dust burdens found in coal miners suggests that overloading may occur in the lungs of coal miners exposed at the current PEL of 2 mg/m^3 for respirable coal mine dust. However, these comparisons do not take into account additional factors that may be important—such as duration of exposure, dust composition (e.g., silica content), or differences in clearance rates or lung morphology of animals and humans.

4.3.3 Biological Factors in Individual Susceptibility to Fibrosis

The process of lung fibrosis is a multi-faceted, cascading process involving various inflammatory cells (e.g., macrophages, polymorphonuclear leukocytes, and lymphocytes) and distinct mediators [Lehnert 1990; Bowden 1987]. Thus, it is not known why some coal miners develop simple CWP or PMF and others with similar exposures do not [Lassalle et al. 1990]. Differences in individual susceptibility probably play a role [Borm et al. 1992, 1988].

Table 4-10. Findings of chronic inhalation study* of test toner in F-344 rats

Mean concentration (mg/m^3)	Mean dust retained in lungs (mg/g lung)	Pulmonary response at end of study
0.35	0.21	No evidence of overloading
1.43	1.80	Symptoms of overloading: slight decrease in clearance/ increase in retention; slight chronic inflammation Limited, very slight fibrosis in 25% of animals
5.63	15.0	Extensive symptoms of overloading: decrease in clearance/ increase in retention; chronic inflammation; decrease in pulmonary function; increase in lung weight Slight to moderate fibrosis in all animals

Adapted from Mermelstein and Kilpper [1990].

*Study duration was 24 months (6 hr/day, 5 days/week).

Table 4-11. Cumulative exposure, retained dust levels, and disease in British coal miners

Coal rank (% carbon)	Number of miners	Mean cumulative exposure (gh/m^3)*	Mean dust retained in lungs (mg/g lung)	Pathology group†
91.4–94.0	31	136.9	5.4	M
88.8–90.6	26	192.1	5.8	M
81.1–85.5	26	140.6	7.0	M
81.1–85.5	43	194.6	11.3	F
81.1–85.5	41	184.8	15.0	PMF

Based on data from Douglas et al. [1986].

*In U.S. coal miners, estimates of cumulative exposure to respirable coal mine dust range from 122 to 180 gh/m^3 (i.e., 35 years of exposure at 2 mg/m^3 and 1,740 hr/year equals 122 gh/m^3; or, 45 years of exposure at 2 mg/m^3 and 2,000 hr/year equals 180 gh/m^3).

†M: Focal dust deposits (macules) with minimal evidence of fibrosis (rarely had radiographic evidence of CWP).

F: M + one or more fibrotic dust lesions between 1 and 9 mm in diameter.

PMF: Fibrotic dust lesions 10 mm or more in diameter.

Bronchoalveolar lavage in humans has been used to recover alveolar macrophages to study the differences in factors released from alveolar macrophages of dust-exposed miners and unexposed controls. In coal miners who worked underground for a mean of 17 years and had no clinically detectable pneumoconiosis, a statistically significant increase in alveolar macrophages with surface ruffling (an indicator of alveolar macrophage activation) was observed [Lapp et al. 1991]. Significant increases in surface ruffling were also observed in alveolar macrophages from coal miners with pneumoconiosis [Takemura et al. 1989] and in rats chronically exposed to coal dust [Castranova et al. 1985; Lewis et al. 1989]. Coal miners with pneumoconiosis [Takemura et al. 1989] (but not those without pneumoconiosis [Lapp et al. 1991]) also had significantly larger numbers of lysosomes and significantly higher frequencies of multinucleated alveolar macrophages than comparison workers [Takemura et al. 1989].

Lassalle et al. [1990] compared the secretion of the cytokines TNF-alpha and IL-1 by alveolar macrophages from French coal miners and control subjects (11 nonminers living in the same area). A total of 40 coal miners were studied—19 with simple CWP; 11 with PMF; and 10 without CWP, including 5 retired coal miners. Alveolar macrophages were harvested by bronchoalveolar lavage. The investigators found that the alveolar macrophages from patients with CWP spontaneously secreted higher levels of TNF-alpha and IL-1 than did alveolar macrophages from controls. Among miners without radiographic evidence of simple CWP or PMF, high levels of both TNF-alpha and IL-1 were secreted from alveolar macrophages of working miners—but not from those of retired miners. Kuhn et al. [1991] also found that the alveolar macrophage production of eicosanoids and cytokines was lower in former U.S. coal miners than in working miners.

Rom [1991] reported that among individuals exposed to inorganic dust (including some coal miners), only those with respiratory impairment had alveolar macrophages that released significantly increased amounts of the oxidants superoxide anion and hydrogen peroxide. Furthermore, occupational exposures were similar among individuals with or without impairment, which indicates possible differences in individual susceptibility.

Chronic smokers may have impaired clearance of particles deposited in the lungs and persistent inflammatory responses [Mauderly et al. 1990; Bohning et al. 1982]. The slowing of particle clearance from the alveolar region of the lung would promote sequestration of larger lung dust burdens in smokers than in similarly exposed nonsmokers. Inflammatory and epithelial changes in smokers are centered primarily in conducting airways rather than the alveolar lung. Rats chronically exposed to cigarette smoke had impaired alveolar clearance of tracer particles; the magnitude of this impairmant was similar to the magnitude of impairments reported for human smokers [Bohning et al. 1982]. However, epidemiological studies of coal miners have found that the development of CWP was correlated with dust exposure and was not modified by smoking history [Jacobsen et al. 1977; Muir et al. 1977].

Lung dust burdens may not be a simple reflection of dust exposure: patterns of deposition or clearance may differ between miners who develop pneumoconiosis and those who do not. Pathological studies have shown that miners with PMF (or complicated CWP) accumulated more dust in their lungs *and* more dust per unit of dust exposure than miners without PMF [Douglas et al. 1986].

5 ENVIRONMENTAL MONITORING

5.1 CURRENT SAMPLING CRITERIA

5.1.1 Characteristics of the Currently Approved Sampling Device

The Federal Mine Safety and Health Act of 1977* defines respirable dust as dust measured with a device approved by the Secretary of Labor and the Secretary of Health and Human Services [30 USC 842(e)]. The approved sampler for respirable coal mine dust is the coal mine dust personal sampler unit (CPSU) [30 CFR 74; Jacobson 1971; Jacobson and Lamonica 1969]. The CPSU is generally called the 10-mm nylon cyclone, although the 10-mm nylon cyclone is actually just one component of the CPSU. The CPSU may either be mounted on a worker (with the sampling head positioned in the breathing zone for personal exposure monitoring) or in a fixed location for area sampling [Tomb 1990].

The CPSU consists of a pump unit, a sampling head assembly, and a battery charger if rechargeable batteries are used in the pump unit [30 CFR 74.2]. The sampling head assembly contains two stages. The first stage is a 10-mm nylon cyclone, which has collection characteristics similar to an elutriator. The amount of dust penetration depends on the flow rate [Jacobson and Lamonica 1969]. The second stage is a membrane filter (vinyl, pore size 5 µm) that collects the dust passing through the cyclone. The dust collected on the membrane filter is weighed to a precision (standard deviation) of 81 µg [Parobeck et al. 1981], and the respirable dust concentration in the mine atmosphere is then determined from the mass of dust collected and the volume of air sampled [Tomb 1990].

5.1.2 Current Regulations for Sampler Certification

The specifications for the design and performance of the CPSU are listed in 30 CFR 74. NIOSH is responsible for conducting tests for the certification of the CPSU according to the requirements in 30 CFR 74.4. MSHA is responsible for conducting tests for the intrinsic safety of the pump unit of the CPSU.

Current regulations require that sampling devices be approved in accordance with 30 CFR 74 and calibrated in accordance with MSHA criteria [MSHA 1992a] by a certified person. Approved samplers must be calibrated and operated at the flowrate of 2.0 L of air/min, or at a different flowrate as prescribed by the Secretary of Labor and the Secretary of Health and Human Services [30 CFR 70.204(b)]. To convert a respirable dust concentration measured with an approved

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*This Act amended the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173).

sampling device to an equivalent concentration measured with an MRE[†] instrument, current regulations require that the concentration measured with the approved sampling device be multiplied by the constant factor prescribed by the Secretary of Labor [30 CFR 70.206].

A constant factor of 1.6 was originally used to convert concentrations measured with the CPSU to the equivalent MRE concentration. The 1.6 factor was based on dust measurements taken by the U.S. Bureau of Mines (BOM) with an earlier version of the CPSU [Jacobson 1970]. Another study had reported a conversion factor of 1.88 [Doyle 1970]. In a subsequent study, it was determined that the collection characteristics of the 10-mm nylon cyclone portion of the CPSU depended on the inherent pulsations of the pump [Lamonica and Treaftis 1971]. Thus, the specifications of the approved CPSU were modified to require pulsation damping of at least 80%, which would result in measured concentrations within 5% of those obtained using a sampling unit with constant flow. A new conversion factor of 1.38 was established for converting CPSU dust concentrations to MRE concentrations [Tomb et al. 1973].

5.1.3 Construction of the Sampling Device

Three studies have reported that charge effects on particles passing through the nylon cyclone can lead to bias in the collection of dust by nonconducting samplers [Briant and Moss 1984; Knight and Kirk 1982; Almich and Carson 1974]. Localized sources of electric field occur in nonconducting samplers, which influence the collection of charged aerosol particles in the air near the sampler. Briant and Moss [1984] reported a 40% reduction in the collection efficiency of a moderately-charged aerosol with a nonconducting, charged sampler. Knight and Kirk [1982] reported a 25% reduction in aerosol collection caused by charge effects of the filter holder of CPSUs. Almich and Carson [1974] reported a 10% variability associated with charge effects. Additional studies have reported charge effects during sampling with nonconductive filter cassettes [Puskar et al. 1991; Demange et al. 1990; Mark 1990; Liu et al. 1985; Turner et al. 1984]. Current specifications for the CPSU state that the cyclone must be constructed of nylon or a material equivalent in performance [30 CFR Part 74.3(b)(1)]. However, other available samplers are constructed of metal and are less sensitive to charge effects than the nylon CPSU (e.g., the Higgins-Dewell cyclone with a 37-mm filter cassette made of conductive material such as graphite-filled plastic) [Higgins and Dewell 1968].

5.2 RECOMMENDED SAMPLING CRITERIA

NIOSH recommends a revision of the current MSHA definition of respirable coal mine dust, which is the mass fraction of dust collected with the CPSU when operated at 2.0 L/min (and multiplied by 1.38 for the MRE equivalent concentration). Instead, NIOSH recommends the recently developed international definition of respirable dust, which represents a compromise between previous definitions of particle-size-selective sampling by the International Standards Organization (ISO), the Comité Européen de Normalisation (CEN), and the American Conference of Governmental Industrial Hygienists (ACGIH) [ACGIH 1984, 1994; CEN 1993; ISO 1993; Soderholm 1989, 1991a,b]. Table 5-1 presents the collection efficiencies for sampling devices that operate in accordance with the international definitions of either respirable, thoracic, or inhalable

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[†] Mining Research Establishment of the National Coal Board, London, England.

Table 5-1. Collection efficiencies for particle-size-selective sampling

Respirable dust*		Thoracic dust		Inhalable dust	
Particle aerodynamic diameter (μm)	Respirable particulate mass (%)	Particle aerodynamic diameter (μm)	Thoracic particulate mass (%)	Particle aerodynamic diameter (μm)	Inhalable particulate mass (%)
0	100	0	100	0	100
1	97	2	94	1	97
2	91	4	89	2	94
3	74	6	80.5	5	87
4	50	8	67	10	77
5	30	10	50	20	65
6	17	12	35	30	58
7	9	14	23	40	54.5
8	5	16	15	50	52.5
10	1	18	9.5	100	50
		20	6		
		25	2		

Source: ACGIH [1994].

*The median cut point for a respirable dust sampler (4.0 mm) is in accordance with the international definition [ISO 1993].

dust. The respirable convention (E_R) is the target sampling curve for instruments approximating the respirable fraction. E_R is defined at aerodynamic diameter D by ISO [1993], CEN [1993], and ACGIH [1994] in terms of the cumulative normal function Φ as:

$$E_R = E_I \, \Phi[\ln[D_R / D] / \sigma_R]$$

where the indicated constants are $D_R = 4.25$ μm and $\sigma_R = \ln[1.5]$, and where the *inhalable* convention E_I is defined by:

$$E_I = 0.50\,(1 + \exp[-0.06\,D]),\ D < 100\ \mu\text{m}.$$

Two approaches to the approval of samplers may be considered: (1) the testing and approval of a single sampling device (e.g., the CPSU), or (2) the performance-based approval of a variety of sampling devices according to international criteria. Advantages of the single-sampler approach are that it provides consistency in sampling and avoids the potential for intersampler bias in the measurements. A disadvantage of the single-sampler approach is that it creates a disincentive for the development of improved samplers. Advantages of the performance-based sampler approach are that it stimulates the development of improved samplers and facilitates comparison to world exposure and effects data. A disadvantage of the performance-based approach is the extensive and expensive testing that would be required before samplers could be approved.

NIOSH recommends use of the international definition of respirable dust for sampling respirable coal mine dust for the following reasons:

- The particle size distributions reported for respirable dust in U.S. underground coal mines are within the approximate 2- to 10-μm range in which the collection efficiency of the sampler (operated in accordance with the international definition of respirable dust) is reasonably consistent with the fractional deposition of particles in the alveolar region of the human respiratory tract of healthy persons (Figure 5-1).

- The international definition of respirable dust better approximates the fraction of particles deposited in the alveolar region of the human respiratory tract than does the British Medical Research Council (BMRC) definition (see Figure 5-1).

- Respirable coal mine dust concentrations measured according to the current sampling criteria have been compared with those expected to be measured according to the international definition (see Section 5.7).

- Consistency with international standards for respirable dust sampling would be attained. This consistency would facilitate comparisons of the world literature about the health effects of exposure to respirable coal mine dust.

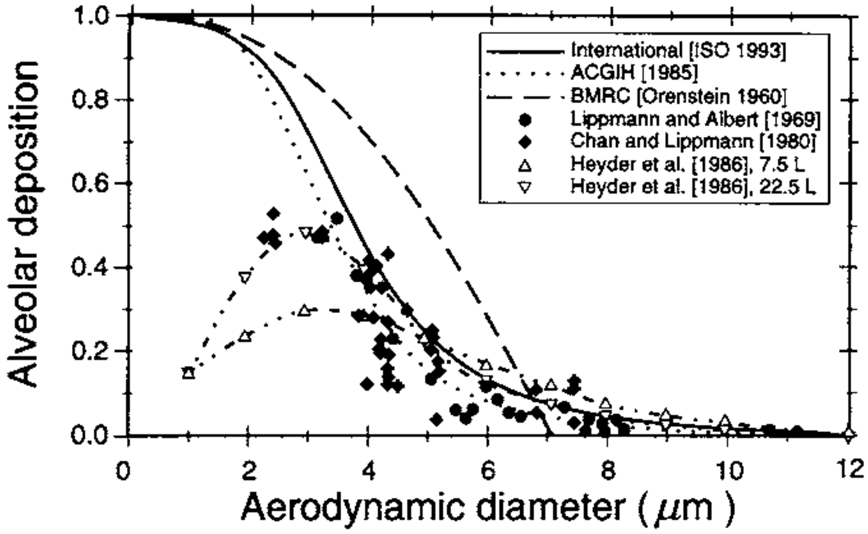
NIOSH recognizes the need to resolve the remaining technical questions associated with the recommended move to samplers that meet the international definition of respirable dust. In the interim, NIOSH recommends the use of the CPSU at a flow rate of 1.7 L/min without MRE conversion (versus 2.0 L/min with MRE conversion currently used by MSHA) for sampling respirable coal mine dust in accordance with the international definition of respirable dust. This NIOSH recommendation should be followed until acceptable criteria are developed for the performance-based approval of alternative samplers that also operate in accordance with the international definition of respirable dust. For example, the Higgins-Dewell sampler [Higgins and Dewell 1968] has been evaluated for performance according to the international definition [Bartley et al. 1994]. An additional advantage of using the flow rate of 1.7 L/min for the CPSU is that it would facilitate the use of a single sample for determining both respirable coal mine dust and respirable crystalline silica (which is currently sampled at 1.7 L/min).

The British MRE factor of 1.38 would not be applied to the values of respirable coal mine dust obtained from sampling according to the international definition. When the REL was derived from data based on the current MSHA sampling method, a conversion factor (Section 5.4) was used to compare the current method with the recommended sampling criteria. Thus, concentrations measured according to the recommended sampling criteria (international definition) do not require the use of a conversion factor.

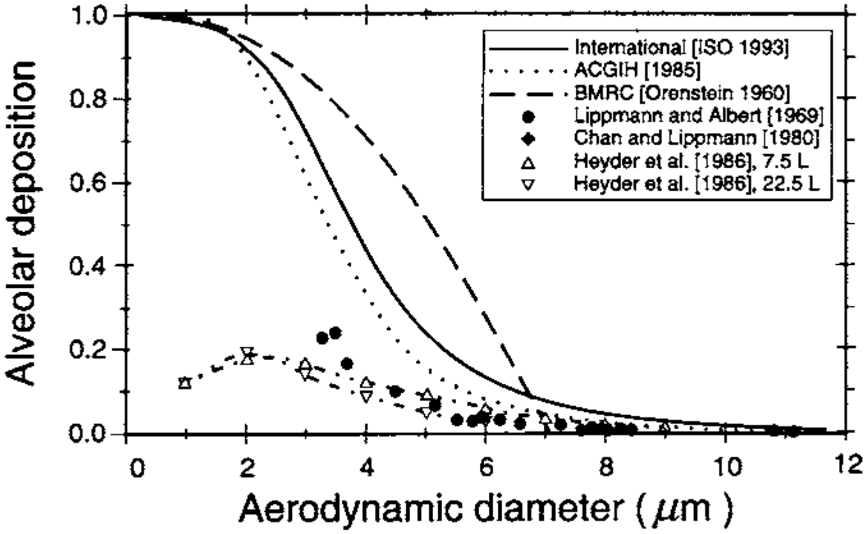
5.3 BASIS FOR PARTICLE-SIZE-SELECTIVE SAMPLING

5.3.1 Early Definitions of Particle-Size-Selective Sampling

The concept of the CPSU and similar sampling devices (including those operating in accordance with the international particle-size-selective sampling definitions) is based on the following experimental evidence:



A. MOUTH BREATHING



B. NOSE BREATHING

Figure 5–1. Comparison of the particle fraction deposited in the alveolar region of the lungs of healthy subjects [Heyder et al. 1986; Chan and Lippmann 1980; Lippmann and Albert 1969] with the ACGIH [1985], BMRC [Orenstein 1960], and international [ISO 1993] definitions of respirable dust. (Adapted from Soderholm [1989].)

- The deposition of particles in the respiratory tract depends on the size and shape of the particles (i.e., the aerodynamic diameter) [Chan and Lippmann 1980; Lippmann and Albert 1969; Task Group on Lung Dynamics 1966].

- The adverse health effects of inhaled particles depend on where the particles are deposited within the respiratory tract [Lippmann 1985; Nagelschmidt 1965].

As stated by Schlick and Peluso [1970], ". . . the instruments used to evaluate the atmosphere should simulate the respiratory tract in selecting the dust particles." The three major regions of the respiratory tract include the head airways region, the tracheobronchial region (including the trachea and ciliated airways in the lungs), and the alveolar region (including nonciliated airways and alveolar sacs in the lungs) [Soderholm 1989].

Early definitions for sampling respirable dust were developed by the U.S. Atomic Energy Commission (AEC) [Lippmann and Harris 1962] and by the BMRC. The BMRC definitions were adopted by the Johannesburg Pneumoconiosis Conference [Orenstein 1960]. The AEC curve has a sampling efficiency of 50% at a particle diameter of 3.5 µm (unit density, sphere), and the BMRC curve has a 50% sampling efficiency at 5 µm. An objective of particle-size-selective sampling has been to exclude from sampling those particles that are too large to enter the region of the lungs where the particles exert adverse health effects.

5.3.2 Deposition and Clearance of Particles in the Human Respiratory Tract

Data on the deposition of particles in various regions of the human respiratory tract are based on the use of radiotracer techniques [Emmett et al. 1982; Chan and Lippmann 1980; Lippmann and Albert 1969; Albert and Arnett 1955]. Deposition of particles in the small bronchi, bronchioles, and the parenchymal (gas exchange) region of the lung usually occurs by sedimentation for particles as small as 0.5 to 1.0 µm (aerodynamic diameter) [Stuart et al. 1984]. For particles smaller than 0.5 µm, deposition by diffusion occurs in small airways and gas exchange regions. Nonspherical shape of particles such as fibers may alter the deposition pattern. The electrical charges on particles also influence the fraction that is deposited. Freshly generated particles may be highly charged [Mercer 1973], and respiratory tract deposition can increase by 30% after inhalation of highly charged particles [Melandri et al. 1977].

Studies have been conducted on the clearance of particles from the lungs using radioactive particles to noninvasively determine the amount of material retained in the respiratory tract following aerosol exposure [Philipson et al. 1985; Bohning et al. 1982; Stahlhofen et al. 1981; Morrow et al. 1967; Albert and Arnett 1955]. Clearance of particles deposited in the respiratory tract is a continuous process that begins immediately after deposition [Stuart et al. 1984]. For insoluble particles such as coal mine dust, clearance is determined by the mechanical removal of particles by mucociliary transport from the airways. The phases of particle removal include a very rapid phase from extrathoracic airways, a fast phase from ciliated thoracic airways, and a slow phase from nonciliated thoracic airspaces [Stahlhofen et al. 1989; Heyder et al. 1986]. Clearance from ciliated portions of the lungs is called bronchial clearance, and clearance from nonciliated portions is called alveolar clearance [Heyder et al. 1986]. Thus, the partitioning of the lungs into bronchial and alveolar regions is based on the behavior of material deposited in the lungs and not on anatomical or physiological characteristics [Heyder et al. 1986]. The inhaled, insoluble particles that are deposited beyond the ciliated epithelium (i.e., in the respiratory bronchioles, alveolar ducts, and alveoli) can be phagocytized by alveolar macrophages and then cleared to the gastrointestinal tract or gradually dissolved [Phalen 1984; Stuart et al. 1984].

For the quantitation of risk from inhaled particles, the quantity of material deposited in a specified region of the respiratory tract and the amount remaining after physiological clearance from that region must be known [Stuart et al. 1984, 1986]. The amount of retained material may determine the effective dose of a contaminant that can produce acute or chronic pulmonary disease [Phalen et al. 1988]. Factors that affect particle deposition and retention include characteristics of the particles (size, shape, solubility), breathing rates and patterns, health status, and morphology of the respiratory tract [Miller et al. 1988; Phalen et al. 1986; Phalen 1984].

5.3.3 Deposition-Based and Penetration-Based Sampling Criteria

The design of the CPSU and similar sampling devices is based on the concept of the penetration of particles in the lungs (i.e., the ability of a particle to reach but not necessarily be deposited in a region of the lung [Soderholm and McCawley 1990]). Similarly, the international definition of respirable dust is based on the size of particles that enter the alveolar region of the human lungs (i.e., particle penetration, but not necessarily particle deposition or retention) (Figure 5-1). The international definitions of respirable, thoracic, and inhalable dust were influenced, in part, by the status of existing sampler technology and by the need to retain continuity with historical data bases (including respirable coal mine dust data collected according to the BMRC definition). The CEN working group has proposed that samplers purported to meet the international definition of respirable dust should be shown to be effective when sampling particle size distributions that have a median aerodynamic diameter between 1 and 25 µm and a geometric standard deviation between 1.5 and 3.5 [Kenny 1992].

The particle size distributions reported for respirable dust in U.S. underground coal mines are within the approximate 2- to 10-µm range in which the collection efficiency of the sampler (operated in accordance with the international definition of respirable dust) is reasonably consistent with the fractional deposition of particles in the alveolar region of the human respiratory tract (Figure 5-1). Figure 5-1 illustrates the fraction of particles that are deposited in the alveolar region of the human respiratory tract compared with the BMRC, ACGIH, and international definitions of respirable dust. Figure 5-1 also illustrates that although dust samplers conforming to these definitions collect up to 100% of the particles below approximately 2 µm, the alveolar deposition of particles below 2 µm in the human lungs is only about 20%. The deposition-based, size-selective sampling criteria are in better agreement with the deposition of particles in the human respiratory tract [Soderholm and McCawley 1990]. However, this approach would require more complicated size-selective samplers using several substrates. A deposition curve would also need to be determined based on the mean fraction of particles deposited in the respiratory tracts of a given human population. Because of the large variability among individuals in the particle deposition fraction, the deposition curve of the population would not necessarily provide a reasonable approximation of deposition in an individual. Thus, for occupational exposures (including respirable coal mine dust) in which the penetration curves provide a reasonable approximation and are proportional to deposition curves, there is little justification for using the more complicated deposition samplers for routine sampling. However, it is important to determine that the particle size distributions to be sampled lie within the measurable range of the sampler [Liden and Kenny 1991]. This determination should be repeated at periodic intervals because changes in working conditions may alter particle size distributions [Soderholm and McCawley 1990].

The criteria for sampler performance based on particle penetration into the lungs are protective for workers because it is unlikely that penetration-based samplers would underestimate the amount of material that could be deposited [Soderholm and McCawley 1990]. However, the effect of systematically over-estimating the dust deposition is to weaken the exposure-response relationship and potentially to overlook the need to develop appropriate exposure standards [Hewett 1991; Soderholm and McCawley 1990]. Despite this possible limitation, epidemiologic studies have found significant exposure-response relationships based on dust measurements collected with these penetration-based sampling devices (see Chapter 4).

5.4 CONVERSION FACTOR FOR COMPARING CURRENT AND RECOMMENDED SAMPLING CRITERIA

The international definition of respirable dust is shown in Figure 5-2 in terms of sampling efficiency at a given aerodynamic diameter. A quantitative description of the curve is given in CEN [1993]. Figure 5-2 also depicts recently measured sampling efficiencies for the CPSU at 2.0 L/min and at 1.7 L/min and for the Higgins-Dewell sampler at 2.2 L/min [Maynard 1993; Bartley et al. 1994]. These flow rates were chosen to match as closely as possible the international definition of the diameter at which the sampling efficiency equals 50% [Liden and Kenny 1993; Bartley et al. 1994]. This "cut-diameter" has been shown to dominate other cyclone parameters (such as the sampling efficiency sharpness) in characterizing the sampling of dusts distributed over diameters [Bowman et al. 1984] The data presented in Figure 5-2 are consistent with data from earlier studies [Caplan et al. 1973; Blachman and Lippmann 1974; Chan and Lippmann 1977; and Bartley and Breuer 1982].

To calculate a conversion factor for comparing current sampling criteria (Section 5.1) and recommended sampling criteria (Section 5.2), sampling efficiency curves are combined numerically with the aerosol size distributions (mass per unit particle diameter interval) measured in coal mines using data from Mutmansky and Lee [1987]. Liden and Kenny [1991] have documented that computed respirable mass concentrations are equivalent to measured concentrations in assessing distributed aerosol sizes.

Mutmansky and Lee [1987] provide detailed data about the measured concentrations of coal mine dust at various locations within 11 underground coal mine sections using continuous mining machines. The data in Mutmansky and Lee [1987] are consistent with other data on the particle size distributions measured in coal mines [Hinds and Bellin 1988; Bowman et al. 1984]; however, these studies present only a summary of data for each size distribution. The data from Mutmansky and Lee [1987] in Appendix 5 are suitable for accurately estimating the respirable fractions that

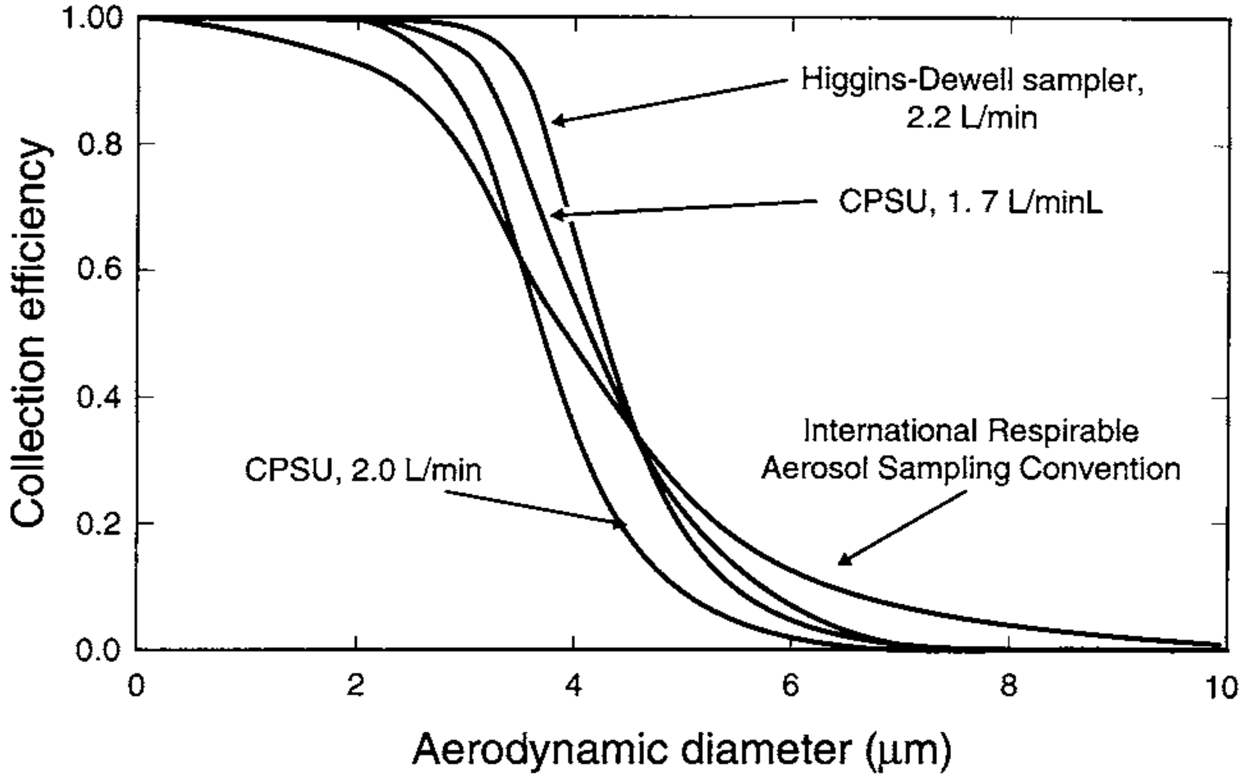


Figure 5-2. Respirable aerosol collection efficiencies.

would be obtained using any of the respirable dust definitions or various sampling systems. Hence, conversion factors can be obtained. The data are presented as cumulative fractions of the dust mass sampled (using the cascade impactor, Sierra Model 298) at diameters smaller than 0.5, 0.9, 2.0, 3.5, 6, 10, 15, and 21 µm. Because the respirable sampling efficiencies are close to zero at diameter D 10 µm, the two fractions of the largest size dust are not needed here. Similarly, the contribution of the 0.5-µm fraction to the total respirable mass is generally less than 10% and is therefore ignored (except insofar as it is a part of the 2.0-µm fraction).

To compute conversion factors, the remaining five cumulative fractions are modelled mathematically. The purpose is twofold: (1) uncertainty in the individual measurements is smoothed out through linear regression, and (2) models are convenient for computation in which a smooth size distribution is needed. Lognormal parameters consisting of mass median diameter (MMD) and geometric standard deviation (GSD) are used. An inverse-lognormal transformation of the data followed by simple linear regression provides two parameters (i.e., section or location). Note that uncertainty in the total dust concentration leaves the cumulative (measured) fractions in error by an unknown constant. Changes from the constant assumed by Mutmansky and Lee [1987] would shift the MMD and GSD in a correlated manner. Insofar as lognormality is a good approximation, however, such shifts are along curves of constant conversion factors and are therefore insignificant (Figures 5-3 and 5-4).

In Figures 5-3 and 5-4, the MMD and GSD for the size distribution of each particular coal mine section or location are shown as solid dots. Figures 5-3 and 5-4 also depict the factors for converting (at any given values of MMD and GSD) from current MSHA sampling criteria (including the 1.38 factor) to the international sampling criteria. The CPSU and the Higgins-Dewell sampler are among those that have been shown to perform within the criteria required for the international definition [Bartley et al. 1994]. Figure 5-3 provides the conversion factor for the CPSU operated at 1.7 L/min, and Figure 5-4 provides the conversion factor for the Higgins-Dewell sampler operated at 2.2 L/min. Both figures indicate the appropriate conversion factor corresponding to any given values of MMD and GSD. But because the size distribution to be sampled is not fixed, the MMD and GSD cannot be specified, and an average conversion factor must be calculated over a range of MMD and GSD values expected in U.S. coal mines.

On the basis of MMD and GSD values from the data of Mutmansky and Lee [1987], the following average conversion factors can be applied to concentrations measured by the current MSHA criteria (Section 5.1) to obtain the equivalent concentration measured according to the international definition of respirable dust (Section 5.2):

CPSU operated at 1.7 L/min: 0.857

SD[‡] = 0.029

Higgins-Dewell sampler operated at 2.2 L/min: 0.867

SD = 0.028

The above GSD values indicate the size-distribution-induced component of the variability expected in side-by-side sampling. This component is small relative to the spacial variability estimated in Appendix K.

Thus, with a concentration of 1.00 mg/m^3 measured with the CPSU according to current MSHA sampling criteria (Section 5.1), the corresponding concentration would be 0.86 mg/m3 with the CPSU operated according to the recommended criteria, or 0.87 mg/m^3 with the Higgins-Dewell sampler operated according to the recommended criteria (Section 5.2). A separate preliminary analysis of particle size distributions collected over a 10-year period by different investigators using similar methodology yielded a similar conversion factor of 0.85 for the CPSU operated according to current versus recommended sampling criteria [Hewett 1993]. These conversion factors are considered in the derivation of the REL (see Chapter 7).

[‡] SD = arithmetic standard deviation.

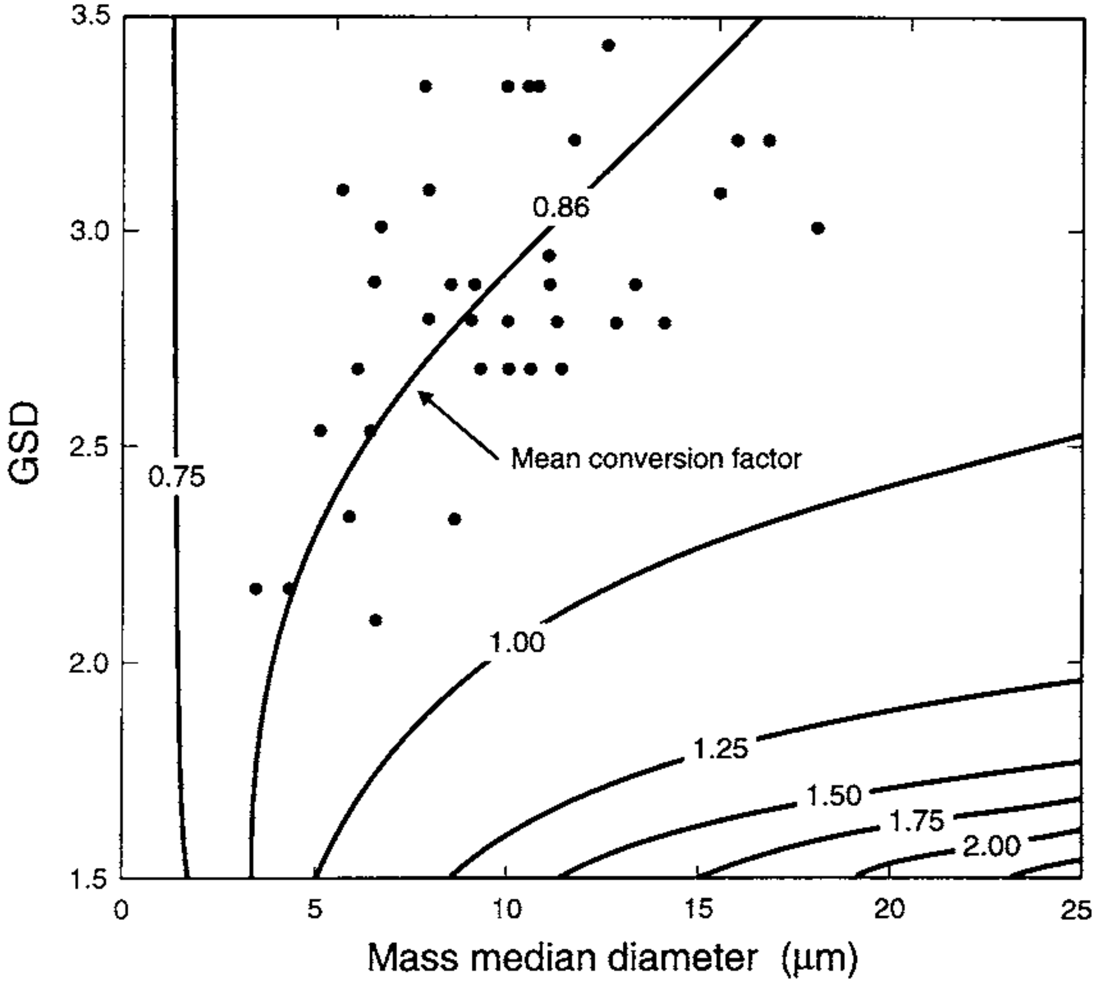


Figure 5–3. Conversion factor: MSHA standard to CPSU at 1.7 L/min.

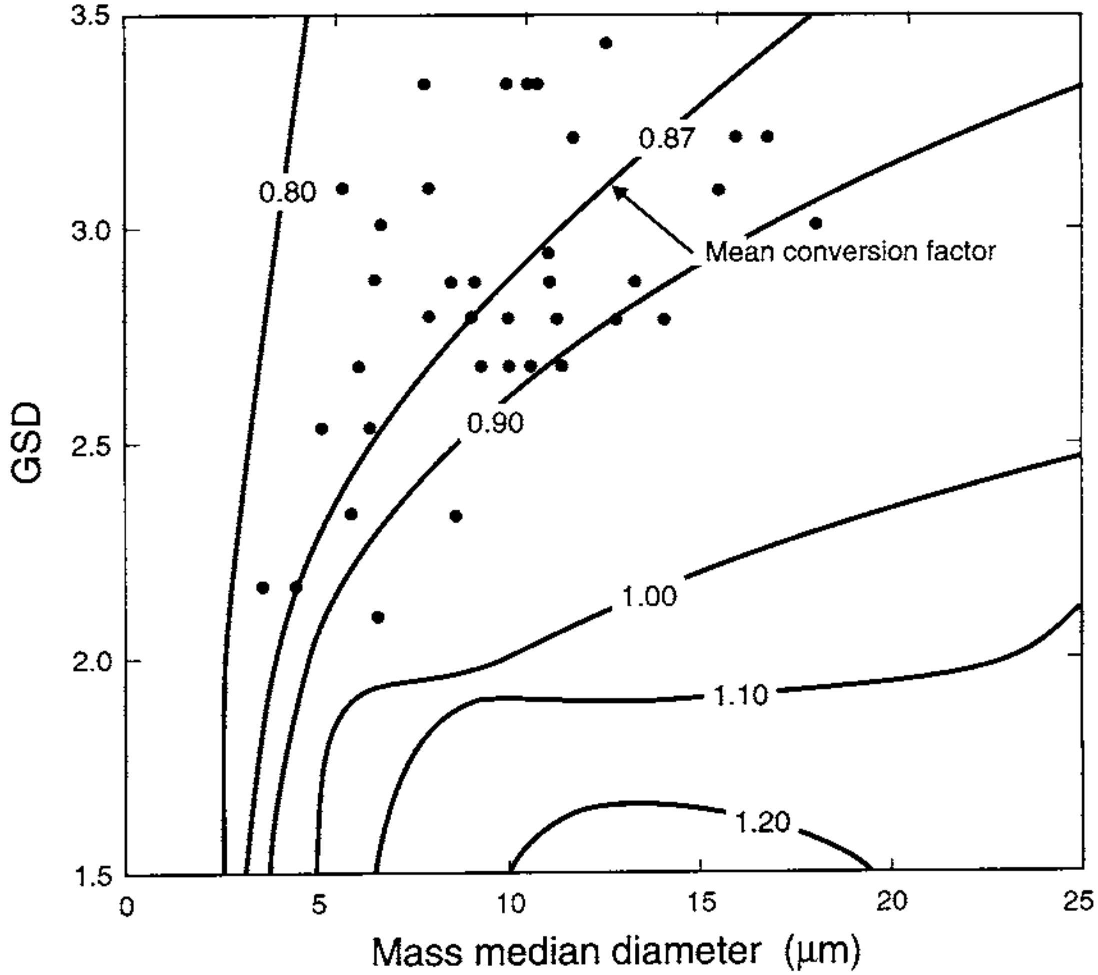


Figure 5–4. Conversion factor: MSHA standard to Higgins-Dewell sampler at 2.2 L/min. Excluded are points from a diesel-operated mine where the size distribution is clearly bimodal over the respirable region. Also, 6 points with GSD >3.5 μm are not plotted (yet fall within the iso-factor curves of the points shown).

5.5 CURRENT SAMPLING PROGRAM

5.5.1 MSHA Inspector Sampling

MSHA inspectors sample at least five occupations in each mechanized mining unit (MMU), including the designated occupation and any roof bolter occupations on the MMU that were not established as designated areas [MSHA 1989a]. MSHA inspectors collect one designated area sample per year at the location specified in the operator's Ventilation System and Methane and Dust Control Plan [30 CFR 75.316]. MSHA inspectors may also collect full-shift respirable dust samples from nondesignated entities (which represent either nondesignated areas or nondesignated occupations) if an inspection is requested by a miner or a miner's representative [according to 30 USC 813(g)] or if the inspector suspects that the concentrations of respirable coal mine dust or respirable quartz exceed the PEL. MSHA inspectors collect one personal sample per year from the environment of all underground and surface coal miners who are designated as "Part 90 miners" [MSHA 1989a]. At surface coal mines or surface work areas of underground coal mines, MSHA inspectors collect one sample per year from all designated work positions and at least three other occupations, if available, at these sites. MSHA inspectors also collect full-shift respirable dust samples of the intake air, with placement of the sampling device in the intake airway within 200 ft outby a working face [30 CFR 70.100(b)].

MSHA inspectors determine which entities to sample based on the following: (1) the compliance record of the mine, (2) the adequacy of the dust control parameters, (3) the number of entities being sampled by the operator as designated occupations or areas, Part 90 miners, or designated work positions, (4) the number of entities available for sampling, and (5) changes in mining conditions (since the last inspection) that may affect the concentration of respirable coal mine dust or respirable quartz [MSHA 1989a]. Designated area, nondesignated entity, and intake air samples are area samples, and Part 90 samples are personal samples. Inspections are currently required four times per year in underground coal mines to determine (among other safety and health issues) whether the parameters of the approved dust control plan are being maintained. However, exposure monitoring may be performed during just one of these inspections. Inspections are currently required at least twice per year in surface coal mines [30 USC 813(a)].

5.5.2 Coal Mine Operator Sampling

Current regulations require coal mine operators to take five valid respirable dust samples from designated occupations in each MMU for each bimonthly sampling period; samples are to be collected on consecutive normal production shifts [30 CFR 70.207]. Designated occupations for sampling are listed by mining method [30 CFR 70.207(e)] in Table 5-2. One requirement of designated-occupation sampling is that the sampling device must remain in the location of the occupation being sampled [MSHA 1989a]. Thus, the sampler may be transferred from one miner to another if the first miner moves to another location in the mine. Mine operators are also required to take one valid respirable dust sample from each designated area on a production shift during each bimonthly period [30 CFR 70.208]. The minimum production level required for valid bimonthly operator-collected samples is currently 50% of the average production reported for the last set of five valid samples [30 CFR 70.2(k)]. However, any sample with greater than 2.5 mg/m^3 of respirable coal mine dust is considered a valid sample, regardless of production level [30 CFR Part 70.207(d)].

Table 5-2. MSHA-required operator sampling of designated occupations in underground coal mines*

Mining method of section	Designated occupation for section	Position of sampling devices relative to designated occupation
Conventional	Cutting machine	On miner or on cutting machine within 36 in. inby normal working position
Conventional	Loading machine operator	On miner or on loading machine within 36 in. inby normal working position
Continuous mining (other than auger type)	Continuous mining machine operator	On miner or on continuous mining machine within 36 in. inby normal working position
Continuous mining (auger type)	Jacksetter working nearest working face on return-air side of continuous mining machine	On miner (as described) or at location representing maximum concentration of dust to which person is exposed
Scoop using cutting machine	Cutting machine operator	On miner or on cutting machine within 36 in. inby normal working position
Scoop (shooting off solid)	Coal drill operator	On miner or on coal drill within 36 in. inby normal working position
Longwall	Miner working nearest return-air side of longwall working face	On miner (as described) or along working face on return side within 48 in. of corner
Hand loading with cutting machine	Cutting machine operator	On miner or on cutting machine within 36 in. inby normal working position
Hand loading (shooting off solid)	Hand loader exposed to greatest concentration of dust	On miner or at location representing maximum concentration of dust to which miner is exposed
Anthracite mine	Hand loader exposed to greatest concentration of dust	On miner or at location representing maximum concentration of dust to which miner is exposed

*30 CFR 70.207 (e).

Mine operators are also required to sample surface coal mines or surface work areas of underground coal mines on a bimonthly basis [30 CFR 71.208]. Designated work positions are determined by the MSHA district manager for each work position with an average concentration of respirable dust exceeding 1 mg/m^3 (or less if the applicable standard is less than 1 mg/m^3)

[30 CFR 71.208(e)]. In both underground and surface coal mines, the PEL for respirable coal mine dust is currently reduced if the quartz content exceeds 5% [30 CFR 70.101; 30 CFR 71.101].

Since 1985, samples collected by coal mine operators have been used in addition to MSHA inspector samples to determine the reduced PEL. Under this system, if the sample collected by the MSHA inspector contains more than 5% quartz, the operator has the option of submitting a sample for quartz analysis and subsequent averaging with the inspector quartz sample [Niewiadomski et al. 1990]. If the quartz content of the operator sample differs by more than 2% (e.g., 4% vs. 6% or 10% vs. 12%) from the inspector sample, the operator is given the opportunity to submit another sample. The standard is then based on the average of quartz percentages from one inspector sample and two operator samples (see Table 2-1 for formula). Once an entity (i.e., job, area, or work position) is placed on a reduced standard, it is reevaluated approximately every 6 months by quartz analysis of a valid, operator-collected respirable dust sample of sufficient weight. MSHA uses the low-temperature ashing, infrared method to determine the amount of quartz in respirable dust samples, and individual dust samples weighing 0.5 mg or more can be analyzed for quartz [Niewiadomski et al. 1990].

5.5.3 Ventilation System and Methane and Dust Control Plan

According to 30 CFR 75.316, underground coal mine operators are required to submit a "Ventilation System and Methane and Dust Control Plan," which must be reviewed by the operator and MSHA at least every 6 months. The plan must include information about the mechanical ventilation equipment, the quantity and velocity of air, the operating parameters for required dust control devices, and the locations of designated area sampling (required in accordance with 30 CFR Part 70.208). The minimum production required for approval of the dust control plan is 60% of the average production over the last 30 production shifts [MSHA 1992b].

The Coal Mine Respirable Dust Task Group has evaluated the dust control plan approval process and has made recommendations for improving its effectiveness [MSHA 1992b]. The Task Group noted that primary reliance on environmental controls minimizes the possibility that workers will be exposed to excessive concentrations of respirable coal mine dust. They identified several important factors for improving the effectiveness of dust control plans: (1) sufficient detail and specificity in the dust control plans, (2) proper consideration of production levels, (3) upgrading of plans following abatement of citations, (4) and frequent sampling.

NIOSH makes the following recommendations, which are consistent with those of the Task Group:

- Mine operators should specify dust control parameters for typical production levels.
- Mine operators should evaluate the effectiveness of dust controls at typical production levels.
- Mine operators should perform additional sampling to evaluate dust controls whenever changes in controls or processes (e.g., increased production) might result in worker exposures exceeding the REL.

5.6 SAMPLING RECOMMENDATIONS

5.6.1 Sampling Strategy Issues

The sampling goals determine the approach needed to monitor concentrations of respirable coal mine dust and respirable crystalline silica. These goals may include determining the effectiveness of dust control systems, determining compliance with an exposure limit, and determining individual exposures to investigate exposure-response relationships.

Section 5.5 describes the current MSHA regulations for MSHA inspectors and coal mine operators sampling respirable coal mine dust and respirable crystalline silica at underground and surface worksites. The current sampling program generates more than 100,000 respirable dust samples per year. NIOSH recommends further evaluation of the current sampling program to ensure that exposures are below the REL for each miner during each shift. Numerous types of sampling strategies have been published and could be considered in such an evaluation (see Publications Examined, Sampling Strategies).

The mine operator is responsible for ensuring that the hazards from respirable coal mine dust are minimized or eliminated within each work environment throughout the mine and support facilities. The objective of an effective exposure sampling strategy is to periodically obtain sufficient, valid, and representative exposure estimates so that the work environment is reliably classified as either acceptable or unacceptable.

5.6.1.1 Frequency of Sampling

Exposure sampling should be periodic and should occur frequently enough that a significant and deleterious change in the contaminant generation process or the exposure controls is not permitted to persist. This is particularly true for face areas in underground coal mining where mining conditions can change dramatically within a short span of time.

5.6.1.2 Number of Exposure Measurements

Exposure measurements provide estimates of the magnitude of worker exposures in the recent past. Exposure measurements to determine the efficacy of existing exposure controls are used to predict exposures in the near future. Consequently, a critical attribute of a collection of exposure measurements is their predictive value. Although a single, full-shift sample will accurately measure the average airborne concentration during that shift, a single exposure measurement has little predictive value for demonstrating that a work environment is (and is likely to remain) acceptable. Note, however, that a single exposure measurement above the REL has a high predictive value, since exposures above the REL should occur infrequently (if at all) in a well-controlled work environment. The number of representative full-shift measurements collected should be sufficient to reliably detect work environments where exposure conditions are routinely unacceptable.[§]

[§] Where the work environment is particularly dynamic, it may be desirable to adopt a quality control approach when collecting exposure measurements. For example, one or more measurements could be collected at closely spaced intervals instead of monitoring a number of consecutive work shifts at 2-month intervals, as is the current practice.

5.6.1.3 Validity of Exposure Measurements

A valid exposure estimate measures what it is purported to measure [Leidel and Busch 1994]. Validity refers to possible nonrandom (systematic) sampling errors or biases in exposure measurements that can result in unrepresentative estimates of exposure. Systematic bias cannot be detected with statistical methods based on probability theory and must therefore be considered when designing the sampling strategy. Quality control programs can be useful for identifying systematic measurement errors. For example, proper calibration and periodic checks of the sampling pump flowrate and the condition of the sampling unit and sample cassette are needed for valid exposure measurements.

5.6.1.4 Representative Exposure Measurements

5.6.1.4.1 Sampling design

Each exposure measurement should be representative; that is, when measurements are collected, worker exposures should be comparable with those during unsampled shifts. In principle, a group of exposure measurements is considered representative if the measurements are collected randomly—that is, with no systematic bias in the selection of workers or sampling shifts. Randomly collected samples would include exposure measurements from both above- and below-average production shifts (see section 5.6.1.4.2). A design for statistically representative sampling may be used, for example, when the goal is to determine the distribution of all worker exposures over time to evaluate exposure-response relationships.

However, when the goal of sampling is to determine whether or not worker exposures are being kept below the REL, random sampling is usually not included in the sampling design. Instead, strategies are used that focus sampling efforts on those workers with the highest exposures (i.e., the maximum-risk worker concept discussed by Leidel et al. [1977] and Leidel and Busch [1994]). Such strategies may be more efficient (i.e., use fewer resources) for identifying potential exposures above the REL, but sufficient periodic sampling of all workers or groups of workers should also be performed to ensure that the targeted sampling groups include all workers with the potential for exposures above the REL.

5.6.1.4.2 Level of coal production

The level of coal production significantly affects the amount of airborne respirable coal mine dust [MSHA 1992b]. Thus, for example, a measurement collected from a worker at the coal face during a shift with abnormally low production has little or no predictive value for estimating exposures during unsampled shifts with typical coal production. The mine operator should therefore establish a production-level threshold to ensure that exposure conditions are comparable between sampled and unsampled shifts.

A sample shift with a production level equal to or greater than the production-level threshold is considered typical (i.e., a normal production shift). The definition of a normal production shift should be similar to or more stringent than that used when seeking approval of the dust control plan.[**] Consistent with standard industrial hygiene practice (which requires exposure measurements to be collected during typical work shifts), NIOSH recommends that for a production shift to be considered a "normal production shift," it must produce at least 80% of the average production over the last 30 production shifts.[††] The ventilation rate and the dust suppression devices and techniques used during sampled shifts should also be typical of normal production shifts.

In principle, the distribution of sample shift production levels should be similar to the overall distribution of production levels (truncated at the production level threshold). A significant difference between these distributions should not normally occur. A more stringent threshold should be imposed if it appears that sample shift production levels are routinely lower than those of unsampled shifts. These recommendations may evolve with additional data analyses and future evaluations of the current sampling program.

5.6.1.5 Reliable Classification of Work Environments as Acceptable or Unacceptable

A properly designed exposure sampling strategy will reliably classify a work environment: that is, it will have a high probability of classifying a work environment as acceptable when exposures are well-controlled, or unacceptable when exposures are poorly controlled.

The REL is defined here as the upper limit of exposure to respirable coal mine dust as a TWA concentration for up to 10 hr/day during a 40-hr workweek. Consistent with this definition, NIOSH defines an acceptable work environment as one where single-shift excursions above the REL occur infrequently, if at all. Consequently, NIOSH expects that in a well-controlled, acceptable work environment, the long-term average exposure for each miner will be sufficiently low to preclude the development of adverse health effects or the progression of existing disease.

5.6.1.6 Additional Personal Monitoring

An additional component of an effective sampling program is the need for additional personal exposure monitoring for miners who show early signs of occupational respiratory disease. Such monitoring should be part of an intervention program to prevent further development of disease.

5.6.2 Single, Full-Shift Sampling

The MSHA PEL is based on the standard specified in the Federal Mine Safety and Health Act of 1977 [30 USC 801-962].[‡‡] The Act states that "each operator shall continuously maintain the

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[**] The Coal Mine Respirable Dust Task Group [MSHA 1992b] concluded that the current procedure for defining a normal production shift "for sampling purposes" (see Section 5.5.2) is inadequate and makes the current sampling program susceptible to intentionally reduced production during shifts when exposure measurements are being collected.

[††] The minimum production level currently required for bimonthly operator-collected samples is 50% of the average production reported for the last set of five valid samples [30 CFR 70.2(k)], and the minimum production level required for approval of the dust control plan is 60% of the average production over the last 30 production shifts[MSHA 1992b].

[‡‡] This Act amended the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173).

average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of such mine is exposed at or below 2.0 milligrams of respirable dust per cubic meter of air" [30 USC 842(b)(2)]. The Act defines "average concentration" as that measured over a single shift:

> [T]he term 'average concentration' means a determination which accurately represents the atmospheric conditions with regard to respirable dust to which each miner in the active workings of a mine is exposed (1) as measured, during the 18 month period following December 30, 1969, over a number of continuous productions shifts to be determined by the Secretary (of Labor) and the Secretary of Health and Human Services, and (2) as measured thereafter, over a single shift only, unless the Secretary (of Labor) and the Secretary of Health and Human Services find, in accordance with the provisions of section 811 of this title, that such single shift measurement will not, after applying valid statistical techniques to such measurement, accurately represent such atmospheric conditions during such shift [30 USC 842(f)].

NIOSH recommends the use of single, full-shift samples to compare worker exposures with the REL. For single, full-shift samples used to determine noncompliance, NIOSH recommends that MSHA make no upward adjustment of the REL to account for measurement uncertainty [NIOSH 1994c]. By enforcing the exposure limit without any upward adjustment, MSHA would provide an equitable sampling program in which (given frequent sampling) the burden of measurement error is shared equally by miners and operators.

Statistical methods that account for measurement uncertainty [e.g., Leidel et al. 1977] may be a useful component of a mine operator's program to keep worker exposures to respirable coal mine dust below the REL during each work shift. Quality control approaches may involve determining long-term average exposures as part of a program for monitoring the effectiveness of engineering controls.

5.6.3 Types of Environmental Monitoring

The three types of environmental monitoring generally used include personal, breathing zone, and area sampling [Leidel et al. 1977]. For personal sampling, the sampling device is attached to the worker and is worn continuously for all work and rest periods during the shift. For breathing zone sampling, the sampling device is placed in the breathing zone of the worker; a second individual may be required to hold the sampling device in this location. For area sampling, the sampler is placed in a fixed location in the workplace.

When the purpose of the environmental monitoring is to determine worker exposures, personal sampling or breathing zone sampling should be used [Leidel et al. 1977]. Area sampling to determine worker exposures should demonstrate that such samples accurately measure worker exposures [Leidel et al. 1977].

5.6.3.1 Personal Sampling

NIOSH recommends personal exposure monitoring, based on an evaluation of the literature

(Section 5.6.3.2). The following summarizes the advantages of personal sampling to estimate worker exposures:

- Personal samples correlate best with exposures judged by biological indicators.
- Personal samples represent variations in worker exposures better than fixed-point area samples.
- Personal samples estimate worker exposures better than area samples, which tend to underestimate worker exposures.
- Personal exposure estimates may be used to evaluate exposure-response and the effectiveness of exposure standards.
- Personal sampling must be used to accurately assess the effectiveness of dust avoidance technologies (e.g., those with remote control operations). Such technologies may be useful for improving worker safety and reducing workplace exposures.

5.6.3.2 Studies Comparing Personal and Area Monitoring

Personal sampling provides the best estimate of worker exposures and the temporal and spatial variability in those exposures [Vincent 1994]. In nearly all the studies where personal and area monitoring were compared with clinical measures of occupation-related adverse health effects, the personal exposure measurements provided the best correlations [Stopford et al. 1978; Linch et al. 1970; Linch and Pfaff 1971]. Also, the personal exposures are frequently higher than the exposures measured by area monitoring [Niven et al. 1992; Cinkotai et al. 1984; Yoshida et al. 1980; Tomb and Ondrey 1976].

In a study of British longwall mines by the Institute of Occupational Medicine, Hadden et al. [1977] compared personal samplers with area samplers placed in the return airway. This sampling location presumably represents the maximum concentration of dust to which longwall miners are exposed. Nevertheless, the average dust concentration of the personal samples taken on a section was 10% higher than that in the area sample. The personal sampler data for the high-risk miners averaged 38% higher than the corresponding area samples. In a companion study for continuous and conventional mining, Garland et al. [1979] concluded that fixed-point gravimetric samples were unreliable for estimating worker exposures over a work shift. The authors also found that the creation of localized dust clouds at the coal face contributes greatly to individual exposure patterns; thus, the use of fixed-point (e.g., area) monitors may underestimate worker exposures at the coal face.

Studies have also reported large spatial variability in workplace dust concentrations. For example, in a study of various workplaces, Vaughan et al. [1990] report that lapel-to-lapel variations on a single worker can be so large that in 5% of the comparisons, a personal sampler on one lapel yielded more than twice the inhalable dust concentration of a sampler on the other lapel (although variability in concentrations of smaller particles such as respirable dust might be less). Variations from lapel to lapel are smaller than personal to area monitoring gradients, as demonstrated by

BOM data that showed large dust concentration gradients in underground coal mines over a 10-year period [Kissel and Jankowski 1993]. Near the continuous miner, gradients were reported to increase up to 1 mg/m^3 per foot in the direction of the coal mine face. Dust gradients are also large in longwall coal mines, as shown by increases in dust concentration by a factor of 10 in the 9-meter distance along the face in the walkway downwind of the shearer. The associated measurement bias can be quite large and variable (17% to 36%) [Kost and Saltsman 1977].

5.6.3.3 Area Sampling

NIOSH recognizes that sampling to assess controls and personal exposures may require separate approaches. Area sampling may be preferable during the development of controls to detect sources of dust or to assess the efficacy of a particular control measure. However, the ultimate acceptance of a new control depends on its ability to reduce personal exposure to respirable coal mine dust and respirable crystalline silica.

The Federal Mine Safety and Health Act of 1977 refers to "the average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of such mine is exposed" [30 USC 842(b)]. The reference to "atmosphere" could be interpreted as an indication that area sampling is sufficient. However, NIOSH believes that the intent of the Act is to provide for the control of each miner's personal exposure and that personal sampling is therefore preferable. Area sampling should be substituted for personal sampling only where area sampling has been shown to measure an equivalent or higher concentration.

5.7 Analytical Methods

The concentration of respirable coal mine dust in the mine atmosphere is determined gravimetrically [Tomb 1990]. Sampling and analysis for respirable crystalline silica should be performed in accordance with NIOSH Method 7500, 7602, or a demonstrated equivalent [NIOSH 1994b]. Sampling devices that may be used for Method 7500 or 7602 include the CPSU (with a 0.8-µm or 5-µm polyvinyl chloride (PVC) or mixed cellulose ester membrane filter) operated at a flow rate of 1.7 L/min, the Higgins-Dewell sampler operated at 2.2 L/min, or an equivalent sampler [NIOSH 1994b]. The presence of the minerals kaolinite ($Al_2Si_2O_5(OH)_4$) and calcite ($CaCO_3$) in the dust sample may interfere with analysis by Method 7602. This method provides correction procedures to use if either kaolinite or calcite is present. When respirable coal mine dust is to be analyzed in the same sample, mixed cellulose ester membrane filters should not be used because of their high weight variability. A preweighed polyvinyl chloride filter should be used and a final weight should be taken before ashing when Method 7602 is used to analyze crystalline silica in coal mine dust. In Method 7500, the presence of kaolinite and calcite do not interfere with the method if the samples are ashed in a low-temperature asher or if they are suspended in tetrahydrofuran [NIOSH 1994b].

The current analytical method used by MSHA (known as MSHA P-7) [MSHA 1989b] differs from NIOSH Method 7602 in the sample preparation procedures. The uneven deposition of ash that has been observed in the filtration step of MSHA P-7 can adversely affect the quantitation of the quartz [Lorberau 1990]. NIOSH Method 7603 [NIOSH 1994b] is similar to MSHA P-7 both in its use of the same filtration technique and in its specification of a 2.0-L/min flow rate for sample collection. NIOSH Method 7603 and MSHA P-7 are designed specifically to analyze respirable crystalline silica in coal mine dust and thus may reduce some of the interferences that can occur in samples collected in the mining environment. However, NIOSH Method 7602 is the preferred infrared method because it avoids the uneven deposition of ash and has the more appropriate sample collection flow rate of 1.7 L/min (see Appendix J).

In lieu of either NIOSH Method 7603 or MSHA P-7, NIOSH Method 7602 is recommended for the analysis of respirable crystalline silica.

6 MEDICAL SCREENING AND SURVEILLANCE

6.1 OBJECTIVES OF MEDICAL SCREENING AND SURVEILLANCE

The REL of 1 mg/m^3 for respirable coal mine dust does not assure a zero risk for the development of occupational respiratory diseases among all miners exposed during a full working lifetime. Consequently, a medical screening and surveillance program that includes initial and periodic chest X-rays and spirometric examinations is important for the early detection of disease and the prevention of "material impairment of health or functional capacity" [30 USC 811(a)(6)(A)]. The medical screening and surveillance program is also useful for disease surveillance, which includes the tracking trends, the setting of prevention and intervention priorities, and the assessment of prevention and intervention efforts. NIOSH encourages both underground and surface coal miners to participate in the medical screening and surveillance program.

6.1.1 Definitions

Medical screening is "the application of an examination, historical question, or laboratory test to apparently healthy persons with the goal of detecting absorption of intoxicants or early pathology before the worker would normally seek clinical care for symptomatic disease" [Halperin et al. 1986]. In contrast, medical surveillance involves the evaluation of a population's health status through the periodic collection, analysis, and reporting of data for the purpose of disease prevention [Halperin and Baker 1992]. Medical surveillance data are useful for evaluating the effectiveness of disease prevention and intervention programs. Primary prevention of work-related disease depends on the effective control of worker exposures below occupational exposure limits. Secondary prevention measures include medical screening for the early detection of diseases and medical intervention, which is aimed at reversing or impeding progression of disease.

6.1.2 Criteria for Medical Screening and Surveillance Tests

Acceptable performance of a medical screening test depends on the prevalence of disease in the population as well as the risk of toxicity and the consequences of false positive test results [Matte et al. 1990]. Additional criteria for effective medical screening tests and programs include the following [Weeks et al. 1991; Levy and Halperin 1988]:

- The screening test must have acceptable sensitivity, specificity, and predictive value.
- The screening test must be valid and reliable.
- The screening test must identify disease early and lead to treatment that impedes disease progression.

- Adequate followup, further diagnostic tests, and effective management of the disease must be available, accessible, and acceptable.

- Benefits of the screening program must outweigh the costs.

If a medical screening test indicates the presence of a disease or the increased probability of the presence of disease, further evaluation and diagnostic testing are needed.

NIOSH believes that the tests recommended in the medical screening and surveillance program for coal miners (i.e., chest X-rays and spirometry) reasonably fulfill the criteria for effective screening tests. These recommended tests are performed using standardized methods for administering them and interpreting results. They represent the best available methods for detecting occupation-related respiratory diseases among coal miners. In addition to the medical screening function, the recommended tests are also important for medical surveillance. The characteristics of medical tests used in disease surveillance of a population may differ from those required for the clinical evaluations of individuals [Weeks et al. 1991; Silverstein 1990].

6.2 CURRENT MEDICAL SURVEILLANCE PROGRAM AND RECOMMENDED REVISIONS

6.2.1. Current Chest X-Ray Program

The Coal Workers' X-Ray Surveillance Program was established under the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173), which was amended by the Federal Mine Safety and Health Act of 1977 [30 USC 843]. The specifications for giving, interpreting, classifying, and submitting chest X-rays for underground coal miners are provided in 42 CFR 37. Currently, mandatory X-rays include the following:

- An initial chest X-ray within 6 months of beginning employment

- Another chest X-ray 3 years after the initial examination

- A third chest X-ray 2 years following the second one if a miner is still engaged in underground coal mining and if the second chest X-ray shows evidence of category 1 or higher pneumoconiosis according to the ILO classification [ILO 1980]

In addition to these mandatory chest X-rays, mine operators are required to offer an opportunity for periodic, voluntary chest X-rays approximately every 5 years. These chest X-rays must be interpreted by approved, qualified readers [42 CFR Part 37]. Radiographic findings of simple CWP or PMF are reported to MSHA by NIOSH and to the miners by MSHA. All chest X-rays given under the Coal Workers' X-Ray Surveillance Program are submitted to and become the property of NIOSH. Operators of underground coal mines are required to provide chest X-rays at a convenient time and place for all miners who work in underground coal mines or in surface areas of underground coal mines [42 CFR Part 37].

6.2.2 Spirometry Recommendations

The Federal Coal Mine Safety and Health Act of 1977 specifies that the chest X-rays are to be supplemented by "such other tests as the Secretary of Health and Human Services deems necessary" [30 USC 843(a)]. The definition of pneumoconiosis was modified in the Black Lung Benefits Reform Act of 1977 as a chronic dust disease of the lung and its sequelae, including respiratory and pulmonary impairments arising out of "coal mine employment" [30 USC 902(b)]. NIOSH therefore recommends that spirometric examinations be included in the medical screening and surveillance program for coal miners based on

- the definition of pneumoconiosis in the Black Lung Benefits Reform Act of 1977 (which includes respiratory and pulmonary impairments that might not be detected on a chest X-ray but would be detected with spirometry), and

- the evidence (see Chapters 4 and 7) that coal miners can develop COPD from their exposures to respirable coal mine dust—even without radiographic evidence of simple CWP and apart from the effects of cigarette smoking.

The recommended schedule for spirometric examinations is provided in Section 6.3.

6.2.3 Recommendations for Surface Coal Miners

NIOSH also recommends inclusion of surface coal miners in the medical screening and surveillance program based on the evidence (see Chapters 4 and 7) that these miners can develop simple CWP, PMF, silicosis, and decrements in lung function as a result of their exposures to respirable coal mine dust and respirable crystalline silica.

6.2.4 Current and Recommended Option to Work in a Low-Dust Environment

Currently, any miner who shows evidence of the development of pneumoconiosis based on the chest X-ray or other medical examinations has the option to work in a low-dust environment in the mine where the concentration of respirable coal mine dust is not more than 1.0 mg/m^3—or where the concentration is the lowest attainable below 2.0 mg/m^3 if the 1.0 mg/m^3 concentration is not attainable in the mine where the miner works [30 USC 843(b)]. If it is necessary for the miner to transfer to another position in the mine to reduce exposure, the transfer is offered without loss of pay. These miners also receive periodic personal exposure monitoring [30 CFR 90].

The current regulations [30 CFR 90] include only underground coal miners and workers at surface work areas of underground coal mines. NIOSH recommends that the regulations governing eligibility and procedures for the transfer option be amended to include both surface and underground coal miners with radiographic evidence of pneumoconiosis or with confirmed finding of a chronic airways disease based on spirometry and other medical examinations or tests deemed necessary by a licensed physician. NIOSH believes that affording miners with evidence of occupation-related respiratory disease the opportunity to work in a low-dust environment is consistent with the intent of the Americans with Disabilities Act of 1990 [42 USC 10227-13643].

6.3 RECOMMENDED MEDICAL SCREENING AND SURVEILLANCE PROGRAM FOR UNDERGROUND AND SURFACE COAL MINERS

This document refers to the recommended revisions to the Coal Workers' X-Ray Surveillance Program as the "Coal Workers' Medical Screening and Surveillance Program" to better reflect the functions of the program. The recommended preplacement and periodic medical examinations include the following:

- An initial (preplacement) spirometric examination and chest X-ray as soon as possible after beginning employment (within 3 months for a spirometric examination and within 3 to 6 months for a chest X-ray)
- A spirometric examination each year for the first 3 years after beginning employment and every 2 to 3 years thereafter if the miner is still engaged in coal mining
- A chest X-ray every 4 to 5 years for the first 15 years of employment and every 3 years thereafter if the miner is still engaged in coal mining
- A chest X-ray and spirometric examination when employment ends if more than 6 months have passed since the last examination
- A standardized respiratory symptom questionnaire—such as the American Thoracic Society (ATS) respiratory questionnaire [Ferris 1978 (or the most current equivalent)]—to be administered at the preplacement examination and updated at each periodic examination
- A standardized occupational history questionnaire (including a listing of all jobs held up to and including present employment, a description of all duties and potential exposures, and a description of all protective equipment the miner has used or may be required to use) to be administered at the preplacement examination and updated at each periodic examination

6.3.1 Worker Participation

Miners should be provided with information about the purposes of the medical screening and surveillance program, the health-protection benefits of participation, and a description of the procedural aspects of the program. This information should include how screening test results are used, what actions may be taken based on screening results, who has access to screening test results, and how confidentiality is maintained [Matte et al. 1990]. The initial examination (which is currently mandatory) is important for providing baseline values for individuals. Comparing test results for an individual (including baseline values) may indicate a clinically important change that would not be apparent from comparing an individual's results with group reference values. The reason is that normal variation in test results among healthy group members is generally greater than test-to-test variation in individuals [Hankinson and Wagner 1993; Matte et al. 1990]. The fact that periodic examinations are voluntary may improve the reliability of data based on questionnaires and medical tests requiring worker cooperation. Each miner should sign a consent form indicating that he or she has been informed about the purposes of the medical screening and surveillance program and accepts or declines participation. Miners should not suffer consequences because of their choices for or against participation. Recent improvements in the Coal Workers'

X-Ray Surveillance Program (including increased education and communication) have resulted in an encouraging increase in the voluntary participation of coal miners [Wagner et al. 1993a].

6.3.2 NIOSH-Approved Facilities

NIOSH recommends that each mine operator make arrangements with a local NIOSH-approved facility or organization to conduct the medical examinations. The local examination facility or organization should transmit to NIOSH all chest X-rays, pulmonary function test results (including spirograms), completed medical questionnaires, and work histories. NIOSH shall evaluate the technical quality of the chest X-rays and interpret them. In addition, NIOSH shall do the following:

- Evaluate the results of spirometric examinations, completed medical questionnaires, and work histories
- Prepare letters to notify miners of the examination results and to recommend any followup examinations
- Permanently store the medical and questionnaire data

6.3.3 Smoking

NIOSH recommends that the mine operator prohibit smoking and strictly enforce this policy in all underground and surface coal mines and in all other work areas associated with coal mining. The mine operator or the physician should counsel tobacco-smoking miners about their increased risk of developing lung cancer and COPD; the mine operator or physician should also counsel such miners to participate in a smoking cessation program.

6.4 INTERPRETATION OF MEDICAL SCREENING EXAMINATIONS

6.4.1 Evidence of Pneumoconiosis on Chest X-Rays

NIOSH recommends that chest X-rays be classified according to the 1980 ILO Classification of Radiographs of Pneumoconioses (or the most current equivalent) [42 CFR 37 (1989)]. Evidence of pneumoconiosis is present when the chest X-ray is classified as ILO category 1/0 or greater or when large shadows are recorded as likely to be due to PMF or complicated CWP. NIOSH considers two physicians to be in agreement when their classifications meet one of the following criteria:

- They each find complicated pneumoconiosis of any category.
- Their findings with regard to simple pneumoconiosis are both in the same major category.
- Their findings are within one minor category (ILO category 12-point scale) of each other. In this case, the higher of the two interpretations should be reported. The only exception to this criterion is a reading sequence of 0/1, 1/0, or 1/0, 0/1. Such a sequence is not considered agreement, and additional classifications are required until the readers reach a consensus involving two or more readings in the same major category.

6.4.2 Evaluation of Spirometric Examinations

NIOSH recommends that the results of spirometric examinations be evaluated as follows:

- Use the highest FEV_1 and FVC values from each miner's examination when comparing the FEV_1, FVC, and $FEV_1/FVC\%$* with the lower limit of normal (LLN)†.

- Compute the miner's decline in FEV_1 by comparing his or her FEV_1 values over a period of time; a decline of 15% or greater (adjusted for the expected interval decline in FEV_1) is considered significant and warrants further medical evaluation [Hankinson and Wagner 1993; ATS 1991].

A spirometric examination should be repeated within 3 months if it is unacceptable according to ATS criteria [ATS 1991].

Evidence of impaired lung function is present when there is a confirmed finding (based on two or more spirometric examinations) of either of the following:

- The FEV_1, FVC, or FEV_1/FVC value from an acceptable test is below the LLN (Knudson et al. [1983] and Appendix E, or the most current equivalent).

- A decline in FEV_1 (adjusted for the expected interval decline in FEV_1) is 15% or greater [Hankinson and Wagner 1993; ATS 1991].

6.4.3 Worker Notification

Workers should be notified in a timely manner regarding the results of their medical examinations, including whether or not any abnormalities were detected. A NIOSH contact person should be provided for further information.

When a miner first shows evidence of impaired lung function based on the results of the spirometric examination (Section 6.4.2), he or she should be notified that the spirometric examination should be repeated within 3 months.

Any miner with either radiographic evidence of pneumoconiosis (as described in Section 6.4.1) or a confirmed finding of impaired lung function (as described in Section 6.4.2) should be notified of his or her option to work in an environment where the exposures are as far as feasible below the RELs for respirable coal mine dust and respirable crystalline silica. In addition, the miner should be advised to consult a licensed physician or other qualified health care provider regarding appropriate medical followup and intervention measures, which may include those listed in Section 6.4.4.

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*The ratio of FEV_1/FVC is conventionally expressed as a percentage. The miner's highest FEV_1 and FVC values are used to compute this ratio.

†The LLN is calculated with the equations published by Knudson et al. [1983] (Appendix E) or the most current equivalent. See Section 6.5.4 for a discussion of the LLN.

6.4.4 Medical Followup and Intervention

Medical followup and intervention that should be considered by the physician and the miner include the following measures:

- Further medical examination and testing determined by and performed by or under the direction of a licensed physician
- Annual spirometric examination
- Participation in a smoking-cessation program, if applicable
- The option to work in an environment with exposures as far as feasible below the RELs for respirable coal mine dust and respirable crystalline silica

6.5 LUNG FUNCTION TESTS FOR MEDICAL SCREENING AND SURVEILLANCE

Spirometry is the most important test for evaluating a miner's lung function [Attfield and Wagner 1992b]. The most widely accepted spirometry tests for screening workers are those for FEV_1 and FVC [Hankinson 1986]. The detection of lung function values below normal reference values or the detection of a significant decline in lung function over time indicates that further examination and testing are needed to confirm the test results, to determine the cause(s) of the reduced lung function, and to identify appropriate intervention or therapeutic measures.

6.5.1 Determining Obstructive and Restrictive Ventilatory Defects

Obstructive and restrictive ventilatory defects are two basic disease patterns detected by spirometry. An obstructive ventilatory defect indicates airflow limitation caused by airway narrowing during expiration [ATS 1991]. A greater reduction in FEV_1 than in VC (i.e., FEV_1/FVC decreased) suggests an obstructive ventilatory defect [ATS 1991]. Diseases associated with this pattern include asthma, chronic bronchitis, and emphysema [Garay 1992].

Reduced VC and normal or increased FEV_1/FVC suggest a restrictive ventilatory defect [ATS 1991]. Pneumoconiosis and other interstitial lung diseases can cause restrictive ventilatory defects. Exposure to respirable coal mine dust may cause obstructive, restrictive, or mixed ventilatory defects.

FEV_1 is ideal as a screening tool because it detects ventilatory defects reflecting either restrictive or obstructive patterns. However, FEV_1 should not be used without the FEV_1/FVC[‡] ratio to distinguish between disease patterns because FEV_1 may be decreased in both the obstructive and restrictive patterns, as shown here:

[‡] FVC may be lower than VC in persons with airways obstruction because of gas trapping; thus, the ratio of FEV_1/FVC appears to be more normal than the ratio of FEV_1/VC. For this reason, the ATS recommends using FEV_1/VC to determine the ventilatory disease pattern [ATS 1991]. However, FVC is used for screening because it is easily obtained when measuring FEV_1.

Obstructive pattern	*Restrictive pattern*
FVC normal or slightly decreased	FVC decreased
FEV_1 decreased	FEV_1 decreased
FEV_1/FVC decreased	FEV_1/FVC normal or slightly increased

Determining the disease pattern is more relevant to clinical diagnosis and treatment than to workplace spirometry screening, where early identification of a ventilatory defect is the primary ojective.

Once a ventilatory defect is identified, its severity is determined using the percentage of FEV_1 loss (for obstructive deficits) or the percentage of FVC loss (for restrictive deficits) [ATS 1991]. Medical followup to determine the nature of any loss in FEV_1 or FVC may include further testing such as TLC, airways resistance, and diffusing capacity.

Similarly, FEV_1/FVC should not be used to determine the severity of the deficit because both FEV_1 and FVC may be decreased—either as a result of a restrictive or a mixed ventilatory defect. Such a pattern of parallel reduction in FVC and FEV_1 has been reported among U.S. and U.K. coal miners [Attfield and Hodous 1992; Soutar and Hurley 1986] (see section 4.2.2 for discussion of epidemiological studies of lung function and respiratory symptoms in coal miners).

The LLN for a spirometric test may be defined as the 5th percentile of the reference population [ATS 1991] (see section 6.5.4 for further discussion). Patterns of restrictive and obstructive ventilatory defects observed with other lung function tests are listed in Table 6-1. Figure 6-1 illustrates determination of FEV_1 and FVC on a spirogram.

6.5.2 Quality Control and Instrumentation

Criteria for improving the accuracy and reproducibility of spirometry test results include the following [ATS 1991]:

- Adherence to ATS guidelines for equipment performance and calibration [ATS 1987a, 1979]
- Maintenance of spirometer temperature between 17° and 40°C to reduce temperature-related errors
- Validation of computer calculations following any changes in hardware or software
- Quality assurance reviews by each laboratory to maintain the precision and accuracy of spirometry measurements, and
- Provision of high-quality of training for technicians (technicians should complete a NIOSH-approved course on spirometry, and laboratories should receive NIOSH certification)

Table 6–1. Characteristics and common causes of restrictive and obstructive ventilatory defects detected from lung function tests

Type of ventilatory defect	Characteristics	Supplemental characteristics	Common causes
Restrictive defect	Decreased VC Relatively normal expiratory flow rate Relatively normal MVV*	Decreased TLC Decreased lung compliance Chronic alveolar hyperventilation Increased (A-a)PO_2 Abnormal distribution of inspired gas Decreased DL_{co}	Interstitial lung disease: Interstitial pneumonitis Fibrosis Pneumoconiosis: Granulomatosis Edema Space-occupying lesions: Tumors Cysts Pleural diseases: Pneumothrorax Hemothorax Pleural effusion, emphysema Fibrothorax Chest-wall diseases: Injury Kyphoscoliosis Spondylitis Neuromuscular disease Extrathoracic conditions: Obesity Peritonitis Ascites Pregnancy

(Continued)

See footnotes at end of table.

Table 6–1 (Continued). Characteristics and common causes of restrictive and obstructive ventilatory defects detected from lung function tests

Type of ventilatory defect	Characteristics	Supplemental characteristics	Common causes
Obstructive defect	Normal or decreased VC Decreased maximum expiratory airflow Decreased MVV	Increased RV Increased airway resistance Abnormal distribution of inspired gas Significant response to bronchodilator Decreased DL_{co} Decreased lung elastic recoil	Upper airway: Pharyngeal and laryngeal tumors Edema infections Foreign bodies Tumors, collapse, and stenosis of trachea Central and peripheral airway: Bronchitis Bronchiectasis Bronchiolitis Bronchial asthma Parenchymal disease: Emphysema

Source: Gold and Boushey [1988].
*MMV = maximum voluntary ventilation.

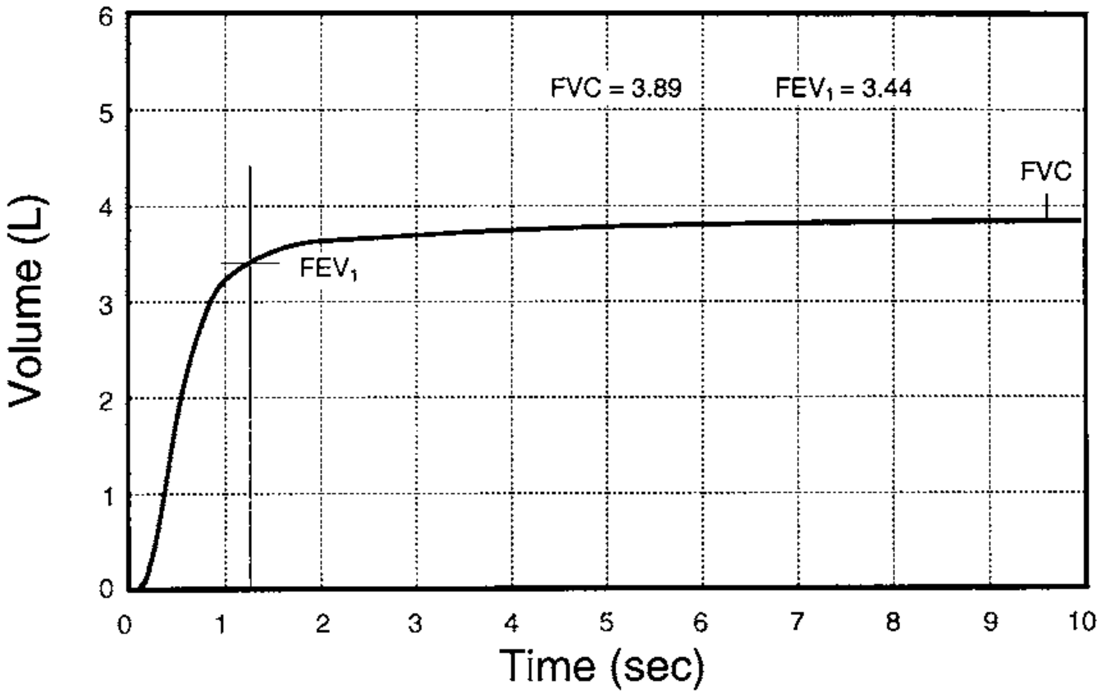

Figure 6-1. FVC and FEV_1 on a normal volume-time curve.

Two basic types of spirometers are available for determining FEV_1, FVC, or FEV_1/FVC: the flow spirometer and the volume spirometer [Hankinson 1993]. The flow spirometer measures the rate at which air is exhaled, and it must integrate flow to determine volume. The volume spirometer collects exhaled air and directly measures volume. A significant advantage of the volume spirometer is its simplicity and direct measurement of volume; a significant disadvantage is that a small error in estimating zero flow can affect the resulting volume, particularly for measurements of FVC [Hankinson 1993]. Further information about quality control, instrumentation, and interpretation of spirometry tests is provided in the ATS reports mentioned above [ATS 1991, 1987a, 1979], in other publications [Hankinson 1993; McKay and Lockey 1992; Harber and Lockey 1992], and in Appendix G of this document. Hankinson et al. [1994] describe a method that uses ceramic flow sensors to estimate body temperature and pressure-saturated (BTPS) correction factors for spirometers.

6.5.3 ATS Acceptability and Reproducibility Criteria for Spirometry Tests

The ATS criteria for acceptability of a spirometry curve is based on the technician's observation that the individual performed the test with a smooth, continuous exhalation, apparent maximal effort, and a satisfactory start—and without coughing, glottis closure, early termination, a leak, or an obstructed mouthpiece [ATS 1987a]. A minimum of three acceptable maneuvers are required according to ATS guidelines [ATS 1987a]. The spirometry testing administered as part of the National Study of Coal Workers' Pneumoconiosis includes five maneuvers, and the maximum FEV_1 and FVC values are used for epidemiological analysis [Attfield and Hodous 1992].

The ATS acceptability and reproducibility criteria are intended to be spirometry testing goals—not criteria for determining the inclusion or exclusion of subjects in an epidemiological study. As shown in two separate studies [Kellie et al. 1987; Eisen et al. 1984, 1983], the ATS reproducibility criteria to determine which subjects should be included in an epidemiological analysis resulted in biased estimates of FEV_1. Eisen [1987] reported that individuals with persistent test failure had twice the annual average rate of FEV_1 decline than those without persistent test failure. Kellie et al. [1987] found that coal miners who failed the reproducibility criteria had a lower mean FEV_1 and significantly more respiratory symptoms (i.e., cough, phlegm, wheeze, and dyspnea) than miners with reproducible tests.

Height has also been shown to affect a person's ability to meet ATS reproducibility criteria (i.e., shorter persons have more difficulty than taller subjects in satisfying ATS reproducibility criteria) [Hankinson and Bang 1991]. The largest FVC and FEV_1 should be reported regardless of the spirometry curve(s) on which they occur [Hankinson 1986; ATS 1987a]. Miller and Scacci [1981] have suggested criteria that can be used to determine whether an individual has used full effort. NIOSH recommends that the ATS acceptability and reproducibility guidelines be used to describe spirometry test results but not to dismiss a finding of abnormality.

6.5.4 Cross-Sectional Spirometry Testing

For spirometry used to assess a person's lung function at one point in time, his or her values for FEV_1, FVC, and FEV_1/FVC are compared with normal reference values for persons of similar gender, age, height, and race. This approach (referred to as cross-sectional spirometry testing) is used to determine whether spirometry test values are within normal limits.

The percentile of the lung function distribution chosen to define the LLN depends on the desired levels of sensitivity and specificity. The 5th percentile has been recommended for use as the LLN in clinical evaluation and diagnosis [ATS 1991].[§] Thus, spirometry values below the 5th percentile are below the expected normal range. Although the use of the 5th percentile as the LLN provides a high degree of specificity (i.e., few false positives), it is implicitly insensitive to detecting early abnormalities, particularly in a healthy population. Greater sensitivity for screening purposes may result from using a higher percentile (e.g., the 10th) as the cutoff point for recommending further medical evaluation or testing [WHO 1995].[**]

NIOSH recommends that the 5th percentile be used to define the LLN for the recommended spirometry tests in the medical screening and surveillance program for coal miners (Appendix E). Miners with a confirmed finding of FEV_1, FVC, or FEV_1/FVC below the LLN are eligible to participate in medical intervention programs (see Section 6.4.4).

NIOSH also recommends that the 10th percentile be used as the cutoff point for recommending further evaluation. Thus, miners with lung function at or below the 10th percentile of the distribution should be advised to seek further clinical evaluation from a qualified health care provider.

[§] The 5th percentile is equivalent to the "normal 95th percentile" used by Knudson et al. [1983].

[**] WHO [1995] uses the terminology from Knudson et al. [1983] (i.e., 90th percentile).

If a miner has respiratory symptoms that suggest an abnormality (whether or not his or her lung function values are below the LLN), he or she may submit medical records and request a review for eligibility to participate in the medical intervention programs.

Spirometry test results that are less than 80% of the predicted values are often used to identify abnormal results, but this criterion has no statistical basis [ATS 1991] and is not recommended. If the data used for deriving the prediction equation are distributed normally (i.e., Gausian distribution) with variability reasonably constant over the age range of interest, then the LLN may be calculated as a defined percentile point of that distribution using the estimated standard error. However, this approach is not recommended because assumptions of normality and homogeneity of variance are rarely met in actual spirometric surveys of adults [Knudson et al. 1983]. Instead, Knudson et al. [1983] advise determining the LLN as a defined lower percentile point of the actual distribution of data.

The Knudson et al. [1983] equations are recommended as the basis for the normal reference values for spirometry tests (i.e., the LLN for FEV_1, FVC, and FEV_1/FVC) of U.S. coal miners for the following reasons:

- The analyses described by Knudson et al. [1983] meet the methodological, epidemiological, and statistical criteria recommended by the ATS [1991] for the selection of reference values.

- The estimate of the age-related decline in FEV_1 found by Knudson et al. [1983] is very similar to that reported by Attfield and Hodous [1992] for nonsmoking coal miners.

- The Knudson et al. [1983] data are based on cross-sectional studies of lifetime nonsmokers; thus, the spirometry test results will be applicable to the respiratory health surveillance of miners as a group and to the medical evaluation of individual miners for diagnosis and other clinical purposes.

As additional data become available, NIOSH may update these recommendations for reference values in spirometry testing. In particular, future studies may provide reference values for several ethnic groups that are not currently available in the literature.

6.5.5 Longitudinal Spirometry Testing

Longitudinal spirometry used in medical screening allows comparisons of a worker's preplacement lung function values with those determined in later spirometric examinations. Such periodic spirometry testing may be useful for early identification of a worker with excessive loss of lung function (i.e., before the loss is apparent from cross-sectional testing) [Hankinson and Wagner 1993]. This identification is possible because workers as a group are often healthier than the general population and have above-average lung function [Becklake and White 1993]. Thus, comparing a worker's lung function values with general population reference values may not detect an actual loss in that worker's lung function [Hankinson and Wagner 1993]. About half of a worker population may benefit from longitudinal (in addition to cross-sectional) evaluation of spirometry [Hankinson and Wagner 1993].

Hankinson and Wagner [1993] recommend establishing a baseline FEV_1 value for each worker from several initial spirometric examinations. They then recommend calculating the longitudinal LLN by taking 85 percent of this baseline value minus the expected decline over a period of time (based on the individual's age).

6.5.6 Additional Medical Tests of Lung Function

Additional lung function tests may be required for further evaluation of miners with abnormal spirometric examinations or with respiratory symptoms. Such tests may be too complicated or expensive to administer during routine screening, or they may have large variability within a normal population [Miller and Scacci 1981; Hankinson 1986; WHO 1995].

Recommended methods are available for measuring the diffusing capacity of the lung for carbon monoxide (DLCO) [Ferris 1978] and for calculating predicted values [Crapo and Morris 1981]. Changes in the membrane-diffusing capacity or in the capillary volume that are caused by structural lung damage can influence the diffusing capacity of the lung [Miller and Scacci 1981]. The single-breath method of measuring DLCO is the most widely used and best standardized method of measuring diffusing capacity [Gold and Boushey 1988; Hankinson 1986]. Because DLCO can be abnormal in numerous respiratory disorders, the test lacks specificity for work-related respiratory diseases. Also, cigarette smoking has been associated with reduced DLCO (because of elevated carboxyhemoglobin) and should be considered in the diagnosis [Hankinson 1986]. Measuring the DLCO is indicated when other tests such as spirometry do not show sufficient lung impairment to explain a patient's respiratory symptoms [Hankinson 1986; Miller and Scacci 1981].

6.6 OTHER ISSUES PERTAINING TO RECOMMENDATIONS FOR MEDICAL SCREENING AND SURVEILLANCE

6.6.1 Evaluating the Work-Relatedness of COPD Among Coal Miners

The evidence implicating exposure to coal mine dust as a cause of COPD in coal miners has been reviewed in Chapter 4 and is used in Chapter 7 as part of the basis for the NIOSH REL for respirable coal mine dust. Becklake [1985] concluded that the causal link between occupational exposure and chronic airflow limitation among coal miners has been demonstrated "beyond reasonable doubt." Becklake's conclusion refers to the epidemiological evidence from studies of exposures and responses in groups of miners. In these studies [Attfield and Hodous 1992; Seixas et al. 1993, 1992; Marine et al. 1988; Soutar et al. 1988; Soutar and Hurley 1986; Rogan et al. 1973], the variability among individuals' lung function responses to similar exposures implies that a certain proportion of miners will respond either more or less severely than the average. Among miners who respond more severely than the average, some may have clinically significant reductions in lung function, as shown by Marine et al. [1988]. Soutar and Hurley [1986] found that studies limited to working miners may underestimate the clinical importance of dust-associated reductions in lung function. Hurley and Soutar [1986] identified a subgroup of coal miners (including those who had left the industry voluntarily before normal retirement age) for whom the average effect of dust exposure on reduction in FEV_1 was more than twice that reported by Marine et al. [1988].

The findings of these epidemiological studies indicate that exposure to coal mine dust may lead to clinically significant COPD. But as Becklake [1985] notes, it is unlikely that medical evidence could provide scientific proof of the work-relatedness of a particular case of COPD, even though "a reasonable statement of probability" may often be obtained. Kusnetz and Hutchinson [1979] identified the various elements that need to be considered when physicians attempt to make such an individual assessment of probability:

- Verification of convincing epidemiological evidence that occupational exposure may cause COPD
- Clinical evidence that the disease exists in the individual concerned
- Evidence that there has been an exposure of sufficient degree or duration to result in disease
- An assessment of other relevant factors such as nonoccupational exposures that might cause COPD or other special circumstances.

The spirometric examinations and questionnaires on respiratory symptoms and work history (which are included in the recommended medical screening and surveillance program for coal miners) will provide important information for effective workplace surveillance, medical diagnoses, and individual advice to miners.

6.6.2 Medical Intervention Strategies

The risk of developing PMF increases with increasing initial category of simple CWP [Attfield and Seixas 1995; Attfield and Morring 1992b; Hurley and Maclaren 1987; Hurley et al. 1987; McLintock et al. 1971; Cochrane 1962]. Furthermore, the risk of progression to a higher category of simple CWP increases with increasing intensity of exposure (mean dust concentration) [Jacobsen et al. 1970, 1971] and increasing cumulative exposure (i.e., intensity × duration) [Jacobsen 1973, 1979]. Thus, the risk of PMF increases systematically both with initial category of simple CWP and with the amount of progression (over 5-year periods) from each initial category (including categories 0/0, 0/1, and 1/0) [McLintock et al. 1971]. The amount of time spent in a disease category of simple CWP may also influence the risk of progression to a higher category [Morfeld et al. 1992].

The weight of evidence from these studies suggests that a reduction in worker exposures to respirable coal mine dust will decrease the risk of simple CWP progression and thus the risk of PMF. However, other factors may influence the effectiveness of dust reduction in decreasing the risk of disease progression. Cumulative exposure and residence time of dust in the lungs may be important factors in the development of PMF [Maclaren et al. 1989; Hurley et al. 1987]. Maclaren and Soutar [1985] found that 32% of the miners who developed PMF after they left mining had no evidence of CWP (i.e., category 0) when they terminated their employment in mining. The effectiveness of dust reduction may also depend on the magnitude of that reduction. Hurley and Maclaren [1987] estimated that just 1 in 10,000 cases of PMF would be prevented if all miners who had developed simple CWP category 1/0 or greater at a mean concentration of 2.0 mg/m^3 of respirable coal mine dust were then allowed to work at a mean concentration of 1.0 mg/m^3. However, the same report also shows that reducing average dust concentrations from 2 to 1 mg/m^3 over a 40-year working lifetime would more than halve the risk of PMF—from between 7 and 18 cases per 1,000, to between 3 and 7 cases per 1,000, depending on coal rank [Hurley and Maclaren 1987].

The effectiveness of reducing exposures to respirable coal mine dust has not been adequately studied with regard to reversing or reducing lung function deficits. However, some evidence shows that reduction or cessation of smoking can at least partially reverse the functional abnormalities associated with smoking [McCarthy et al. 1976] and the structural changes in the peripheral airways of asymptomatic young smokers [Ingram and O'Cain 1971]. These studies of smoking suggest that reducing or ceasing exposures to other contaminants associated with airways obstruction and loss of lung function (e.g., respirable coal mine dust and respirable crystalline silica) may also effectively reverse or further reduce adverse effects. NIOSH therefore recommends, as a prudent public health measure, that miners be permitted to work in a low-dust environment if they have evidence of COPD caused or exacerbated by exposure to coal mine dust.

Further research is needed to evaluate the effectiveness of medical interventions such as reducing or ceasing exposures to respirable coal mine dust or respirable crystalline silica. Any analysis of the effectiveness of the transfer program would need to consider possible bias from the low rate of participation: only 23% of eligible coal miners (2,119 of 9,138 miners) elected to participate [Wagner and Spieler 1990]. Goldenhar and Schulte [1994] have described additional methodological issues in intervention research.

A related research need is to evaluate the availability of mine areas where exposures to respirable coal mine dust and respirable crystalline silica are as far below the respective RELs as feasible. The tables in Appendix B show that mean concentrations for most occupations have been below the PEL of 1 mg/m^3 for miners transferred under 30 CFR 90. However, the mean concentrations for some occupations (e.g., roof bolter and continuous miner helper) exceed the PEL of 1 mg/m^3, and a substantial percentage of samples show measured concentrations greater than 1 mg/m^3. Limited data from sampling required for miners transferred under 30 CFR 90 also show that concentrations of respirable crystalline silica exceeded the NIOSH REL and the MSHA PEL for some occupations. NIOSH advocates primary prevention (through reducing exposures) rather than secondary intervention as the most effective means of eliminating occupational diseases.

7 BASIS FOR THE RECOMMENDED STANDARD

7.1 THE NIOSH REL FOR RESPIRABLE COAL MINE DUST

NIOSH recommends that exposures to respirable coal mine dust be limited to 1 mg/m^3 as a TWA concentration for up to 10 hr/day during a 40-hr workweek, measured according to current MSHA methods (see Section 5.1 and Appendix J). NIOSH recommends that sampling be conducted with a device that operates in accordance with the NIOSH accuracy criteria [Busch 1977; Busch and Taylor 1981] and the international definition of respirable dust [ACGIH 1994; CEN 1993; ISO 1993; Soderholm 1991a,b; 1989].*

The REL represents the upper limit of exposure for each worker during each work shift. For single, full-shift samples used to determine noncompliance, NIOSH recommends that MSHA make no upward adjustment of the REL to account for measurement uncertainties [NIOSH 1994c] (see also Section 5.6.2). NIOSH further recommends that all reasonable efforts be made to reduce exposures to respirable coal mine dust below the REL through the use of engineering controls and work practices.

7.2 BASIS FOR THE CURRENT U.S. STANDARD

The current U.S. standard of 2 mg/m^3 for respirable coal mine dust [30 USC 842(b)] is based primarily on studies of coal miners in the United Kingdom [Jacobsen et al. 1971; McLintock et al. 1971; Cochrane 1962]. Studies of U.S. coal miners during the 1960s investigated the prevalence of simple CWP and PMF using the number of years worked underground to estimate exposures to respirable coal mine dust (see Section 4.2). By contrast, U.K. studies during that period investigated both (1) the relationship between increasing category of simple CWP and the development of PMF [Cochrane 1962; McLintock et al. 1971], and (2) the relationship between the concentration of respirable coal mine dust and the risk of developing simple CWP [Jacobsen et al. 1971] or PMF [McLintock et al. 1971].

Cochrane [1962] reported in an 8-year study of 1,429 Welsh miners and ex-miners that the incidence of PMF was nearly zero among miners who either had no evidence of simple CWP (category 0) or who had simple CWP category 1 when the study began. However, the incidence of PMF was 15% or 30%, respectively, among miners who had had simple CWP category 2 or 3 when the study began (Figure 7-1). McLintock et al. [1971] found a similar relationship between increasing category of simple CWP and the development of PMF (Figure 7-1). Thus, the strategy for preventing PMF was directed at preventing progression to simple CWP category 2.

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*The REL of 1 mg/m^3 is equivalent to 0.9 mg/m^3 when measured according to the NIOSH recommended sampling criteria (see Sections 5.2 and 5.4).

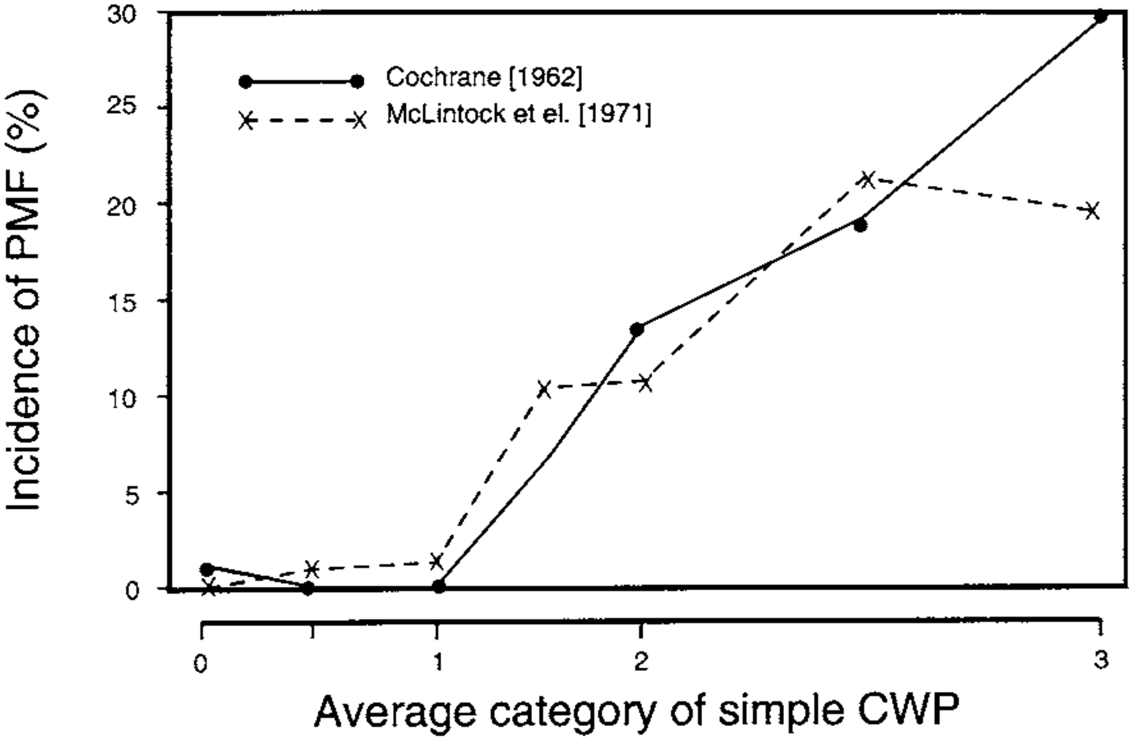


Figure 7–1. Incidence of PMF among U.K. coal miners during an 8-year period by average category of simple CWP. Adapted from McLintock et al. [1971].

The first quantitative, exposure-specific estimates of simple CWP risk from the United Kingdom [Jacobsen et al. 1971] suggested that the probability of progression to category 2/1[†] or greater was essentially zero for miners exposed to respirable coal mine dust at an average concentration of 2 mg/m^3 over a 35-year working lifetime (Figure 7–2). Thus, to prevent the development of simple CWP category 2 (and therefore to prevent PMF), 2 mg/m^3 was adopted as the U.S. standard for respirable coal mine dust [30 USC 842(b)].

7.3 BASIS FOR THE NIOSH REL

The NIOSH REL for respirable coal mine dust is based primarily on epidemiological exposure-response studies of occupational respiratory disease among U.S. coal miners. Additional considerations include sampling and analytical feasibility and the technological feasibility of reducing exposures. The intent of the REL (given the limits of technical feasibility) is to keep the daily exposures of workers low enough to reduce or eliminate the risk of impaired health or functional capacity over a working lifetime.

7.3.1 Epidemiological Studies Evaluated

Since 1969, several large, well-designed epidemiological studies have been conducted in both the United States and the United Kingdom to investigate the relationship between exposure to respirable coal mine dust and the development of simple CWP, PMF, and COPD.

[†] See Section 4.1.2.1 for a discussion of radiographic classifications.

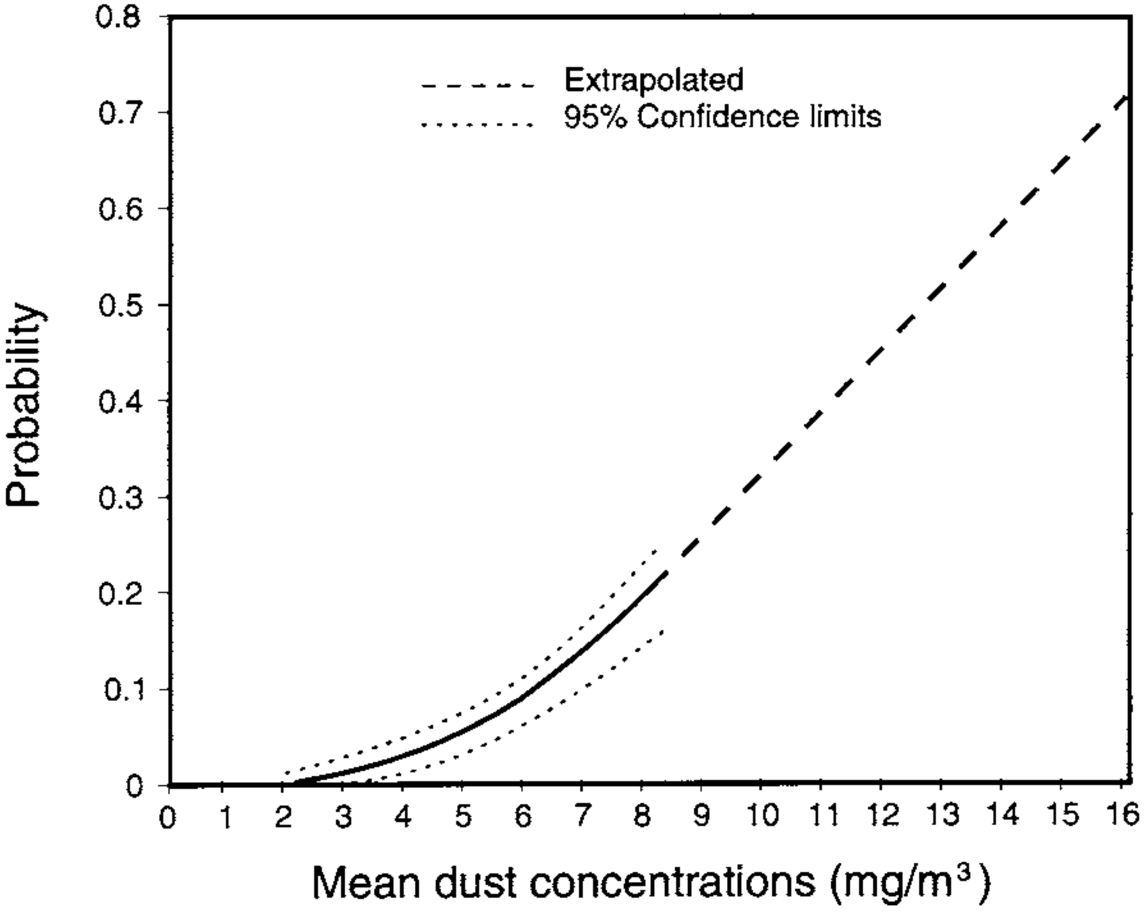
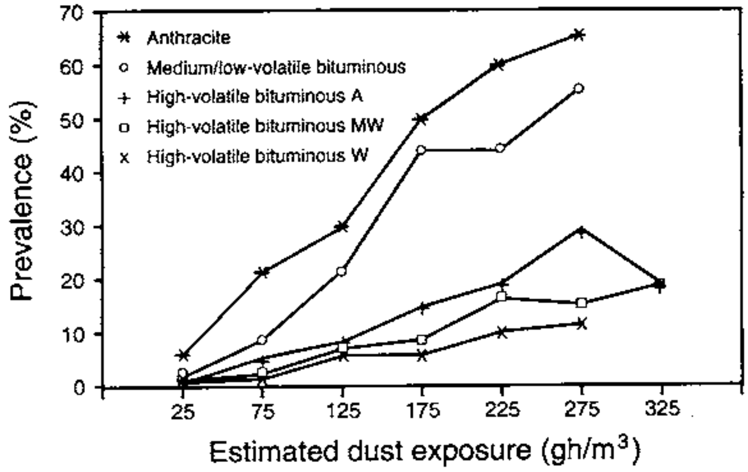


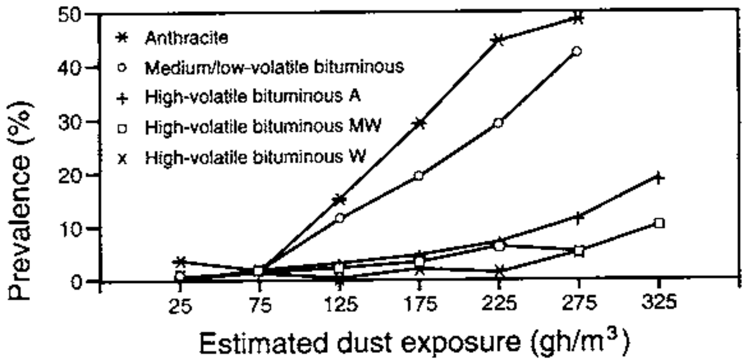
Figure 7-2. Probability that a man starting with no pneumoconiosis (category 0/0) will be classified as category 2 or higher after 35 years of exposure to various concentrations of coal mine dust. (Source: Jacobsen et al. [1971].)

Exposure-response studies of coal miners in the United States [Attfield and Seixas 1995; Attfield and Morring 1992b] and the United Kingdom [Hurley and Maclaren 1987] indicate that miners exposed to respirable coal mine dust for a working lifetime at the current U.S. standard of 2 mg/m^3 have a substantial risk of developing simple CWP and PMF (Figures 7-3 through 7-6). PMF has been associated with impaired lung function, disability, and early death [Parkes 1982]. Additional exposure-response studies of U.K. miners [Soutar et al. 1988; Marine et al. 1988; Hurley and Soutar 1986; Rogan et al. 1973] and U.S. miners [Attfield and Hodous 1992; Seixas et al. 1992] have shown that miners may also develop severe decrements in lung function as a result of their exposures to respirable coal mine dust—whether or not pneumoconiosis is present. The weight of evidence and the adverse health effects observed consistently in numerous independent studies of U.S. and U.K. coal miners provide a substantial basis for recommending an exposure limit for respirable coal mine dust. Table 7-1 lists the exposure-response studies that were used as the basis for the REL.

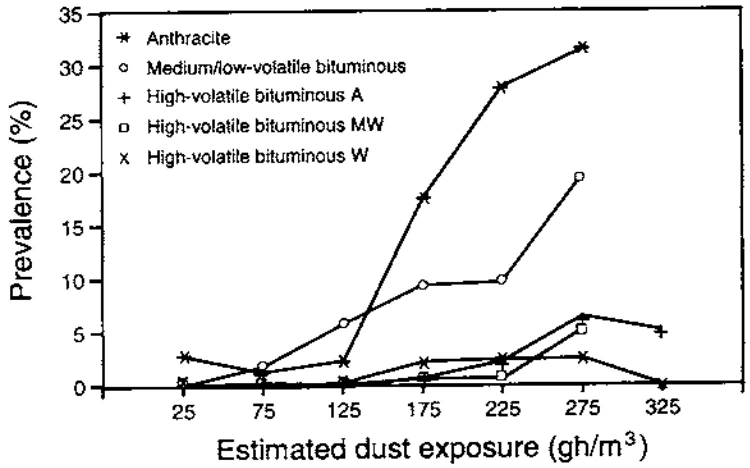
The exposure-response studies of U.S. coal miners, which provide the primary basis for the REL, were based on both the health effects data from the National Study of Coal Workers'



A. PREVALENCE OF CWP CATEGORY 1 OR GREATER



B. PREVALENCE OF CWP CATEGORY 2 OR GREATER



C. PREVALENCE OF PMF

Figure 7–3. Prevalence of simple CWP and PMF among U.S. coal miners by estimated cumulative exposure and coal rank. Note: Exposure to 2 mg/m^3 for 45 years (i.e., 90 mg-years/m^3) is equivalent to 180 gh/m^3 (based on 2,000 hr/year). (Source: Attfield and Morring [1992b].)

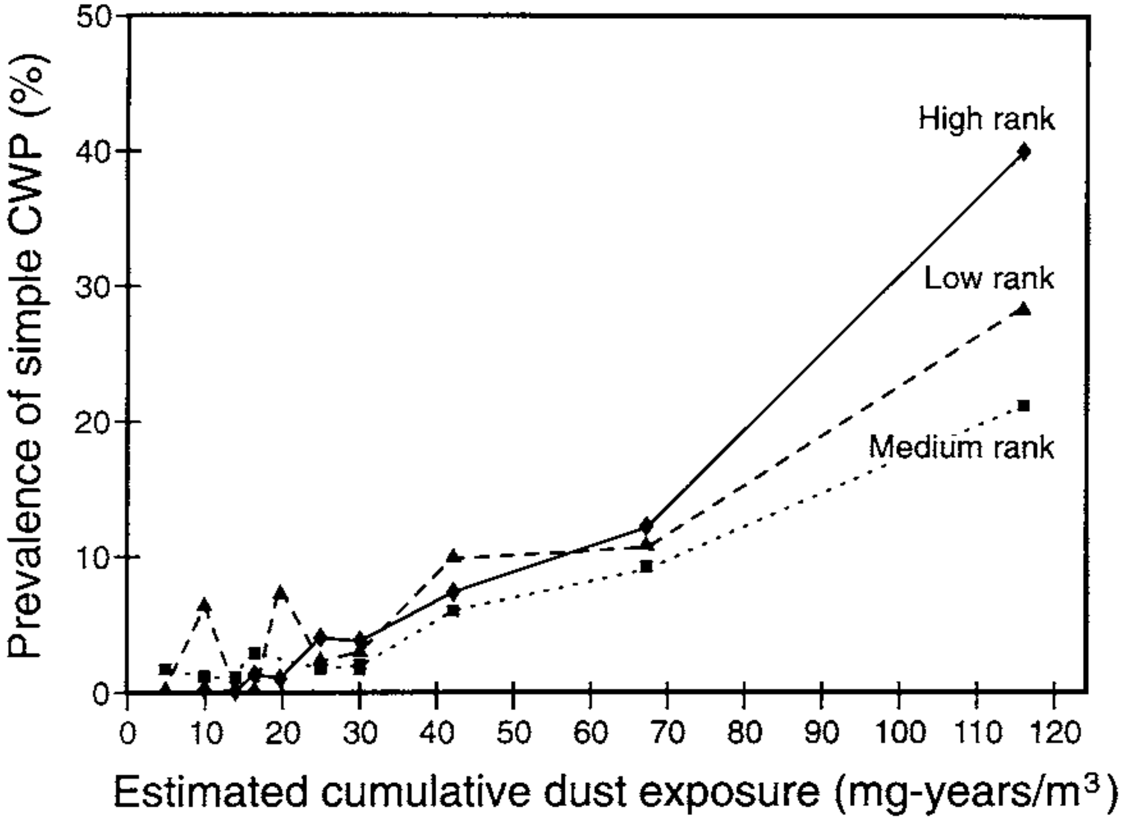


Figure 7–4. Prevalence of simple CWP category 1 or greater among U.S. coal miners by estimated cumulative dust exposure and coal rank (median reading of three X-ray readers). Note: Exposure to 2 mg/m^3 for 45 years is equivalent to 90 mg-yr/m^3. (Source: Attfield and Seixas [1995].)

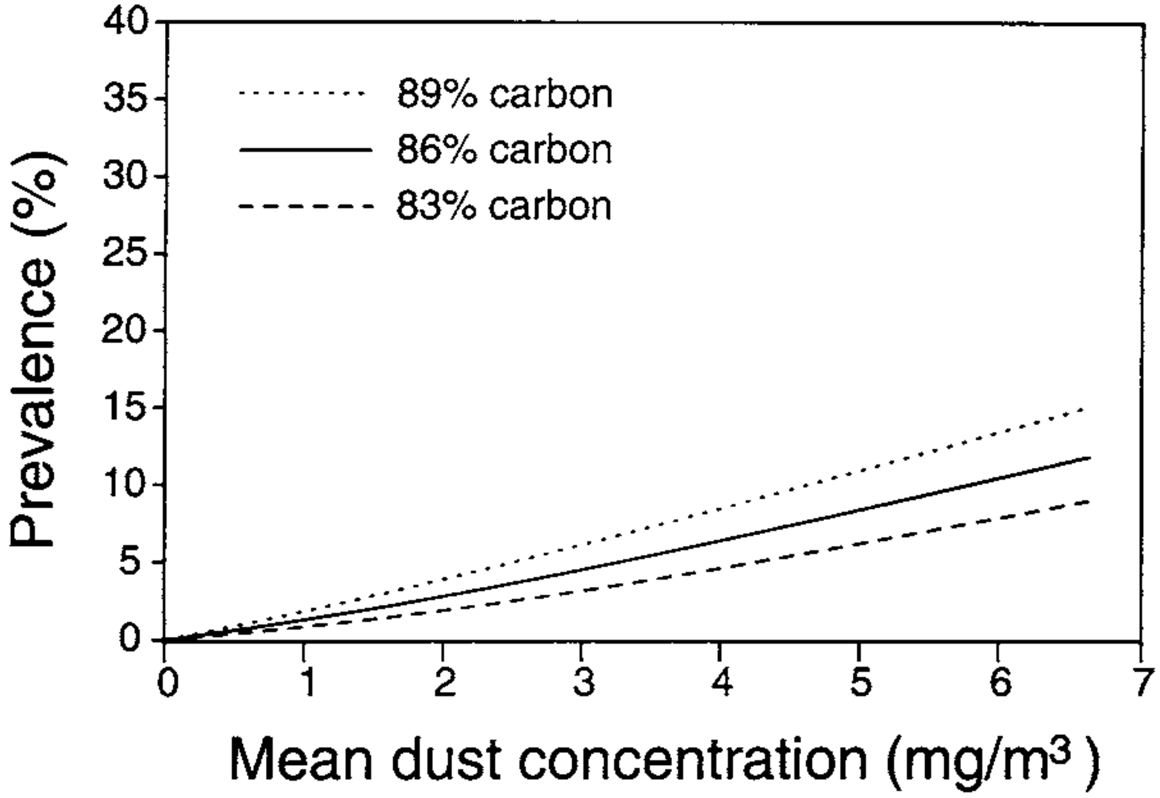


Figure 7-5. Predicted prevalence of simple CWP category 2 or higher among U.K. coal miners after a 35-year working lifetime (1,631 hr/year), by mean concentration of respirable coal mine dust and coal rank (expressed as percentage of carbon). (Source: Hurley and Maclaren [1987].)

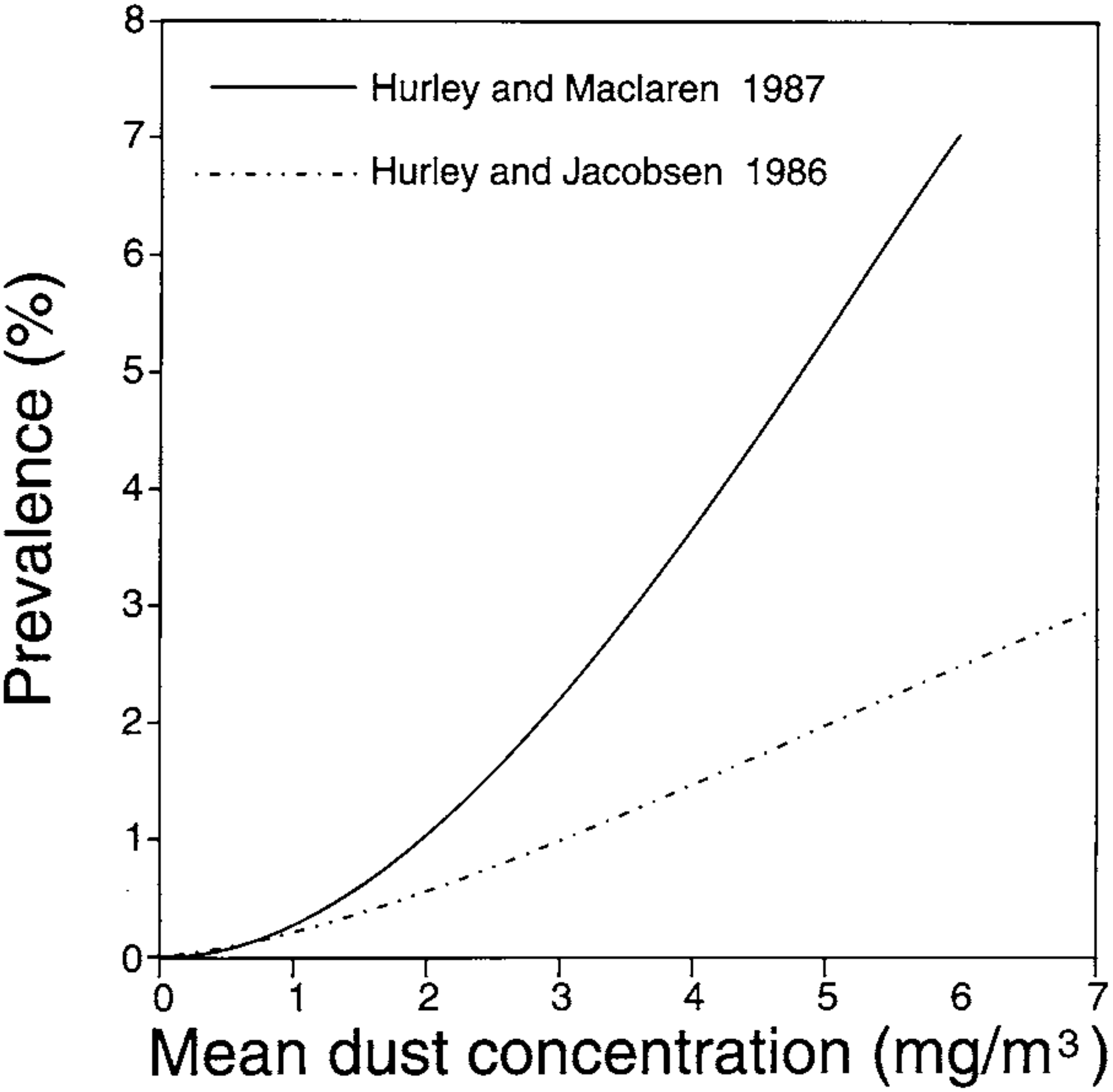


Figure 7-6. Predicted prevalence of PMF among U.K. coal miners after a 35-year working lifetime (1,631 hr/year), by mean concentration of respirable coal mine dust. (Source: Hurley and Maclaren [1987].)

Table 7-1. Epidemiological exposure-response studies used as the basis for the recommended U.S. standard for respirable coal mine dust

Type of study and reference	Country	Number of miners	Date of medical examination
Simple CWP or PMF:			
Attfield and Morring [1992b]	U.S.	9,078	1969–71
Attfield and Seixas [1995]	U.S.	3,194	1969–71; followup in 1985–88
Hurley and Maclaren [1987]	U.K.	>30,000[*]	At least two examinations between 1953 and 1978
Decrements in lung function:[†]			
Attfield and Hodous [1992]	U.S.	7,139	1969–71
Seixas et al. [1992; 1993][‡]	U.S.	1,185 or 977	1969–71 or 1972–75; followup in 1985–88
Marine et al. [1988]	U.K.	3,380	1963

[*] Analysis based on 52,264 five-year risk periods.

[†] FEV_1 <65% or >80% of predicted normal values.

[‡] Study of miners new to coal mining during or after 1970.

Pneumoconiosis and the exposure data from sampling programs of MSHA and BOM. The National Study of Coal Workers' Pneumoconiosis is an epidemiological research program that includes data from the medical examinations and work histories of more than 17,000 U.S. coal miners from 1969 through 1988 [Attfield and Castellan 1992]. The BOM data include measurements of respirable coal mine dust collected during 1968 and 1969 in 29 underground coal mines across the United States [Jacobson 1971; Attfield and Morring 1992a]. The MSHA data include measurements of respirable coal mine dust and respirable crystalline silica collected from 1970 to the present by both MSHA inspectors and coal mine operators for the purpose of evaluating compliance with the standard of 2 mg/m^3 [30 USC 842].

In addition, several exposure-response studies of coal miners in the United Kingdom [Maclaren et al. 1989; Marine et al. 1988; Soutar et al. 1988; Hurley and Maclaren 1987; Hurley et al. 1987] provide an important basis for comparison with the U.S. studies. The data for the U.K. coal miners are from the British Pneumoconiosis Field Research Program, which includes medical examinations and individual exposure estimates for more than 50,000 coal miners for up to 30 years.

7.3.2 Estimated Risks of Occupational Respiratory Diseases

7.3.2.1 Background Prevalence

The background prevalence of simple CWP, PMF, or a clinically significant deficit in lung function is defined here as the predicted prevalence of disease among persons with no occupational exposure to respirable coal mine dust. Each predicted prevalence of simple CWP, PMF, or decreased lung function (reported in Section 4.2.3) includes a background prevalence. Because there were no miners without exposure to respirable coal mine dust in these studies, these background prevalences were defined in the statistical models as the predicted prevalence of each disease at zero exposure.

Two studies have reported a prevalence of radiographic small opacities resembling simple CWP among persons not employed in coal mining [Castellan et al. 1985; Epstein et al. 1984] (see discussion in Section 4.2.1.6). However, no radiographic large opacities resembling PMF were reported. The predicted prevalence of PMF (Section 4.2.3) includes a background prevalence of radiographic large opacities predicted by the model. This model-based background prevalence of large opacities could be interpreted as reflecting the presence of diseases such as lung cancer or tuberculosis (which may also present as large opacities) in the general population. The background prevalence could also indicate that exposures were underestimated in miners with low exposures (which could result in a fitted model with higher disease prevalences among miners with low or zero exposures).

A background prevalence of decreased lung function (e.g., FEV_1 of <65% or <80% of predicted normal values) has been associated with age and smoking in studies of both coal miners [Seixas et al. 1993, 1992; Attfield and Hodous 1992; Marine et al. 1988; Rogan et al. 1973] and nonminers [Samet 1989; Fletcher and Peto 1977; Fletcher et al. 1976].

7.3.2.2 Excess Risk in U.S. Coal Miners

Tables 7-2 and 7-3 provide the excess (exposure-attributable) prevalence estimates for simple CWP, PMF, and decreased lung function[‡] among U.S. coal miners at age 65 following exposure to respirable coal mine dust during a 45-year working lifetime.[§] Excess prevalence (EX), as cases per 1,000, was defined as follows:

$$EX(X) = P(X) - P(O)$$

where P(X) is the prevalence from the fitted model at exposure X, and P(O) is the prevalence attributable to all factors except exposure to respirable coal mine dust. Excess prevalence was computed using regression coefficients from the statistical models described in the published exposure-response studies of U.S. coal miners. These prevalence estimates were for simple CWP and PMF [Attfield and Seixas 1995; Attfield and Morring 1992b] and for decreased lung function [Seixas et al. 1992; Attfield and Hodous 1992].

[‡] Decreased lung function is defined here as an FEV_1 <80% of predicted normal values. The dichotomous responses of FEV_1 (either <65% or <80% of predicted normal values) were selected because they represent clinically important deficits. An FEV_1 80% of predicted normal values is approximately equal to the LLN (5th percentile), a measure that is used to determine ventilatory defects (see Section 6.5.3 for further discussion) [ATS 1991; Boehlecke 1986]. An FEV_1 <65% of predicted normal values is approximately equal to FEV_1 deficits associated with severe exertional dyspnea in U.K. coal miners [Marine et al. 1988; Soutar et al. 1993].

[§] U.K. estimates are generally based on a 35-year working lifetime, whereas U.S. estimates are generally based on either a 40-year or a 45-year working lifetime.

Table 7-2. Excess (exposure-attributable) prevalence of simple CWP or PMF among U.S. coal miners at age 65 following exposure to respirable coal mine dust over a 45-year working lifetime.

		Cases/1,000 at various mean dust concentrations		
Study and coal rank	**Disease category**	**0.5 mg/m^3**	**1.0 mg/m^3**	**2.0 mg/m^3**
Attfield and Seixas [1995]:[*]				
High-rank bituminous	CWP ≥1	48	119	341
	CWP ≥2	20	58	230
	PMF	13	36	155
Medium/low-rank bituminous	CWP ≥1	27	63	165
	CWP ≥2	9	22	65
	PMF	4	10	29
Attfield and Morring [1992b]:[†]				
Anthracite	CWP ≥1	45	120	380
	CWP ≥2	17	51	212
	PMF	17	46	167
High-rank bituminous (89% carbon)	CWP ≥1	41	108	338
	CWP ≥2	15	43	168
	PMF	13	34	114
Medium/low-rank bituminous (83% carbon)	CWP ≥1	18	42	111
	CWP ≥2	6	15	42
	PMF	4	9	21
Medium/low-rank bituminous (Midwest)	CWP ≥1	12	26	64
	CWP ≥2	4	9	22
	PMF[‡]	1	3	6
Medium/low-rank bituminous (West)	CWP ≥1	7	14	32
	CWP ≥2	<1	<1	1
	PMF[‡]	<1	<1	1

[*] Attfield and Seixas [1995] define the coal rank groups as follows:

1. High-rank bituminous (89%-90% carbon): central Pennsylvania and southeastern West Virginia
2. Medium/low-rank bituminous (80%-87% carbon): medium-rank—western Pennsylvania, northern and southwestern West Virginia, eastern Ohio, eastern Kentucky, western Virginia, and Alabama; low-rank—western Kentucky, Illinois, Utah, and Colorado.

[†] Attfield and Morring [1992b] define the coal rank groups as follows:

1. Anthracite: two mines in eastern Pennsylvania (about 93% carbon)
2. Medium/low-volatile bituminous (89%-90% carbon): three mines in central Pennsylvania and three in southeastern West Virginia
3. High-volatile A bituminous (80%-87% carbon): 16 mines in western Pennsylvania, north and southwestern West Virginia, eastern Ohio, eastern Kentucky, western Virginia, and Alabama
4. High-volatile midwest: four mines in western Kentucky and Illinois
5. High-volatile west: three mines in Utah and Colorado

Coal rank groups 4 and 5 contained mines for which the rank of the coal was generally lower than in the high-volatile A bituminous group.

[‡] The coefficients of the logistic regression models (which were used to compute excess prevalence estimates) were not statistically significant ($P > 0.4$) for these outcomes.

Table 7-3. Excess (exposure-attributable) prevalence of decreased lung function[*] among U.S. coal miners at age 65 following exposure to respirable coal mine dust over a 45-year working lifetime.

			Cases/1,000 at various mean dust concentrations		
Study and region	Lung function decrement	Smoking status	0.5 mg/m^3	1.0 mg/m^3	2.0 mg/m^3
Attfield and Hodous [1992]:[†]					
East	<80% FEV_1	Never smoked	10	21	44
		Smoker	12	24	51
West	<80% FEV_1	Never smoked	9	19	40
		Smoker	11	23	48
East	<65% FEV_1	Never smoked	2	5	12
		Smoker	4	8	19
West	<65% FEV_1	Never smoked	2	4	9
		Smoker	3	7	15
Seixas et al. [1993][‡]	<80% FEV_1	Never smoked	60	134	315
		Smoker	68	149	338
	<65% FEV_1	Never smoked	18	45	139
		Smoker	27	67	188

[*] Decreased lung function is defined as FEV_1 <80% of predicted normal values. Clinically important deficits are FEV_1 <80% (which equals approximately the LLN, or the 5th percentile) and FEV_1 <65% (which has been associated with exertional dyspnea).

[†] Attfield and Hodous [1992] define the following coal ranks and regions:

East: anthracite (eastern Pennsylvania), and bituminous (central Pennsylvania, northern Appalachia [Ohio, northern West Virginia, western Pennsylvania], southern Appalachia [southern West Virginia, eastern Kentucky, western Virginia], Midwest [Illinois, western Kentucky], South [Alabama]).

West: Colorado and Utah.

[‡] Coal rank was not provided in Seixas et al. [1993]. However, miners were included from bituminous coal ranks and regions across the United States, as described in Attfield and Seixas [1995]:

1. High-rank bituminous (89%-90% carbon): central Pennsylvania and southeastern West Virginia
2. Medium/low-rank bituminous (80%-87% carbon): medium-rank—western Pennsylvania, northern and southwestern West Virginia, eastern Ohio, eastern Kentucky, western Virginia, and Alabama; low-rank—western Kentucky, Illinois, Utah, and Colorado.

As shown in Tables 7-2 and 7-3, the excess prevalence of simple CWP, PMF, and decreased lung function is estimated to be substantially reduced if lifetime average exposure to respirable coal mine dust is reduced from 2.0 to 0.5 mg/m^3. However, even at a mean concentration of 0.5 mg/m^3, miners have a >1/1,000 risk of developing these conditions (Tables 7-2 and 7-3). A 1/1,000 risk was defined as significant by the U.S. Supreme Court in the 1980 benzene decision:

> If the odds are one in a thousand that regular inhalation of gasoline vapors that are two percent benzene will be fatal, a reasonable person might well consider the risk significant and take appropriate steps to decrease or eliminate it [U.S. Supreme Court 1980].

PMF and FEV_1 <65% (of predicted normal values) indicate the presence of severe respiratory diseases. The exposure-attributable risks for these diseases are estimated to exceed 1/1,000 in coal miners with 45-year working lifetime exposures. NIOSH therefore recommends additional protective measures to minimize the risk of adverse health effects among coal miners (Section 7.3.4.7).

7.3.2.3 Risk Estimates at Low Exposures

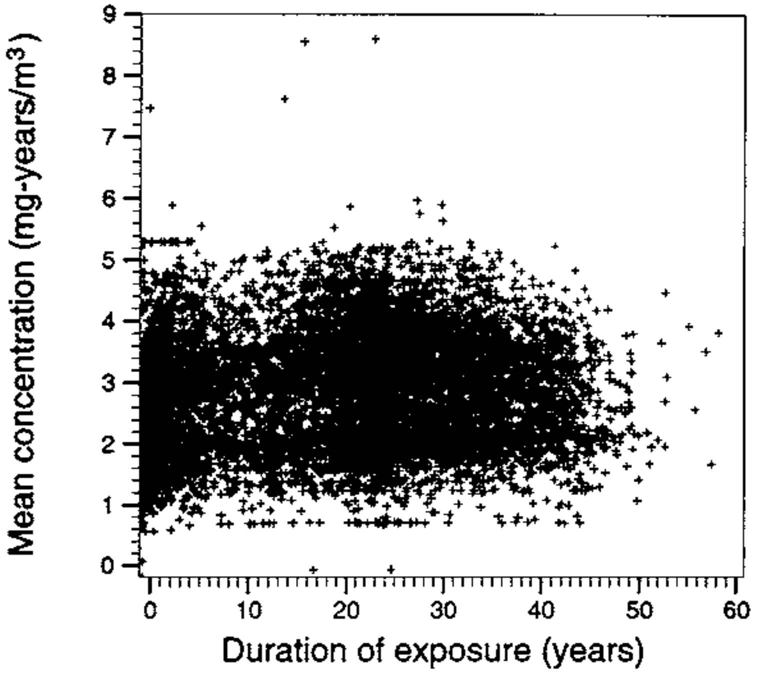
Figure 7-7 shows exposure data from the National Study of Coal Workers' Pneumoconiosis. These graphs show that the lower range of the data is about 1.0 and 0.5 mg/m^3 for exposures of miners participating in round 1 (1969-71) and round 4 (1985-88), respectively. These data indicate that risk estimates below 0.5 mg/m^3 would be based on extrapolations beyond the range of the data and would carry considerable uncertainty.

7.3.2.4 Excess Risk of PMF at Age 65 by Duration and Intensity of Exposure

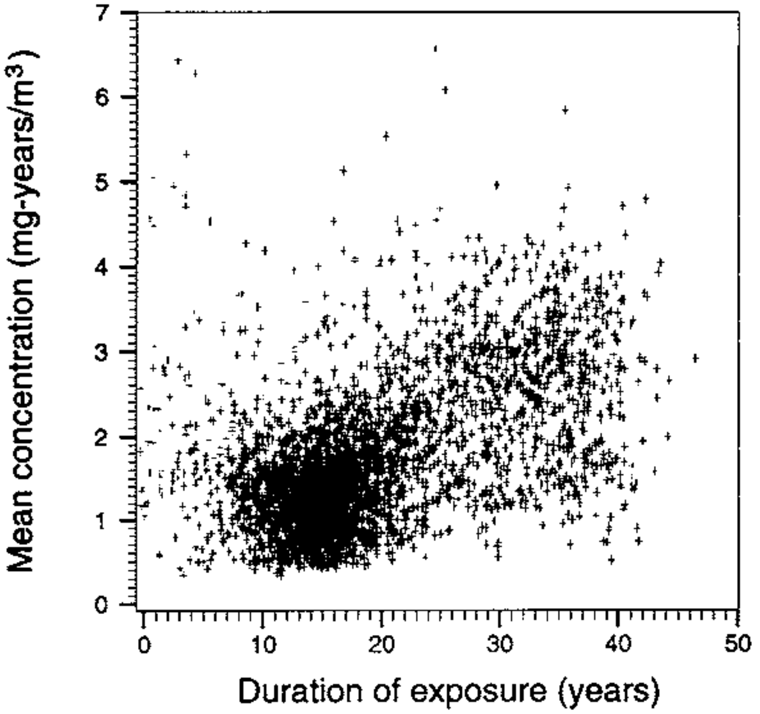
NIOSH is authorized to recommend occupational safety and health standards and to describe exposures that are safe for various periods of employment, including but not limited to exposures at which no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience [29 USC 651(b)(7), 669(a)(3), 671(c); 30 USC 811(a)(6)(B)]. Tables 7-2 and 7-3 provide excess risk estimates for miners exposed to respirable dust of various coal ranks over a 45-year working lifetime. Figure 7-8 illustrates the excess risk of PMF among miners at age 65 by intensity (concentration) and duration (years) of exposure to different ranks of coal. These excess (or exposure-attributable) risk estimates were determined for exposures to dust of both high-rank bituminous coal and medium/low-rank bituminous coal as defined by Attfield and Seixas [1995] (see Table 7-2, footnote*).

The Attfield and Seixas [1995] study (shown in Table 7-2) included 3,194 miners who participated in round 1 of the National Study of Coal Workers' Pneumoconiosis (1969-71) and who were followed in round 4 (1985-88). The Attfield and Morring [1992b] study (also shown in Table 7-2) included 9,023 miners who participated in round 1. Table 7-2 shows that the excess risk estimates for simple CWP and PMF within similar coal ranks are comparable for these two studies.

The Attfield and Hodous [1992] study (shown in Table 7-3) included a subset of miners who participated in round 1 (i.e., 7,139 white miners aged 25 or older). The Seixas et al. [1993] study included the 977 miners who began working after 1969 and who participated in rounds 2 and 4. The excess risk estimates for decreased lung function based on the Seixas et al. [1993] study are higher than those based on the Attfield and Hodous [1992] study. Seixas et al. [1993] suggest that the greater effect of dust exposure observed in their study is attributable to a nonlinear effect of dust on the lungs. That is, miners who are new to mining have a greater loss of lung function per unit of exposure than the more experienced miners.



A. ROUND 1 (1969-71)



B. ROUND 4 (1985-88)

Figure 7-7. Exposures of miners participating in rounds 1 and 4 of the National Study of Coal Workers' Pneumoconiosis.

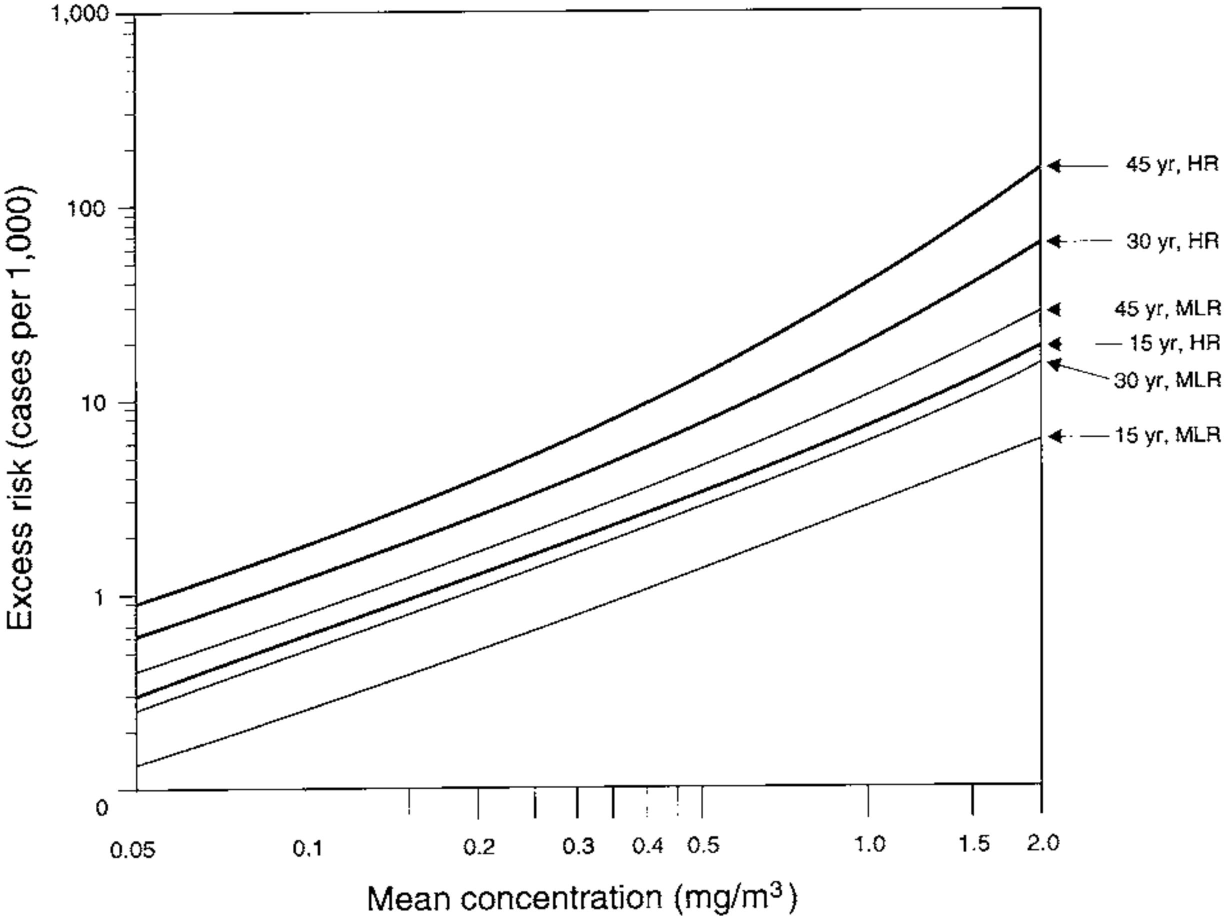


Figure 7-8. Excess risk of PMF in U.S. miners at age 65 by intensity (concentration) and duration (years) of exposure to high-rank coal (HR) or medium/low-rank coal (MLR). (Based on data from Attfield and Seixas [1995].)

Figure 7-8 shows that the excess risk of developing PMF by age 65 increases with increasing duration of employment and with increasing intensity of exposure (mean concentration). Excess risks are higher for miners exposed to dust of higher-rank coal—at any given duration and intensity of exposure.

At a mean concentration of 0.5 mg/m^3, the excess risk of PMF at age 65 exceeds 1/1,000 (Section 7.3.2.2) for all durations of exposure and coal ranks evaluated, including 15 years of exposure to medium/low-rank coal. This mean concentration of 0.5 mg/m^3 represents the lower range of the exposure data (Section 7.3.2.3; Figure 7-7). Long-term average concentrations of respirable coal mine dust are expected to be below 0.5 mg/m^3 if miners' daily exposures are kept below the REL of 1 mg/m^3 (Section 7.3.3).

7.3.3 Expected Long-Term Average Exposures When Work-Shift Exposures Are Below the REL

The REL represents the exposure limit during each work shift (8- to 10-hr TWA, 40-hr workweek). In developing the REL for respirable coal mine dust, NIOSH has computed the work-shift exposure limit associated with the long-term mean concentration of 0.5 mg/m^3 (Appendix K). The average concentration of 0.5 mg/m^3 was used because it constitutes the lower range of the exposure data; thus, estimates of disease risk at that average concentration do not represent extrapolation beyond the range of the data (Section 7.3.2.3). NIOSH did not use extrapolated risk estimates in developing the REL because of the limitations in sampling and analytical feasibility (Section 7.4 and Appendix I) and technological feasibility (Section 7.7).

The association between a work-shift exposure limit and a long-term mean concentration depends on the variability of exposures for a given workplace or job and on the desired level of confidence. In Appendix K, an analysis of variance was used to determine the within-occupation GSDs after accounting for the variability by mine and section within a mine. This analysis shows that the GSDs are fairly uniform for the following five occupations: continuous miner operator, 1.79; cutting machine operator, 1.75; handloader operator, 1.68; longwall shear operator, 1.82; and roof bolter, 1.70.

Figure 7-9 illustrates the relationship between the GSD and the ratio of the REL to the long-term mean concentration. This ratio is approximately 2 with the GSDs reported in Appendix K. Thus, this analysis indicates that the long-term average exposures will be below 0.5 mg/m^3 if at least 95% of the exposures during each work shift are below 1.0 mg/m^3.

The exposure data used to derive the NIOSH REL for respirable coal mine dust are based on sampling according to the current MSHA method (Section 5.1). NIOSH recommends sampling according to the international definition of respirable dust (Section 5.2). Thus, the NIOSH REL of 1 mg/m^3 for respirable coal mine dust, measured according to the current MSHA method, is equivalent to 0.9 mg/m^3 when measured according to the recommended sampling criteria (Sections 5.2 and 5.4).

The relationship between the single-shift and long-term mean concentrations assumes that the exposure limit is not adjusted upward to account for measurement uncertainty. Thus, a worker's

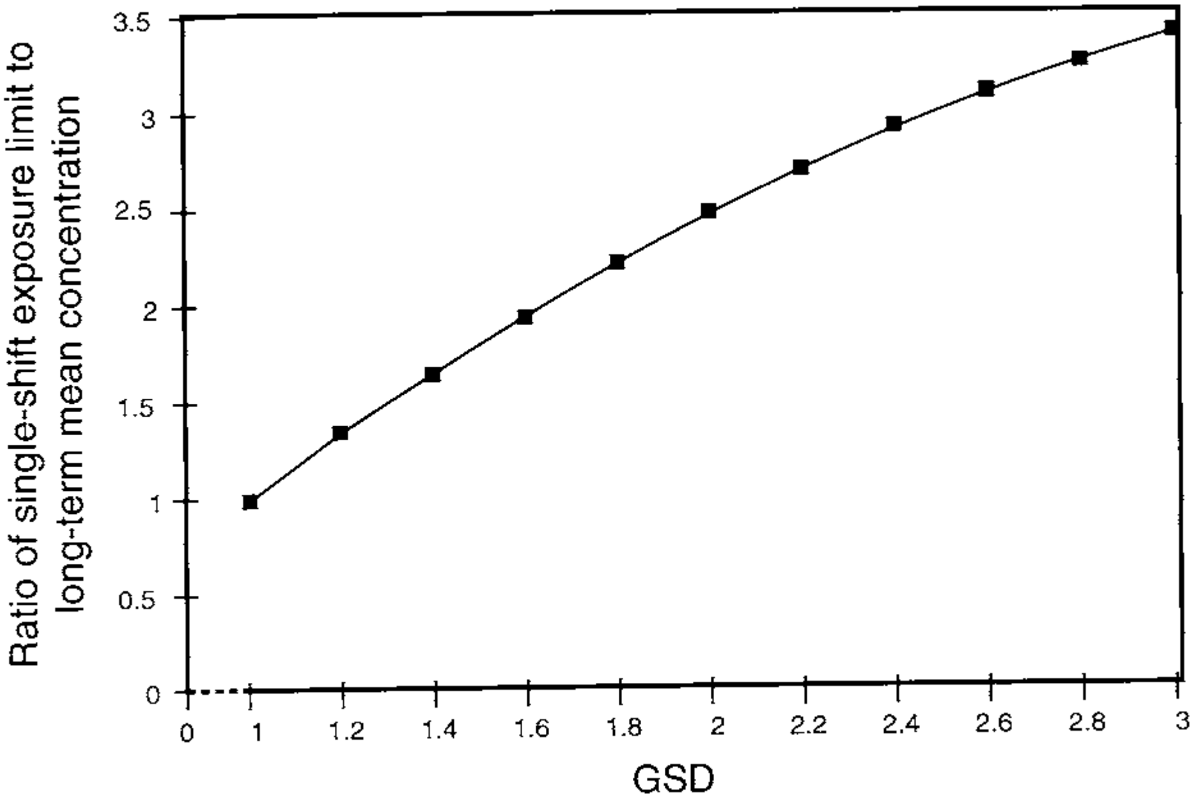


Figure 7–9. Relationship between the ratio of the single-shift exposure limit to the long-term average exposure (mean) and the variability in exposures (GSD), assuming that the probability of any measured single-shift concentration (C) exceeding the REL is 5% (i.e., probability [C>REL] = 0.05).

exposure is considered to have exceeded the REL for respirable coal mine dust if the measured concentration exceeds 1 mg/m^3 in any valid, single, full-shift sample (Section 5.6.2), measured according to the current MSHA method (Section 5.1 and Appendix J)—or if it exceeds 0.9 mg/m^3 in any valid, single, full-shift sample measured according to the NIOSH recommended criteria (Sections 5.2 and 5.4).

7.3.4 Factors Considered in Determining the REL

7.3.4.1 Strength of Evidence

The epidemiological studies of U.S. and U.K. coal miners provide a substantial basis for evaluating the effectiveness of the current U.S. standard for respirable coal mine dust. These studies involve thousands of miners and include data on both health effects and exposures. The health effects data are based on medical evaluations that used standardized methods of chest radiography, spirometric examinations, and medical history questionnaires. The exposure data are based on in-mine respirable dust sampling and occupational history questionnaires. These studies included both cross-sectional and longitudinal evaluations of exposure-response data for adverse health effects ranging from relatively minor deficits in lung function and simple CWP to severe deficits in lung function and PMF. Some studies include predicted prevalences of disease among miners with working lifetime exposures at various average concentrations—including 2 mg/m^3, the current U.S. standard for respirable coal mine dust. The numerous studies of U.S. and U.K. coal miners enable comparisons of independently derived risk estimates associated with working lifetime exposures.

Comparisons of data from the U.S. and U.K. studies (Table 4-6) show that the U.S. predicted prevalences of simple CWP and PMF are higher than those from the U.K. for comparable exposures to dust of similarly ranked coals (see Section 3.1.1 for a discussion of coal rank). Differences in exposure conditions, dust characteristics, or study design could account for some of this variation. The U.K. studies are based on medical and personal exposure data collected specifically for epidemiological study (Pneumoconioses Field Research Program). The U.S. studies are based on medical data collected as part of an epidemiological program (the National Study of Coal Workers' Pneumonoconiosis); the exposure data are from in-mine sampling surveys by the BOM (in 1968 and 1969) and from samples collected by coal mine operators or MSHA inspectors for compliance purposes (from 1970 through 1988). Possible biases in exposure data collected for compliance purposes have been reported [Boden and Gold 1984; Seixas et al. 1990]. The prevalence estimates based on the U.K. studies may therefore be more intrinsically reliable. However, the U.S. studies are more relevant to conditions in the United States. Therefore, the U.S. studies were selected to determine the excess (exposure-attributable) risks in this chapter.

7.3.4.2 Limitations of the Risk Estimates

7.3.4.2.1 Range of exposure data

Estimating the risk of disease at low exposures is often uncertain because of limits in the lower region of the exposure data—which is often the region of special interest for standard setting.

All of the epidemiological studies used as the basis for the REL (Table 7-1) demonstrated significant exposure-responses. These studies project that miners exposed to respirable coal mine dust at a mean concentration of 2 mg/m^3 over a working lifetime have an elevated risk of developing simple CWP, PMF, or decreased lung function (Tables 7-2 and 7-3; Figure 7-8). Furthermore, these studies project elevated risks for less than working-lifetime exposures, although these risks are smaller. Figure 7-8 illustrates the relationship between mean concentration and PMF among miners with 15, 30, or 45 years of exposure. The mean concentration of 2 mg/m^3 and durations of 15 and 30 years are well within the range of the data, but the exposure data become sparse near 45 years (Figure 7-7). Hence, the estimates for 0.5 mg/m^3 or for 45 years of exposure carry considerable uncertainty, since the uncertainty of interpolating models near the boundary of the data is well known [Attfield and Seixas, 1995].

7.3.4.2.2 Range of risk estimates

The risk estimates used in these studies are based on the mean response, not on the upper 95% confidence limit for the mean. Thus, for some individuals, the risks may be higher than predicted by the mean response. On the other hand, the risk of some adverse health effects may be underestimated because affected miners who left mining for health reasons would be omitted from the cross-sectional studies. Risk may also be underestimated because miners with simple CWP may have progressed to PMF after they left mining [Soutar et al. 1986].

7.3.4.2.3 Uncertainty factors

Unlike most Federal standards set for the general population in the United States, occupational exposure limits often include no uncertainty factors because of feasibility constraints. Likewise, the REL for respirable coal mine dust includes no uncertainty factors. Allowance was made for the long-term average exposures expected when daily exposures are maintained below the REL (Section 7.3.3). The risk estimates used as the basis for the REL are those thought to represent the lower range of the data; thus, these estimates are not based on extrapolation beyond the range of the data. In view of these factors, the health-based need to reduce exposures to respirable coal mine dust to concentrations below the REL is well supported by the risk estimates from the existing epidemiological studies. In addition to the health effects estimates, information about sampling and analytical feasibility and technological feasibility was considered when determining the REL for respirable coal mine dust.

7.3.4.3 Statistical Models Evaluated

The epidemiological studies that formed the basis for the REL (Table 7-1) used either the linear regression model (for continuous responses such as FEV_1) or the logistic regression model (for dichotomous responses such as presence or absence of a particular radiographic category). The models predict elevated disease risks at all exposures greater than zero. Hurley et al. [1984, 1979] evaluated several models for describing the relationship between exposure to respirable coal mine dust and the development of simple CWP and PMF. They selected the logistic regression model using cumulative exposure because it best fit the data and best described the observed exposure-response relationship. Attfield and Seixas [1995] also provide support for using cumulative exposure.

Experimental evidence from animal studies (Section 4.3) suggests that a nonthreshold model is more consistent with the plausible biological mechanisms of disease development than a threshold model. In these studies [Soderholm 1981; Vostal et al. 1982; Vincent et al. 1985, 1987], the investigators found that lung burden increased in proportion to the respirable dust exposure over the entire range of exposures, suggesting that some fraction of the dust is sequestered or retained in the lungs even at low exposures. Studies have also found that at higher lung dust burdens, alveolar clearance becomes saturated or overloaded [Bolton et al. 1983; Vincent et al. 1985; Morrow 1988] and pathogenic events (including fibrogenesis) increase.

A logistic regression model to describe the risk of simple CWP or PMF among coal miners is consistent with the findings from these animal studies because the logistic model allows for a relatively small but nonzero risk of disease at low exposures and a more rapid increase in risk as cumulative exposure increases. In contrast, a threshold model would assume a zero risk of disease associated with dust retained in the lungs if the lung burden did not exceed the threshold concentration. Even if a threshold model reasonably fit the exposure-response data, it would not constitute definitive evidence of a threshold concentration for disease development. Rather, it could simply indicate the limitations in the data: a larger or better designed study with a greater proportion of low exposures might provide evidence of disease at exposures below the previously estimated threshold concentration. Furthermore, it is unreasonable to assume that any single threshold concentration would adequately describe the biological response to exposure in all individuals of a population.

Evaluation of alternative statistical models becomes more important for estimating disease risk in regions of the exposure-response curve where data are lacking (e.g., the low-exposure region). However, such evaluation is less likely to alter the basic conclusions drawn from the exposure-response studies and used as the basis for the REL for respirable coal mine dust. The reasons are as follows: (1) the statistical models used to describe the exposure-response relationships provided a reasonable fit to the data and are consistent with plausible biological mechanisms; (2) these studies clearly demonstrate elevated risk of simple CWP, PMF, and decreased lung function among miners exposed for a working lifetime at the current standard of 2 mg/m^3 for respirable coal mine dust; (3) the risk estimates used as the basis for the REL do not represent extrapolation beyond the range of the data; and (4) other factors (limitations in sampling, analytical, technological feasibility) were also considered in developing the REL.

7.3.4.4 Comparison of Predicted and Observed Prevalences of Simple CWP

Comparison of observed disease prevalences with those predicted by the statistical models provides an important basis for evaluating the validity of model-based risk estimates. One such analysis compared the estimated and observed decreases in PMF incidence among U.K. miners following a reduction in the U.K. standard for respirable coal mine dust in 1970 [Jacobsen et al. 1970]. Appendix J compares prevalence data from U.S. coal miners in the Coal Workers' X-Ray Surveillance Program with model-derived prevalence estimates for simple CWP category 1 or greater and for simple CWP category 2 or greater. This analysis shows good agreement between the predicted and observed prevalences. For simple CWP category 1 or greater, the model-based prevalences were lower (underestimated) than the observed prevalences. For simple CWP category 2 or greater, the model-based prevalences were slightly higher (overestimated) relative to the observed prevalences in the Coal Workers' X-Ray Surveillance Program.

7.3.4.5 Cumulative Exposure As the Metric of Exposure

The exposure-response analyses that form the basis for the REL use cumulative exposure (intensity × duration) as the metric of exposure. Disease risk is assumed to be a function of cumulative exposure and not to depend on the specific values of intensity or duration used to compute cumulative exposure. For example, the exposure-related risk of a given disease is assumed to be equal among miners exposed to 2 mg/m^3 for 20 years (i.e., 40 $mg\text{-}yr/m^3$) and for miners exposed to 1 mg/m^3 for 40 years (also 40 $mg\text{-}yr/m^3$). Evidence suggests that this is a reasonable assumption provided the duration of exposure has been sufficient [Hurley et al. 1982, 1979]—usually considered to be 10 or more years [Althouse et al. 1986].

7.3.4.6 Coal Rank

Several epidemiological studies have shown that the prevalence of simple CWP and PMF increases with increasing coal rank [McLintock et al. 1971; Lainhart 1969; McBride et al. 1966; 1963]. Recent exposure-response studies have estimated that the probability of developing PMF over a working lifetime is also higher for miners exposed to respirable dust of high-rank coal [Attfield and Seixas 1995; Attfield and Morring 1992b; Hurley and Maclaren 1987]. One study found that U.S. miners exposed to respirable dust from medium- and high-rank bituminous coal in the midwestern and eastern United States had greater decrements in lung function than miners exposed to respirable dust from low-rank bituminous coal in the western United States [Attfield and Hodous 1992].

Epidemiological studies clearly demonstrate that miners exposed to respirable dust from coal of all ranks studied are at risk of developing adverse health effects from working lifetime exposures at the current U.S. standard of 2 mg/m^3. Technological feasibility limits the control of exposures to respirable dust of all coal ranks. Thus, it may not be technologically feasible to reduce exposures to dust of high-rank coal to a greater extent than dust of low-rank coal. NIOSH therefore recommends that all reasonable efforts be made to keep exposures to respirable dust from coal of all ranks below the REL—with particular emphasis on reducing exposures to respirable dust of high-rank coal.

7.3.4.7 Additional Measures to Minimize the Risk of Adverse Health Effects

The REL may not be sufficiently protective to prevent all occurrences of simple CWP, PMF, and COPD among coal miners exposed for a working lifetime. NIOSH therefore recommends that worker exposures be maintained as far below the REL as feasible during each work shift. NIOSH also recommends

- that miners participate in the medical screening and surveillance program,
- that improved dust control techniques for respirable coal mine dust and respirable crystalline silica be developed and applied,

- that exposures to respirable coal mine dust and respirable crystalline silica be closely monitored, and
- that miners use personal protective equipment as an interim measure if exposures exceed the REL.

7.4 SAMPLING AND ANALYTICAL FEASIBILITY

Appendix I presents an evaluation of the minimum accurately quantifiable concentration (MAQ) of respirable coal mine dust. The MAQ varies depending on the precision of the sampling device and the balances used to weigh the filters before and after sampling. The MAQ also depends on the sampling method—that is, whether the sampler is calibrated to operate in accordance with the current MSHA method (Section 5.1 and Appendix J) or the international definition of respirable dust (Section 5.2). In computing the MAQ for either method, both the NIOSH accuracy criteria [Busch 1977; Busch and Taylor 1981] and a recent evaluation of weighing imprecision [Kogut 1944] were used. The MAQ of respirable coal mine dust is 0.46 mg/m^3 (Section I.2 in Appendix I) when the sampler (CPSU) is calibrated in accordance with the current MSHA method. Thus, the sampling and analytical method for respirable coal mine dust poses no limitation relative to the NIOSH REL of 1 mg/m^3. For sampling according to the international definition, the MAQ is 0.66 mg/m^3 (CPSU) or 0.51 mg/m^3 (Higgins-Dewell sampler) (Table I-1 in Appendix I; Kogut [1994]). Thus, the sampling and analytical method also poses no limitation relative to the NIOSH REL when measured according to the recommended sampling criteria.**

The MAQ of approximately 0.5 mg/m^3 is based on single, full-shift sampling. Because the precision of sampling increases as the number of samples increases, the MAQ for the mean concentration from multiple samples would be less than 0.5 mg/m^3. Thus, the sampling and analytical method would not limit the measurement of long-term average exposures of mg/m^3, which are expected to be associated with the REL of 1 mg/m^3 (Section 7.3.3).

7.5 APPLICABILITY OF THE REL TO WORKERS OTHER THAN UNDERGROUND COAL MINERS

7.5.1 Surface Coal Miners

Studies have shown that U.S. surface coal miners (particularly workers on drill crews) are at risk of developing CWP (see Tables 4-8 and 4-9) [Amandus et al. 1989; Amandus et al. 1984; Fairman et al. 1977]. Furthermore, Amandus et al. [1989] found that decreased lung function (measured by FEV_1, FVC, and peak flow) is significantly related to the number of years worked as drill operators or drill helpers at surface mines. NIOSH therefore recommends including surface miners in the same programs for environmental monitoring (Chapter 5) and medical screening and surveillance (Chapter 6) as those recommended in this document for underground coal miners. The RELs for respirable crystalline silica and respirable coal mine dust should also apply to surface coal miners.

**The REL of 1 mg/m^3 (current MSHA method) is equivalent to 0.9 mg/m^3 when the international definition is used (Section 5.4).

7.5.2 Workers Exposed to Coal Dust in Occupations Other Than Mining

Environmental sampling data and health effects data have been studied extensively for underground coal miners (Chapter 4). Some studies have examined health effects among surface coal miners [Amandus et al. 1989; Amandus et al. 1984; Fairman et al. 1977] and workers exposed to silica [CDC 1990; Suratt et al. 1977; NIOSH 1974]. However, few studies have evaluated possible adverse health effects among workers exposed to respirable coal dust in occupations other than coal mining. A BOM survey of 21 coal-preparation and mineral-processing plants (about 500 exist in the United States) found that one-third had high dust concentrations in localized areas of the plant (up to 11 mg/m^3), although worker occupancy in those areas was often temporary [Divers and Cecala 1990].

Several NIOSH health hazard evaluations concluded that coal dust and quartz may pose health hazards for workers at coal-powered electrical generating plants [Lewis 1983; Zey and Donohue 1983; Hartle 1981]. In a combined environmental study and medical evaluation of workers exposed to coal dust and boiler gases (including sulfur dioxide), Zey and Donohue [1983] observed twice the number of expected respiratory symptoms (cough, phlegm, and wheezing). They found four cases of pneumoconiosis, but no decrements in lung function. In a study of surface miners and coal-cleaning plant workers in the anthracite coal mining region of the United States, Amandus et al. [1989] found that lung function (measured by FEV_1, FVC, and peak flow) was not related to the number of years worked in coal-cleaning plants in anthracite coal mining regions.

Although the exposure and health effects data are limited for exposed workers other than miners, the available evidence indicates a potential for exposures sufficient to cause pneumoconiosis. It is reasonable to assume that the etiology of pneumoconiosis would be similar for workers with comparable exposures to coal mine dust or coal dust. NIOSH therefore recommends that the REL for respirable coal mine dust apply to workers exposed to respirable coal dust in occupations other than mining.

7.6 RECOMMENDED EXPOSURE LIMIT FOR RESPIRABLE CRYSTALLINE SILICA

The NIOSH REL for respirable crystalline silica is 0.05 mg/m^3 as a TWA for up to 10 hr/day during a 40-hr workweek [NIOSH 1988b, 1974]. NIOSH recommends that single, full-shift samples be used for comparing worker exposures with the REL for respirable crystalline silica. In the current MSHA procedure [30 CFR 70.101; 30 CFR 71.101], the percentage of quartz in respirable coal mine dust is determined, and the PEL for respirable coal mine dust is reduced if the respirable quartz content exceeds 5%.

NIOSH also recommends personal monitoring of worker exposures to respirable crystalline silica. Exposure to respirable crystalline silica has been associated with the risk of simple CWP, PMF, and silicosis in both surface coal miners [Love et al. 1992; Amandus et al. 1984, 1989; Jacobsen and Maclaren 1982; Fairman et at. 1977] and underground coal miners [Robertson et al. 1987; Hurley et al. 1982; Seaton et al. 1981]. Rapid development and progression of simple CWP occurred in coal miners who had relatively low average exposures (1.4 mg/m^3) to respirable coal mine dust containing higher-than-average concentrations (about 13%) of respirable crystalline silica [Seaton et al. 1981]. This high silica contact was caused by difficult mining conditions that involved the cutting of silica-containing rock above and below the coal seam. These studies suggest that the role of respirable crystalline silica in the development and progression of simple CWP and silicosis may become more important as the concentration of respirable coal mine dust is reduced.

Worker exposures to respirable crystalline silica may vary with the job or other factors and may therefore be underestimated in the current sampling program. Personal exposure monitoring is the most effective method for estimating these worker exposures and for detecting exposures above the REL (Section 5.6.3). Exposure monitoring programs for coal miners (Section 5.6.1) should provide sufficient sampling of respirable crystalline silica to ensure that worker exposures are kept below the REL.

7.7 TECHNOLOGICAL FEASIBILITY OF KEEPING WORKER EXPOSURES BELOW THE REL FOR RESPIRABLE COAL MINE DUST

The Federal Mine Safety and Health Act of 1977 requires NIOSH to develop and revise recommended occupational safety and health standards for miners [30 USC 811]. Specifically, the Secretary of Health and Human Services is required to consider, "in addition to the attainment of the highest degree of health protection for the miner . . . the latest available scientific data in the field, the technical feasibility of the standards, and experience gained under this and other health statutes" [30 USC 811(6)(A)].

NIOSH has performed a preliminary evaluation of the technological feasibility of keeping worker exposures to respirable coal mine dust below 1 mg/m^3[††] during each work shift. This evaluation is based on (1) a survey of the percentage of samples below the REL during the period 1988–92 (see Section 7.7.1 and Appendix A), and (2) studies of available and experimental or prototype dust control measures (Sections 7.7.2 and 7.7.3).

7.7.1 Percentage of Samples Below the REL

During the period of 1988-92, the average concentration of respirable coal mine dust in underground coal mines for all occupations combined was approximately 1.0 mg/m^3 based on MSHA inspector samples (Tables A-4 and A-5), however, this average concentration exceeded 2 mg/m^3 for some occupations. In occupations with average concentrations below 2 mg/m^3, up to 42% of individual samples exceeded 2 mg/m^3. For these occupations, as few as 19% of individual samples were below 1 mg/m^3. For all underground occupations combined, 65% to 68% of all samples were below 1 mg/m^3 (Tables A-4 and A-5).

At surface coal mines, the average concentration of respirable coal mine dust for all occupations combined was 0.56 mg/m^3 based on inspector samples (Table A-6) or 0.71 mg/m^3 based on operator samples (Table A-7). For every surface occupation, the average concentration of respirable

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[††] Measured according to the current MSHA method (Section 5.1); 1 mg/m^3 is equivalent to 0.9 mg/m^3 when measured according to NIOSH recommended sampling criteria (Sections 5.2 and 5.4).

coal mine dust was below the current standard of 2 mg/m^3, though some individual samples exceeded it. For all surface occupations combined, 79% to 88% of all samples were below 1 mg/m^3 (Tables A-6 and A-7).

The exposure data in Appendix A represent dust control efforts to keep exposures below the standard of 2 mg/m^3 for respirable coal mine dust (which is currently enforced as an average of five samples). Appendix B provides exposure data for miners with simple CWP category 1 or greater who elected to transfer [30 CFR 90; 30 USC 843(b)]. Average exposures to respirable coal mine dust exceeded 1 mg/m^3 for some underground occupations (Tables B-1 and B-2), but they were below 1 mg/m^3 for all surface occupations (Tables B-3 and B-4).

On the basis of these data, NIOSH believes that the REL of 1 mg/m^3 for respirable coal mine dust is technologically feasible for most occupations in underground and surface coal mines. For occupations in which average exposures currently exceed the REL, studies of available and experimental or prototype dust controls indicate the potential for substantial exposure reduction. On the basis of these studies, NIOSH believes that the REL for respirable coal mine dust is technologically feasible for these operations as well.

Sections 7.7.2 and 7.7.3 discuss studies of dust control techniques in underground coal mines. Appendix C provides a list of available control techniques by mining method, and Appendix D describes methods for controlling dust during drilling and other operations at surface coal mines.

7.7.2 Sources of Dust and Control Methods Used in Underground Coal Mines

7.7.2.1 Sources

A primary source of dust in underground mines using longwall methods is the shearer or plow that cuts the coal face [Jankowski et al. 1989]. Double-drum shearers disperse more dust than single-drum shearers because the drum on the shearer cannot rotate in the same direction as the airflow [Mundell et al. 1984]. The respirable dust exposure of a worker at the coal face is influenced by his/her work position relative to the cutting drum and the direction of airflow [Mundell et al. 1984]. Another major source of dust exposure for the shearer operator is the dust generated by roof supports in longwall operations; the amount of dust generated is inversely related to roof strength [Organiscak et al. 1985]. On longwall plow operations, the stageloader-crusher is a primary source of dust, producing up to 60% of the dust along the face [McClelland and Jankowski 1987]. In continuous mining operations, the major source of dust is the continuous miner machine [Divers et al. 1987]. In auger mining, the coal cutting and loading processes are the primary sources of dust, but machine and bridge conveyors also generate dust [Divers et al. 1987]. Geological factors (coal seam parameters) also influence the production of airborne respirable dust; low-ash, high-volatile bituminous coals are associated with higher concentrations of respirable dust [Organiscak et al. 1992].

7.7.2.2 Controls

The methods for controlling worker exposures to respirable dust include (1) engineering controls, (2) work practices, and (3) personal protective equipment. Engineering controls for respirable coal mine dust include dilution of the dust by the intake air stream, removal of the dust by localized air streams and water sprays flowing away from the miners, water infusion into the coal seam to reduce the formation of respirable dust, and improved cutting machine parameters [Jankowski and Organiscak 1983; Mundell et al. 1984; Jankowski et al. 1986; McClelland et al. 1987]. The effectiveness of various engineering controls depends on basic mining variables such as mining technique, type of MMU, coal seam characteristics, and ventilation parameters.

Work practices to control worker exposures to respirable dust in longwall mining sections include remote location of the shearer operator, and modified cutting sequence or cutting in one direction [Mundell et al. 1984]. The disadvantages of remote shearer operation include difficulty in maintaining the desired cutting height. The disadvantages of modified cutting sequence include the loss of production [Mundell et al. 1984]. If it is not possible to use a double-split ventilation system in continuous mining sections, the roof bolter's exposures may be reduced by keeping this worker upwind of the continuous miner whenever possible [Divers et al. 1987].

Personal protective equipment consists of approved respirators that are used and maintained according to a respiratory protection program. The use of respirators in the active workings of a mine is restricted by 30 CFR 70.300. Respirators are not permitted as a substitute for environmental controls.

In a study of dust controls for continuous mining machines, Colinet et al. [1991] found that the use of optimum water sprays and local airflow reduced operator exposures up to 99%. However, they found an upper limit of airflow (8,400 cubic feet per minute [cfm] in the box cut), above which counterproductive airflow patterns developed and operator exposures increased. Similarly, water pressures above 140 pounds per square inch (psi) increased dust concentrations. Jayaraman et al. [1990] found that a water-powered scrubber for continuous mining machines was equally effective in reducing respirable coal mine dust and respirable crystalline silica. This scrubber had a collection efficiency of 72% for all respirable dust when a double filter panel was used. Use of enclosed cabs on underground and surface mining equipment has been shown to reduce dust concentrations inside the cab (up to 44% in underground equipment) [Volkwein et al. 1979].

Of the cutting machine parameters, the depth of cut and the bit sharpness appear to have the greatest effects on the generation of respirable dust [Mundell et al. 1984]. Routine inspection of the cutting drum and replacement of dull or broken bits improve cutting efficiency and minimize dust generation [Divers et al. 1987]. Proper maintenance of dust collectors on roof bolting operations and replacement of worn bits can reduce exposures to roof bolter operators [Divers et al. 1987].

Dust generated in areas outby the coal face (e.g., from conveyor belts, coal haulage transfer points, and haulroads) is generally controlled through the use of water sprays [Divers et al. 1987]. Because intake air to the coal face usually contains dust generated by operations outby the face area, control of dust in outby areas will reduce dust exposures of workers at the coal face. In longwall mining, the outby dust sources that can contaminate intake air to the coal face include the stageloader-crusher, panel belt, and intake roadway [Organiscak et al. 1986]. The most effective method for controlling intake dust on longwall faces is homotropal ventilation, which routes air in the direction of coal transport along the face (tailgate to headgate) [Organiscak et al.

1986]. However, tailgate to headgate face ventilation is only applicable on longwalls that maintain an open tailgate to serve as a primary intake [Jankowski et al. 1993].

Ventilation is the primary means of controlling dust in all mining methods [Niewiadomski et al. 1982]. In a study of longwall mining operations, the minimum air velocity for the effective control of respirable dust at the coal face was approximately 400 to 450 ft/min [Jankowski et al. 1993]. Haney et al. [1993] studied the influence of airflow and production on longwall dust control and found that dust concentrations were reduced when airflow was increased in proportion with increased coal production. The installation of curtains in the headgate can provide better direction of the air and can increase air velocity down the face [Jankowski et al. 1993]. Jankowski et al. [1986] discuss three additional dust control techniques in longwall mining: (1) a water spray system (e.g., the shearer-clearer system, which keeps shearer-generated dust near the face and away from the shearer operator), (2) a drum spray system (which helps prevent dust from becoming airborne), and (3) a cutting sequence that allows shearer operators to work on the intake-air side of the lead-cutting drum.

7.7.3 Feasibility of Keeping Exposures Below the Current MSHA PEL for Respirable Coal Mine Dust

Keeping respirable coal mine dust concentrations below the MSHA PEL of 2.0 mg/m^3 has been difficult in mines using longwall methods. Tomb et al. [1990] concluded that the technology is available to limit concentrations of respirable coal mine dust to 2.0 mg/m^3 in longwall mining operations (e.g., by upgrading controls at the headgate of the panel and by using larger quantities of air to ventilate the face). In one study of a high-productivity longwall mining operation, a critical factor in achieving effective compliance with the PEL of 2 mg/m^3 was the daily evaluation of each mining situation [Webster et al. 1990].

In a study of six high-tonnage longwall mines by BOM, the production average was 4,600 tons/shift even though effective dust control measures were used to keep the mines in compliance with the MSHA PEL of 2 mg/m^3 [Jankowski et al. 1991]. The major sources of respirable dust were the shearer during the tail-to-head-cut pass (40% to 59% of total respirable dust) and the stageloader/crusher (17% to 28% of total dust generated on the longwall face) [Jankowski et al. 1991]. In another BOM study, Jankowski et al. [1989] tested an improved design of the shearer drum (the major source of respirable dust generated in longwall mining). This design used a high-pressure, inward-facing drum spray. The 800-psi, 30°-inward-facing system was the best method for reducing dust concentrations (up to 68%) along the longwall face.

Although the concentration of respirable dust in a coal mine is directly related to the level of active coal production, some reports have shown that improvements in mining equipment reduced respirable coal mine dust and increased production as well. Howe [1987] reported that the use of new mining equipment (including the flooded-bed scrubber and radio remote control) reduced respirable coal mine dust from a range of 1.5 to 1.8 mg/m^3 to a range of 0.5 to 0.8 mg/m^3 at the coal face. In addition, production increased by 32%. Rice [1987] reported on an electronic longwall mining system that included electronic sensing devices, remote control shearers, and shields with microprocessors. This system improved roof control and reduced respirable dust exposure by 31% at the coal face by shunting dust away from workers. Roepke and Strebig [1989] and Olson and Roepke [1984] describe a modified cutting drum design (the constant-depth linear cutting drum). When this cutting drum was mounted on a continuous mining machine in laboratory tests, it reduced the shearer-generated respirable dust by 95%. The shearer contributes one- to two-thirds of the total respirable dust generated underground. Compared with conventional rotary drums, the constant-depth linear cutting drum also improved the size of the coal produced by effecting a 50% reduction in the >1/4-in.-mesh product. This cutting drum also reduced horsepower, torque, and thrust by 40% to 70% without loss of production. A trend in technology may be toward automated coal faces operated from a remote location so that miners are not at the coal face during production [Fisher 1991; Green 1987; Rice 1987].

7.7.4 Economic Considerations for Keeping Exposures Below the REL

The scope of this document does not include evaluating the economic feasibility of keeping worker exposures below the REL for respirable coal mine dust or respirable crystalline silica (including the cost of upgrading or retrofitting mining equipment and the cost of reduced production levels). However, those who evaluate the economics must consider the benefits of eliminating occupational respiratory disease (including lower costs for black lung benefits, litigation fees, and administration) and an improved work environment. Evidence also indicates that the careful design and application of mining equipment to reduce dust generation can also increase productivity and improve the quality of the coal [Cervik et al. 1985; Howe 1987; Roepke and Strebig 1989].

8 METHODS FOR PROTECTING COAL MINERS

The following methods should be used to protect miners from the adverse health effects of exposure to respirable coal mine dust and respirable crystalline silica:

- Informing workers about hazards
- Establishing written emergency procedures
- Using engineering controls, work practices, and personal protective equipment (including respiratory protection when dust control equipment is being installed, maintained, or repaired)
- Monitoring exposures
- Conducting medical screening and surveillance
- Encouraging smoking cessation
- Maintaining medical records

8.1 INFORMING WORKERS ABOUT HAZARDS

8.1.1 Training Programs

Employers should establish a training program for all coal miners and other workers exposed to respirable coal mine dust and respirable crystalline silica. Training should be provided whenever a new job is assigned, and workers should be informed about the health and safety hazards of the worksite. Training should include information about measures workers can take to protect themselves from exposure to respirable dust (e.g., the use of appropriate work practices, emergency procedures, and personal protective equipment--including the emergency use of respiratory protective equipment).

8.1.2 Posting

All warning signs should be printed in both English and the predominant language of workers who do not read English. Workers who cannot read posted signs should be identified so that they may receive information about hazardous areas and be informed of the instructions printed on the signs.

8.2 ESTABLISHING WRITTEN EMERGENCY PROCEDURES

The employer should formulate a set of written procedures covering fire, explosion, asphyxiation, and any other foreseeable emergency that may arise during coal mining or in other occupations where workers are exposed to respirable coal dust. All potentially affected workers should receive regular training in fire or emergency evacuation procedures and the proper use of self-contained self-rescuer (SCSR) and other rescue and evacuation equipment. Selected workers should be given training in first aid, cardiopulmonary resuscitation, and fire control. Procedures should include prearranged plans for transportation of injured workers and provisions for emergency medical care. At least two trained persons in every work area should have received extensive emergency training. Necessary emergency equipment, including appropriate respirators and other personal protective equipment, should be stored in readily accessible locations.

8.3 ENGINEERING CONTROLS

Engineering controls should be the principal method for minimizing exposure to respirable coal mine dust and respirable crystalline silica in the workplace. Engineering control measures include diluting the dust generated (by adequate ventilation at the coal face), controlling the respirable dust generated and entrained (e.g., with improved shearer drum design), and suppressing the dust generated (e.g., by water application).

8.3.1 Dust Control

To be effective, the dust control system in a mine should be evaluated as soon as possible after any change in geological conditions, production, processes, or controls that might increase the concentrations of respirable coal mine dust or respirable crystalline silica.

Jobs that require rock drilling (e.g., roof bolters) can generate dust containing respirable crystalline silica. Wet drills (including use of surface-active agents) or drills with attached dust collectors are advisable [Olishifski 1971; NIOSH 1992]. Dry drilling without dust controls should be prohibited. Appendix C contains further information about reducing respirable dust concentrations during overburden drilling in surface coal mining operations.

8.3.2 Ventilation

Underground coal mines are required to be mechanically ventilated [30 CFR 75.300-75.330]. The purpose of mechanical ventilation is to provide fresh air to the underground miners and to carry off toxic and explosive gases and dusts. The primary purposes of ventilation are to dilute respirable coal dust, to remove explosive concentrations of coal dust and methane from the working faces, and to remove methane from mined-out areas. In addition to supplying fresh air and exhausting noxious and explosive gases and dusts, mine ventilation systems must furnish paths of escape in the event of an underground fire. Ventilation and escape considerations relating to fire safety are extremely complex.

The portions of the mine used as part of the ventilation system are sometimes referred to as "air courses" [McAteer 1981]. Air courses are often described as follows:

- Intake air courses, which bring in fresh air to the working face
- Return air courses, which exhaust air from the working face

The number of entries available for ventilation vary with the mining method used and the geological characteristics of the rock strata mined.

Exhaust fans are commonly used to ventilate underground coal mines. Positive-pressure fans are used infrequently—usually where the mine is close to the surface and there is leakage to the surface through the air intakes. The volume of air flow through an underground mine is a function of the fan capacity and the "resistance" of the mine ventilation configuration [McAteer 1981].

Because of the multiple functions imposed on underground coal mine ventilation systems and the wide variations in underground mining methods, no general statements can be made about the availability of intake air to dilute respirable dust at the working face. Current ventilation techniques are largely dictated by regulations relating to available types of air courses, escapeway requirements, and methane regulation. The ventilation plan for each underground coal mine must be approved by MSHA [30 CFR 75.316].

Guidelines for the design of mine ventilation systems may be found in *Mine Ventilation and Air Conditioning* [Hartman et al. 1982]. Principles for the design and operation of local exhaust systems are presented in *Industrial Ventilation—A Manual of Recommended Practice* [ACGIH 1995]; *American National Standard: Fundamentals Governing the Design and Operation of Local Exhaust Systems, Z9.2 (1971)* [ANSI 1979]; and *Recommended Industrial Ventilation Guidelines*, published by NIOSH [Hagopian and Bastress 1976].

8.4 WORK PRACTICES

8.4.1 Worker Isolation

If feasible, workers should be isolated from work areas where the concentration of respirable coal mine dust or respirable crystalline silica exceeds the REL. This can be done by using automated equipment operated from a closed control booth or room. The control room should be maintained at a positive pressure so that air flows out of rather than into the room. However, personal protective clothing and equipment (including respiratory protective equipment) may be necessary when workers must perform process checks, adjustments, maintenance, or other related operations in work areas where respirable dust concentrations exceed the RELs.

8.4.2 Sanitation and Hygiene

Tobacco products should not be smoked, chewed, or carried into work areas. Workers should be provided with and advised to use facilities for showering and changing clothes at the end of each work shift. Tools and protective clothing and equipment should be cleaned as needed to maintain sanitary conditions. The work area should be kept free of flammable debris. Flammable work materials (rags, solvents, etc.) should be stored in approved safety cans.

8.5 PERSONAL PROTECTIVE EQUIPMENT

8.5.1 Protective Clothing and Equipment

Workers should wear work uniforms, coveralls, or similar full-body coverings that are laundered each day. Employers should provide lockers or other closed areas for workers to store their street clothes separately. Employers should also ensure that protective clothing is inspected and maintained to preserve its effectiveness. At the end of each workshift, employers should collect work clothing and provide for its laundering. Laundry personnel should be informed about the potential hazards of handling contaminated clothing, and they should be instructed about measures to minimize their health risk.

Workers and persons responsible for worker health and safety should be informed that protective clothing may interfere with the body's heat dissipation, especially during hot weather (e.g., in surface coal mines) or in hot work situations (e.g., in confined spaces). Additional monitoring is required to prevent heat-related illness when protective clothing is worn under these conditions [NIOSH 1986].

8.5.2 Respiratory Protection

8.5.2.1 The Need for Respiratory Protection

The need for respiratory protection in U.S. coal mines has changed considerably since 1969. The use of sophisticated extraction machines has greatly increased coal production and the quantity of dust generated. New chemicals have also been introduced for use in dust control systems, and viable biological matter has been discovered in the mining environment. Other potentially hazardous exposures include diesel exhaust, coal tar pitch volatiles from creosote-treated timbers, and polyurethane resins used in some roof support systems. The current MSHA regulations for respiratory equipment are contained in 30 CFR 70.300–70.305-1.

Engineering controls should be the primary method used to control exposures to airborne contaminants. Respiratory protection is the least preferred method of controlling worker exposures and should not be used routinely to prevent or minimize exposures. Respirators should be used by workers only in the following circumstances:

- During the development, installation, or testing of required engineering controls
- When engineering controls are not feasible to control exposures to airborne contaminants during short-term operations such as maintenance and repair
- During emergencies

8.5.2.2 Selection of Respirators

Several factors in the mine environment affect the selection of respirators. Safety factors are a particular concern, and impairment of vision must be avoided. For example, the use of water sprays to suppress dust may result in dirty water droplets that can quickly obscure vision in full-facepiece respirators. Silt can also collect around respirator face seals and irritate the skin.

The particulate filter in the respirator can become saturated and change its filtration and breathing resistance characteristics.

The *NIOSH Respirator Decision Logic* [NIOSH 1987b] should be followed to select the correct respirator. The following issues should be evaluated:

- Other available means of reducing exposure, such as increased or redirected ventilation and improved dust and vapor control systems
- The nature of the task to be performed (location, physical demands, industrial processes involved, and frequency and duration of respirator use)
- The space restrictions within the work location
- The physical nature of the air contaminant, including odor threshold, eye irritation, and other warning properties
- The interaction of contaminants with the respirator filter medium
- The concentrations of respirable coal mine dust, respirable crystalline silica, and other toxic contaminants in the miner's breathing zone
- Toxicological data, RELs, and PELs
- The required use of protective devices for the eyes and face
- The level of respiratory protection needed by the miner
- The worker's fitness to wear a respirator as determined by his or her health, potential hypersensitivity to a substance, type of respirator, fit testing, training, and conditions of respirator use (this issue is particularly important with the use of self-contained breathing apparatus)
- The performance characteristics, capabilities, and limitations of different types of respirators

8.5.2.3 Respiratory Protection Program

When respirators are used, employers should institute a complete respiratory protection program that includes, at regular intervals, worker training in the use and limitations of respirators, routine air monitoring, and the inspection, cleaning, maintenance, and proper storage of respirators. Any respiratory protection program must, at a minimum, meet the requirements of 29 CFR 1910.134. Respirators should be used according to the manufacturer's instructions.

Each respirator user should be fit-tested and the wearer's physical ability to wear a respirator should be periodically evaluated by a physician [Appendix H of NIOSH 1991b; NIOSH 1994d].

The miners should be informed annually about the hazard of dust exposure, and they should be trained in the use and care of the respirators. In addition, the program should be periodically reviewed, and if necessary, corrective action should be taken to maintain program effectiveness. For additional information about the use of respiratory protection, refer to the *NIOSH Guide to Industrial Respiratory Protection* [NIOSH 1987a] or the *NIOSH Respirator Decision Logic* [NIOSH 1987b].

Table 8-1 lists the recommended minimum respiratory protection for respirable coal mine dust and respirable crystalline silica. The *NIOSH Respirator Decision Logic* [NIOSH 1987b (or subsequent revised editions)] should be consulted if a certain condition requires a specific type of respirator other than those listed in Table 8-1.

When respirators are indicated, the employer should provide them at no cost to the worker and should assure the appropriate respirator is used. The employer should select respirators that are approved under the new NIOSH respirator certification regulation (42 CFR 84).*

8.6 EXPOSURE MONITORING

Routine environmental monitoring is an important part of an occupational health program designed to protect workers from the adverse effects of exposure to respirable coal mine dust and respirable crystalline silica. Such monitoring provides a means of assessing the effectiveness of engineering controls and work practices. The environmental monitoring (including both the initial and periodic surveys) should be conducted by competent industrial hygiene and engineering personnel. Chapter 5 and Appendices I and J contain additional information about sampling respirable coal mine dust and respirable crystalline silica.

The concentration of respirable coal mine dust or respirable crystalline silica shall be determined as a time-weighted average (TWA) by collecting samples over an 8- or 10-hr shift for up to a 40-hr workweek. For extended workshifts, Brief and Scala [1975] present a method for estimating an exposure-limit reduction factor. When the mine environment contains concentrations that exceed the REL for respirable coal mine dust or respirable crystalline silica, workers must wear respirators for protection until adequate engineering controls or work practices are instituted.

8.7 MEDICAL SCREENING AND SURVEILLANCE

First priority should be given to primary prevention of occupational respiratory diseases through the reduction of exposures. However, a secondary program of medical screening and surveillance is necessary to identify miners who develop respiratory diseases as a result of their workplace exposures. Chapter 6 contains provisions for preplacement and periodic medical examinations and recommendations for medical intervention.

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*42 CFR 84 became effective July 10, 1995, and replaces the provisions under 30 CFR 11.

Table 8–1. NIOSH-recommended respiratory protection for workers exposed to respirable coal mine dust and respirable crystalline silica

Condition	Airborne concentration (mg/m^3)[*]		Minimum respiratory protection
	Respirable coal mine dust	Respirable crystalline silica	
Entry into environments containing respirable dust	≤1 (1 × REL)[†,‡]	≤0.05 (1 × REL)	No respirator required
	≤5 (5 × REL)	≤0.25 (5 × REL)	Single-use or quarter-mask respirator equipped with any type of particulate filter[§]
	≤10 (10 × REL)	≤0.5 (10 × REL)	Any air-purifying, half-mask respirator equipped with any type of particulate filter,[§] or
			Any supplied-air respirator equipped with a half mask and operated in a demand (negative-pressure) mode
	≤25 (25 × REL)	≤1.25 (25 × REL)	Any powered, air-purifying respirator equipped with a hood or helmet and any type of particulate filter,[§] or
			Any supplied-air respirator equipped with a hood or helmet and operated in a continuous-flow mode
	≤50 (50 × REL)	≤2.5 (50 × REL)	Any air-purifying, full-facepiece respirator equipped with a high-efficiency filter,[§] or
			Any powered, air-purifying respirator equipped with a tight-fitting facepiece and a high-efficiency filter,[§] or
			Any supplied-air respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode, or
			Any supplied-air respirator equipped with a tight-fitting facepiece and operated in a continuous-flow mode, or
			Any self-contained respirator equipped with a full facepiece and operated in a demand (negative-pressure) mode
	≤500 (500 × REL)[**]	≤25 (500 × REL)	Any supplied-air respirator operated in a pressure-demand or other positive-pressure mode

(Continued)

See footnotes at end of table.

Table 8–1 (Continued). NIOSH-recommended respiratory protection for workers exposed to respirable coal mine dust and respirable crystalline silica

Condition	Airborne concentration (mg/m^3)[*]		Minimum respiratory protection
	Respirable coal mine dust	Respirable crystalline silica	
Planned or emergency entry into environments containing respirable dust	>500 (500 × REL) or unknown concentrations	>25 (500 × REL) or unknown concentrations	Any self-contained breathing apparatus equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode, or
			Any supplied-air respirator equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode
Firefighting	——	——	Any self-contained breathing apparatus equipped with a full facepiece and operated in a pressure-demand or other positive-pressure mode
Escape only	——	——	Any air-purifying, full-facepiece respirator with a high-efficiency filter,[§] or
			Any appropriate escape-type, self-contained breathing apparatus or self-contained self rescuer (SCSR)

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[*] The highest measured concentration of respirable coal mine dust or silica determines the minimum respiratory protection to be supplied to and worn by the miner.

[†] Assigned protection factor (APF) times the NIOSH REL. The APF [NIOSH 1987b] is the minimum anticipated level of protection provided by each type of respirator.

[‡] The values in this table were computed using the NIOSH REL of 1 mg/m^3 for respirable coal mine dust measured according to current MSHA methods (see Section 5.1). This REL of 1 mg/m^3 is equivalent to 0.9 mg/m^3 when measured according to the international definition of respirable dust (see Sections 5.2 and 5.4).

[§] The new NIOSH respirator certification regulation (42 CFR 84) became effective July 10, 1995, and replaces the old regulation (30 CFR 11). High-efficiency is the appropriate filter for respirable crystalline silica under 30 CFR 11; N100, R100, and P100 are the appropriate filters for respirable crystalline silica under 42 CFR 84.

[**] For airborne particulates, 500 × REL is the concentration above which only the most protective respirators are recommended [NIOSH 1994a].

8.8 SMOKING CESSATION

Overwhelming evidence exists for the adverse health consequences of smoking, the number of workers affected, and the additive effects of smoking and dust exposures on the development of occupational respiratory diseases (e.g., chronic bronchitis, emphysema, and lung cancer). Because of this evidence, NIOSH and the Association of Schools of Public Health cosponsored a *Proposed National Strategy for the Prevention of Occupational Lung Diseases*, which recommended the elimination of smoking in the workplace as an important strategy for preventing occupational lung diseases [ASPH 1986]. The recommendation was further supported by the NIOSH conclusion that nonsmokers exposed to environmental tobacco smoke[†] in the workplace had an increased risk of lung cancer [NIOSH 1991a].

NIOSH recommends the following regarding smoking in the workplace:

- Workers should be prohibited from smoking in the workplace.
- Information about health promotion and the harmful effects of smoking should be disseminated.
- Smoking cessation classes should be offered to workers at no cost to the participant.

Therefore, in addition to the MSHA prohibition of smoking in all underground mines and in surface mines where fire or explosion may result [30 CFR 75.1072 and 77.1711], NIOSH recommends that smoking be prohibited in all underground and surface coal mines and all other work areas associated with coal mining to prevent exposure to environmental tobacco smoke, a potential occupational carcinogen [NIOSH 1991a]. NIOSH also recommends that all miners who smoke participate in a smoking cessation program.

8.9 RECORDKEEPING

Medical records must be maintained for workers as specified in Section 1.11 of this document. They must be kept for at least 40 years after termination of employment. Copies of environmental exposure records for each worker must be included with the medical records. These records must be made available to past or present workers or to anyone having the specific written consent of a worker, as specified in 42 CFR 37.80.

8.10 PROTECTING CONTRACT MINERS

Some provisions of the standard recommended in this criteria document may be difficult to apply to a special category of miners known as contract miners. Coal miners who are contracted to work on specific jobs at various mines for relatively short periods may not gain the full benefits of exposure monitoring, medical surveillance, hazard training, and transfer programs normally available to other mine workers. NIOSH recognizes the need to include these contract miners in a recommended standard and will continue to explore options that will address their occupational safety and health needs.

[†] Environmental tobacco smoke is tobacco smoke in the ambient atmosphere composed of sidestream smoke and exhaled mainstream smoke [NIOSH 1991a].

9 RESEARCH NEEDS

Additional research and data analysis are needed for improvements in engineering control methods, respiratory protection, sampling devices and strategies, medical screening and intervention, adverse health effects of dust exposure, characterization of dust for future recommended standards, and training and education. The following is a list of such research needs:

Engineering control methods

- Assess current control technology in the coal mining industry by examining state-of-the-art technologies and work practices.
- Develop and recommend improved methods for keeping worker exposures below the RELs for respirable coal mine dust and respirable crystalline silica in underground and surface coal mines.

Respiratory protection

- Evaluate the physiological stress placed on miners who must wear respiratory protection.

Sampling devices

- Develop sampling devices with improved design for greater accuracy and precision and more rugged construction.
- Develop continuous monitors for use in sampling respirable coal mine dust.

Sampling strategy

- Evaluate sampling strategies for the accurate monitoring and control of worker exposures.
- Evaluate sampling strategies for effective enforcement of the standard.

Medical screening and intervention

- Evaluate the effectiveness of the existing transfer program in preventing the progression of simple CWP. The transfer program enables miners with CWP category 1/0 or greater to transfer to jobs in areas of the mine where mean concentrations of respirable coal mine dust are 1 mg/m^3.

- Identify early markers of disease to help identify adverse health effects of exposure to respirable coal mine dust and respirable crystalline silica and to prevent or impede disease progression.
- Determine the factors affecting the incidence of PMF in miners without prior radiographic evidence of simple CWP. Determining these factors will facilitate early identification and intervention.
- Evaluate exposure-response relationships affecting lung function in surface coal miners.
- Evaluate the effectiveness of reducing or eliminating exposures to respirable coal mine dust (and tobacco smoke, if applicable) in halting or impeding decline in lung function.
- Determine the prevalence of miners who have normal spirometry values and chest X-rays but abnormal gas exchange values. Knowledge of this prevalence would help determine the need for lung function tests in addition to spirometry tests (FEV_1 and FVC): DLCO or transcutaneous measurements of arterial oxygen pressure, for example.

Adverse health effects of dust exposure

- Investigate exposure, dose, and response relationships—including the effect of exposure patterns (intensity and duration) on the development of occupational respiratory diseases in coal miners.
- Assess the influence of dust composition and characteristics (e.g., quartz concentration, thoracic dust) on the development of simple CWP, PMF, and COPD in coal miners.
- Evaluate the role of overloaded lung clearance mechanisms in the development of occupational respiratory diseases in coal miners.
- Evaluate the ways in which the statistical model may affect risk estimates for occupational respiratory diseases—particularly in the low-exposure regions of the exposure-response curves.
- Analyze the relationship between exposure to thoracic coal mine dust and COPD.

Characterization of dust

- Compare the particle size distribution and the composition of airborne respirable dust in underground coal mines, surface mines, and other worksites where workers are exposed to coal dust.

Training and education

- Determine the training and education needed to promote occupational safety and health awareness in coal miners and coal mine operators, including safe work practices and use of engineering controls and personal protective equipment.

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PUBLICATIONS EXAMINED

Publications examined is arranged by category, as follows:

Sampling Strategies and Exposure Assessment
Sampling and Analytical Methods
Coal Mine Dust Characteristics and Concentrations
Engineering Controls
Medical Evaluation and Testing
Chronic Obstructive Pulmonary Disease
Lung Function
Coal Workers' Pneumoconiosis
Particle Deposition and Clearance from Lungs
Cellular and Animal Studies
Silica Exposures and Silicosis
Diesel Exposures, Controls, and Health Effects
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APPENDIX A

CONCENTRATIONS OF RESPIRABLE COAL MINE DUST AND RESPIRABLE CRYSTALLINE SILICA IN UNDERGROUND AND SURFACE COAL MINES

Table A-1. Number of underground coal mines and samples collected for underground occupations, 1988-92

Type of sample and year collected	Total number of mines in operation*	Inspector samples			Operator samples		
		Number of mines sampled	Number of samples	Number of samples per mine	Number of mines sampled	Number of samples	Number of samples per mine
Coal mine dust:							
1988	1,923	1,299	15,412	11.9	1,679	61,992	36.9
1989	1,766	1,146	13,397	11.7	1,601	59,649	37.3
1990	1,796	1,121	12,193	10.9	1,571	59,296	37.7
1991	1,602	964	11,117	11.5	1,411	56,316	39.9
1992	1,483	1,000	10,057	10.1	1,285	51,429	40.0
Respirable quartz:							
1988	1,923	944	2,882	3.1	327	665	2.0
1989	1,766	841	2,551	3.0	334	638	1.9
1990	1,796	801	2,323	2.9	347	712	2.1
1991	1,602	785	3,920	5.0	334	747	2.2
1992	1,483	875	4,577	5.2	340	748	2.2

*"In operation" indicates that the mine had at least one employee for the specified year.

Table A-2. Number of surface coal mines and samples collected for surface occupations, 1988–92

Type of sample and year collected	Total number of mines in operation*	Inspector samples			Operator samples		
		Number of mines sampled	Number of samples	Number of samples per mine	Number of mines sampled	Number of samples	Number of samples per mine
Coal mine dust:							
1988	2,751	1,386	6,921	5.0	604	5,862	9.7
1989	2,583	1,410	6,917	4.9	577	5,402	9.4
1990	2,524	1,368	6,926	5.1	576	5,160	9.0
1991	2,384	886	4,204	4.7	489	4,473	9.1
1992	2,220	984	4,368	4.4	426	3,747	8.8
Respirable quartz:							
1988	2,751	411	902	2.2	83	126	1.5
1989	2,583	357	648	1.8	79	121	1.5
1990	2,524	356	645	1.8	76	130	1.7
1991	2,384	204	366	1.8	51	76	1.5
1992	2,220	374	703	1.9	56	80	1.4

*"In operation" indicates that the mine had at least one employee for the specified year.

Table A-3. Number of underground coal mines with surface operations* and samples collected for surface occupations, 1988–92

Type of sample and year collected	Total number of mines in operation†	Inspector samples			Operator samples		
		Number of mines sampled	Number of samples	Number of samples per mine	Number of mines sampled	Number of samples	Number of samples per mine
Coal mine dust:							
1988	1,669	210	695	3.3	99	1,003	10.1
1989	1,580	401	878	2.2	87	906	10.4
1990	1,622	468	1,023	2.2	83	774	9.3
1991	1,484	256	564	2.2	81	729	9.0
1992	1,378	257	688	2.7	72	545	7.6
Respirable quartz:							
1988	1,669	31	60	1.9	2	3	1.5
1989	1,580	30	41	1.4	6	8	1.3
1990	1,622	30	46	1.5	2	3	1.5
1991	1,484	21	30	1.4	2	2	1.0
1992	1,378	52	101	1.9	6	8	1.3

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*These mines are included in the total number of underground mines reported in Table A-1.

†"In operation" indicates that the mine had at least one employee for the specified year.

Table A-4. Summary of respirable coal mine dust samples collected by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m³)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m³	≤1.0 mg/m³	≤1.5 mg/m³	≤2.0 mg/m³	>2.0 mg/m³
106 Rock duster	8	2.54	2.19	1.58	3.21	13	38	50	50	50
006 Rock duster	1	2.40	——	2.40	——	0	0	0	0	100
060 Longwall (return face worker)	95	1.95	1.10	1.64	1.92	6	19	42	58	42
044 Shear operator/plow operator, longwall	1,183	1.79	1.19	1.50	1.84	6	25	52	71	29
064 Longwall operator (headgate)	705	1.78	3.22	1.37	1.88	7	30	62	77	23
017 Auger (timberman-return side)	89	1.72	2.79	0.66	4.08	48	63	76	81	19
011 Wireman	1	1.70	——	1.70	——	0	0	0	100	0
055 Jack setter (auger-return side)	75	1.70	2.97	0.62	4.06	51	68	72	77	23
041 Jack setter (longwall)	2,238	1.67	2.27	1.35	1.85	8	30	61	78	22
052 Tailgate operator	105	1.66	1.78	1.00	3.08	26	39	64	72	28
154 Belt cleaner, belt picker	19	1.45	0.95	1.15	2.23	11	42	68	84	16
061 Longwall (return fixed position)	1	1.40	——	1.40	——	0	0	100	100	0
110 Timberman	1	1.40	——	1.40	——	0	0	100	100	0
010 Timberman, propman, jack setter	94	1.39	2.90	0.64	3.22	46	65	82	87	13
038 Cutting machine operator	1,348	1.32	2.23	0.71	3.10	41	60	75	83	17
036 Continuous miner operator	9,990	1.28	1.75	0.84	2.55	31	56	76	85	15

See footnotes at end of table.

(Continued)

Table A–4 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
048 Roof bolter mounted	337	1.28	0.84	1.05	2.01	16	45	75	88	12
418 Maintenance foreman	14	1.26	3.45	0.34	3.56	86	86	93	93	7
019 Roof bolter mounted (intake)	283	1.22	0.72	1.03	1.88	16	43	77	90	10
035 Continuous miner helper	4,950	1.22	2.16	0.80	2.52	32	58	79	88	12
042 Loading machine helper	33	1.22	1.39	0.76	2.88	36	58	70	91	9
051 Stall driver	25	1.22	0.64	1.07	1.69	12	56	80	88	12
033 Coal drill helper	61	1.19	1.03	0.76	2.93	34	46	72	84	16
423 Surveyor	2	1.15	1.34	0.65	5.27	50	50	50	50	50
014 Roof bolter (twin head-return)	2,474	1.12	1.21	0.79	2.38	32	61	80	88	12
032 Brattice man	54	1.10	0.93	0.80	2.41	31	61	80	89	11
043 Loading machine operator	681	1.10	1.70	0.67	2.74	44	66	81	88	12
018 Auger (timberman-intake side)	72	1.08	1.49	0.49	3.58	53	76	81	85	15
012 Roof bolter (twin head-intake)	2,158	1.04	1.03	0.73	2.40	36	64	83	90	10
047 Roof bolter helper	973	1.04	1.16	0.67	2.72	41	64	81	89	11
046 Roof bolter	6,664	1.03	1.69	0.63	2.70	44	67	83	90	10
070 Auger operator	173	1.01	1.33	0.53	3.17	53	71	81	86	14
071 Auger helper	40	0.83	0.64	0.59	2.54	43	68	90	98	3

(Continued)

Table A–4 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
037 Cutting machine helper	138	0.99	0.93	0.65	2.70	43	64	82	88	12
109 Supply man	8	0.98	0.32	0.92	1.43	13	50	100	100	0
053 Utility man	1,161	0.96	1.47	0.63	2.55	42	69	86	92	8
008 Mason, stopping builder, ventilation man	47	0.93	0.66	0.67	2.47	36	70	85	87	13
034 Coal drill operator	1,269	0.93	2.33	0.51	2.80	54	75	88	93	7
001 Belt man/conveyor man	157	0.90	1.55	0.50	2.76	57	81	89	92	8
007 Blaster, shotfirer, shooter	220	0.90	1.20	0.48	3.15	53	70	82	90	10
111 Wireman	2	0.90	0.14	0.89	1.17	0	100	100	100	0
040 Headgate operator	822	0.89	0.76	0.67	2.16	40	70	89	95	5
072 Mobile bridge operator	1,425	0.88	1.08	0.54	2.76	51	73	87	92	8
004 Mechanic	692	0.86	3.21	0.50	2.64	53	79	91	95	5
269 Motorman	38	0.86	0.40	0.75	1.84	26	71	95	100	0
462 Fireboss, preshift examiner	4	0.85	0.39	0.78	1.67	25	75	100	100	0
050 Shuttle car operator (on side)	9,125	0.83	1.12	0.56	2.50	48	74	90	94	6
016 Laborer	191	0.80	1.07	0.47	2.78	58	79	87	94	6
054 Scoop car operator	3,701	0.79	1.35	0.49	2.65	56	78	90	94	6

(Continued)

Table A–4 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
073 Shuttle car operator (off side)	4,696	0.77	1.10	0.51	2.52	53	78	91	95	5
013 Cleanup man	34	0.76	0.57	0.52	2.69	50	68	85	100	0
049 Section foreman	1,137	0.74	0.77	0.51	2.46	52	79	91	96	4
156 Rock driller	1	0.70	——	0.70	——	0	100	100	100	0
009 Supply man	32	0.68	0.65	0.43	2.81	56	72	94	97	3
002 Electrician	358	0.63	0.59	0.42	2.55	60	82	93	97	3
031 Shotfire helper, beater	38	0.62	0.53	0.41	2.65	58	79	92	97	3
074 Tractor operator/motorman	785	0.61	0.92	0.40	2.47	67	86	95	97	3
116 Laborer	8	0.61	0.38	0.45	2.66	38	88	100	100	0
146 Roof bolter	2	0.55	0.64	0.32	5.09	50	100	100	100	0
104 Mechanic	5	0.54	0.38	0.42	2.46	60	80	100	100	0
430 Assistant mine foreman/ assistant mine manager	23	0.53	0.78	0.27	3.06	70	83	96	96	4
045 Rockman	6	0.52	0.21	0.47	1.63	67	100	100	100	0
216 Trackman	1	0.50	——	0.50	——	100	100	100	100	0
039 Hand loader	279	0.49	1.17	0.25	2.74	76	90	95	96	4
449 Mine foreman, mine manager	108	0.47	1.32	0.22	2.61	85	94	97	98	2

(Continued)

Table A–4 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for underground occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
101 Belt man/conveyor man	2	0.45	0.07	0.45	1.17	100	100	100	100	0
497 Clerk, timekeeper	9	0.40	0.44	0.23	2.99	67	78	100	100	0
495 Safety director	3	0.37	0.38	0.25	2.88	67	100	100	100	0
494 Preparation plant foreman	100	0.35	0.33	0.24	2.31	82	94	100	100	0
489 Outside foreman	77	0.32	0.41	0.22	2.23	88	97	99	99	1
402 Master electrician	2	0.30	0.14	0.28	1.63	100	100	100	100	0
122 Coal dump operator	2	0.25	0.21	0.20	2.67	100	100	100	100	0
496 Union representative	2	0.25	0.21	0.20	2.67	100	100	100	100	0
414 Dust sampler	3	0.23	0.15	0.20	2.00	100	100	100	100	0
456 Engineer	3	0.20	0.17	0.16	2.23	100	100	100	100	0
464 Operator	3	0.20	0.17	0.16	2.23	100	100	100	100	0
481 Superintendent	29	0.19	0.19	0.15	1.84	97	100	100	100	0
404 Master mechanic	2	0.15	0.07	0.14	1.63	100	100	100	100	0
999 Summary for valid occupations	61,697	1.05	1.63	0.67	2.65	41	65	82	90	10

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[*] Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

[†] Samples with invalid occupation codes (34 samples) and the Part-90 samples (445 samples) are excluded.

Table A–5. Summary of respirable coal mine dust samples collected by mine operators for underground occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
106 Rock duster	6	3.77	3.23	2.16	3.89	33	33	33	33	67
033 Coal drill helper	13	2.12	1.32	1.72	2.04	8	31	38	46	54
003 Electrician helper	1	2.10	——	2.10	——	0	0	0	0	100
060 Longwall (return face worker)	702	1.94	1.31	1.58	1.99	7	22	46	60	40
048 Roof bolter mounted	62	1.70	1.70	1.23	2.16	18	44	69	74	26
044 Shear operator/plow operator, longwall	11,581	1.67	1.17	1.33	2.08	11	30	57	73	27
041 Jack setter (longwall)	1,685	1.66	1.23	1.28	2.17	14	35	59	72	28
040 Headgate operator	89	1.50	0.98	1.19	2.15	15	36	62	79	21
064 Longwall operator (headgate)	145	1.39	0.96	1.11	2.12	14	38	70	85	15
052 Tailgate operator	582	1.34	1.22	0.81	3.12	35	49	65	79	21
050 Shuttle car operator (on side)	567	1.26	1.06	0.87	2.64	30	51	72	82	18
019 Roof bolter mounted (intake)	12	1.23	1.31	0.72	4.34	17	58	92	92	8
002 Electrician	26	1.15	1.31	0.76	2.55	35	73	77	88	12
036 Continuous miner operator	211,266	1.01	1.15	0.62	2.83	44	66	82	89	11
035 Continuous miner helper	482	1.00	0.94	0.65	2.78	41	64	81	89	11
043 Loading machine operator	678	0.94	1.10	0.56	2.85	53	71	82	86	14

(Continued)

See footnotes at end of table.

Table A-5 (Continued). Summary of respirable coal mine dust samples collected by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
073 Shuttle car operator (off side)	148	0.92	1.04	0.55	2.95	51	70	83	92	8
012 Roof bolter (twin head-intake)	1,267	0.88	1.04	0.55	2.77	50	73	87	92	8
014 Roof bolter (twin head-return)	1,597	0.88	0.87	0.58	2.63	46	73	86	92	8
015 Fan attendant	3	0.87	0.32	0.82	1.54	33	67	100	100	0
046 Roof bolter	3,656	0.85	1.01	0.52	2.80	50	74	88	93	7
101 Belt man/conveyor man	53	0.84	0.52	0.68	2.03	32	74	92	98	2
016 Laborer	49	0.83	0.76	0.55	2.69	49	71	90	92	8
418 Maintenance foreman	31	0.83	0.55	0.61	2.48	29	71	87	97	3
116 Laborer	357	0.81	0.89	0.53	2.56	52	77	88	94	6
018 Auger (timberman-intake side)	10	0.78	0.30	0.72	1.53	40	80	100	100	0
070 Auger operator	2,738	0.76	0.89	0.46	2.74	56	78	90	94	6
104 Mechanic	73	0.75	0.67	0.55	2.24	55	78	90	93	7
038 Cutting machine operator	30,125	0.73	0.92	0.44	2.79	58	79	91	94	6
055 Jack setter (auger-return side)	1,953	0.73	0.60	0.52	2.44	49	77	94	97	3
489 Outside foreman	71	0.73	0.68	0.46	2.85	54	76	89	94	6
054 Scoop car operator	544	0.72	0.82	0.43	2.84	57	79	91	94	6
047 Roof bolter helper	52	0.71	0.62	0.47	2.81	48	81	92	94	6

(Continued)

Table A-5 (Continued). Summary of respirable coal mine dust samples collected by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
072 Mobile bridge operator	151	0.71	0.99	0.45	2.57	57	85	93	97	3
430 Assistant mine foreman/ assistant mine manager	14	0.69	0.46	0.53	2.26	57	71	100	100	0
004 Mechanic	53	0.68	0.86	0.41	2.73	70	83	92	92	8
110 Timberman	10	0.68	0.54	0.54	2.02	70	80	90	100	0
122 Coal dump operator	11	0.66	0.54	0.45	2.70	64	64	100	100	0
053 Utility man	65	0.64	0.54	0.43	2.64	60	82	91	98	2
049 Section foreman	77	0.62	0.63	0.38	3.11	60	82	95	96	4
108 Mason stopping builder, ventilation man	36	0.62	0.44	0.50	1.95	64	92	92	100	0
494 Preparation plant foreman	37	0.62	0.67	0.36	3.00	62	73	92	97	3
269 Motorman	82	0.60	0.51	0.42	2.45	60	84	95	99	1
007 Blaster, shotfirer, shooter	22	0.56	0.59	0.35	2.75	68	86	91	95	5
154 Belt cleaner, belt picker	80	0.55	0.55	0.37	2.51	68	86	96	99	1
034 Coal drill operator	6,204	0.54	0.67	0.32	2.73	70	87	95	97	3
017 Auger (timberman-return side)	397	0.53	0.49	0.38	2.35	68	88	97	98	2
013 Cleanup man	1	0.50	——	0.50	——	100	100	100	100	0

(Continued)

Table A–5 (Continued). Summary of respirable coal mine dust samples collected by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
449 Mine foreman, mine manager	38	0.50	0.42	0.37	2.25	74	92	97	97	3
074 Tractor operator/motorman	20	0.47	0.27	0.39	1.96	60	100	100	100	0
263 Track foreman	6	0.42	0.22	0.37	1.71	83	100	100	100	0
146 Roof bolter	9	0.39	0.50	0.22	2.81	78	78	100	100	0
109 Supply man	45	0.35	0.33	0.25	2.21	84	96	98	100	0
009 Supply man	5	0.34	0.22	0.30	1.77	80	100	100	100	0
497 Clerk, timekeeper	9	0.33	0.41	0.23	2.21	89	89	100	100	0
102 Electrician	11	0.32	0.32	0.24	2.05	91	91	100	100	0
216 Trackman	5	0.32	0.24	0.26	2.11	80	100	100	100	0
045 Rockman	17	0.28	0.26	0.19	2.34	82	100	100	100	0
037 Cutting machine helper	7	0.26	0.14	0.22	1.87	100	100	100	100	0
001 Belt man/conveyor man	29	0.23	0.23	0.17	2.14	93	100	100	100	0
039 Hand loader	8,844	0.23	0.47	0.15	2.02	94	98	99	99	1
462 Fireboss, pre-shift examiner	13	0.23	0.14	0.19	1.87	100	100	100	100	0
201 Belt man/conveyor man	2	0.15	0.07	0.14	1.63	100	100	100	100	0
414 Dust sampler	6	0.12	0.04	0.11	1.33	100	100	100	100	0
111 Wireman	1	0.10	—	0.10	—	100	100	100	100	0

(Continued)

Table A–5 (Continued). Summary of respirable coal mine dust samples collected by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
999 Summary for valid occupations	286,931	0.97	1.12	0.58	2.91	46	68	83	89	11

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[*] Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

[†] The Part-90 samples (1,751 samples) are excluded.

Table A–6. Summary of respirable coal mine dust samples collected by MSHA inspectors for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
320 Cage attendant/cager	3	1.40	1.68	0.64	5.80	33	67	67	67	33
384 Driller, highwall operator	2,696	1.32	2.97	0.62	3.29	48	67	78	84	16
325 Diester table operator	60	1.29	1.79	0.73	3.05	32	55	80	90	10
347 Froth cell operator	97	1.29	1.48	0.95	2.30	21	49	75	88	12
388 Scalper-screen operator	273	1.20	2.54	0.58	3.28	50	67	77	85	15
334 Coal drill operator	63	1.14	1.73	0.55	3.35	52	73	83	86	14
379 Dryer operator	151	1.13	5.48	0.46	2.88	53	78	92	97	3
380 Fine coal plant operator	555	1.13	1.19	0.79	2.48	29	57	79	91	9
319 Welder, (shop) blacksmith	187	1.04	1.52	0.49	3.44	52	69	82	85	15
317 Rodman	1	1.00	——	1.00	——	0	100	100	100	0
329 Vacuum filter operator	38	0.93	0.51	0.76	2.10	26	58	92	95	5
313 Cleanup man	442	0.88	1.19	0.54	2.79	46	72	87	93	7
306 Welder (non-shop)	132	0.78	1.37	0.38	3.24	60	79	89	92	8
301 Conveyor operator	98	0.74	2.77	0.26	3.12	79	93	96	96	4
374 Cleaning plant operator	857	0.74	1.96	0.42	2.75	59	82	93	96	4
316 Laborer, blacksmith	1,269	0.72	1.32	0.36	3.09	64	80	90	94	6
330 Face worker-shaft/slope sinking	5	0.72	0.60	0.51	2.84	40	80	80	100	0

See footnotes at end of table.

(Continued)

Table A–6 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	<2.0 mg/m^3	>2.0 mg/m^3
356 Rock driller	62	0.67	0.72	0.43	2.61	65	84	89	92	8
383 Driller, highwall helper	117	0.62	0.84	0.36	2.75	68	85	94	95	5
314 Coal sampler	295	0.61	1.27	0.36	2.60	67	86	95	97	3
357 Washer operator	233	0.61	0.54	0.42	2.55	58	82	96	99	1
324 Backhoe operator	264	0.60	4.83	0.20	2.46	88	96	98	99	1
392 Tipple operator	1,358	0.59	0.95	0.32	2.84	70	85	92	96	4
394 Carpenter	4	0.58	0.40	0.42	2.82	50	100	100	100	0
341 Beltman/conveyor man	197	0.56	0.79	0.32	2.73	73	85	93	97	3
340 Boom operator	18	0.55	0.64	0.29	3.28	61	83	94	94	6
386 Refuse truck driver	2,893	0.55	0.80	0.37	2.45	69	88	96	98	2
307 Blaster, shotfirer, shooter	199	0.53	0.61	0.35	2.44	70	89	96	97	3
345 Crusher attendant	226	0.53	1.28	0.28	2.63	76	92	95	97	3
352 Steel worker	3	0.53	0.29	0.46	2.06	33	100	100	100	0
328 Utility man	682	0.51	0.90	0.28	2.71	76	89	95	97	3
302 Electrician	449	0.48	0.49	0.31	2.53	71	91	96	98	2
390 Silo operator	23	0.48	0.35	0.35	2.42	61	96	100	100	0
304 Mechanic	1,337	0.47	0.76	0.27	2.68	75	90	96	98	2

(Continued)

Table A–6 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
381 Hoist operator helper	3	0.47	0.35	0.34	2.98	67	100	100	100	0
368 Bulldozer operator	5,761	0.46	0.73	0.29	2.49	77	91	97	98	2
327 Pumper	21	0.45	0.44	0.29	2.71	67	95	95	100	0
323 Transit man	3	0.43	0.58	0.22	3.99	67	67	100	100	0
358 Water circuit operator	10	0.41	0.32	0.31	2.29	80	100	100	100	0
369 Motorman	31	0.41	0.46	0.24	2.70	77	84	97	100	0
371 Auger helper	268	0.40	1.05	0.24	2.31	85	96	98	99	1
305 Mechanic helper	45	0.39	0.63	0.23	2.59	82	93	98	98	2
308 Mason	11	0.39	0.25	0.30	2.24	82	100	100	100	0
310 Pan scraper operator	699	0.39	0.77	0.23	2.43	86	94	97	98	2
370 Auger operator	336	0.39	0.59	0.25	2.35	84	94	97	98	2
376 Coal truck driver	655	0.39	0.67	0.26	2.35	83	93	98	99	1
354 Sweeper operator	16	0.38	0.53	0.22	2.61	88	88	94	94	6
344 Car shake-out operator	19	0.37	0.24	0.29	2.09	74	100	100	100	0
391 Stripping shovel operator	160	0.36	0.47	0.23	2.35	86	96	98	98	2
318 Greaser, oiler	448	0.35	0.34	0.24	2.33	83	96	98	100	0
366 Waterboy	6	0.35	0.25	0.28	2.07	83	100	100	100	0

(Continued)

Table A–6 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m³) Arithmetic mean	SD	Geometric mean	GSD	Percentage of samples ≤0.5 mg/m³	≤1.0 mg/m³	≤1.5 mg/m³	≤2.0 mg/m³	>2.0 mg/m³
398 Groundman	56	0.35	0.41	0.23	2.35	80	96	98	98	2
375 Road grader operator	378	0.34	0.79	0.22	2.26	88	97	99	100	0
382 Highlift operator	6,714	0.34	0.79	0.22	2.29	86	96	99	99	1
342 Bit sharpener	4	0.33	0.21	0.27	2.19	100	100	100	100	0
349 Rotary dump operator	16	0.33	0.19	0.27	1.97	94	100	100	100	0
343 Car trimmer/car loader	235	0.32	0.47	0.20	2.32	89	94	96	98	2
373 Car dropper	288	0.32	0.39	0.22	2.30	84	95	99	99	1
395 Water truck operator	68	0.30	0.27	0.22	2.08	91	97	99	100	0
396 Watchman	3	0.30	0.10	0.29	1.42	100	100	100	100	0
303 Electrician helper	7	0.29	0.25	0.20	2.45	86	100	100	100	0
393 Weighman	179	0.27	0.26	0.19	2.15	89	97	100	100	0
365 Dispatcher	7	0.26	0.14	0.22	1.87	100	100	100	100	0
367 Coal shovel operator	188	0.26	0.46	0.17	2.19	91	98	99	99	1
348 Machinist	58	0.25	0.25	0.18	2.12	95	97	100	100	0
372 Barge attendant	152	0.25	0.34	0.17	2.30	93	98	99	99	1
387 Rotary bucket excavator operator	51	0.25	0.22	0.19	2.03	96	98	100	100	0
326 Forklift operator	55	0.24	0.19	0.19	1.96	96	98	100	100	0

(Continued)

Table A–6 (Continued). Summary of respirable coal mine dust samples collected by MSHA inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
351 Scoop operator	12	0.24	0.18	0.20	1.89	92	100	100	100	0
362 Brakeman	12	0.24	0.20	0.19	2.08	92	100	100	100	0
322 Coal strip operator	8	0.23	0.15	0.18	1.99	100	100	100	100	0
360 Shopman repair cars	3	0.23	0.15	0.20	2.00	100	100	100	100	0
309 Supply man	93	0.22	0.22	0.17	1.99	95	99	100	100	0
378 Dragline operator, crane operator	474	0.22	0.50	0.16	1.90	97	99	100	100	0
331 Clam operator	4	0.20	0.14	0.17	1.94	100	100	100	100	0
350 Shuttle car operator	1	0.20	——	0.20	——	100	100	100	100	0
321 Hoist engineer/operator	62	0.19	0.13	0.15	1.78	98	100	100	100	0
385 Lampman	24	0.19	0.13	0.16	1.82	100	100	100	100	0
312 Belt vulcanizer	3	0.17	0.12	0.14	1.89	100	100	100	100	0
397 Yard engine operator	11	0.17	0.13	0.15	1.77	100	100	100	100	0
333 Coal drill helper	2	0.15	0.07	0.14	1.63	100	100	100	100	0
999 Summary for valid occupations	32,947	0.56	1.38	0.30	2.73	74	88	94	96	4

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†Samples with invalid occupation codes (8 samples) and the Part-90 samples (229 samples) are excluded.

Table A-7. Summary of respirable coal mine dust samples collected by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
319 Welder, (shop) blacksmith	56	1.19	2.23	0.43	3.90	64	73	80	86	14
347 Froth cell operator	307	1.10	0.63	0.90	2.01	24	52	82	90	10
388 Scalper-screen operator	662	1.07	1.12	0.66	2.94	39	60	80	87	13
390 Silo operator	31	1.03	0.75	0.78	2.35	19	55	87	94	6
329 Vacuum filter operator	91	1.00	0.74	0.79	2.12	26	56	89	95	5
306 Welder (non-shop)	208	0.97	1.43	0.52	3.05	54	70	84	89	11
379 Dryer operator	191	0.95	0.77	0.63	2.75	37	64	81	90	10
380 Fine coal plant operator	1,609	0.94	0.75	0.68	2.38	36	63	86	93	7
391 Stripping shovel operator	45	0.89	1.28	0.48	2.98	58	78	84	89	11
325 Diester table operator	136	0.87	0.52	0.69	2.12	33	66	91	99	1
316 Laborer, blacksmith	2,155	0.85	0.84	0.55	2.74	47	69	87	92	8
344 Car shake-out operator	4	0.85	0.39	0.79	1.54	25	75	100	100	0
384 Driller, highwall operator	5,688	0.84	1.84	0.41	3.14	62	78	88	91	9
305 Mechanic helper	12	0.83	0.59	0.63	2.38	42	58	92	92	8
313 Cleanup man	1,107	0.83	1.52	0.53	2.64	48	73	88	95	5
357 Washer operator	317	0.83	0.58	0.60	2.44	38	69	91	95	5
374 Cleaning plant operator	1,120	0.81	0.63	0.59	2.42	41	71	91	95	5

(Continued)

See footnotes at end of table.

Table A-7 (Continued). Summary of respirable coal mine dust samples collected by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
302 Electrician	350	0.79	0.95	0.45	2.88	56	73	87	93	7
304 Mechanic	1,272	0.79	0.82	0.51	2.71	47	76	90	94	6
356 Rock driller	75	0.75	0.75	0.48	2.65	57	77	91	93	7
392 Tipple operator	1,406	0.73	0.87	0.44	2.77	56	78	91	94	6
328 Utility man	365	0.68	0.76	0.41	2.77	60	77	92	96	4
345 Crusher attendant	146	0.67	0.66	0.43	2.66	59	78	92	95	5
370 Auger operator	53	0.61	0.67	0.40	2.47	66	83	94	94	6
314 Coal sampler	329	0.58	0.50	0.41	2.40	59	88	96	98	2
301 Conveyor operator	34	0.57	0.41	0.43	2.27	56	88	97	100	0
334 Coal drill operator	194	0.57	0.83	0.32	2.75	73	89	93	93	7
398 Groundman	14	0.56	0.87	0.28	3.12	71	93	93	93	7
373 Car dropper	201	0.55	0.57	0.35	2.62	64	86	94	99	1
326 Forklift operator	7	0.54	0.40	0.46	1.81	57	86	100	100	0
383 Driller, highwall helper	397	0.54	0.82	0.30	2.78	74	87	94	95	5
386 Refuse truck driver	1,826	0.54	1.20	0.32	2.64	70	89	95	97	3
307 Blaster, shotfirer, shooter	158	0.50	0.50	0.35	2.46	72	92	97	97	3
376 Coal truck driver	295	0.48	0.92	0.31	2.42	77	93	98	99	1

(Continued)

Table A-7 (Continued). Summary of respirable coal mine dust samples collected by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
382 Highlift operator	1,492	0.48	1.47	0.27	2.56	78	91	96	98	2
324 Backhoe operator	41	0.47	0.41	0.31	2.64	68	88	100	100	0
368 Bulldozer operator	3,993	0.47	0.65	0.28	2.62	75	90	96	97	3
318 Greaser, oiler	246	0.46	0.42	0.31	2.44	74	90	98	100	0
310 Pan scraper operator	390	0.43	0.63	0.26	2.56	79	93	96	98	2
341 Beltman/conveyor man	111	0.40	0.34	0.29	2.29	77	95	99	100	0
372 Barge attendant	9	0.40	0.43	0.25	2.71	78	89	100	100	0
343 Car trimmer/car loader	77	0.39	0.41	0.26	2.41	83	91	99	99	1
367 Coal shovel operator	36	0.39	0.29	0.30	2.22	72	94	100	100	0
354 Sweeper operator	21	0.38	0.30	0.28	2.27	81	95	100	100	0
375 Road grader operator	74	0.38	0.37	0.26	2.37	80	93	99	100	0
395 Water truck operator	31	0.38	0.30	0.30	2.06	81	97	100	100	0
371 Auger helper	31	0.34	0.36	0.22	2.41	84	94	97	100	0
348 Machinist	7	0.33	0.21	0.27	2.08	86	100	100	100	0
321 Hoist engineer/operator	11	0.22	0.13	0.19	1.69	100	100	100	100	0
378 Dragline operator, crane operator	76	0.22	0.21	0.17	1.96	93	99	100	100	0

(Continued)

Table A–7 (Continued). Summary of respirable coal mine dust samples collected by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
303 Electrician helper	16	0.21	0.17	0.16	1.96	94	100	100	100	0
385 Lampman	76	0.21	0.19	0.17	1.86	95	100	100	100	0
365 Dispatcher	13	0.19	0.13	0.16	1.74	100	100	100	100	0
387 Rotary bucket excavator operator	7	0.19	0.11	0.16	1.69	100	100	100	100	0
309 Supply man	25	0.18	0.13	0.16	1.65	96	100	100	100	0
394 Carpenter	5	0.16	0.13	0.13	1.86	100	100	100	100	0
999 Summary for valid occupations	27,649	0.71	1.19	0.41	2.85	60	79	91	94	6

*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†The Part-90 samples (952 samples) are excluded.

Table A–8. Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3‡	>0.100 mg/m^3
003 Electrician helper	2	0.23	0.32	0.06	18.93	50	50	50
017 Auger (timberman-return side)	15	0.19	0.34	0.06	4.97	53	80	20
055 Jack setter (auger-return side)	22	0.16	0.26	0.05	6.70	45	64	36
269 Motorman	9	0.16	0.16	0.09	3.82	44	56	44
046 Roof bolter	2,862	0.12	0.17	0.07	3.17	41	64	36
010 Timberman, propman, jack setter	10	0.10	0.10	0.07	2.67	30	80	20
012 Roof bolter (twin head-intake)	894	0.10	0.15	0.06	3.23	47	71	29
036 Continuous miner operator	5,464	0.10	0.22	0.04	4.10	56	75	25
047 Roof bolter helper	136	0.10	0.11	0.07	2.63	46	71	29
014 Roof bolter (twin head-return)	1,311	0.09	0.15	0.05	3.57	51	70	30
035 Continuous miner helper	527	0.08	0.17	0.04	3.41	60	81	19
060 Longwall (return face worker)	44	0.08	0.07	0.06	2.47	41	77	23
102 Electrician	1	0.08	——	0.08	——	0	100	0
116 Laborer	1	0.08	——	0.08	——	0	100	0
008 Mason, stopping builder, ventilation man	7	0.07	0.06	0.05	2.42	43	71	29

See footnotes at end of table.

(Continued)

Table A–8 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3‡	>0.100 mg/m^3
052 Tailgate operator	30	0.07	0.09	0.03	5.31	63	70	30
074 Tractor operator/motorman	51	0.07	0.21	0.03	3.11	76	92	8
001 Belt man/conveyor man	17	0.06	0.07	0.02	5.01	65	82	18
032 Brattice man	3	0.06	0.07	0.02	13.17	67	67	33
041 Jack setter (longwall)	451	0.06	0.08	0.03	3.30	67	85	15
044 Shear operator/plow operator, longwall	633	0.06	0.09	0.03	4.09	67	82	18
048 Roof bolter mounted	180	0.06	0.10	0.03	4.67	70	86	14
054 Scoop car operator	338	0.06	0.11	0.03	2.88	72	88	12
073 Shuttle car operator (off side)	385	0.06	0.10	0.03	3.38	76	88	12
019 Roof bolter mounted (intake)	147	0.05	0.11	0.02	4.18	82	91	9
031 Shotfire helper, beater	6	0.05	0.03	0.04	1.95	83	100	0
034 Coal drill operator	206	0.05	0.10	0.02	4.02	82	91	9
038 Cutting machine operator	640	0.05	0.11	0.02	4.58	81	91	9
043 Loading machine operator	87	0.05	0.16	0.01	4.82	90	94	6
050 Shuttle car operator (on side)	743	0.05	0.10	0.03	3.48	73	87	13
064 Longwall operator (headgate)	162	0.05	0.05	0.03	2.87	72	88	12
070 Auger operator	49	0.05	0.08	0.02	4.72	82	88	12

(Continued)

Table A–8 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3‡	>0.100 mg/m^3
072 Mobile bridge operator	127	0.05	0.05	0.03	3.18	69	90	10
109 Supply man	3	0.05	0.04	0.02	11.93	33	100	0
430 Assistant mine foreman/ assistant mine manager	2	0.05	0.05	0.03	5.09	50	100	0
016 Laborer	26	0.04	0.05	0.02	3.64	77	88	12
039 Hand loader	38	0.04	0.06	0.01	6.30	71	84	16
053 Utility man	130	0.04	0.06	0.02	3.82	73	90	10
002 Electrician	34	0.03	0.03	0.01	4.01	85	97	3
004 Mechanic	63	0.03	0.06	0.02	3.59	89	94	6
006 Rock duster	1	0.03	——	0.03	——	100	100	0
015 Fan attendant	2	0.03	0.03	0.02	3.61	100	100	0
033 Coal drill helper	8	0.03	0.04	0.02	2.50	88	88	13
049 Section foreman	164	0.03	0.04	0.02	3.61	86	93	7
051 Stall driver	1	0.03	——	0.03	——	100	100	0
110 Timberman	2	0.03	0.02	0.03	2.20	100	100	0
418 Maintenance foreman	1	0.03	——	0.03	——	100	100	0
423 Surveyor	1	0.03	——	0.03	——	100	100	0

(Continued)

Table A-8 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for underground occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[‡]	≤0.100 mg/m^3[§]	>0.100 mg/m^3
449 Mine foreman, mine manager	9	0.03	0.06	0.01	7.20	89	89	11
007 Blaster, shotfirer, shooter	15	0.02	0.02	0.02	2.13	87	100	0
013 Cleanup man	7	0.02	0.02	0.01	5.17	100	100	0
018 Auger (timberman-intake side)	4	0.02	0.02	0.01	5.44	100	100	0
037 Cutting machine helper	10	0.02	0.02	0.02	1.88	90	100	0
040 Headgate operator	131	0.02	0.04	0.01	3.65	91	98	2
042 Loading machine helper	8	0.02	0.02	0.01	2.64	88	100	0
005 Mechanic helper	1	0.01	——	0.01	——	100	100	0
009 Supply man	6	0.01	0.01	0.01	4.74	100	100	0
071 Auger helper	1	0.01	——	0.01	——	100	100	0
101 Belt man/conveyor man	2	0.01	0.01	0.01	2.11	100	100	0
154 Belt cleaner, belt picker	4	0.01	0.01	0.01	3.78	100	100	0
494 Preparation plant foreman	6	0.01	0.01	0.01	2.95	100	100	0
999 Summary for valid occupations	16,240	0.09	0.17	0.04	3.92	58	76	24

[*] Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

[†] Samples with invalid occupation codes (14 samples) and the Part-90 samples (69 samples) are excluded.

[‡] Equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

[§] MSHA PEL.

Table A–9. Summary of respirable crystalline silica samples collected by coal mine operators for underground occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[‡]	≤0.100 mg/m^3[‡]	>0.100 mg/m^3
019 Roof bolter mounted (intake)	2	0.32	0.45	0.03	95.89	50	50	50
040 Headgate operator	1	0.19	——	0.19	——	0	0	100
060 Longwall (return face worker)	6	0.18	0.11	0.16	1.86	0	33	67
047 Roof bolter helper	3	0.17	0.27	0.02	22.22	67	67	33
072 Mobile bridge operator	6	0.16	0.20	0.07	4.32	33	67	33
036 Continuous miner operator	2,298	0.12	0.35	0.04	5.17	53	69	31
044 Shear operator/plow operator, longwall	104	0.12	0.14	0.07	3.43	41	64	36
004 Mechanic	2	0.10	0.13	0.05	7.48	50	50	50
041 Jack setter (longwall)	21	0.10	0.10	0.05	4.06	48	57	43
014 Roof bolter (twin head-return)	241	0.09	0.14	0.04	4.94	55	70	30
046 Roof bolter	468	0.09	0.18	0.03	5.13	61	79	21
052 Tailgate operator	4	0.09	0.06	0.07	2.15	50	50	50
012 Roof bolter (twin head-intake)	175	0.08	0.14	0.03	5.79	62	78	22
035 Continuous miner helper	18	0.08	0.20	0.01	8.52	67	89	11
054 Scoop car operator	7	0.08	0.14	0.03	4.57	71	86	14

(Continued)

See footnotes at end of table.

Table A–9 (Continued). Summary of respirable crystalline silica samples collected by coal mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3‡	>0.100 mg/m^3
070 Auger operator	12	0.08	0.13	0.02	6.65	67	83	17
055 Jack setter (auger-return side)	8	0.06	0.05	0.03	5.03	63	88	13
269 Motorman	2	0.06	0.01	0.05	1.14	50	100	0
016 Laborer	1	0.05	——	0.05	——	100	100	0
034 Coal drill operator	16	0.05	0.09	0.02	5.87	75	88	13
039 Hand loader	1	0.05	——	0.05	——	100	100	0
050 Shuttle car operator (on side)	25	0.05	0.06	0.03	3.74	72	88	12
038 Cutting machine operator	62	0.04	0.06	0.01	4.99	85	94	6
073 Shuttle car operator (off side)	10	0.04	0.04	0.02	5.32	80	90	10
017 Auger (timberman-return side)	7	0.03	0.02	0.02	2.05	100	100	0
043 Loading machine operator	3	0.03	0.02	0.01	8.35	100	100	0
146 Roof bolter	1	0.03	——	0.03	——	100	100	0
064 Longwall operator (headgate)	3	0.02	0.02	0.01	7.34	100	100	0
489 Outside foreman	1	0.02	——	0.02	——	100	100	0
048 Roof bolter mounted	4	0.01	0.01	0.00	5.80	100	100	0
049 Section foreman	2	0.00	0.00	0.00	1.00	100	100	0

(Continued)

Table A–9 (Continued). Summary of respirable crystalline silica samples collected by coal mine operators for underground occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[‡]	≤0.100 mg/m^3[§]	>0.100 mg/m^3
999 Summary for valid occupations	3,514	0.11	0.29	0.04	5.21	56	72	28

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[*] Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

[†] Samples with invalid occupation codes (5 samples) and the Part-90 samples (2 samples) are excluded.

[‡] 0.058 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

[§] MSHA PEL.

Table A-10. Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[‡]	≤0.100 mg/m^3[§]	>0.100 mg/m^3
383 Driller, highwall helper	20	0.48	0.82	0.21	3.40	20	30	70
356 Rock driller	8	0.36	0.61	0.05	17.49	38	38	63
384 Driller, highwall operator	548	0.35	0.64	0.15	3.91	19	33	67
330 Face worker-shaft/slope sinking	2	0.25	0.10	0.25	1.47	0	0	100
368 Bulldozer operator	586	0.17	0.25	0.06	5.62	40	55	45
334 Coal drill operator	13	0.16	0.19	0.07	5.20	38	54	46
310 Pan scraper operator	55	0.14	0.21	0.06	5.19	42	56	44
307 Blaster, shotfirer, shooter	24	0.12	0.18	0.07	3.23	38	58	42
390 Silo operator	3	0.12	0.17	0.05	5.74	67	67	33
301 Conveyor operator	6	0.11	0.17	0.06	2.60	83	83	17
366 Waterboy	1	0.09	—	0.09	—	0	100	0
376 Coal truck driver	44	0.08	0.22	0.02	6.19	68	82	18
386 Refuse truck driver	374	0.07	0.09	0.03	4.15	59	81	19
398 Groundman	4	0.05	0.03	0.02	7.88	50	100	0
340 Boom operator	6	0.04	0.06	0.01	7.51	83	83	17
344 Car shake-out operator	2	0.04	0.05	0.03	4.28	50	100	0

See footnotes at end of table.

(Continued)

Table A-10 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3§	>0.100 mg/m^3
345 Crusher attendant	24	0.04	0.11	0.01	4.94	96	96	4
370 Auger operator	17	0.04	0.06	0.01	6.06	71	82	18
375 Road grader operator	18	0.04	0.04	0.02	4.17	72	89	11
382 Highlift operator	373	0.04	0.08	0.01	5.14	82	93	7
314 Coal sampler	38	0.03	0.04	0.01	5.13	87	92	8
326 Forklift operator	2	0.03	0.05	0.01	19.48	50	100	0
328 Utility man	49	0.03	0.04	0.01	4.09	90	94	6
341 Beltman/conveyor man	16	0.03	0.05	0.02	3.91	94	94	6
391 Stripping shovel operator	4	0.03	0.03	0.03	2.23	75	100	0
313 Cleanup man	107	0.02	0.03	0.01	4.47	93	94	6
316 Laborer, blacksmith	196	0.02	0.09	0.01	4.91	95	97	3
318 Greaser, oiler	37	0.02	0.04	0.01	5.33	89	95	5
320 Cage attendant/cager	1	0.02	——	0.02	——	100	100	0
324 Backhoe operator	10	0.02	0.03	0.01	5.50	90	100	0
329 Vacuum filter operator	10	0.02	0.03	0.01	4.30	90	100	0
343 Car trimmer/car loader	5	0.02	0.02	0.01	4.24	100	100	0

(Continued)

Table A–10 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples[†]	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[‡]	≤0.100 mg/m^3[‡]	>0.100 mg/m^3
351 Scoop operator	1	0.02	——	0.02	——	100	100	0
357 Washer operator	42	0.02	0.05	0.01	4.42	95	95	5
367 Coal shovel operator	6	0.02	0.03	0.01	4.17	83	100	0
371 Auger helper	11	0.02	0.02	0.01	4.19	100	100	0
380 Fine coal plant operator	171	0.02	0.03	0.01	4.42	96	98	2
388 Scalper-screen operator	82	0.02	0.03	0.01	5.45	90	98	2
302 Electrician	36	0.01	0.02	0.00	4.33	97	100	0
304 Mechanic	123	0.01	0.02	0.01	4.51	93	98	2
306 Welder (non-shop)	17	0.01	0.01	0.00	3.62	100	100	0
309 Supply man	1	0.01	——	0.01	——	100	100	0
319 Welder, (shop) blacksmith	21	0.01	0.03	0.00	4.49	95	95	5
325 Diester table operator	18	0.01	0.01	0.01	3.45	100	100	0
327 Pumper	2	0.01	0.01	0.00	5.09	100	100	0
347 Froth cell operator	40	0.01	0.01	0.01	3.51	100	100	0
372 Barge attendant	3	0.01	0.01	0.01	5.18	100	100	0
373 Car dropper	18	0.01	0.01	0.00	3.30	100	100	0

(Continued)

Table A–10 (Continued). Summary of respirable crystalline silica samples collected by MSHA coal mine inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples†	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3‡	≤0.100 mg/m^3§	>0.100 mg/m^3
374 Cleaning plant operator	135	0.01	0.02	0.00	4.05	97	99	1
378 Dragline operator, crane operator	8	0.01	0.01	0.01	3.06	100	100	0
379 Dryer operator	27	0.01	0.01	0.00	3.27	100	100	0
392 Tipple operator	166	0.01	0.02	0.00	4.21	98	99	1
394 Carpenter	1	0.01	——	0.01	——	100	100	0
395 Water truck operator	2	0.01	0.00	0.01	1.14	100	100	0
305 Mechanic helper	3	0.00	0.01	0.00	3.78	100	100	0
348 Machinist	1	0.00	——	0.00	——	100	100	0
369 Motorman	1	0.00	——	0.00	——	100	100	0
393 Weighman	4	0.00	0.01	0.00	3.54	100	100	0
999 Summary for valid occupations	3,543	0.11	0.31	0.02	7.28	66	76	24

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†Samples with invalid occupation codes (2 samples) and the Part-90 samples (10 samples) are excluded.

‡0.058 mg/m^3 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

§MSHA PEL.

Table A–11. Summary of respirable crystalline silica samples collected by coal mine operators for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3[†]	≤0.100 mg/m^3[‡]	>0.100 mg/m^3
383 Driller, highwall helper	11	0.51	0.49	0.24	4.46	18	36	64
384 Driller, highwall operator	196	0.24	0.42	0.09	4.82	29	49	51
356 Rock driller	6	0.15	0.24	0.05	5.74	50	67	33
368 Bulldozer operator	126	0.14	0.16	0.06	4.81	40	56	44
324 Backhoe operator	3	0.10	0.05	0.09	1.63	0	67	33
375 Road grader operator	2	0.09	0.01	0.09	1.12	0	50	50
307 Blaster, shotfirer, shooter	9	0.08	0.05	0.05	5.04	22	56	44
310 Pan scraper operator	13	0.08	0.15	0.04	2.70	69	92	8
318 Greaser, oiler	8	0.08	0.10	0.03	6.32	50	75	25
313 Cleanup man	9	0.07	0.08	0.03	5.04	67	67	33
376 Coal truck driver	11	0.06	0.05	0.02	7.94	45	82	18
382 Highlift operator	20	0.06	0.06	0.03	4.63	60	75	25
386 Refuse truck driver	85	0.05	0.15	0.02	5.09	71	82	18
334 Coal drill operator	3	0.04	0.02	0.03	1.69	100	100	0
304 Mechanic	3	0.03	0.03	0.02	2.74	100	100	0
316 Laborer, blacksmith	5	0.03	0.02	0.03	1.92	100	100	0

See footnotes at end of table.

(Continued)

Table A-11 (Continued). Summary of respirable crystalline silica samples collected by coal mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3†	≤0.100 mg/m^3‡	>0.100 mg/m^3
398 Groundman	2	0.03	0.02	0.03	2.39	100	100	0
341 Beltman/conveyor man	4	0.02	0.01	0.02	1.77	100	100	0
345 Crusher attendant	3	0.02	0.02	0.01	2.90	100	100	0
370 Auger operator	1	0.02	——	0.02	——	100	100	0
388 Scalper-screen operator	3	0.02	0.02	0.00	8.79	100	100	0
392 Tipple operator	4	0.02	0.02	0.01	4.78	100	100	0
301 Conveyor operator	3	0.01	0.01	0.01	1.84	100	100	0
314 Coal sampler	1	0.01	——	0.01	——	100	100	0
328 Utility man	5	0.01	0.01	0.01	2.05	100	100	0
344 Car shake-out operator	1	0.01	——	0.01	——	100	100	0
354 Sweeper operator	2	0.01	0.02	0.01	9.98	100	100	0
357 Washer operator	4	0.01	0.01	0.01	1.49	100	100	0
380 Fine coal plant operator	10	0.01	0.01	0.00	4.11	100	100	0
390 Silo operator	1	0.01	——	0.01	——	100	100	0
391 Stripping shovel operator	1	0.01	——	0.01	——	100	100	0
302 Electrician	1	0.00	——	0.00	——	100	100	0

(Continued)

Table A-11 (Continued). Summary of respirable crystalline silica samples collected by coal mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3†	≤0.100 mg/m^3‡	>0.100 mg/m^3
340 Boom operator	1	0.00	——	0.00	——	100	100	0
999 Summary for valid occupations	557	0.15	0.29	0.05	5.65	48	64	36

*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†0.058 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

‡MSHA PEL.

Table A–12. Summary of respirable coal mine dust area samples collected in coal mines, 1988–92*

Type of sample	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
Inspector	16,194	0.61	1.35	0.3	3.13	69	83	92	95	5
Operator	71,837	0.66	1.05	0.39	2.78	64	82	92	95	5

*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

Table A–13. Summary of respirable crystalline silica area samples collected in coal mines, 1988–92*

Type of sample	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3†	≤0.100 mg/m^3‡	>0.100 mg/m^3
Inspector	2,244	0.08	0.13	0.04	4.24	61	78	22
Operator	1,783	0.09	0.15	0.04	4.22	56	76	24

*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†0.058 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

‡MSHA PEL.

APPENDIX B

CONCENTRATIONS OF RESPIRABLE COAL MINE DUST AND RESPIRABLE CRYSTALLINE SILICA IN SAMPLES REQUIRED BY 30 CFR 90

Table B-1. Summary of respirable coal mine dust samples collected under 30 CFR 90 by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤ 0.5 mg/m^3	≤ 1.0 mg/m^3	≤ 1.5 mg/m^3	≤ 2.0 mg/m^3	>2.0 mg/m^3
019 Roof bolter mounted (intake)	1	3.80	——	3.80	——	0	0	0	0	100
046 Roof bolter	5	1.66	0.38	1.62	1.28	0	0	40	100	0
002 Electrician	11	0.97	0.75	0.77	2.07	36	64	82	91	9
269 Motorman	48	0.79	0.69	0.56	2.41	50	67	94	96	4
053 Utility man	5	0.78	0.22	0.75	1.34	20	100	100	100	0
001 Belt man/conveyor man	6	0.77	0.37	0.66	1.94	33	83	100	100	0
116 Laborer	173	0.77	0.67	0.57	2.27	47	80	92	97	3
016 Laborer	8	0.76	0.86	0.52	2.36	63	88	88	88	13
050 Shuttle car operator (on side)	5	0.74	0.28	0.69	1.52	40	100	100	100	0
109 Supply man	32	0.71	0.64	0.54	2.12	53	78	94	97	3
049 Section foreman	10	0.70	0.69	0.45	2.82	60	80	90	90	10
101 Belt man/conveyor man	23	0.66	0.36	0.53	2.19	43	87	100	100	0

See footnote at end of table.

(Continued)

Table B–1 (Continued). Summary of respirable coal mine dust samples collected under 30 CFR 90 by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
035 Continuous miner helper	9	0.61	0.33	0.51	2.04	33	100	100	100	0
004 Mechanic	14	0.60	0.32	0.51	1.94	57	93	100	100	0
154 Belt cleaner, belt picker	10	0.60	0.50	0.39	2.97	50	80	100	100	0
108 Mason stopping builder, ventilation man	6	0.58	0.51	0.41	2.63	67	83	100	100	0
149 Bullgang foreman, labor foreman	1	0.50	——	0.50	——	100	100	100	100	0
102 Electrician	23	0.41	0.35	0.30	2.21	78	91	100	100	0
110 Timberman	7	0.40	0.35	0.30	2.24	86	86	100	100	0
111 Wireman	1	0.40	——	0.40	——	100	100	100	100	0
263 Track foreman	1	0.40	——	0.40	——	100	100	100	100	0
122 Coal dump operator	3	0.37	0.15	0.34	1.61	100	100	100	100	0
104 Mechanic	26	0.28	0.17	0.23	1.91	96	100	100	100	0
414 Dust sampler	4	0.28	0.29	0.19	2.50	75	100	100	100	0
009 Supply man	1	0.20	——	0.20	——	100	100	100	100	0
418 Maintenance foreman	3	0.20	0.17	0.16	2.23	100	100	100	100	0
216 Trackman	2	0.15	0.07	0.14	1.63	100	100	100	100	0

(Continued)

Table B–1 (Continued). Summary of respirable coal mine dust samples collected under 30 CFR 90 by MSHA inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
430 Assistant mine foreman/ assistant mine manager	2	0.15	0.07	0.14	1.63	100	100	100	100	0
221 Hoistman	1	0.10	——	0.10	——	100	100	100	100	0
265 Dispatcher	2	0.10	0.00	0.10	1.00	100	100	100	100	0
462 Fireboss, preshift examiner	2	0.10	0.00	0.10	1.00	100	100	100	100	0
999 Summary for valid occupations	445	0.69	0.62	0.48	2.38	55	82	94	97	3

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

Table B–2. Summary of respirable coal mine dust samples collected under 30 CFR 90 by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
019 Roof bolter mounted (intake)	13	4.76	7.60	0.88	8.45	46	54	62	62	38
012 Roof bolter (twin head-intake)	4	1.30	0.62	1.13	2.01	25	25	50	100	0
035 Continuous miner helper	10	1.22	0.91	0.87	2.72	30	40	80	80	20
430 Assistant mine foreman/ assistant mine manager	40	1.15	1.55	0.45	4.05	60	73	75	83	18
008 Mason, stopping builder, ventilation man	5	1.12	0.41	1.07	1.40	0	60	80	100	0
046 Roof bolter	13	0.95	0.40	0.86	1.72	15	62	92	100	0
114 Coal sampler	5	0.88	0.36	0.82	1.50	20	60	100	100	0
049 Section foreman	31	0.83	0.51	0.70	1.79	35	77	94	94	6
050 Shuttle car operator (on side)	33	0.82	0.64	0.58	2.50	48	70	82	97	3
108 Mason, stopping builder, ventilation man	72	0.78	1.61	0.40	2.80	69	82	93	94	6
154 Belt cleaner, belt picker	47	0.76	0.82	0.41	3.32	55	72	85	94	6
122 Coal dump operator	17	0.71	0.40	0.58	2.09	47	76	100	100	0
116 Laborer	688	0.69	0.97	0.44	2.55	59	83	93	97	3
110 Timberman	65	0.66	0.68	0.42	2.59	63	82	89	95	5
016 Laborer	38	0.63	0.92	0.33	2.94	68	87	89	92	8

(Continued)

See footnote at end of table.

Table B-2 (Continued). Summary of respirable coal mine dust samples collected under 30 CFR 90 by mine operators for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
156 Rock driller	8	0.60	0.19	0.57	1.40	50	100	100	100	0
101 Belt man/conveyor man	72	0.54	0.58	0.34	2.60	69	89	96	96	4
002 Electrician	33	0.52	0.31	0.43	1.92	64	94	100	100	0
109 Supply man	51	0.50	0.31	0.40	2.05	71	92	100	100	0
149 Bullgang foreman/labor foreman	8	0.49	0.34	0.38	2.23	75	88	100	100	0
104 Mechanic	190	0.46	0.43	0.33	2.26	77	92	97	99	1
004 Mechanic	66	0.43	0.31	0.32	2.21	76	94	100	100	0
102 Electrician	105	0.34	0.39	0.23	2.26	86	94	99	99	1
157 Pumper	5	0.34	0.18	0.29	2.02	100	100	100	100	0
269 Motorman	75	0.34	0.21	0.28	1.89	88	99	100	100	0
216 Trackman	16	0.31	0.29	0.23	2.18	88	94	100	100	0
053 Utility man	6	0.30	0.39	0.19	2.53	83	83	100	100	0
462 Fireboss, preshift examiner	13	0.19	0.10	0.17	1.65	100	100	100	100	0
414 Dust sampler	22	0.15	0.09	0.13	1.55	100	100	100	100	0
999 Summary for valid occupations	1,751	0.64	1.10	0.39	2.60	66	85	94	97	3

*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

Table B–3. Summary of respirable coal mine dust samples collected under 30 CFR 90 by MSHA inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
398 Groundman	1	0.60	——	0.60	——	0	100	100	100	0
380 Fine coal plant operator	4	0.55	0.13	0.54	1.27	50	100	100	100	0
341 Beltman/conveyor man	29	0.44	0.46	0.29	2.40	79	90	97	97	3
304 Mechanic	22	0.40	0.32	0.29	2.32	77	91	100	100	0
321 Hoist engineer/operator	1	0.40	——	0.40	——	100	100	100	100	0
374 Cleaning plant operator	10	0.37	0.18	0.33	1.77	90	100	100	100	0
386 Refuse truck driver	9	0.36	0.31	0.26	2.31	89	89	100	100	0
313 Cleanup man	2	0.35	0.21	0.32	1.91	100	100	100	100	0
316 Laborer, blacksmith	43	0.35	0.39	0.23	2.39	79	95	98	100	0
368 Bulldozer operator	6	0.35	0.35	0.23	2.68	83	100	100	100	0
392 Tipple operator	6	0.33	0.15	0.29	1.85	100	100	100	100	0
318 Greaser, oiler	2	0.30	0.14	0.28	1.63	100	100	100	100	0
373 Car dropper	3	0.30	0.17	0.25	2.23	100	100	100	100	0
394 Carpenter	1	0.30	——	0.30	——	100	100	100	100	0
395 Water truck operator	1	0.30	——	0.30	——	100	100	100	100	0
382 Highlift operator	7	0.24	0.11	0.22	1.75	100	100	100	100	0

(Continued)

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*See footnote at end of table

Table B–3 (Continued). Summary of respirable coal mine dust samples collected under 30 CFR 90 by MSHA inspectors for surface occupations, 1988–92[*]

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
328 Utility man	15	0.22	0.17	0.18	1.85	93	100	100	100	0
309 Supply man	7	0.21	0.09	0.20	1.49	100	100	100	100	0
343 Car trimmer/car loader	4	0.20	0.14	0.17	1.94	100	100	100	100	0
369 Motorman	2	0.20	0.14	0.17	2.17	100	100	100	100	0
385 Lampman	33	0.19	0.12	0.16	1.78	100	100	100	100	0
314 Coal sampler	5	0.18	0.04	0.17	1.36	100	100	100	100	0
365 Dispatcher	14	0.18	0.17	0.14	1.87	93	100	100	100	0
319 Welder, (shop) blacksmith	2	0.15	0.07	0.14	1.63	100	100	100	100	0
999 Summary for valid occupations	229	0.31	0.30	0.23	2.13	88	97	99	100	0

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[*] Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

Table B–4. Summary of respirable coal mine dust samples collected under 30 CFR 90 by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
341 Beltman/conveyor man	87	0.55	2.14	0.19	2.56	94	95	97	97	3
374 Cleaning plant operator	104	0.55	0.41	0.40	2.42	57	83	98	100	0
380 Fine coal plant operator	28	0.52	0.36	0.39	2.32	68	93	100	100	0
392 Tipple operator	14	0.50	0.21	0.46	1.48	71	100	100	100	0
304 Mechanic	57	0.48	0.37	0.35	2.30	63	93	98	100	0
386 Refuse truck driver	42	0.45	0.97	0.25	2.47	88	95	98	98	2
343 Car trimmer/car loader	24	0.35	0.22	0.28	2.06	79	100	100	100	0
314 Coal sampler	32	0.30	0.60	0.17	2.31	94	94	97	97	3
365 Dispatcher	85	0.23	0.19	0.17	1.99	94	100	100	100	0
368 Bulldozer operator	21	0.23	0.18	0.18	1.91	95	100	100	100	0
373 Car dropper	41	0.23	0.24	0.17	2.03	88	98	100	100	0
313 Cleanup man	25	0.22	0.13	0.19	1.81	100	100	100	100	0
321 Hoist engineer/operator	20	0.22	0.13	0.18	1.79	100	100	100	100	0
398 Groundman	6	0.22	0.24	0.16	2.20	83	100	100	100	0
379 Dryer operator	22	0.20	0.10	0.18	1.64	100	100	100	100	0
385 Lampman	140	0.20	0.30	0.15	1.90	95	99	99	99	1

(Continued)

See footnote at end of table.

Table B–4 (Continued). Summary of respirable coal mine dust samples collected under 30 CFR 90 by mine operators for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable coal mine dust (mg/m^3)				Percentage of samples				
		Arithmetic mean	SD	Geometric mean	GSD	≤0.5 mg/m^3	≤1.0 mg/m^3	≤1.5 mg/m^3	≤2.0 mg/m^3	>2.0 mg/m^3
316 Laborer, blacksmith	112	0.19	0.16	0.16	1.85	96	100	100	100	0
382 Highlift operator	16	0.19	0.10	0.16	1.76	100	100	100	100	0
328 Utility man	33	0.18	0.20	0.14	1.81	94	97	100	100	0
369 Motorman	7	0.17	0.11	0.15	1.73	100	100	100	100	0
309 Supply man	33	0.16	0.10	0.14	1.61	100	100	100	100	0
394 Carpenter	3	0.10	0.00	0.10	1.00	100	100	100	100	0
999 Summary for valid occupations	952	0.32	0.74	0.20	2.25	87	96	99	99	1

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

Table B-5. Summary of respirable crystalline silica samples collected under 30 CFR 90 by MSHA coal mine inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m³) Arithmetic mean	SD	Geometric mean	GSD	Percentage of samples ≤0.058 mg/m³†	≤0.100 mg/m³‡	>0.100 mg/m³
019 Roof bolter mounted (intake)	1	2.68	——	2.68	——	0	0	100
046 Roof bolter	1	0.38	——	0.38	——	0	0	100
109 Supply man	5	0.13	0.21	0.06	3.47	80	80	20
154 Belt cleaner, belt picker	4	0.07	0.11	0.02	4.59	75	75	25
269 Motorman	7	0.06	0.03	0.05	1.71	57	86	14
035 Continuous miner helper	2	0.05	0.04	0.05	2.22	50	100	0
050 Shuttle car operator (on side)	2	0.05	0.01	0.05	1.17	100	100	0
101 Belt man/conveyor man	8	0.04	0.03	0.03	2.26	75	88	13
002 Electrician	1	0.02	——	0.02	——	100	100	0
016 Laborer	2	0.02	0.01	0.01	2.17	100	100	0
108 Mason stopping builder, ventilation man	1	0.02	——	0.02	——	100	100	0
116 Laborer	30	0.02	0.03	0.02	2.42	97	97	3
004 Mechanic	1	0.01	——	0.01	——	100	100	0
102 Electrician	2	0.01	0.01	0.00	5.09	100	100	0
110 Timberman	1	0.01	——	0.01	——	100	100	0
001 Belt man/conveyor man	1	0.00	——	0.00	——	100	100	0

(Continued)

See footnotes at end of table.

Table B-5 (Continued). Summary of respirable crystalline silica samples collected under 30 CFR 90 by MSHA coal mine inspectors for underground occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3†	≤0.100 mg/m^3‡	>0.100 mg/m^3
999 Summary for valid occupations	69	0.08	0.33	0.02	3.58	84	90	10

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†0.058 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

‡MSHA PEL.

Table B–6. Summary of respirable crystalline silica samples collected under 30 CFR 90 by MSHA coal mine inspectors for surface occupations, 1988–92*

MSHA code and occupation	Number of samples	Concentration of respirable crystalline silica (mg/m^3)				Percentage of samples		
		Arithmetic mean	SD	Geometric mean	GSD	≤0.058 mg/m^3†	≤0.100 mg/m^3‡	>0.100 mg/m^3
382 Highlift operator	1	0.03	——	0.03	——	100	100	0
304 Mechanic	4	0.02	0.01	0.02	1.92	100	100	0
374 Cleaning plant operator	1	0.01	——	0.01	——	100	100	0
380 Fine coal plant operator	1	0.01	——	0.01	——	100	100	0
316 Laborer, blacksmith	2	0.00	0.00	0.00	1.00	100	100	0
341 Beltman/conveyor man	1	0.00	——	0.00	——	100	100	0
999 Summary for valid occupations	10	0.01	0.01	0.01	4.00	100	100	0

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*Concentrations are based on a sampling flow rate of 2.0 L/min and use of the MRE conversion factor of 1.38.

†0.058 is equivalent to the NIOSH REL of 0.050 mg/m^3, which is based on a sampling flow rate of 1.7 L/min and no use of the MRE conversion factor.

‡MSHA PEL.

APPENDIX C

OPTIONAL DUST CONTROL TECHNIQUES FOR COAL MINING ENVIRONMENTS

The following sections list optional dust control techniques for various types of mining (conventional, auger-type continuous, continuous miner-type, and longwall), for underground areas outby mining sections, and for preparation plants.

C.1 CONVENTIONAL MINING

Hollow-steel, drilling-auger-based, dry dust collection systems for face drills [Chander et al. 1988]

Hollow-steel, drilling-auger-based, water suppression systems for face drills [Chander et al. 1988]

Water-filled dummies for stemming shotholes to reduce dust in coal breaking [Cummins and Given 1973]

External cutter bar sprays machine-mounted at the front and rear of the cutter bar on cutting machines [Kost et al. 1981]

External sprays mounted on loading machines near the gathering arms on the pan and directed at the conveyor [Kost et al. 1981]

Cardox® (liquified carbon dioxide), Airdox® (compressed air), or Hydrox® (sodium nitrate and ammonium chloride reaction) chemical and hydraulic coal burster systems for high pressure breakage of face coals [Bourgoyne et al. 1986]

Low porosity line brattice with tight top and bottom seals for single-split and double-split ventilation systems [Kost et al. 1981]

Double-split ventilation systems to keep extraction and roof bolting activities in separate fresh air currents [Kost et al. 1981]

Improved stopping-construction techniques using mortar supplemented with steel or fiberglass fibers brushed on as sealant coatings [Kost et al. 1981]

Machine-mounted water spray systems to (1) wet coal surfaces to immobilize dust and prevent it from becoming airborne, and (2) generate water droplets to collide with and engulf airborne dust particles accelerating settlement from the airstream [Kost et al. 1981]

Upgraded water supply systems incorporating increased pump capacity for additional flow and pressure with increased line sizes to decrease pressure losses [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

"Non-clogging" filtration system that uses hydrocyclone, flushable Y-strainer, and micropolishing filter devices to improve water quality and reduce maintenance downtime [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

Haulroads that have been wet, with calcium chloride applied to maintain moisture content and minimize airborne dust in intake airstreams [Kost et al. 1981]

Belt scrapers, installed on the return side of the belt near the drive, for cleaning the load-bearing side of the belt [Shirey et al. 1985; Organiscak et al. 1986; Kost et al. 1981]

C.2 AUGER-TYPE CONTINUOUS MINING

Double-split ventilation systems to keep extraction and roof-bolting activities in separate fresh air currents [Kost et al. 1981]

Combination line brattice plus auxiliary fan face ventilation systems for improved continuous face ventilation [Kost et al. 1981]

Improved stopping-construction techniques using mortar supplemented with steel or fiberglass fibers brushed on as sealant coatings [Kost et al. 1981]

Machine-mounted external water spray systems to (1) wet coal surfaces to immobilize dust and prevent it from becoming airborne, and (2) generate water droplets to collide with and engulf airborne dust particles accelerating settlement from the airstream [Kost et al. 1981]

Wet-auger water spray systems supplying nozzles on the auger shaft and at cutting bits for dust suppression [Kost et al. 1981]

Upgraded water supply systems incorporating increased pump capacity for additional flow and pressure with increased line sizes to decrease pressure losses [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

"Non-clogging" filtration system that uses hydrocyclone, flushable Y-strainer, and micropolishing filter devices to improve water quality and reduce maintenance downtime [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

Nonionic surfactant additives and wetting agents for improved performance of water-spray, dust-suppression systems [Chander et al. 1988; Kost et al. 1981]

Machine-mounted, high-pressure, water-powered scrubber for reducing dusts on blowing ventilation systems [Campbell 1988; Bourgoyne et al. 1986]

Haulroads that have been wet with water, with calcium chloride applied to maintain moisture content and minimize airborne dust in intake airstreams [Kost et al. 1981]

Belt scrapers, installed on the return side of the belt near the drive, for cleaning the load-bearing side of the belt [Shirey et al. 1985; Organiscak et al. 1986; Kost et al. 1981]

C.3 CONTINUOUS MINER-TYPE MINING

Double-split ventilation systems to keep extraction and roof bolting activities in separate fresh air currents [Kost et al. 1981]

Combination line brattice plus auxiliary fan face ventilation systems for improved continuous face ventilation [Kost et al. 1981]

Blowing diffuser fans mounted on the continuous miner opposite the exhaust tubing or brattice to sweep dust into the exhaust ventilation system [Kost et al. 1981]

Improved stopping-construction techniques using mortar supplemented with steel or fiberglass fibers brushed on as sealant coatings [Kost et al. 1981]

Large bits (conical and others) used on drum-type continuous miners and operation at reduced speed to break the coal out in larger chunks and reduce dust generation [Cummins and Given 1973]

Machine-mounted water spray systems that use additional sprays or improved mounting positions to (1) wet coal surfaces to immobilize dust and prevent it from becoming airborne, and (2) generate water droplets to collide with and engulf airborne dust particles accelerating settlement from the airstream [Kost et al. 1981]

Continuous miner-mounted conveyor throat venturi sprays to prevent dispersion of dust clouds into the operator's station [Kost et al. 1981]

Machine-mounted, high-pressure, water-powered scrubber for dust collection [Kost et al. 1981]

Nonionic surfactant additives and wetting agents for improved performance of water-spray, dust-suppression systems [Chander et al. 1988; Shirey et al. 1985; Kost et al. 1981]

Continuous miner-mounted venturi scrubber and ducting systems for dust capture and removal [Jayaraman 1979]

Upgraded water supply systems incorporating increased pump capacity for additional flow and pressure with increased line sizes to decrease pressure losses [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

"Non-clogging" filtration system that uses hydrocyclone, flushable Y-strainer, and micropolishing filter devices to improve water quality and reduce maintenance downtime [Shirey et al. 1985; Jankowski and Organiscak 1983; Kost et al. 1981]

Remote control operation systems for continuous miners to keep operators out of the zone of dust production [Cummins and Given 1973]

Half-curtain, face-ventilation techniques to redirect dusts [Jayaraman et al. 1988]

High-pressure, shrouded, water sprays mounted on continuous miner cutting head [Jayaraman et al. 1981]

Campbell flooded bed scrubber systems installed on the continuous miner [Campbell 1988; Frantz and Ramani 1988]

Twin-flooded, fibrous-bed scrubber and water droplet eliminator systems [Divers et al. 1981; Kost et al. 1981]

Auxiliary ventilation tubing on the exhaust of face ventilation fans to reroute dust from the continuous miner past downstream roof bolter working places directly into return entries [Babbitt and Jayaraman 1988]

Roof-bolter, flooded-bed scrubber and fan modules that receive a split of dusty air from the continuous miner, extracts the respirable dust, and delivers it to the roof bolters as a split of fresh air [Babbitt and Jayaraman 1988]

Wet drilling with or without water-jet-assisted cutting in roof bolting operations [Adam 1990]

Belt scrapers, installed on the return side of the belt near the drive, for cleaning the load-bearing side of the belt [Shirey et al. 1985; Organiscak et al. 1986; Kost et al. 1981; Barrett et al. 1983]

Machine-mounted, high-pressure, water-powered scrubber [Campbell 1988]

Venturi scrubbers and ceramic flow-through filters for particulate emission control on diesel powered equipment [Wheeler 1986]

Haulroads that have been wet, with calcium chloride applied to maintain moisture content and minimize airborne dust in intake airstreams [Kost et al. 1981]

Short-hole water infusion from horizontal holes drilled into the working face to a depth equal to the daily advance of the face to increase the moisture content of the coal [Kost et al. 1981]

Long-hole water infusion holes drilled parallel into the coal seam in advance of the face and before extraction to increase the moisture content of the coal [Shirey et al. 1985; Cervik et al. 1983; Taylor and Evans 1985; Taylor et al. 1986; Kost et al. 1981]

C.4 LONGWALL MINING

Increased ventilation air quantity and face velocities for increased dust dilution [Shirey et al. 1985]

Longwall-shearer remote controls for operators [Shirey et al. 1985]

Computer-controlled systems for automated advancement of roof support systems from a direction downwind of the shearer or plow [Shirey et al. 1985; Organiscak et al. 1985]

Water sprays directed over shield and chock roof support canopies to suppress dust generated during support movement [Jankowski and Organiscak 1983; Organiscak et al. 1985]

Large bits (conical and others) used on drum-type shearer and operation at reduced drum rotational speed to break the coal out in larger chunks and reduce dust generation [Cummins and Given 1973]

Deep-cut-shearer cutting drums with lower drum rotational speeds [Shirey et al. 1985]; Shearer-Clearer external water spray system using high-pressure, air-moving water sprays to confine shearer-generated dust near the face and away from operators [Shirey et al. 1985; Jankowski and Organiscak 1983; Jayaraman et al. 1985]

Splitter-arm, passive belting barriers [Shirey et al. 1985; Jankowski and Organiscak 1983; Jankowski and Babbitt 1986; Jayaraman et al. 1985]

Machine cooling water relocated into panline sprays or a crescent spray ring wrapped around shearer ranging arms [Shirey et al. 1985; Jayaraman et al. 1985]

Alternate-design mining sequence taking the primary face cut downwind with operators positioned upwind ahead of the lead cutting drum [Shirey et al. 1985; Jankowski and Organiscak 1983; Organiscak et al. 1985]

Special fabricated shearer cutting drums incorporating cavity filling, water-through-the-bit, and pick-face flushing sprays [Shirey et al. 1985]

Upgraded water supply systems incorporating increased pump capacity for additional flow and pressure with increased line sizes to decrease pressure losses [Shirey et al. 1985; Jankowski and Organiscak 1983]

Installation of a "non-clogging" filtration system utilizing hydrocyclone, flushable Y-strainer, and microfilter devices to improve water quality and reduce maintenance downtime [Shirey et al. 1985; Jankowski and Organiscak 1983]

Ventilation curtains (wing curtain, gob curtain, and stage loader curtain) used in the headgate area to minimize air leakage into the gob and reduce the shearer operator's dust exposure when cutting out at the headgate [Shirey et al. 1985; Jankowski and Organiscak 1983; Organiscak et al. 1986]

Stageloader and crusher enclosed with steel plates or strips of conveyor belting to isolate conveyed material from the airstream and reduce dust entrainment [Shirey et al. 1985; Jankowski and Organiscak 1983; Organiscak et al. 1986]

Spraybars containing multiple full-cone water sprays mounted in the stageloader/crusher and at the stageloader-belt conveyor transfer point to provide uniform coverage of the coal stream [Shirey et al. 1985; Jankowski and Organiscak 1983; Organiscak et al. 1986]

A water-powered scrubber and brattice partition to reduce tailgate worker's dust exposure [Shirey et al. 1985; Organiscak et al. 1983]

Belt scrapers, installed on the return side of the belt near the drive, for cleaning the load-bearing side of the belt [Shirey et al. 1985; Organiscak et al. 1986; Kost et al. 1981]

High-pressure, water-jet-assisted cutting for shearers [Taylor et al. 1986]

Nonionic surfactant additives and wetting agents for enhanced performance of water-spray, dust-suppression systems [Chander et al. 1988; Shirey et al. 1985]

Water infusion holes drilled into the coal seam before extraction to increase the moisture content of the coal [Shirey et al. 1985; Cervik et al. 1983; Taylor and Evans 1985; Taylor et al. 1986]

C.5 UNDERGROUND AREAS OUTBY MINING SECTIONS

Water sprinkled on empty coal cars, the tops of loaded cars, and coal on conveyor belts to reduce or eliminate dust blown into ventilating airstreams [Cummins and Given 1973]

A water-powered scrubber at belt conveyor transfer points to capture and eliminate dusts suspended in the airstream [Shirey et al. 1985; Organiscak et al. 1983]

Filter cartridge-based compact dry dust collectors for dust control at transfer points and airlock stations [Barrett et al. 1983]

C.6 SURFACE OPEN PIT MINING

Steel-collar-vacuum dust collection systems drilled with cyclones and baghouses for drill units [Gadomski and Chiz 1988]

Water-based or oil-based wet drilling techniques to eliminate dusts generated during shothole drilling and reduce dusts during subsequent rock and coal breakage [Cummins and Given 1973; Bourgoyne et al. 1986]

Environmentally-controlled, airtight cab enclosures for highwall rotary blasthole drill units and bulldozers [Gadomski and Chiz 1988; Frantz and Ramani 1988]

Trucks equipped with water sprays optionally using wetting agents for roadway and haulroad dust control [Cummins and Given 1973]

Wood-based adhesive polymer foam for roadway dust and materials handling [Charlton 1988]

Building conveyors with elevated discharge chutes around a steel tube with discharge windows at appropriate intervals, or the use of telescopic chutes to materially cut blowage of dusts [Cummins and Given 1973]

C.7 PREPARATION PLANTS

Nonionic surfactant additives for water-spray, dust-suppression systems at conveyor transfer points, crushers, and vibrating screens [Zimmer et al. 1988]

Overhead air supplied island (OASIS) for operators and maintenance personnel at stationary locations [Volkwein et al. 1988; Frantz and Ramani 1988]

Airtight enclosures around transfer chutes with and without local exhaust systems to control suspended dusts [Cummins and Given 1973]

Airtight housings and hoods with vacuum fans and dust collectors or electrostatic precipitators to clean up dusts at rotary breakers, raw coal screens, and crushers [Cummins and Given 1973; Divers and Cecala 1990; Divers and Jankowski 1988]

A water-powered scrubber at belt conveyor transfer points to capture and eliminate dusts suspended in the airstream [Shirey et al. 1985; Organiscak et al. 1983; Divers and Cecala 1990]

Prepared coal confined in storage bins or silos to prevent dust dispersal [Cummins and Given 1973]

Building conveyors with elevated discharge chutes around a steel tube with discharge windows at appropriate intervals, or the use of telescopic chutes to materially cut blowage of dusts [Cummins and Given 1973]

Sprayed storage piles of fine, prepared coal that will stand for appreciable times with fuel oil to reduce dust blowage [Cummins and Given 1973]

C.8 OTHER DUST EXPOSURE CONTROL OPTIONS

Within the hierarchy of dust control technologies, all available engineering controls should be implemented first. During implementation periods, or after exhausting engineering technologies, two additional dust exposure mediation techniques may be instituted:

1. Use of administrative controls (i.e., rotating workers from high dust-making operations to low dust-making operations to expose the mine personnel to lower average daily dust concentrations) [Barrett et al. 1983]

2. Use of respirators capable of removing respirable-size particulates (which are commercially available from a number of suppliers and may be provided to miners with proper training in their use and maintenance) [Barrett et al. 1983; Divers and Cecala 1990]

REFERENCES CITED IN APPENDIX C

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APPENDIX D

METHODS FOR CONTROLLING RESPIRABLE COAL MINE DUST FROM OVERBURDEN DRILLING AT SURFACE COAL MINES

This appendix focuses on methods of reducing excess respirable dust exposures during overburden drilling, the activity that places surface coal miners at the greatest risk of exposure to respirable crystalline silica.

D.1 ENGINEERING CONTROLS

Engineering controls for overburden drilling include dry dust collection systems, wet dust suppression systems, and enclosed cabs [Zimmer and Lueck 1986; Volkwein et al. 1979]. Proper maintenance of the dust suppression system is critically important for drills using dry dust suppression methods. Failure to rigorously maintain these systems will result in inadequate dust control. Acute silicosis has been reported in miners operating equipment that relies on dry dust suppression [NIOSH 1992].

D.1.1 Dry Dust Collection Systems

Dry dust collection systems typically include a drill platform shroud, a drill stem seal, and a dust collector.

D.1.1.1 Drill Platform Shroud

A drill platform shroud is essentially a skirt made of a flexible material (usually rubber) that hangs from the underside of the drill platform and surrounds the drill hole. The shroud enclosure, which is maintained under negative pressure, contains the dust that comes out of the drill hole. When the system is equipped with an adjustable shroud, the shroud height (the distance between the ground and the bottom of the shroud) should be kept as low as possible. A BOM [Zimmer and Lueck 1986] study found that although results differ with various drills, the control efficiency generally decreases as the shroud height increases. The same study reported that for the two drills tested, control efficiencies varied from 99% to 41% over the 0- to 27-in. height range and the collection system performed most efficiently when the shroud height was no greater than 9 in. In practice, however, maintaining a consistent height around the shroud because of uneven ground surfaces is not always possible.

D.1.1.2 Drill Stem Seal

The point at which the drill stem passes through the drill platform can be a source of dust emission. To control this dust source, a flexible collar that acts like a seal is placed around the drill stem at the platform level. The integrity of the seal must be maintained to prevent dust leakage.

D.1.1.3 Dust Collector

The dust from the shroud enclosure is transported through a duct to a collection chamber containing paper or fabric filters. An exhaust fan located on the clean side of the filters maintains a negative pressure inside the duct and the shroud enclosure and draws the dust-laden air through the filters at rates greater than 4 to 6 times the bailing airflow and varying from 600 to 6,000 cfm, depending on the size of the system. The filtered air is exhausted to the atmosphere and the dust is trapped on the filters. The filters are periodically cleaned with a reverse pulse of compressed air, which sends the collected dust into a hopper for discharge onto the ground away from the drill crew.

Test data have shown that dry dust collection systems are capable of achieving greater than 95% control efficiency [Zimmer and Lueck 1986], but this control efficiency may not always be reproducible in practice. Table D-1 summarizes the advantages and disadvantages of dry dust collection systems.

D.1.2 Wet Dust Suppression Systems

In wet dust suppression systems, water is pumped from a storage tank into a line injecting the bail air into the interior of the drill stem. The water droplets in the bail air coat and aggregate the dust as they are carried upward through the drill hole. Thus, the dust is suppressed by the weight of the moisture as the air bails out the cuttings from the hole. Because the water is expended in the process, the storage tank may have to be refilled one or more times per day. Normally, the water has to be transported to the drilling site.

The effectiveness of the control also depends on the experience and skill of the driller, who controls the flow rate manually with a control valve. The driller often must adjust the flow rate based on his visual estimation of the moisture content of the cuttings. Excessive water in the bail air would make the cuttings too heavy to be bailed up the drill hole. Also, cuttings with excessive moisture would plug up the air orifices of the drill bit. The flow-efficiency relationship may have to be determined more than once in a particular mine because it is affected by different drills, different bit sizes, or different types of geologic strata. A flowmeter should be installed at the control valve to aid this determination [Zimmer and Lueck 1986].

In one study [Zimmer and Lueck 1986], for example, control efficiencies for a selected drill varied from 9% at a water flow rate of 0.2 gallon per minute (gpm) to 96% at 1.2 gpm; the greatest increase in control efficiency was in the range of 0.4 to 0.6 gpm. These figures are valid only for the conditions under which the tests were conducted.

Table D-1. Advantages and disadvantages of dry dust collection systems*

Advantages	Disadvantages
Operate at any outside temperature	Expensive to install
Do not require any expendable material (water)	Expensive to maintain
Function well when properly maintained and operated	Require conscious effort by driller to ensure efficiency
	May not be suitable where ground water or coal-bed fires are present

*Adapted from Zimmer and Lueck [1986].

Bit life can be shortened by 50% or more because of the degrading effects of excessive moisture on the bit [BOM 1988]. When outdoor temperatures drop below the freezing point, the system must be heated to alleviate operational problems. Antifreeze compounds may be added to the water to prevent freezing, but this method could be extremely expensive when large volumes of water are used.

The control efficiency of wet dust suppression is similar to that of dry dust collection [Zimmer and Lueck 1986]. Table D-2 summarizes the advantages and disadvantages of wet dust suppression systems. Figure D-1 illustrates a wet dust suppression system.

D.1.3 Enclosed Cab

Drills come in different sizes. Depending on the size, the drills may or may not be equipped with cabs, and the cabs may be partially or totally enclosed. When a totally enclosed cab is available, an effective way to protect the driller working inside the cab is to pressurize it (positive pressure relative to the outside) with outside air drawn through an air filter capable of removing respirable dust. A NIOSH health hazard evaluation [Cornwell and Hanke 1983] reported that the use of a pressurized cab alone (without dry dust collection or wet dust suppression) could afford a respirable dust concentration that was 70% lower than that outside the cab. Subsequent information [Cornwell 1990] revealed that the air filter used for the cab was graded as 99.9% efficient in removing fine test dust as defined by the Society of Automotive Engineers [SAE 1987]. Thus, the control efficiency may be highly dependent on the grade of the air filter.

Air conditioning should be installed in the cab to eliminate the need for opening the cab door or windows in hot weather. When the cab door or windows are open, even the best dust filtration system will not be effective. The air conditioning unit needs to be rugged in construction. Ordinary automotive air-conditioning units are not able to withstand the severe conditions found in the mining

Table D-2. Advantages and disadvantages of wet dust suppression systems[*]

Advantages	Disadvantages
Inexpensive to install	Must be heated in cold temperatures or used with antifreezing additive
Inexpensive to maintain	Require some expertise on behalf of drill operator for proper operation
Function well when properly operated	Require use of expendable material (water)
Not affected by groundwater or bed fires	May cause decreased bit life and drilling efficiency

[*] Adapted from Zimmer and Lueck [1986].

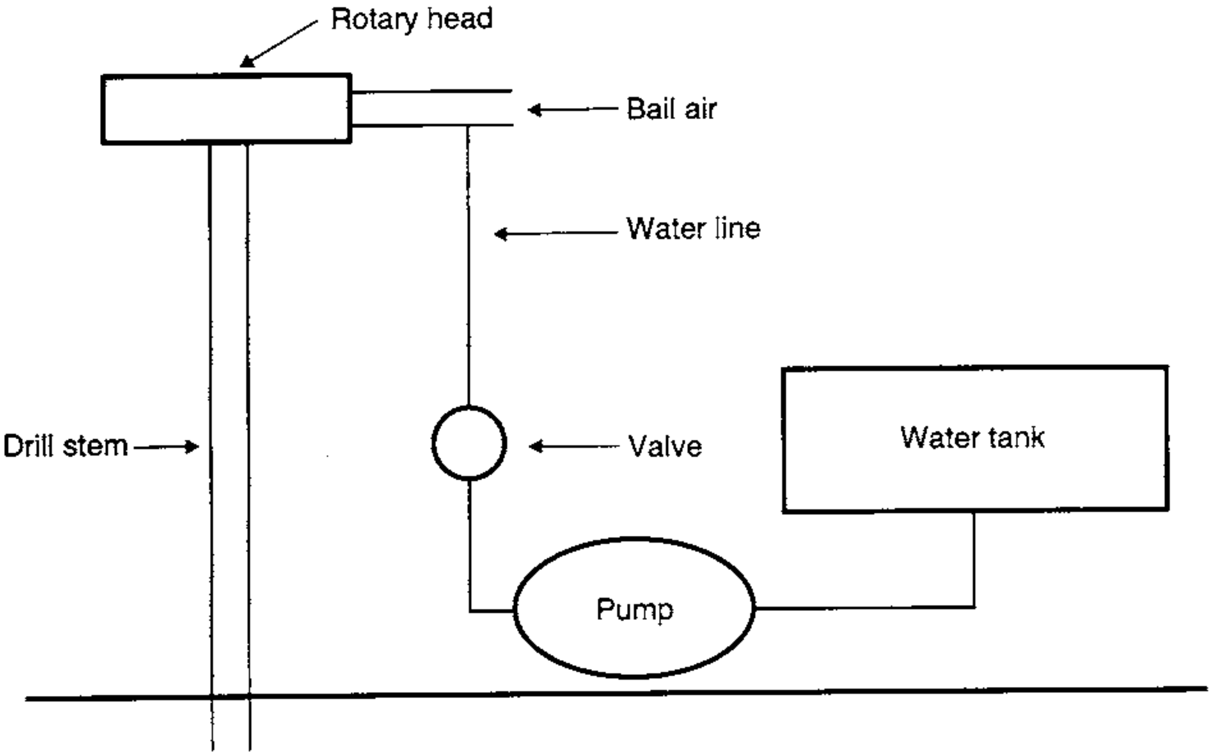

Figure D-1. Wet dust suppression system. (Source: Zimmer and Lueck [1986].)

environment [Volkwein et al. 1979]. Ideally, the air conditioning system should be incorporated into the engine intake system to reduce the number of maintenance items and to insure proper maintenance of both systems [Volkwein et al. 1979].

D.1.4 Improved Control Technology

D.1.4.1 Dust Agglomerator

In a dry dust collection system, the discharge of dust from the dust collector accounts for 40% of the respirable dust emitted [BOM 1989]. The discharged dust can be dispersed by the wind, from impact on the ground, or by equipment driven over dust piles. The dispersed dust poses a potential health hazard not only to the drill crew but also to other miners working in the vicinity. An agglomerator tested by the BOM [1989] offers a solution to these problems. The discharged dust is fed directly into a device that uses gentle water sprays and a spinning motion to coalesce the dust particles into nonrespirable pellets.

D.1.4.2 Water Separation

The moist environment around the drill bit in wet dust suppression has been noted to reduce drill bit life by 50% or more [BOM 1988]. Water separation is a method used to prevent water from reaching the drill bit, thereby prolonging the bit life. In this method, the bail air is guided through one or more sharp turns as it travels down the interior of the drill stem. Because it has a higher inertia than that of air, the water cannot negotiate the turns and thus is separated from the bail air. The dried bail air continues to travel through the drill stem and out of the air orifices of the bit. Under positive pressure, the water is forced out through weep holes into the annular space around the drill stem. Consequently, the drill cuttings are wetted as they are carried upward through this annulus by the bail air below. The BOM [1988] reported that no significant difference in the dust control efficiency was noted between water drilling with and without water separation and that data from one mine showed a greater than 400% increase in average bit life—9,000 ft per bit with water separation versus 1,938 ft per bit without water separation.

D.2 WORK PRACTICES

The selection of a suitable drilling site affects the control efficiency of a dry dust collection system. A drilling site with a flat surface should be selected because this would allow uniform shroud height around the drill. Sometimes the ground surface can be leveled with appropriate equipment.

Where applicable (and coupled with proper maintenance procedures such as replacing worn parts when required), periodic and pre-operational inspections should be made on engineering controls. The following is a checklist of inspection items associated with the different control systems:

- Dry dust collection system
    - Check the integrity of seals and shroud material.

  - — Check fan belts for proper tension and for wear and tear.
  - — Check fan blades for wear and tear.
  - — Check the integrity of dust collector filters.
  - — Check exhaust ductworks for leakage.
- Wet dust suppression system
  - — Check the control valve and the flow meter for proper operation.
  - — Check pipe connections for leakage.
- Pressurized cab
  - — Check the integrity of seals around the door and windows.
  - — Check air filters for dust accumulations.
  - — Check fan belts for proper tension and for wear and tear.

When the drill is operating with a totally enclosed cab, the drill crew should stay inside the cab with the door and windows closed as much as practicable. When work must be done outside the cab, the drill crew members should try to position themselves upwind from dust emissions. The drill crew will drag dust with them into the cab as they enter and exit during the drilling operation. Therefore, good housekeeping is necessary to maintain a relatively dust-free environment inside the cab. Vacuuming is effective but may not be practical at the worksite. Whenever possible, wet wiping is preferred over dry sweeping. If dry sweeping is used, care should be exercised to prevent dispersing the settled dust. Cleaning with compressed air should be avoided.

Where a dry dust collection system is used, the shroud must be raised periodically to let the cuttings spill out of the enclosure. The drill crew should be careful to raise the shroud only enough to clear the cuttings; at the same time, they must keep the shroud height low enough to maintain the dust capture efficiency of the system.

D.3 ENGINEERING CONTROLS AND WORK PRACTICES FOR OTHER OCCUPATIONS

For other surface coal miners who are potentially exposed to respirable crystalline silica and respirable coal mine dust, general industrial hygiene control methods should be applied where they are feasible and appropriate to particular operational conditions. Judicious application of engineering controls (e.g., local exhaust ventilation and enclosures) and work practices (e.g., equipment maintenance and housekeeping) is needed for occupations such as bulldozer operator, shotfirer, pan scraper operator, truck driver, and crusher attendant.

Table D–3. Dust suppressants for controlling particulate emissions from unpaved roads*

Category	Description	Examples
Salts	Hygroscopic compounds that extract moisture from the atmosphere and dampen the road surface	Sodium silicates, calcium chloride, magnesium chloride, hydrated lime
Surfactants	Substances capable of reducing the surface tension of the transport liquid, thereby allowing available moisture to wet more dirt particles per unit volume	Soaps, detergents
Adhesives	Compounds that are mixed with native soils to form a new surface	Sodium lignon sulfonate, ammonium lignon sulfonate, calcium lignon sulfonate, Portland cement
Bitumens	Compounds derived from coal or petroleum and mixed with native soils to form a new surface	Asphalt, oils
Films	Polymers that form discrete layers or membranes	Vinyls, fabrics

*Adapted from Rosbury and Zimmer [1983].

D.4 DUST CONTROL ON UNPAVED ROADS

The application of dust suppressants to unpaved roads in surface mines is generally considered useful in reducing dust emissions and improving driver safety by increasing visibility [Rosbury and Zimmer 1983]. The benefits of reduced dust emissions from treated roads could extend to miners working in the vicinity, and especially to truck drivers, in the form of reduced exposures to respirable crystalline silica and respirable coal mine dust. Table D–3 lists the various types of dust suppressants.

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APPENDIX E

INTERPRETATION OF PULMONARY FUNCTION TESTS: SPIROMETRY

For evaluating the results of spirometric examinations, the largest FVC, the largest FEV_1, and the ratio of the largest FEV_1 to the largest FVC (FEV_1/FVC%) from each worker's pulmonary function examination should each be compared with the lower limit of normal (LLN or 5th percentile [ATS 1991]) derived from the reference equations of Knudson et al. [1983] (Tables E-1, E-2, and E-3 for males and Tables E-4, E-5, and E-6 for females) or the most current equivalent. When previous test results for a worker are available, a physician should also determine whether any significant change in FEV_1 has occurred over a period of time. See Appendix G for the criteria for interpreting longitudinal changes in lung function and for a discussion of technical considerations in the use of spirometry for screening and surveillance programs.

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Table E-1. LLN for FVC for males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	2.89	3.01	3.13	3.25	3.02	2.97	2.92	2.87	2.82	2.77	2.73	2.68	2.38	2.33	2.29	2.25	2.20	2.16	2.12	2.07	2.03	1.98	1.94	1.90	1.85
158	2.94	3.06	3.18	3.29	3.08	3.04	2.99	2.94	2.89	2.84	2.79	2.75	2.44	2.40	2.35	2.31	2.27	2.22	21.8	2.13	2.09	2.05	2.00	1.96	1.92
159	2.99	3.11	3.22	3.34	3.15	3.10	3.06	3.01	2.96	2.91	2.86	2.81	2.50	2.46	2.41	2.37	2.33	2.28	2.24	2.20	2.15	2.11	2.06	2.02	1.98
160	3.04	3.15	3.27	3.39	3.22	3.17	3.12	3.08	3.03	2.98	2.93	2.88	2.56	2.52	2.48	2.43	2.39	2.35	2.30	2.26	2.21	2.17	2.13	2.08	2.04
161	3.08	3.20	3.32	3.44	3.29	3.24	3.19	3.14	3.10	3.05	3.00	2.95	2.63	2.58	2.54	2.50	2.45	2.41	2.36	2.32	2.28	2.23	2.19	2.15	2.10
162	3.13	3.25	3.37	3.48	3.36	3.31	3.26	3.21	3.16	3.12	3.07	3.02	2.69	2.64	2.60	2.56	2.51	2.47	2.43	2.38	2.34	2.29	2.25	2.21	2.16
163	3.18	3.29	3.41	3.53	3.43	3.38	3.33	3.28	3.23	3.18	3.14	3.09	2.75	2.71	2.66	2.62	2.58	2.53	2.49	2.44	2.40	2.36	2.31	2.27	2.23
164	3.22	3.34	3.46	3.58	3.49	3.45	3.40	3.35	3.30	3.25	3.20	3.16	2.81	2.77	2.72	2.68	2.64	2.59	2.55	2.51	2.46	2.42	2.37	2.33	2.29
165	3.27	3.39	3.51	3.62	3.56	3.51	3.47	3.42	3.37	3.32	3.27	3.22	2.87	2.83	2.79	2.74	2.70	2.66	2.61	2.57	2.52	2.48	2.44	2.39	2.35
166	3.32	3.44	3.55	3.67	3.63	3.58	3.53	3.49	3.44	3.39	3.34	3.29	2.94	2.89	2.85	2.80	2.76	2.72	2.67	2.63	2.59	2.54	2.50	2.45	2.41
167	3.36	3.48	3.60	3.72	3.70	3.65	3.60	3.55	3.51	3.46	3.41	3.36	3.00	2.95	2.91	2.87	2.82	2.78	2.74	2.69	2.65	2.60	2.56	2.52	2.47
168	3.41	3.53	3.65	3.77	3.77	3.72	3.67	3.62	3.57	3.53	3.48	3.43	3.06	3.02	2.97	2.93	2.88	2.84	2.80	2.75	2.71	2.67	2.62	2.58	2.53
169	3.46	3.58	3.69	3.81	3.84	3.79	3.74	3.69	3.64	3.59	3.55	3.50	3.12	3.08	3.03	2.99	2.95	2.90	2.86	2.82	2.77	2.73	2.68	2.64	2.60
170	3.51	3.62	3.74	3.86	3.90	3.86	3.81	3.76	3.71	3.66	3.61	3.57	3.18	3.14	3.10	3.05	3.01	2.97	2.92	2.88	2.83	2.79	2.75	2.70	2.66
171	3.55	3.67	3.79	3.91	3.97	3.93	3.88	3.83	3.78	3.73	3.68	3.64	3.25	3.20	3.16	3.11	3.07	3.03	2.98	2.94	2.90	2.85	2.81	2.76	2.72
172	3.60	3.72	3.84	3.95	4.04	3.99	3.95	3.90	3.85	3.80	3.75	3.70	3.31	3.26	3.22	3.18	3.13	3.09	3.05	3.00	2.96	2.91	2.87	2.83	2.78
173	3.65	3.77	3.88	4.00	4.11	4.06	4.01	3.97	3.92	3.87	3.82	3.77	3.37	3.33	3.28	3.24	3.19	3.15	3.11	3.06	3.02	2.98	2.93	2.89	2.84
174	3.69	3.81	3.93	4.05	4.18	4.13	4.08	4.03	3.99	3.94	3.89	3.84	3.43	3.39	3.34	3.30	3.26	3.21	3.17	3.13	3.08	3.04	2.99	2.95	2.91
175	3.74	3.86	3.98	4.10	4.25	4.20	4.15	4.10	4.05	4.01	3.96	3.91	3.49	3.45	3.41	3.36	3.32	3.27	3.23	3.19	3.14	3.10	3.06	3.01	2.97
176	3.79	3.91	4.02	4.14	4.32	4.27	4.22	4.17	4.12	4.07	4.03	3.98	3.56	3.51	3.47	3.42	3.38	3.34	3.29	3.25	3.21	3.16	3.12	3.07	3.03
177	3.84	3.95	4.07	4.19	4.38	4.34	4.29	4.24	4.19	4.14	4.09	4.05	3.62	3.57	3.53	3.49	3.44	3.40	3.35	3.31	3.27	3.22	3.18	3.14	3.09

(Continued)

Table E-1 (Continued). LLN for FVC for males

Height	Age																								
(cm)	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	3.88	4.00	4.12	4.24	4.45	4.40	4.36	4.31	4.26	4.21	4.16	4.11	3.68	3.64	3.59	3.55	3.50	3.46	3.42	3.37	3.33	3.29	3.24	3.20	3.15
179	3.93	4.05	4.17	4.28	4.52	4.47	4.42	4.38	4.33	4.28	4.23	4.18	3.74	3.70	3.65	3.61	3.57	3.52	3.48	3.44	3.39	3.35	3.30	3.26	3.22
180	3.98	4.09	4.21	4.33	4.59	4.54	4.49	4.44	4.40	4.35	4.30	4.25	3.80	3.76	3.72	3.67	3.63	3.58	3.54	3.50	3.45	3.41	3.37	3.32	3.28
181	4.02	4.14	4.26	4.38	4.66	4.61	4.56	4.51	4.46	4.42	4.37	4.32	3.87	3.82	3.78	3.73	3.69	3.65	3.60	3.56	3.52	3.47	3.43	3.38	3.34
182	4.07	4.19	4.31	4.42	4.73	4.68	4.63	4.58	4.53	4.48	4.44	4.39	3.93	3.88	3.84	3.80	3.75	3.71	3.66	3.62	3.58	3.53	3.49	3.45	3.40
183	4.12	4.24	4.35	4.47	4.79	4.75	4.70	4.65	4.60	4.55	4.50	4.46	3.99	3.95	3.90	3.86	3.81	3.77	3.73	3.68	3.64	3.60	3.55	3.51	3.46
184	4.17	4.28	4.40	4.52	4.86	4.81	4.77	4.72	4.67	4.62	4.57	4.52	4.05	4.01	3.96	3.92	3.88	3.83	3.79	3.74	3.70	3.66	3.61	3.57	3.53
185	4.21	4.33	4.45	4.57	4.93	4.88	4.84	4.79	4.74	4.69	4.64	4.59	4.11	4.07	4.03	3.98	3.94	3.89	3.85	3.81	3.76	3.72	3.68	3.63	3.59
186	4.26	4.38	4.50	4.61	5.00	4.95	4.90	4.86	4.81	4.76	4.71	4.66	4.17	4.13	4.09	4.04	4.00	3.96	3.91	3.87	3.83	3.78	3.74	3.69	3.65
187	4.31	4.42	4.54	4.66	5.07	5.02	4.97	4.92	4.88	4.83	4.78	4.73	4.24	4.19	4.15	4.11	4.06	4.02	3.97	3.93	3.89	3.84	3.80	3.76	3.71
188	4.35	4.47	4.59	4.71	5.14	5.09	5.04	4.99	4.94	4.90	4.85	4.80	4.30	4.26	4.21	4.17	4.12	4.08	4.04	3.99	3.95	3.91	3.86	3.82	3.77
189	4.40	4.52	4.64	4.75	5.21	5.16	5.11	5.06	5.01	4.96	4.92	4.87	4.36	4.32	4.27	4.23	4.19	4.14	4.10	4.05	4.01	3.97	3.92	3.88	3.84
190	4.45	4.57	4.68	4.80	5.27	5.23	5.18	5.13	5.08	5.03	4.98	4.94	4.42	4.38	4.34	4.29	4.25	4.20	4.16	4.12	4.07	4.03	3.99	3.94	3.90
191	4.49	4.61	4.73	4.85	5.34	5.29	5.25	5.20	5.15	5.10	5.05	5.00	4.48	4.44	4.40	4.35	4.31	4.27	4.22	4.18	4.13	4.09	4.05	4.00	3.96
192	4.54	4.66	4.78	4.90	5.41	5.36	5.31	5.27	5.22	5.17	5.12	5.07	4.55	4.50	4.46	4.42	4.37	4.33	4.28	4.24	4.20	4.15	4.11	4.07	4.02
193	4.59	4.71	4.82	4.94	5.48	5.43	5.38	5.33	5.29	5.24	5.19	5.14	4.61	4.56	4.52	4.48	4.43	4.39	4.35	4.30	4.26	4.21	4.17	4.13	4.08

Table E–2. LLN for FEV_1 for males

Height	Age																								
(cm)	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	2.52	2.62	2.73	2.83	2.52	2.48	2.43	2.38	2.34	2.29	2.25	2.20	2.10	2.06	2.01	1.97	1.92	1.88	1.83	1.79	1.74	1.70	1.65	1.61	1.56
158	2.56	2.67	2.77	2.87	2.58	2.53	2.48	2.44	2.39	2.34	2.30	2.25	2.15	2.11	2.06	2.02	1.97	1.93	1.88	1.84	1.79	1.75	1.70	1.66	1.61
159	2.61	2.71	2.81	2.92	2.63	2.58	2.54	2.49	2.44	2.40	2.35	2.30	2.20	2.16	2.11	2.07	2.02	1.98	1.93	1.89	1.84	1.80	1.75	1.71	1.66
160	2.65	2.75	2.85	2.96	2.68	2.63	2.59	2.54	2.50	2.45	2.40	2.36	2.26	2.21	2.17	2.12	2.08	2.03	1.98	1.94	1.89	1.85	1.80	1.76	1.71
161	2.69	2.79	2.90	3.00	2.73	2.69	2.64	2.59	2.55	2.50	2.46	2.41	2.31	2.26	2.22	2.17	2.13	2.08	2.04	1.99	1.95	1.90	1.86	1.81	1.77
162	2.73	2.84	2.94	3.04	2.79	2.74	2.69	2.65	2.60	2.55	2.51	2.46	2.36	2.31	2.27	2.22	2.18	2.13	2.09	2.04	2.00	1.95	1.91	1.86	1.82
163	2.77	2.88	2.98	3.08	2.84	2.79	2.75	2.70	2.65	2.61	2.56	2.52	2.41	2.36	2.32	2.27	2.23	2.18	2.14	2.09	2.05	2.00	1.96	1.91	1.87
164	2.82	2.92	3.02	3.13	2.89	2.84	2.80	2.75	2.71	2.66	2.61	2.57	2.46	2.42	2.37	2.33	2.28	2.24	2.19	2.15	2.10	2.06	2.01	1.96	1.92
165	2.86	2.96	3.07	3.17	2.94	2.90	2.85	2.81	2.76	2.71	2.67	2.62	2.51	2.47	2.42	2.38	2.33	2.29	2.24	2.20	2.15	2.11	2.06	2.02	1.97
166	2.90	3.00	3.11	3.21	3.00	2.95	2.90	2.86	2.81	2.77	2.72	2.67	2.56	2.52	2.47	2.43	2.38	2.34	2.29	2.25	2.20	2.16	2.11	2.07	2.02
167	2.94	3.05	3.15	3.25	3.05	3.00	2.96	2.91	2.86	2.82	2.77	2.73	2.61	2.57	2.52	2.48	2.43	2.39	2.34	2.30	2.25	2.21	2.16	2.12	2.07
168	2.99	3.09	3.19	3.29	3.10	3.06	3.01	2.96	2.92	2.87	2.82	2.78	2.67	2.62	2.58	2.53	2.49	2.44	2.40	2.35	2.31	2.26	2.22	2.17	2.13
169	3.03	3.13	3.23	3.34	3.15	3.11	3.06	3.02	2.97	2.92	2.88	2.83	2.72	2.67	2.63	2.58	2.54	2.49	2.45	2.40	2.36	2.31	2.27	2.22	2.18
170	3.07	3.17	3.28	3.38	3.21	3.16	3.11	3.07	3.02	2.98	2.93	2.88	2.77	2.72	2.68	2.63	2.59	2.54	2.50	2.45	2.41	2.36	2.32	2.27	2.23
171	3.11	3.21	3.32	3.42	3.26	3.21	3.17	3.12	3.07	3.03	2.98	2.94	2.82	2.78	2.73	2.68	2.64	2.59	2.55	2.50	2.46	2.41	2.37	2.32	2.28
172	3.15	3.26	3.36	3.46	3.31	3.27	3.22	3.17	3.13	3.08	3.03	2.99	2.87	2.83	2.78	2.74	2.69	2.65	2.60	2.56	2.51	2.47	2.42	2.38	2.33
173	3.20	3.30	3.40	3.51	3.36	3.32	3.27	3.23	3.18	3.13	3.09	3.04	2.92	2.88	2.83	2.79	2.74	2.70	2.65	2.61	2.56	2.52	2.47	2.43	2.38
174	3.24	3.34	3.44	3.55	3.42	3.37	3.32	3.28	3.23	3.19	3.14	3.09	2.97	2.93	2.88	2.84	2.79	2.75	2.70	2.66	2.61	2.57	2.52	2.48	2.43
175	3.28	3.38	3.49	3.59	3.47	3.42	3.38	3.33	3.28	3.24	3.19	3.15	3.03	2.98	2.94	2.89	2.85	2.80	2.76	2.71	2.66	2.62	2.57	2.53	2.48
176	3.32	3.43	3.53	3.63	3.52	3.48	3.43	3.38	3.34	3.29	3.25	3.20	3.08	3.03	2.99	2.94	2.90	2.85	2.81	2.76	2.72	2.67	2.63	2.58	2.54
177	3.36	3.47	3.57	3.67	3.57	3.53	3.48	3.44	3.39	3.34	3.30	3.25	3.13	3.08	3.04	2.99	2.95	2.90	2.86	2.81	2.77	2.72	2.68	2.63	2.59

(Continued)

Table E-2 (Continued). LLN for FEV_1 for males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	3.41	3.51	3.61	3.72	3.63	3.58	3.54	3.49	3.44	3.40	3.35	3.30	3.18	3.13	3.09	3.04	3.00	2.95	2.91	2.86	2.82	2.77	2.73	2.68	2.64
179	3.45	3.55	3.66	3.76	3.68	3.63	3.59	3.54	3.50	3.45	3.40	3.36	3.23	3.19	3.14	3.10	3.05	3.01	2.96	2.92	2.87	2.83	2.78	2.73	2.69
180	3.49	3.59	3.70	3.80	3.73	3.69	3.64	3.59	3.55	3.50	3.46	3.41	3.28	3.24	3.19	3.15	3.10	3.06	3.01	2.97	2.92	2.88	2.83	2.79	2.74
181	3.53	3.64	3.74	3.84	3.79	3.74	3.69	3.65	3.60	3.55	3.51	3.46	3.33	3.29	3.24	3.20	3.15	3.11	3.06	3.02	2.97	2.93	2.88	2.84	2.79
182	3.58	3.68	3.78	3.88	3.84	3.79	3.75	3.70	3.65	3.61	3.56	3.51	3.38	3.34	3.29	3.25	3.20	3.16	3.11	3.07	3.02	2.98	2.93	2.89	2.84
183	3.62	3.72	3.82	3.93	3.89	3.84	3.80	3.75	3.71	3.66	3.61	3.57	3.44	3.39	3.35	3.30	3.26	3.21	3.17	3.12	3.08	3.03	2.99	2.94	2.90
184	3.66	3.76	3.87	3.97	3.94	3.90	3.85	3.80	3.76	3.71	3.67	3.62	3.49	3.44	3.40	3.35	3.31	3.26	3.22	3.17	3.13	3.08	3.04	2.99	2.95
185	3.70	3.80	3.91	4.01	4.00	3.95	3.90	3.86	3.81	3.76	3.72	3.67	3.54	3.49	3.45	3.40	3.36	3.31	3.27	3.22	3.18	3.13	3.09	3.04	3.00
186	3.74	3.85	3.95	4.05	4.05	4.00	3.96	3.91	3.86	3.82	3.77	3.72	3.59	3.55	3.50	3.46	3.41	3.36	3.32	3.27	3.23	3.18	3.14	3.09	3.05
187	3.79	3.89	3.99	4.10	4.10	4.05	4.01	3.96	3.92	3.87	3.82	3.78	3.64	3.60	3.55	3.51	3.46	3.42	3.37	3.33	3.28	3.24	3.19	3.15	3.10
188	3.83	3.93	4.03	4.14	4.15	4.11	4.06	4.01	3.97	3.92	3.88	3.83	3.69	3.65	3.60	3.56	3.51	3.47	3.42	3.38	3.33	3.29	3.24	3.20	3.15
189	3.87	3.97	4.08	4.18	4.21	4.16	4.11	4.07	4.02	3.98	3.93	3.88	3.74	3.70	3.65	3.61	3.56	3.52	3.47	3.43	3.38	3.34	3.29	3.25	3.20
190	3.91	4.02	4.12	4.22	4.26	4.21	4.17	4.12	4.07	4.03	3.98	3.94	3.80	3.75	3.71	3.66	3.62	3.57	3.53	3.48	3.43	3.39	3.34	3.30	3.25
191	3.95	4.06	4.16	4.26	4.31	4.27	4.22	4.17	4.13	4.08	4.03	3.99	3.85	3.80	3.76	3.71	3.67	3.62	3.58	3.53	3.49	3.44	3.40	3.35	3.31
192	4.00	4.10	4.20	4.31	4.36	4.32	4.27	4.23	4.18	4.13	4.09	4.04	3.90	3.85	3.81	3.76	3.72	3.67	3.63	3.58	3.54	3.49	3.45	3.40	3.36
193	4.04	4.14	4.25	4.35	4.42	4.37	4.32	4.38	4.23	4.19	4.14	4.09	3.95	3.90	3.86	3.81	3.77	3.72	3.68	3.63	3.59	3.54	3.50	3.45	3.41

Table E-3. LLN for FEV_1/FVC% for males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	74.5	74.5	74.5	74.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
158	74.4	74.4	74.4	74.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
159	74.3	74.3	74.3	74.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
160	74.3	74.3	74.3	74.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
161	74.2	74.2	74.2	74.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
162	74.1	74.1	74.1	74.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
163	74.1	74.1	74.1	74.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
164	74.0	74.0	74.0	74.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
165	73.9	73.9	73.9	73.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
166	73.9	73.9	73.9	73.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
167	73.8	73.8	73.8	73.8	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
168	73.7	73.7	73.7	73.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
169	73.6	73.6	73.6	73.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
170	73.6	73.6	73.6	73.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
171	73.5	73.5	73.5	73.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
172	73.4	73.4	73.4	73.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
173	73.4	73.4	73.4	73.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
174	73.3	73.3	73.3	73.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
175	73.2	73.2	73.2	73.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
176	73.2	73.2	73.2	73.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
177	73.1	73.1	73.1	73.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3

(Continued)

Table E–3 (Continued). LLN for FEV_1/FVC% for males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	73.0	73.0	73.0	73.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
179	73.0	73.0	73.0	73.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
180	72.9	72.9	72.9	72.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
181	72.8	72.8	72.8	72.8	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
182	72.7	72.7	72.7	72.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
183	72.7	72.7	72.7	72.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
184	72.6	72.6	72.6	72.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
185	72.5	72.5	72.5	72.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
186	72.5	72.5	72.5	72.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
187	72.4	72.4	72.4	72.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
188	72.3	72.3	72.3	72.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
189	72.3	72.3	72.3	72.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
190	72.2	72.2	72.2	72.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
191	72.1	72.1	72.1	72.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
192	72.1	72.1	72.1	72.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
193	72.0	72.0	72.0	72.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3

Table E–4. LLN for FVC for females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
148	2.17	2.27	2.32	2.29	2.27	2.24	2.21	2.19	2.16	2.14	2.11	2.08	2.01	1.99	1.96	1.94	1.91	1.89	1.86	1.84	1.81	1.78	1.76	1.73	1.71
149	2.20	2.30	2.35	2.33	2.30	2.27	2.25	2.22	2.20	2.17	2.14	2.12	2.05	2.02	2.00	1.97	1.94	1.92	1.89	1.87	1.84	1.82	1.79	1.77	1.74
150	2.23	2.33	2.39	2.36	2.33	2.31	2.28	2.26	2.23	2.20	2.18	2.15	2.08	2.05	2.03	2.00	1.98	1.95	1.93	1.90	1.88	1.85	1.83	1.80	1.77
151	2.26	2.36	2.42	2.40	2.37	2.34	2.32	2.29	2.27	2.24	2.21	2.19	2.11	2.09	2.06	2.04	2.01	1.99	1.96	1.94	1.91	1.88	1.86	1.83	1.81
152	2.29	2.40	2.46	2.43	2.40	2.38	2.35	2.33	2.30	2.27	2.25	2.22	2.15	2.12	2.10	2.07	2.04	2.02	1.99	1.97	1.94	1.92	1.89	1.87	1.84
153	2.32	2.43	2.49	2.46	2.44	2.41	2.39	2.36	2.33	2.31	2.28	2.26	2.18	2.15	2.13	2.10	2.08	2.05	2.03	2.00	1.98	1.95	1.93	1.90	1.88
154	2.35	2.46	2.52	2.50	2.47	2.45	2.42	2.39	2.37	2.34	2.32	2.29	2.21	2.19	2.16	2.14	2.11	2.09	2.06	2.04	2.01	1.98	1.96	1.93	1.91
155	2.38	2.49	2.56	2.53	2.51	2.48	2.45	2.43	2.40	2.38	2.35	2.32	2.25	2.22	2.20	2.17	2.15	2.12	2.09	2.07	2.04	2.02	1.99	1.97	1.94
156	2.41	2.52	2.59	2.57	2.54	2.51	2.49	2.46	2.44	2.41	2.38	2.36	2.28	2.25	2.23	2.20	2.18	2.15	2.13	2.10	2.08	2.05	2.03	2.00	1.98
157	2.45	2.55	2.63	2.60	2.57	2.55	2.52	2.50	2.47	2.44	2.42	2.39	2.31	2.29	2.26	2.24	2.21	2.19	2.16	2.14	2.11	2.08	2.06	2.03	2.01
158	2.48	2.58	2.66	2.63	2.61	2.58	2.56	2.53	2.50	2.48	2.45	2.43	2.35	2.32	2.30	2.27	2.25	2.22	2.19	2.17	2.14	2.12	2.09	2.07	2.04
159	2.51	2.61	2.69	2.67	2.64	2.62	2.59	2.56	2.54	2.51	2.49	2.46	2.38	2.35	2.33	2.30	2.28	2.25	2.23	2.20	2.18	2.15	2.13	2.10	2.08
160	2.54	2.64	2.73	2.70	2.68	2.65	2.62	2.60	2.57	2.55	2.52	2.49	2.41	2.39	2.36	2.34	2.31	2.29	2.26	2.24	2.21	2.18	2.16	2.13	2.11
161	2.57	2.68	2.76	2.74	2.71	2.68	2.66	2.63	2.61	2.58	2.55	2.53	2.45	2.42	2.40	2.37	2.35	2.32	2.29	2.27	2.24	2.22	2.19	2.17	2.14
162	2.60	2.71	2.80	2.77	2.74	2.72	2.69	2.67	2.64	2.61	2.59	2.56	2.48	2.46	2.43	2.40	2.38	2.35	2.33	2.30	2.28	2.25	2.23	2.20	2.18
163	2.63	2.74	2.83	2.80	2.78	2.75	2.73	2.70	2.67	2.65	2.62	2.60	2.51	2.49	2.46	2.44	2.41	2.39	2.36	2.34	2.31	2.29	2.26	2.23	2.21
164	2.66	2.77	2.86	2.84	2.81	2.79	2.76	2.73	2.71	2.68	2.66	2.63	2.55	2.52	2.50	2.47	2.45	2.42	2.39	2.37	2.34	2.32	2.29	2.27	2.24
165	2.70	2.80	2.90	2.87	2.85	2.82	2.80	2.77	2.74	2.72	2.69	2.67	2.58	2.56	2.53	2.50	2.48	2.45	2.43	2.40	2.38	2.35	2.33	2.30	2.28
166	2.73	2.83	2.93	2.91	2.88	2.86	2.83	2.80	2.78	2.75	2.73	2.70	2.61	2.59	2.56	2.54	2.51	2.49	2.46	2.44	2.41	2.39	2.36	2.33	2.31
167	2.76	2.86	2.97	2.94	2.92	2.89	2.86	2.84	2.81	2.79	2.76	2.73	2.65	2.62	2.60	2.57	2.55	2.52	2.49	2.47	2.44	2.42	2.39	2.37	2.34
168	2.79	2.89	3.00	2.98	2.95	2.92	2.90	2.87	2.85	2.82	2.79	2.77	2.68	2.66	2.63	2.60	2.58	2.55	2.53	2.50	2.48	2.45	2.43	2.40	2.38

(Continued)

Table E–4 (Continued). LLN for FVC for females

Height	Age																								
(cm)	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	2.82	2.92	3.04	3.01	2.98	2.96	2.93	2.91	2.88	2.85	2.83	2.80	2.71	2.69	2.66	2.64	2.61	2.59	2.56	2.54	2.51	2.49	2.46	2.43	2.41
170	2.85	2.96	3.07	3.04	3.02	2.99	2.97	2.94	2.91	2.89	2.86	2.84	2.75	2.72	2.70	2.67	2.65	2.62	2.60	2.56	2.54	2.52	2.49	2.47	2.44
171	2.88	2.99	3.10	3.08	3.05	3.03	3.00	2.97	2.95	2.92	2.90	2.87	2.78	2.76	2.73	2.70	2.68	2.65	2.63	2.60	2.58	2.55	2.53	2.50	2.48
172	2.91	3.02	3.14	3.11	3.09	3.06	3.03	3.01	2.98	2.96	2.93	2.90	2.81	2.79	2.76	2.74	2.71	2.69	2.66	2.64	2.61	2.59	2.56	2.53	2.51
173	2.94	3.05	3.17	3.15	3.12	3.09	3.07	3.04	3.02	2.99	2.96	2.94	2.85	2.82	2.80	2.77	2.75	2.72	2.70	2.67	2.64	2.62	2.59	2.57	2.54
174	2.98	3.08	3.21	3.18	3.15	3.13	3.10	3.08	3.05	3.02	3.00	2.97	2.88	2.86	2.83	2.80	2.78	2.75	2.73	2.70	2.68	2.65	2.63	2.60	2.58
175	3.01	3.11	3.24	3.21	3.19	3.16	3.14	3.11	3.08	3.06	3.03	3.01	2.91	2.89	2.86	2.84	2.81	2.79	2.76	2.74	2.71	2.69	2.66	2.63	2.61
176	3.04	3.14	3.27	3.25	3.22	3.20	3.17	3.14	3.12	3.09	3.07	3.04	2.95	2.92	2.90	2.87	2.85	2.82	2.80	2.77	2.74	2.72	2.69	2.67	2.64
177	3.07	3.17	3.31	3.28	3.26	3.23	3.20	3.18	3.15	3.13	3.10	3.07	2.98	2.96	2.93	2.91	2.88	2.85	2.83	2.80	2.78	2.75	2.73	2.70	2.68
178	3.10	3.21	3.34	3.32	3.29	3.26	3.24	3.21	3.19	3.16	3.13	3.11	3.01	2.99	2.96	2.94	2.91	2.89	2.86	2.84	2.81	2.79	2.76	2.74	2.71
179	3.13	3.24	3.38	3.35	3.33	3.30	3.27	3.25	3.22	3.20	3.17	3.14	3.05	3.02	3.00	2.97	2.95	2.92	2.90	2.87	2.84	2.82	2.79	2.77	2.74
180	3.16	3.27	3.41	3.39	3.36	3.33	3.31	3.28	3.26	3.23	3.20	3.18	3.08	3.06	3.03	3.01	2.98	2.95	2.93	2.90	2.88	2.85	2.83	2.80	2.78
181	3.19	3.30	3.45	3.42	3.39	3.37	3.34	3.32	3.29	3.26	3.24	3.21	3.11	3.09	3.06	3.04	3.01	2.99	2.96	2.94	2.91	2.89	2.86	2.84	2.81
182	3.23	3.33	3.48	3.45	3.43	3.40	3.38	3.35	3.32	3.30	3.27	3.25	3.15	3.12	3.10	3.07	3.05	3.02	3.00	2.97	2.94	2.92	2.89	2.87	2.84
183	3.26	3.36	3.51	3.49	3.46	3.44	3.41	3.38	3.36	3.33	3.31	3.28	3.18	3.16	3.13	3.11	3.08	3.05	3.03	3.00	2.98	2.95	2.93	2.90	2.88
184	3.29	3.39	3.55	3.52	3.50	3.47	3.44	3.42	3.39	3.37	3.34	3.31	3.22	3.19	3.16	3.14	3.11	3.09	3.06	3.04	3.01	2.99	2.96	2.94	2.91

Table E-5. LLN for FEV_1 for females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
148	2.13	2.25	2.09	2.06	2.03	2.00	1.97	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65	1.62	1.59	1.56	1.53	1.50	1.47	1.44
149	2.16	2.27	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.68	1.65	1.62	1.59	1.56	1.53	1.50	1.47
150	2.19	2.30	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.67	1.64	1.61	1.58	1.55	1.52	1.49
151	2.22	2.33	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.85	1.82	1.79	1.76	1.73	1.70	1.67	1.64	1.61	1.58	1.55	1.52
152	2.25	2.36	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75	1.72	1.69	1.66	1.63	1.60	1.58	1.55
153	2.28	2.39	2.22	2.19	2.16	2.13	2.10	2.07	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75	1.72	1.69	1.66	1.63	1.60	1.57
154	2.30	2.42	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.75	1.72	1.69	1.66	1.63	1.60
155	2.33	2.45	2.27	2.24	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65	1.62
156	2.36	2.48	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65
157	2.39	2.50	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.67
158	2.42	2.53	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70
159	2.45	2.56	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.82	1.79	1.76	1.73
160	2.48	2.59	2.40	2.37	2.34	2.31	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75
161	2.51	2.62	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78
162	2.53	2.65	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80
163	2.56	2.68	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83
164	2.59	2.70	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.86
165	2.62	2.73	2.53	2.50	2.47	2.44	2.41	2.38	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88
166	2.65	2.76	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.09	2.06	2.03	2.00	1.97	1.94	1.91
167	2.68	2.79	2.58	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93
168	2.71	2.82	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96

(Continued)

Table E-5 (Continued). LLN for FEV_1 for females

Height	Age																								
(cm)	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	2.73	2.85	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.99
170	2.76	2.88	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01
171	2.79	2.91	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	3.18	2.16	2.13	2.10	2.07	2.04
172	2.82	2.93	2.71	2.68	2.65	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06
173	2.85	2.96	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09
174	2.88	2.99	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11
175	2.91	3.02	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14
176	2.94	3.05	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.20	2.17
177	2.96	3.08	2.84	2.81	2.78	2.75	2.72	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19
178	2.99	3.11	2.87	2.84	2.81	2.78	2.75	2.72	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22
179	3.02	3.14	2.90	2.87	2.84	2.81	2.78	2.75	2.72	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24
180	3.05	3.16	2.92	2.89	2.86	2.83	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27
181	3.08	3.19	2.95	2.92	2.89	2.86	2.83	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.33	2.30
182	3.11	3.22	2.97	2.94	2.91	2.88	2.85	2.82	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32
183	3.14	3.25	3.00	2.97	2.94	2.91	2.88	2.85	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.50	2.47	2.44	2.41	2.38	2.35
184	3.17	3.28	3.02	2.99	2.97	2.94	2.91	2.88	2.85	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37

Table E-6. LLN for FEV_1/FVC % for females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
148	74.8	75.9	77.5	77.2	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.2	73.9	73.6	73.3	72.9	72.6	72.3	72.0	71.6	71.3	71.0	70.7	70.3
149	74.7	75.8	77.3	77.0	76.7	76.4	76.0	75.7	75.4	75.1	74.7	74.4	74.1	73.8	73.4	73.1	72.8	72.5	72.1	71.8	71.5	71.2	70.8	70.5	70.2
150	74.5	75.6	77.2	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.3	70.0
151	74.4	75.5	77.0	76.7	76.4	76.1	75.7	75.4	75.1	74.7	74.4	74.1	73.8	73.4	73.1	72.8	72.5	72.1	71.8	71.5	71.2	70.8	70.5	70.2	69.9
152	74.2	75.3	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7
153	74.1	75.1	76.7	76.4	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.8	70.5	70.2	69.9	69.5
154	73.9	75.0	76.6	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7	69.4
155	73.8	74.8	76.4	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2
156	73.6	74.7	76.2	75.9	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7	69.4	69.1
157	73.5	74.5	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2	68.9
158	73.3	74.4	75.9	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.7
159	73.2	74.2	75.8	75.4	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2	68.9	68.6
160	73.0	74.1	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4
161	72.8	73.9	75.4	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.2	68.9	68.6	68.3
162	72.7	73.8	75.3	75.0	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4	68.1
163	72.5	73.6	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0
164	72.4	73.5	75.0	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4	68.1	67.8
165	72.2	73.3	74.8	74.5	74.2	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0	67.6
166	72.1	73.1	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5
167	71.9	73.0	74.5	74.2	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0	67.6	67.3
168	71.8	72.8	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5	67.2

(Continued)

Table E–6 (Continued). LLN for $FEV_1/FVC\%$ for females

Height (cm)	Age 17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	71.6	72.7	74.2	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0
170	71.5	72.5	74.0	73.7	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5	67.2	66.8
171	71.3	72.4	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0	66.7
172	71.2	72.2	73.7	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.8	66.5
173	71.0	72.1	73.5	73.2	72.9	72.6	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0	66.7	66.4
174	70.8	71.9	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2
175	70.7	71.8	73.2	72.9	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.3	67.0	66.7	66.4	66.0
176	70.5	71.6	73.1	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2	65.9
177	70.4	71.5	72.9	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7
178	70.2	71.3	72.7	72.4	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2	65.9	65.6
179	70.1	71.2	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7	65.4
180	69.9	71.0	72.4	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.2
181	69.8	70.8	72.3	71.9	71.6	71.3	71.0	70.6	70.3	70.0	69.7	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7	65.4	65.1
182	69.6	70.7	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.3	64.9
183	69.5	70.5	71.9	71.6	71.3	71.0	70.6	70.3	70.0	69.7	69.3	69.0	68.7	68.4	68.0	67.7	67.4	67.1	66.7	66.4	66.1	65.7	65.4	65.1	64.8
184	69.3	70.4	71.8	71.5	71.1	70.8	70.5	70.2	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.3	64.9	64.6

APPENDIX F

NIOSH OCCUPATIONAL HISTORY QUESTIONNAIRE FROM THE COAL WORKERS' X-RAY SURVEILLANCE PROGRAM

DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL AND PREVENTION
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
MINER IDENTIFICATION DOCUMENT

FOR ALOSH USE ONLY

RETURN TO

RECEIVING CENTER
APPALACHIAN LABORATORY FOR
OCCUPATIONAL SAFETY AND HEALTH
BOX 4258
MORGANTOWN, WEST VIRGINIA 26505

ASSURANCE OF CONFIDENTIALITY

The U.S. Public Health Service hereby gives assurance that your identity and your relationship to any information obtained by reason of your participation in the Periodic Medical Examination Program will be kept confidential in accordance with Public Health Services (42 CFR Part 1)

Your social security number is required by Public Health Service REGULATIONS (42 CFR Part 37). It will be used for identification purposes only and not be released except as required by law without your written consent.

PLEASE PRINT OR TYPE ALL RESPONSES

X-RAY FACILITY NAME

NIOSH FACILITY CERTIFICATION NO.

DATE OF X-RAY EXAMINATION

TYPE OF X-RAY (Please check one)
Preemployment ☐ Mandatory (newly hired miners) ☐ Voluntary every (3-1/2 - 4-1/2 years) ☐

MINER'S NAME (Please Print) Last First MI

SOCIAL SECURITY NUMBER ☐☐☐ ☐☐ ☐☐☐☐

MAILING ADDRESS STREET CITY COUNTY STATE ZIP CODE

SEX M / F

TELEPHONE # ☐☐☐ ☐☐☐ ☐☐☐☐

AGE

Date of Birth (M-D-Y)

RACE ETHNIC CODE (Please check one)
1.☐ American Indian or Alaskan Native
2.☐ Asian or Pacific Islander
3.☐ Black, not Hispanic origin
4.☐ Hispanic
5.☐ White, not Hispanic origin

EMPLOYER'S NAME

EMPLOYER'S ADDRESS STREET / PO BOX CITY STATE ZIP CODE

MINE NAME

MSHA MINE IDENTIFICATION NO.

EMPLOYER IS: (Please check one)
☐ Mine Operator ☐ Construction Contractor

MSHA CONTRACTOR ID NO.

OCCUPATIONAL HISTORY

UNDERGROUND COAL MINE

Do you now or have you ever worked at an UNDERGROUND coal mine? Yes_____No_____
If yes, list title for any job you have held for more than one (1) year in an UNDERGROUND coal mine.
(Site: S = Surface LF = Longwall Face CMF = Continuous Mine Face CvMF = Conventional Mine Face
UNF = Underground Non Face O = Other)

Please use correct job titles as assigned by Mine Safety and Health Administration.
Job title list available at X-ray facility.

JOB TITLE	JOB SITE						APPROXIMATE YEARS	
	S	LF	CMF	CvMF	UNF	O	FROM 19__	TO 19__
EXAMPLE: *Continuous Miner Operator*			*X*				*1971*	*1975*

If you need additional space for job titles, please use the bottom section of the back of this form

CDC / NIOSH (M) 2.9
REV. 5-91

SURFACE COAL MINE

Do you now or have you ever worked at a SURFACE coal mine? Yes_____No_____
If yes, list title for any job you have held for more than one (1) year in a SURFACE coal mine.

JOB TITLE	APPROXIMATE YEARS (DATES)	
	FROM 19__	TO 19__

OTHER

Have you ever worked in any mine other than coal? (gold, salt, silver, other metals, nonmetals, etc.) Yes_____No_____
If yes, list title for any job you have held for more than one (1) year in any mine other than coal.

TYPE OF MINE	APPROXIMATE YEARS (DATES)	
	FROM 19__	TO 19__

Have you ever worked with asbestos? Yes___ No___

If yes, what was your job? ______________________________

__________________ Dates: From________ To ________
MO / YR MO / YR

Have you ever worked for more than one (1) year in any other dusty job not listed above?

JOB	YES	NO	YRS.	JOB	YES	NO	YRS
Cotten, flax or hemp				Quarry			
Diesel / Diesel Exhaust				Sandblasting			
Drilling				Tunneling			
Foundry				Other (specify)			
Pottery							

CONSENT - I wish to participate in the periodic Medical Examination Program conducted under section 203 of the Federal Mine Safety and Health Act of 1977 (30 U.S.C. 843). I authorize the Public Health Service to furnish any significant medical findings revealed by the X-ray and other medical tests under the program to my personal physician:

Personal Physician's Name			Physician's Telephone Number
Street Address	City	State	Zip

I understand that I will be advised of any findings concerning coal workers pneumoconiosis (black lung disease) directly.

Date Signed	Miner's Signature X

Additional Information:

APPENDIX G

TECHNICAL CONSIDERATIONS IN THE USE OF SPIROMETRY IN SCREENING AND SURVEILLANCE OF MINERAL-DUST-EXPOSED WORKERS*

This appendix describes recommended procedures in the recording and performance (including interpretation) of spirometry in programs of screening and surveillance of mineral-dust-exposed workers.

G.1 RECOMMENDED PROCEDURES AND QUALITY CONTROL

Spirometry tests should be conducted in accordance with the American Thoracic Society (ATS) recommended spirometry standards and the recommendations of the European Respiratory Society (ERS) [ATS 1987; ERS 1993]. These standards establish both the minimum equipment requirements and the procedures to use in administering the test. A quality control (QC) program is also a critical component of the spirometry screening program. The QC program should include adoption of a procedures manual describing the proper calibration, use, and maintenance of all equipment; requirements for record maintenance of calibration checks; and technician training and monitoring. When screening information is being collected from multiple sites, a central system for reviewing test quality is needed.

If spirometry results are to be interpreted longitudinally, the central quality control monitoring center should also attempt to identify "survey" biases. A survey bias is an unexplained change in a group's mean FEV_1 between surveys (which take place at different times and perhaps different locations). A record of calibration checks should be maintained and is particularly useful when a survey bias is suspected to eliminate instrumentation errors as the source.

G.2 INTERPRETATION

G.2.1 Test Reproducibility

The first step in interpreting spirometry is to assess the quality of the test. The lack of a sufficient number of acceptable trials or a reproducible test should be carefully considered during the interpretation

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*This material is currently being prepared for publication as an appendix to a book entitled *Health Screening and Surveillance of Workers Exposed to Mineral Dust* (Geneva, Switzerland: World Health Organization, 1995 [in press]). Printed with permission from the World Health Organization.

interpretation. The presence of excessive flow oscillations in the spirogram, resulting in the curve being eliminated due to a "cough," may indicate a functional structural disorder. The lack of a reproducible test may result from disease and has been shown to be associated with an increased risk of mortality from lung disease in cohorts who are occupationally exposed [Eisen et al. 1985; Kellie et al. 1987]. In addition, shorter individuals may have more difficulty in meeting reproducibility criteria than taller individuals. Therefore, an individual's results may be interpreted even though the test was not considered reproducible by ATS standards [ATS 1987].

G.2.2 Comparison with Reference Values

The recommended method of interpreting a single observation of lung function involves the comparison of an individual's observed values of FEV_1, with a reference value derived from cross-sectional data which takes into account the subject's height (as the main determinant of differences between individual sizes), as well as gender and age. Both ATS and ERS have recently published statements on interpretation of spirometry results [ATS 1991; ERS 1993]. The cutoff values selected to separate individuals for whom no intervention is warranted (presumed "normals") from those for whom a preventive intervention is recommended or required (presumed "abnormals") should be chosen to reflect the goals of screening the program. For purposes of screening where early identification of abnormality is the goal, these test cutoffs may be different from those generally used in clinical practice, which focuses on disease diagnosis and confirmation. Test sensitivity (the ability of a cutoff point for test interpretation to accurately identify a truly abnormal individual), test specificity (the ability of a test cutoff point to accurately identify individuals without disease), and the predictive value of positive and negative test results vary depending on the specific cutoff values adopted and on the extent of disease in the screened population.

G.2.3 Selection of Reference Values

Reference values should be selected based on methodological, epidemiological, and statistical criteria. Reference values are derived from regression equations generated from lung function data gathered in healthy (often non-smoking) populations. Published reference values vary as a result of technical reasons and population differences in groups studied. These differences may relate to socioeconomic, psychosocial, and other factors. The ATS, for example, does not recommend a universal reference value. Instead, it recommends that, to the extent possible, reference values be selected from those obtained using comparable equipment in a population with comparable age, physical characteristics, socio-economic background, and ethnic characteristics [ATS 1991]. By contrast, the ERS guidelines recommend the use of one equation for males and one for females, based on pooled data collected in several countries. Almost all reference values are based on the individual's age and height.

For ethnic groups where reference values may not be available, some adjustment to the caucasian values may be possible. For example, the ERS recommends that for subjects of African descent, the predicted values be multiplied by 0.87. This procedure is not recommended by the ATS, nor does it appear justified based on a recent analysis of published data on over 30,000 men and women of sub-Saharan African descent [White et al. 1994]. Some variability between ethnic groups may be due to differences in trunk length relative to standing height [ERS 1993].

G.2.4 Criteria for Abnormal FEV_1 Based on Reference Value Comparisons

Although the 95th percentile[†] is often used as the lower limit of normal (LLN) for purposes of clinical interpretation, this may not be appropriate for screening and surveillance. In some circumstances, where the purposes of cross sectional screening would be better met by a more sensitive indication of potential abnormality, the 85th or 90th percentile, or another cutoff, might be selected as the LLN or level that stimulates further monitoring, investigation, or other action. The LLN is available or can be calculated from data published for most reference values. For example, the ERS recommends that the LLN approximating the 95th percentile can be estimated by subtracting 0.84 L (males) or 0.62 L (females) from the predicted value.

G.2.5 Criteria for Abnormal FEV_1 Based on Change Over Time

A comparison of an individual's current FEV_1 with his/her own FEV_1 determined in the past may be of some benefit, particularly for those workers whose FEV_1 is above that predicted. A quality control program is especially important if longitudinal changes are to be assessed. Because of considerable short-term variability in FEV_1, a year-to-year change of greater than 15% should occur before a change in FEV_1 is considered significant. For longer periods of observation, adjustment for the expected annual decline in FEV_1 is appropriate. Therefore, the LLN for the follow-up FEV_1 is computed by taking 85% of the baseline value minus the expected decline over the time period. An individual's expected decline over the time period is dependent on his/her age, but for practical considerations, a constant value of 25 ml/year is often recommended. For example, an individual whose initial FEV_1 is 4.00 L would be considered to have an accelerated decline in FEV_1 if his/her FEV_1 is below 3.15 L, 10 years after the baseline value was determined (0.85 × 4.00 L —10 years × 0.025 L). This approach to interpretation of longitudinal test performance has been presented in more detail recently [Hankinson and Wagner 1993].

To increase the sensitivity of screening spirometry, comparisons of an individual's FVC and $FEV_1/FVC\%$ with the appropriate LLNs can also be conducted. However, because the FVC is usually a more difficult parameter to accurately determine (more effort-dependent than the FEV_1), the FVC and $FEV_1/FVC\%$ comparisons should be optional.

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APPENDIX H

THE BLACK LUNG BENEFITS PROGRAM

The Black Lung Benefits Program, initially established in 1969 as part of the Federal Coal Mine Health and Safety Act (Public Law 91-173),* is intended to provide compensation for coal miners who are partially or totally disabled from their normal coal mine employment. Standards for determining coal miners' total disability or death due to pneumoconiosis are based on criteria such as length of employment, radiographic evidence of pneumoconiosis, and/or values for pulmonary function tests or arterial blood-gas tests that are below predicted normal values [29 CFR 718].

The initial program established in 1969 was administered by the Social Security Administration and used public funds to compensate disabled coal miners. It was intended that the second phase of the program would be administered by the U.S. Department of Labor and structured according to general principles of workers' compensation. However, the number of claims filed under the initial program far exceeded estimates, and the Black Lung Benefits Act of 1972 was enacted to provide simplified interim eligibility criteria for claims filed with the Social Security Administration and to delay the transfer of responsibility to the U.S. Department of Labor for processing and paying claims until 1973. The Social Security Administration continues to administer funds for claims filed before July 1, 1973.

In 1978, the Black Lung Benefits Reform Act of 1977 was enacted, which again mandated the use of interim criteria based on the presumption of eligibility to resolve old, unapproved claims. In addition, the Black Lung Benefits Revenue Act of 1977 was enacted, which created the Black Lung Disability Trust Fund, to be financed by an excise tax on coal that is mined and sold in the United States.

In 1981, the Black Lung Benefits Revenue Act of 1981 and the Black Lung Benefits Amendments of 1981 were enacted. The amendments tightened the eligibility standards, eliminated certain presumptions, and temporarily increased the excise tax on coal to reduce the debt of the Trust Fund to the U.S. Treasury, which was more than $1.5 billion in 1981 and $2.8 billion in 1985. In 1985 and 1987, budget-related laws were passed, but further changes were made in the eligibility criteria or adjudication procedures. By the end of 1991, the Trust Fund's cumulative debt to the U.S. Treasury was $3.3 billion. Tables H-1 through H-4 provide information on the number of beneficiaries and the costs of the Black Lung Benefits Program. An in-depth review and evaluation of the Federal Black Lung Benefits Program was performed by Prunty and Solomons [1989].

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*This Act was later amended by the Federal Mine Safety and Health Act of 1977 [30 USC 901-945].

Table H-1. Summary of claims activity, U.S. Department of Labor's Black Lung Benefits Program, fiscal year 1991 and cumulative, July 1, 1973, to December 31, 1991

	Cumulative decisions—all levels* (July 1, 1973, to December 31, 1991)			
Claim category	**Approved**	**Denied**	**Total number of decisions**	**Approval rate (%)**
Section 435 claims filed, 7/1/73 to 2/28/78	56,080	63,725	119,805	46.8
Section 727 claims filed, 3/1/78 to 3/31/80	20,494	41,044	61,538	33.3
Section 718 (PRE) claims filed, 1/1/82 to present	4,125	28,529	32,654	12.6
Section 718 (POST) claims filed, 1/1/82 to present	5,890	77,804	83,694	7.0
Part B denials—denied claims inherited from SSA	21,867	45,917	67,784	32.3
SSA† approvals—claims approved by SSA under the 1977 amendments	15,931	710	16,641	95.7
Subtotal	124,387	257,729	382,116	32.6
Medical only	116,738	1,656	118,394	98.6
Grand total	241,125	259,385	500,510	48.2

Source: DOL [1992].

*Refers to the most recent decision (any level—Division of Coal Mine Workers' Compensation, Administrative Law Judge, Benefits Review Board).

†SSA = Social Security Administration.

Table H-2. Department of Labor's Black Lung Benefits Program obligations for fiscal years 1982–91

Year	Program obligations (in billions)
1982	$1.79
1983	2.15
1984	2.50
1985	2.83
1986	2.88
1987	2.95
1988	2.99
1989	3.05
1990	3.05
1991	3.26

Source: DOL [1992].

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Table H–3. Black lung benefit claims by class of beneficiary, 1983–91

Class of beneficiary	Number of beneficiaries,* by year								
	1983	1984	1985	1986	1987	1988	1989	1990	1991
Primary beneficiaries:									
Minors	$64,181	$62,785	$60,906	$59,004	$56,688	$54,339	$51,588	$45,587	$45,842
Widows	35,178	36,495	37,827	39,049	40,702	41,901	42,923	43,500	43,842
Others	813	854	887	1,119	997	1,054	1,110	1,153	1,186
Total primary beneficiaries	100,172	100,134	99,620	99,172	98,387	97,294	95,621	93,240	90,870
Dependents of primary beneficiaries:									
Dependents of minors	63,040	60,275	58,113	54,747	52,237	49,343	46,053	42,846	39,800
Dependents of widows	2,398	2,298	2,306	2,207	2,199	2,079	2,002	1,902	1,825
Dependents of others	433	409	398	424	466	440	511	503	506
Total dependents	65,871	62,982	60,817	57,378	54,902	51,862	48,566	45,251	42,131
Total of all beneficiaries	166,043	163,116	160,437	156,550	153,289	149,156	144,187	138,491	133,001

Source: DOL [1992].

*Active claims (including those paid by an RMO), cases paid by the Trust Fund, cases in interim pay status, cases being offset as a result of concurrent Federal or State benefits, and cases temporarily suspended.

Table H-4. Monthly black lung benefit rates, 1973–91

	Benefit rates by type of beneficiary			
Period	**Claimant**	**Claimant and 1 dependent**	**Claimant and 2 dependents**	**Claimant and 3 or more dependents**
7/1/73 to 9/30/73	$169.80	$254.70	$297.10	$339.50
10/1/73 to 9/30/74	177.60	226.40	610.80	355.20
10/1/74 to 9/30/75	187.40	281.10	328.00	374.80
10/1/75 to 9/30/76	196.80	295.20	344.40	393.50
10/1/76 to 9/30/77	205.40	308.10	359.50	410.80
10/1/77 to 9/30/78	219.90	329.80	384.80	439.70
10/1/78 to 9/30/79	232.00	348.00	405.90	463.90
10/1/79 to 9/30/80	254.00	381.00	444.50	508.00
10/1/80 to 9/30/81	279.80	419.60	489.60	559.50
10/1/81 to 9/30/82	293.20	439.80	513.10	586.40
10/1/82 to 12/31/83	304.90	457.30	533.60	609.80
1/1/84 to 12/31/84*	317.10	475.60	554.90	634.20
1/1/85 to 12/31/86	328.20	492.30	574.30	656.40
1/1/87 to 12/31/87	338.00	507.00	591.50	676.00
1/1/88 to 12/31/88	344.80	517.20	603.40	689.60
1/1/89 to 12/31/89	358.90	538.30	628.10	717.80
1/1/90 to 12/31/90	371.80	557.70	650.60	743.60
1/1/91 to 12/31/91	387.10	580.60	677.40	774.10

Source: DOL [1992].

*These benefit rates include the additional 0.5% increase that was granted retroactively to January 1, 1984. The rates in effect before the retroactive payments (1/1/84 through 6/30/84) were $315.60 for a claimant only, $473.30 for a claimant and one dependent, $552.20 for a claimant and two dependents, and, $631.10 for a claimant and three or more dependents.

APPENDIX I

CONFIDENCE LIMIT ON MINIMUM ACCURATELY QUANTIFIABLE (MAQ) CONCENTRATION OF RESPIRABLE COAL MINE DUST

The lowest concentration of respirable coal mine dust that can be accurately quantified is estimated here. The accuracy criterion to be used is one that has been referred to as the NIOSH Accuracy Criterion, namely: ". . . measurements by the method will come within 25% of corresponding true air concentrations at least 95% of the time" [Busch and Taylor 1981]. Therefore, the accuracy A itself is defined as the largest percentage of deviation from the true concentration to be found among 95% of measurements; it is given in terms of bias and total imprecision relative standard deviation (rsd) implicitly by

$$\Phi\,[(\text{bias} + A)/\text{rsd}] - \Phi\,[(\text{bias} - A)/\text{rsd}] = 95\%$$

where Φ is the accumulative normal function. Note that the (true) rsd may be denoted by its approximation, the coefficient of variation (CV). The function A (bias, rsd) is shown, together with a planar approximation, in Figure I-1. Then the confidence limit on the minimum (concentration) accurately quantifiable (MAQ) is defined as the smallest concentration at which the 95% confidence limit on accuracy is better than 25%.

If the method were unbiased and the imprecision perfectly known, MAQ equals approximately eight times the method imprecision. Therefore, in this case MAQ differs only slightly from the limit of quantitation (LOQ). LOQ as defined by the American Chemical Society and by NIOSH [NIOSH 1994] is the concentration corresponding to 10 times the method imprecision (i.e., the use of MAQ avoids introducing a second arbitrary number (10) in addition to the value 25%).

Conditions of the calculation:

The pump uncertainty-induced imprecision (rsd_{pump}) is assumed to be less than 1% [Bartley et al. 1994].

The samplers considered are the traditional 10-mm nylon cyclone operated at 1.7 L/min and the Higgins-Dewell cyclone at 2.2 L/min.

The intersampler imprecision (rsd_{samp}) is assumed to be less than 5% [Bartley et al. 1994].

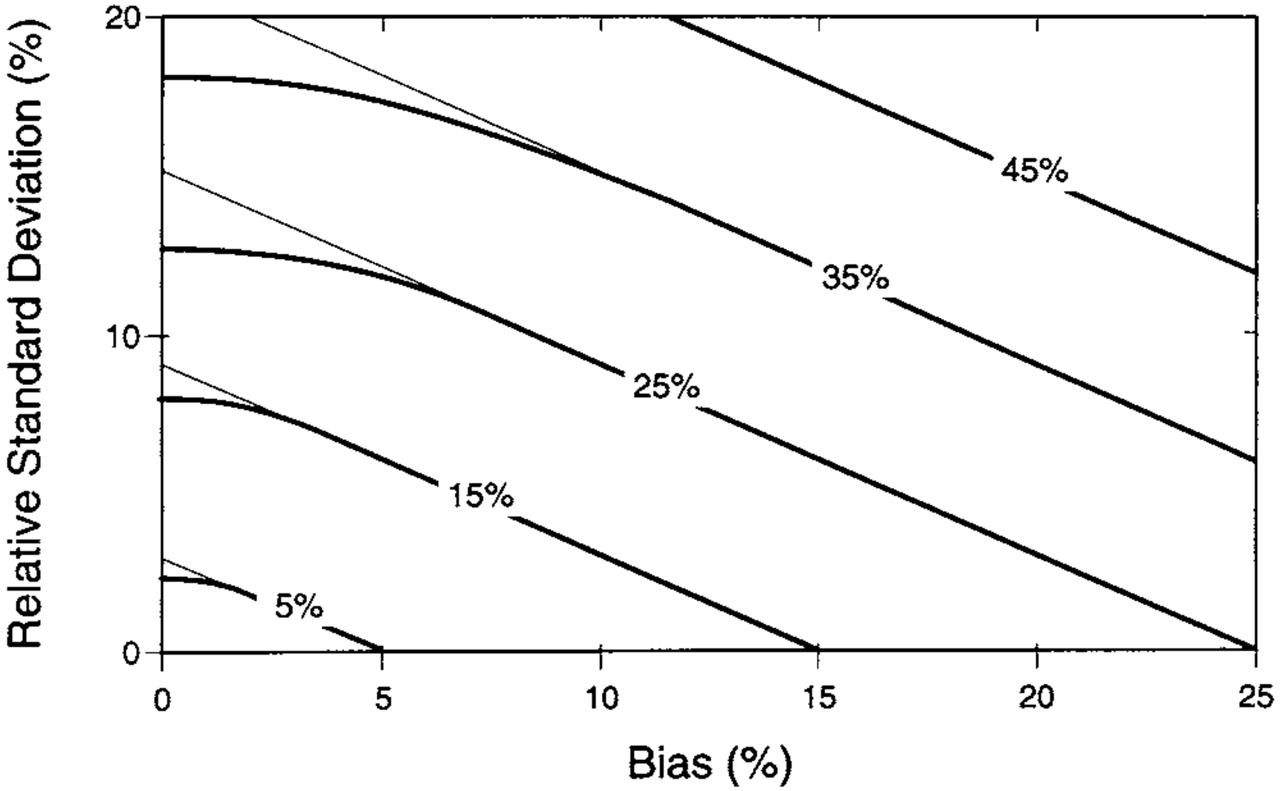

Figure I-1. Accuracy contours: fine lines represent linear approximation.

The maximum bias of each sampler is assumed to equal 7% as indicated by the coal mine dust size distributions of Mutmansky and Lee [1987] and the computation of Bartley et al. [1994].

The sampling time is assumed to equal 8 hr.

I.1 DETAILS OF THE CALCULATION

The confidence limit $_{95\%}A$ on the accuracy for obtaining the above results was computed by approximating the dependence of the true accuracy A on the intersampler variability rsd_{samp} and on the bias as linear. Details of this approximation have been published by Bartley et al. [1994]. Furthermore, regarding the data on S samplers (with v_{rsd} = S-1 degrees of freedom) reported in this paper, the uncertainties in both bias and in the overall imprecision were dominated by the intersampler variability. This results in the following expression for the accuracy confidence limit (hats over variables denote estimates):

$$_{95\%}\,A \equiv \hat{A} + 1.64\,\hat{rsd}_{samp} \cdot \left[\frac{k_1^2}{S} + \frac{k_2^2}{2\upsilon_{rsd}}\right]$$

where the constant k_1 and k_2 solve

$$k_1 = \partial A/\partial\,\text{bias}$$

$$k_1 - 1.64\left[\frac{k_1^2}{S} + \frac{k_2^2}{2\upsilon_{rsd}}\right]^{1/2} = \frac{rsd_{samp}}{rsd} \cdot \partial A/\partial\,rsd$$

where rsd is the total imprecision given by

$$rsd = \sqrt{rsd^2_{weigh} + rsd^2_{samp} = rsd^2_{pump}}$$

The dependence of the accuracy A on the total imprecision rsd and bias is somewhat complicated but is given by

$$\frac{\partial A}{\partial rsd} = \frac{\Phi_+\dfrac{\text{bias} + A}{rsd} - \Phi_-\dfrac{\text{bias} - A}{rsd}}{\Phi_+ + \Phi_-}$$

$$\frac{\partial A}{\partial \Delta} = \frac{\Phi_- - \Phi_+}{\Phi_+ + \Phi_-}$$

$$\Phi_\pm \equiv \exp\left[-\frac{1}{2}(\text{bias} \pm A)^2/rsd^2\right]$$

The weighing-induced imprecision is given by

$$\mathrm{rsd}_{\mathrm{weigh}} = \frac{\sigma_{\mathrm{weigh}} \times 1{,}000\ \mathrm{L/m^3}}{Q\ 8 \times 60\ \mathrm{min}}/\mathrm{MAQ}$$

where Q is the sampler flow rate.

Finally, using these expressions, the equation ${}_{95\%}A = 25\%$ is solved numerically for MAQ in terms of σ_{weigh}, giving the above results.

I.2 BIASLESS ACCURACY

The confidence limit on the accuracy is simple to calculate when the bias is known to be zero. This is consistent with the current MSHA practice for defining respirable dust by the sampler. Specifically, respirable dust is 1.38 × that which is captured by the traditional 10-mm nylon cyclone at 2 L/min.

In this case, the accuracy A is given by

$$\Phi\,[A/\mathrm{rsd}] - \Phi\,[-A/\mathrm{rsd}] = 95\%$$

which implies that

$$A = \Phi^{-1}\,[97.5\%]\ \mathrm{rsd} = 1.96\ \mathrm{rsd}$$

Since $\mathrm{rsd}_{\mathrm{samp}}$ is the only uncertain quantity in rsd and therefore in A, and since A is monotonic in $\mathrm{rsd}_{\mathrm{samp}}$, the 95% confidence limit on A is computed simply by determining the 95% confidence limit on $\mathrm{rsd}_{\mathrm{samp}}$ and substituting into the expression for A. In other words,

$$A_{95\%} = 1.96\sqrt{\mathrm{rsd}^2_{\mathrm{weigh}} + \frac{\hat{\mathrm{rsd}}^2_{\mathrm{samp}}}{\chi^2_{95\%}(\upsilon)/\upsilon} + \mathrm{rsd}^2_{\mathrm{pump}}}$$

With the number of degrees of freedom $\nu = 7$, $\chi^2 = 2.167$. Futhermore, $\mathrm{rsd}_{\mathrm{weigh}}$ is given by

$$\mathrm{rsd}_{\mathrm{weigh}} = 1.38\,\frac{\sigma_{\mathrm{weigh}} \times 1000\ \mathrm{L/m^3}}{Q\ 8 \times 60\ \mathrm{min}}/\mathrm{MAQ}$$

where σ_{weigh} is the weighing imprecision, Q is the flow rate, and MAQ is the minimum accurately quantifiable concentration. Setting $Q = 2.0$ L/min and $\sigma_{\mathrm{weigh}} = 0.029$ mg; MAQ is determined so as to give $A_{95\%} = 25\%$. The result is

$$\mathrm{MAQ} = 0.46\ \mathrm{mg/m^3}$$

I.3 RESULTS

Under these conditions, the confidence limit on the MAQ in terms of the imprecision in the coal dust weight measurements is given in Figure I-2. As seen from the graph, the value of MAQ depends strongly on the precision of the coal dust mass measurement. Several values of this precision may be found in the literature. A figure 0.081 mg was published in an early study of Parobeck et al. [1981] of weighing procedures employed in the past by the Mine Safety and Health Administration (MSHA) in which filters are preweighed by the filter manufacturer and postweighed by MSHA, using balances readable to 0.010 mg.

MSHA [Kogut 1994] has recently completed a study of the accuracy of weighing new "tamper-resistant" (and heavier) capsules. The filter manufacturer's balance, readable to 0.01 mg, was used for preweighing the filters and a 0.001 mg balance was used for the postweighing by MSHA. The results indicate imprecision equal to 0.029 mg (as well as a systematic error equal to -0.012 mg, which is considered negligible or correctable here).

The precision can likely be improved further. Bowman et al. [1984] reported imprecision equal to 0.010 mg, using a single 0.001 mg balance for both preweighing and postweighing. This value is consistent with a study of Vaughan et al. [1989] of repeat filter weighings. It should be noted that the actual attainable precision may depend strongly on the specific environment to which the filters are exposed between the two weighings.

These values are used in Table I-1.

Table I-1. Minimum (concentration) accurately quantifiable (MAQ) at specific values of imprecison

σ_{weigh} (μg)	MAQ$_{nylon}$* (mg/m^3)	MAQ$_{HD}$† (mg/m^3)
81 [Parobeck et al. 1981]	1.83	1.42
29 [Kogut 1994]	0.66	0.51
10 [Bowman et al. 1984]	0.23	0.17

*Minimum concentration accurately quantifiable by the nylon sampler (CPSU) [30 CFR 74].
†Minimum concentration accurately quantifiable by the Higgins-Dewell sampler [Higgins and Dewell 1968].

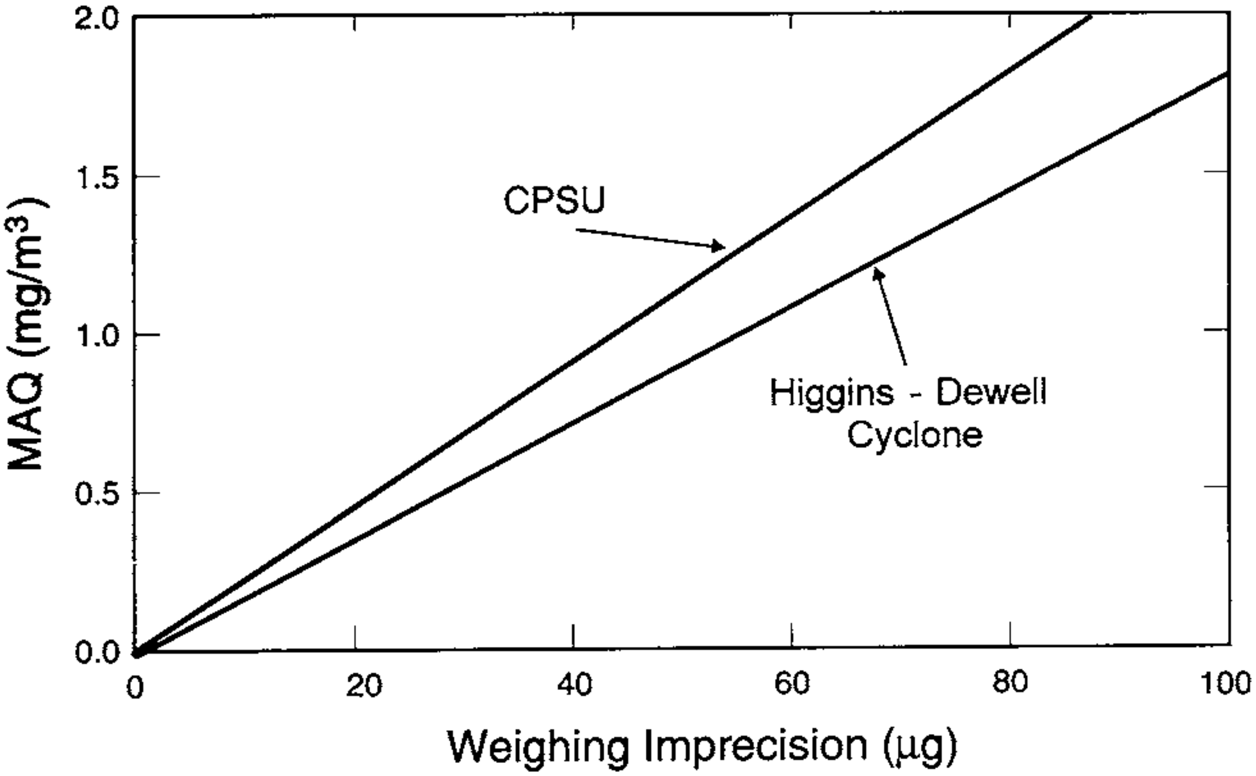

Figure I–2. Minimum accurately quantifiable (MAQ): CPSU and Higgins-Dewell cyclone.

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APPENDIX J

VARIABILITY IN SAMPLING AND ANALYTICAL METHODS*

J.1 MSHA GRAVIMETRIC METHOD FOR RESPIRABLE COAL MINE DUST

The current procedure for measuring the concentration of respirable coal mine dust is as follows. Each filter is preweighed by the filter manufacturer to ±0.1 mg. Following sampling with the Coal Mine Dust Personal Sample Unit (CPSU) at 2.0 L/min, the filter with coal mine dust is sent to MSHA for weighing. The current MSHA procedure for weighing respirable dust samples uses a Mettler Model AE163 analytical balance in conjunction with an automatic weighing system with a precision of ±0.02 mg [Tomb 1990]. Each balance is calibrated twice per day.

Quality control for the automatic weighing system includes the systematic weighing of one in eight filters on a second Mettler AE163 balance. Tolerance is set at ±0.1 mg between the two weighings of the same sample. Weights are truncated at the 0.1 mg level (e.g., 3.457 mg is truncated to 3.4 mg) [Bowman et al. 1985]. The difference of the two truncated weights is then recorded as the weight of coal dust deposited. The respirable concentration (mg/m^3) is computed by multiplying by a correction equal to 1.38 and dividing by the volume of air sampled (2.0 L/min × sampling time [min]).

J.2 WEIGHING IMPRECISION

The weighing inaccuracy corresponding to the MSHA weighing procedure has been estimated and is documented in Parobeck et al. [1981] and Bowman et al. [1985]. Including both the above truncation on the weights prior to subtraction and analytical errors (for example, due to balance inaccuracy or to filter mass instability), the estimated standard deviation σ_{weigh} in the measured deposited mass has been reported as:

$$\sigma_{weigh} = 0.081 \text{ mg}$$

The relative standard deviation (rsd)* in the respirable dust concentration estimates due to a weighing error (rsd_{weigh}) can be estimated, as illustrated in the following examples:

---

*Rsd may be approximated by the coefficient of variation (CV).

Example 1: The following conditions represent sampling at the current PEL for respirable coal mine dust (using the 10-mm nylon cyclone): sampling time, 8 hr; sampler flow rate, 2.0 L/min; respirable dust concentration, 2.0 mg/m^3. The $\text{rsd}_{\text{weigh}}$ is given by the following equation:

$$\begin{aligned}\text{rsd}_{\text{weigh}} &= [(0.081\text{ mg} \times 1.38)/(2.0 \times 10^{-3}\text{ m}^3\text{/min} \times 8\text{ hr} \times 60\text{ min/hr})]/2\text{ mg/m}^3\\ &= 5.8\%\end{aligned}$$

Example 2: The conditions corresponding to sampling at the REL (again using the CPSU): sampling time, 8 hr; sampler flow rate, 1.7 L/min; respirable dust concentration, 0.9 mg/m^3. Note that a correction factor (e.g., 1.38) is not required for the REL. The $\text{rsd}_{\text{weigh}}$ is given by the following:

$$\begin{aligned}\text{rsd}_{\text{weigh}} &= [(0.081\text{ mg})/(1.7 \times 10^{-3}\text{ m}^3\text{/min} \times 8\text{ hr} \times 60\text{ min/hr})]/0.9\text{ mg/m}^3\\ &= 11.0\%.\end{aligned}$$

Example 3: Similarly using the HD cyclone, the following conditions correspond to sampling at the REL: sampling time, 8 hr; sampler flow rate, 2.2 L/min; respirable dust concentration, 0.9 mg/m^3. Then, $\text{rsd}_{\text{weigh}}$ is given by the following:

$$\begin{aligned}\text{rsd}_{\text{weigh}} &= [(0.081\text{ mg})/(2.2 \times 10^{-3}\text{ m}^3\text{/min} \times 8\text{ hr} \times 60\text{ min/hr})]/0.9\text{ mg/m}^3\\ &= 8.5\%\end{aligned}$$

Note that the value $\text{rsd}_{\text{weigh}}$ for sampling at the REL, using either the CPSU or the HD cyclone, is larger than $\text{rsd}_{\text{weigh}}$ for sampling at the current PEL and sampling criteria. The NIOSH accuracy criteria for determining the acceptability of sampling and analytical methods are the following: 95% of a method's concentration estimates should be within 25% of the true concentration [Busch and Taylor 1981]. Translated to the method inaccuracy rsd, this means that rsd (or CV) must be less than 12.8% (even if the method has no systematic error) [Gunderson and Anderson 1980].

J.3 FEASIBILITY OF REDUCING WEIGHING IMPRESSION

For respirable dust samplers, rsd is composed of $\text{rsd}_{\text{weigh}}$ as well as 5% from the sampling pump uncertainty [30 CFR Part 74 (1988)] and 5% from intersampler variability [Bartley et al. 1994]. With $\text{rsd}_{\text{weigh}}$ as large as 11.0% or 8.5%, the weighing errors dominate the method inaccuracy. Thus, the total rsd can be significantly reduced by lowering the true uncertainty in weighing (σ_{weigh}).

σ_{weigh} itself is comprised of two parts:

$$(\sigma_{\text{weigh}})^2 = (\sigma_{\text{trunc}})^2 + (\sigma_{\text{analy}})^2,$$

where σ_{trunc} refers to the truncation procedure and σ_{analy} to the variability in the analysis itself. Truncation errors are analyzed as follows: Define the function $x_{\text{trunc}}(x)$ of a random variable x by dropping the decimal part of x. The error $\Delta = x_{\text{trunc}}(x) - x$ looks like a saw-tooth, falling from 0 to -1 between each integer. The mean or expected error $E(\Delta)$ is thus -1/2 (i.e., truncation is negatively biased). Similarly, $E(\Delta^2) = 1/3$, which means the variance σ^2 is

$$\sigma^2 = E(\Delta^2) - E(\Delta)^2 = 1/12$$

The bias cancels the *difference* between two such independent truncated numbers, but the variance is doubled. Thus, the standard deviation in the difference σ_{diff} is

$$\sigma_{diff} = 1/\mathrm{Sqrt}[6]$$

With dust mass equal to the difference of two weights truncated at the 0.1 mg level, the standard deviation σ_{trunc} is 0.1 mg/Sqrt[6] or about 0.41 × 0.1 mg.

Thus, the two truncations lead to the following:

$$\sigma_{trunc} = 0.41 \times 0.1 \text{ mg}$$

where mass is the sampled mass. Therefore, $\sigma_{weigh} = 0.081$ mg implies that $\sigma_{anal} = 0.070$ mg.

For example, after 8 hr of sampling 0.9 mg/m^3 at 1.7 L/min,

$$\text{mass} = 0.734$$

and therefore,

$$rsd_{trunc} = 5.6\%$$

At $rsd_{weigh} = 11.0\%$, this corresponds to

$$rsd_{analy} = 9.5\%$$

Thus, to reduce rsd_{weigh}, NIOSH recommends the following:

(1) Reduce rsd_{analy} by improving quality control of the weighing procedure itself. The figure 0.081 mg quoted above for the weighing precision is based on an early study [Parobeck et al. 1981] of weighing procedures employed in the past by MSHA in which filters are preweighed by the filter manufacturer and postweighed by MSHA using balances readable to 0.010 mg. MSHA has recently completed a study of the accuracy of weighing new "tamper-resistant" capsules using a 0.001 mg balance for the post-weighing, indicating imprecision equal to 0.029 mg [Kogut 1994]. The precision can probably be improved further. Bowman et al. [1985] reported imprecision equal to 0.010 mg using a single 0.001-mg balance for both preweighing and postweighing. This value is consistent with a study of Vaughan et al. [1989] of repeat filter weighings, although the actual attainable precision may depend strongly on the specific environment to which the filters are exposed between the two weighings.

(2) Essentially eliminate rsd_{trunc} by using scientific rounding (at no greater than the 0.01-mg level) instead of the current MSHA method of truncating measured weights at the 0.1-mg level.

J.4 DETERMINATION OF VARIABILITY IN SAMPLING RESPIRABLE COAL MINE DUST: ADJUSTMENT FOR BIASED METHODS

The statistical evaluation of workplace exposures as measured by unbiased sampling methods is described by Leidel et al. [1977]. However, when the sampling method includes bias, adjustment for that bias is made by adding the estimated value of that bias to the quantity 1.645*CV. Such bias adjustment is required when using performance-based sampling criteria. Performance-based sampling criteria enable the certification of any sampler meeting specified criteria to be used for sampling in accordance with the international definition of respirable dust. This bias associated with performance-based sampling results from the differences in the collection characteristics of an ideal laboratory sampler relative to those of a prospective sampler.

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APPENDIX K

ESTIMATES OF EXPOSURE VARIABILITY AND EXPOSURE PARAMETERS FOR SELECTED DESIGNATED OCCUPATIONS

K.1 INTRODUCTION

The primary purpose of this analysis was to derive the best possible estimates of the *within-occupation* geometric standard deviations (GSDs), using the Spot Inspection Program (SIP) data set [MSHA 1993]. Accurate estimates of the within-occupation GSDs are necessary in order to estimate the true long-term mean for a section that is, at given confidence (e.g., 95%), in compliance with the NIOSH REL for coal mine dust where the REL is defined as the maximum average exposure across a single shift.*

The SIP data set was chosen because it contains fairly recent data and therefore is likely to represent current conditions. Furthermore, the SIP data set is readily available; thus, the results reported here could be easily duplicated by any interested party.

The secondary purpose was to derive estimates of the exposure parameters (mean, standard deviation, geometric mean, and geometric standard deviation) for selected designated occupations. Such parameter estimates are useful for estimating the fraction of measured exposures that exceed the REL or any other value.

K.2 METHODS

A complete description of the SIP data set is provided in an MSHA report [MSHA 1993]. Briefly, the SIP consists of the operator-submitted exposure monitoring data for the three cycles (bimonthly sampling periods) preceding the "spot inspection" by an MSHA inspector. These spot inspections ended on October 31, 1991.

The SIP data set was analyzed using the SAS procedure PROC MEANS to derive estimates of the exposure parameters and SAS procedure PROC VARCOMP to derive estimates of the within-occupation GSD after accounting for variability due to mine and section within a mine.

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*A section that is "in compliance" with the NIOSH REL is one in which single-shift exposures exceed the REL infrequently if at all.

The within-occupation GSDs for roof bolters (occupation code 46) were estimated after accounting only for variability due to mine because the MMU (section) number was not reported with the data.

Five occupations were included in this analysis: continuous miner operator, cutting machine operator, handloader operator, longwall shear operator, and roof bolter. These occupations primarily represent designated occupations, which are those occupations with the highest exposures and the most frequent sampling. The number of samples for these five occupations ranged from 392 to 6,818 (summed across all mines). Other occupations sampled had less than 30 measurements (summed across all mines), and these were excluded from this analysis.

Low-weight-gain (LWG) measurements (i.e., all measurements of 0.1 and 0.2 mg/m^3)[†] were removed from the data set, and the analyses were repeated. Thus, two sets of results were generated: those calculated with the LWG measurements and those without. The distributions of exposure for each occupation were examined to determine which set of results are likely to be the most representative of the true exposures. Justification for excluding LWG measurements was presumed to exist if the number of 0.1 to 0.2 mg/m^3 measurements was inconsistent with the remainder of the distribution.

K.3 RESULTS

The results of the components of variance analysis are given in Table K-1. Descriptive statistics for each of the occupations are given in Table K-2. Table K-3 contains descriptive statistics for the same data, but minus the LWG measurements. The GSDs in Tables K-2 and K-3 are greater than those given in Table K-1 because they were calculated directly from the data; thus, they include the extra variability due to between-mine differences and between-section differences within mines.

The number of measurements by concentration are provided in Figures K-1 through K-5 for each of the five occupations analyzed. The histograms for continuous miner operators (code 36), cutting machine operators (code 38), and roof bolters (code 46) suggest an overabundance of LWG measurements that may not be representative of the true distributions. Thus the estimates of the within-occupation GSD for these occupations (which was derived after excluding LWG measurements [column 7, Table K-1]) are most likely closer to the true values.

The handloader operators (code 39) apparently experienced much lower exposures than other designated occupations so that exposures of 0.1 and 0.2 mg/m^3 were common. The longwall shear operators (code 44) experienced generally greater exposures than the other designated occupations. The number of 0.1 and 0.2 mg/m^3 measurements appeared to be consistent with the overall shape of the exposure distribution. Thus, for both these occupations the GSDs derived using all the data are probably the best estimates of the true GSDs (column 4, Table K-1).

[†] MSHA defines low weight gain measurements as any calculated concentration of 0.1 and 0.2 mg/m^3 [MSHA 1993]. Such measurements, in principle, occur with any exposure distribution for coal mine dust, but an overabundance when compared with the rest of the exposure distribution suggests that some manipulation of the environment or sampling process may have occurred. Evidence of an overabundance of measurements below 0.3 mg/m^3 in mine operator-collected data was reported by Boden and Gold [1984].

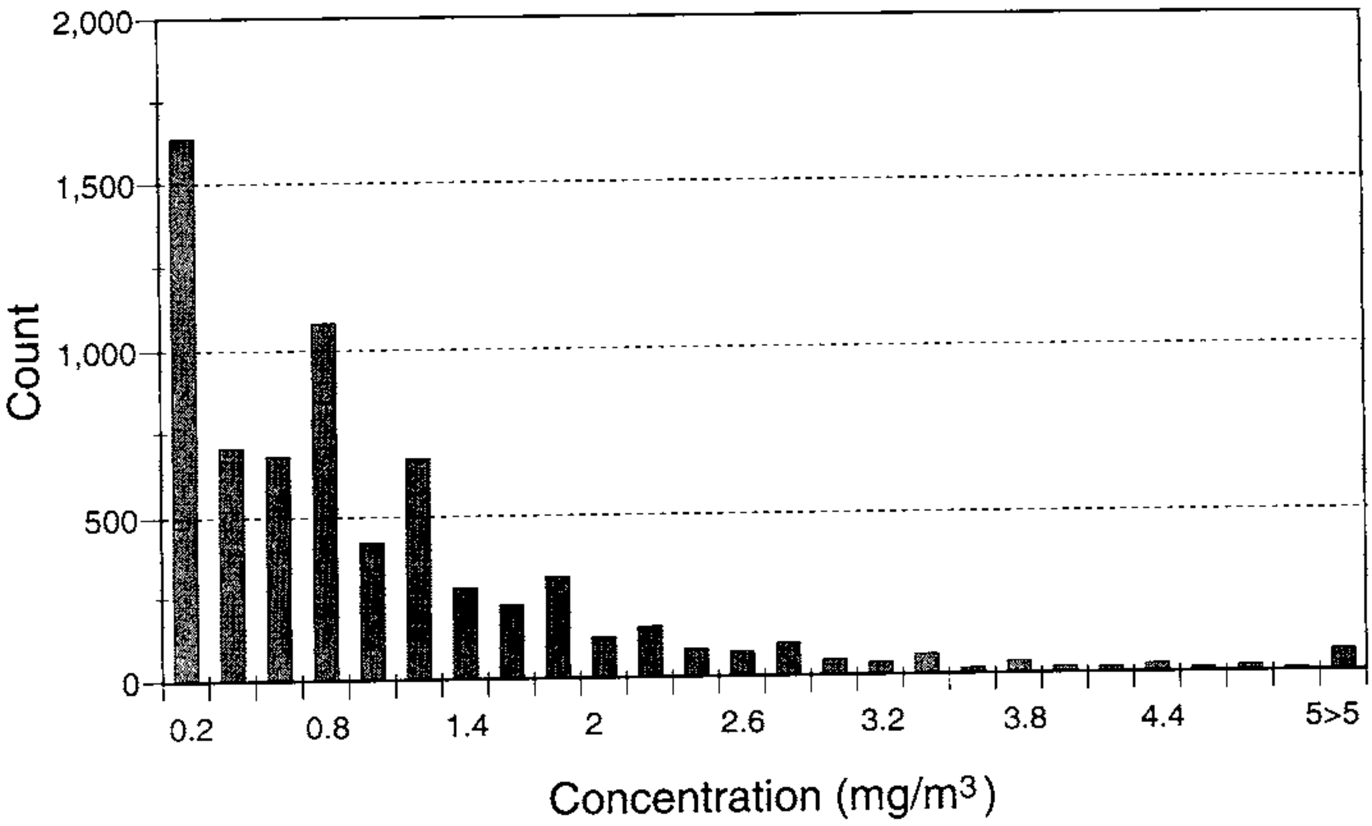

Figure K–1. Number of measurements by concentration for continuous miner operators (code 36) (SIP data).

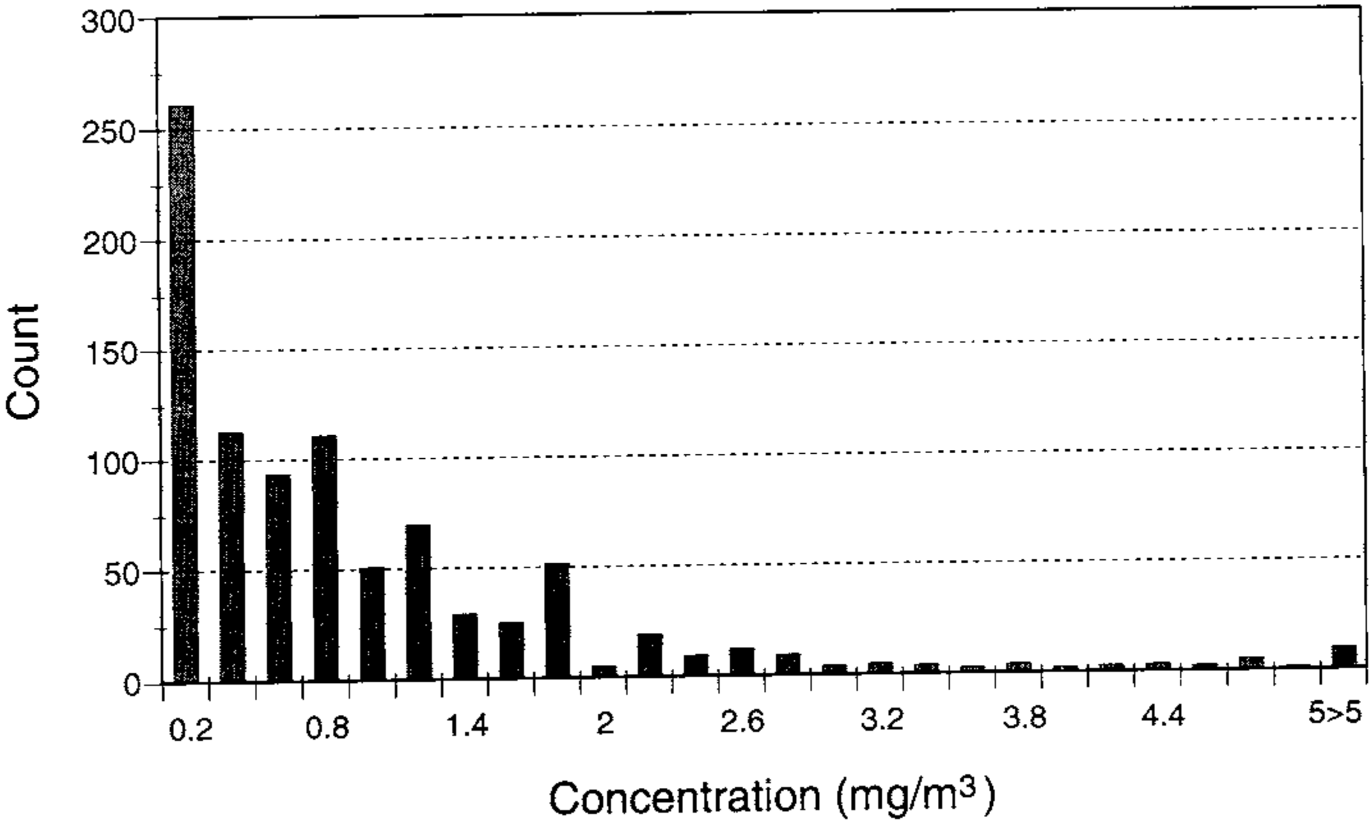

Figure K–2. Number of measurements by concentration for cutting machine operators (code 38) (SIP data).

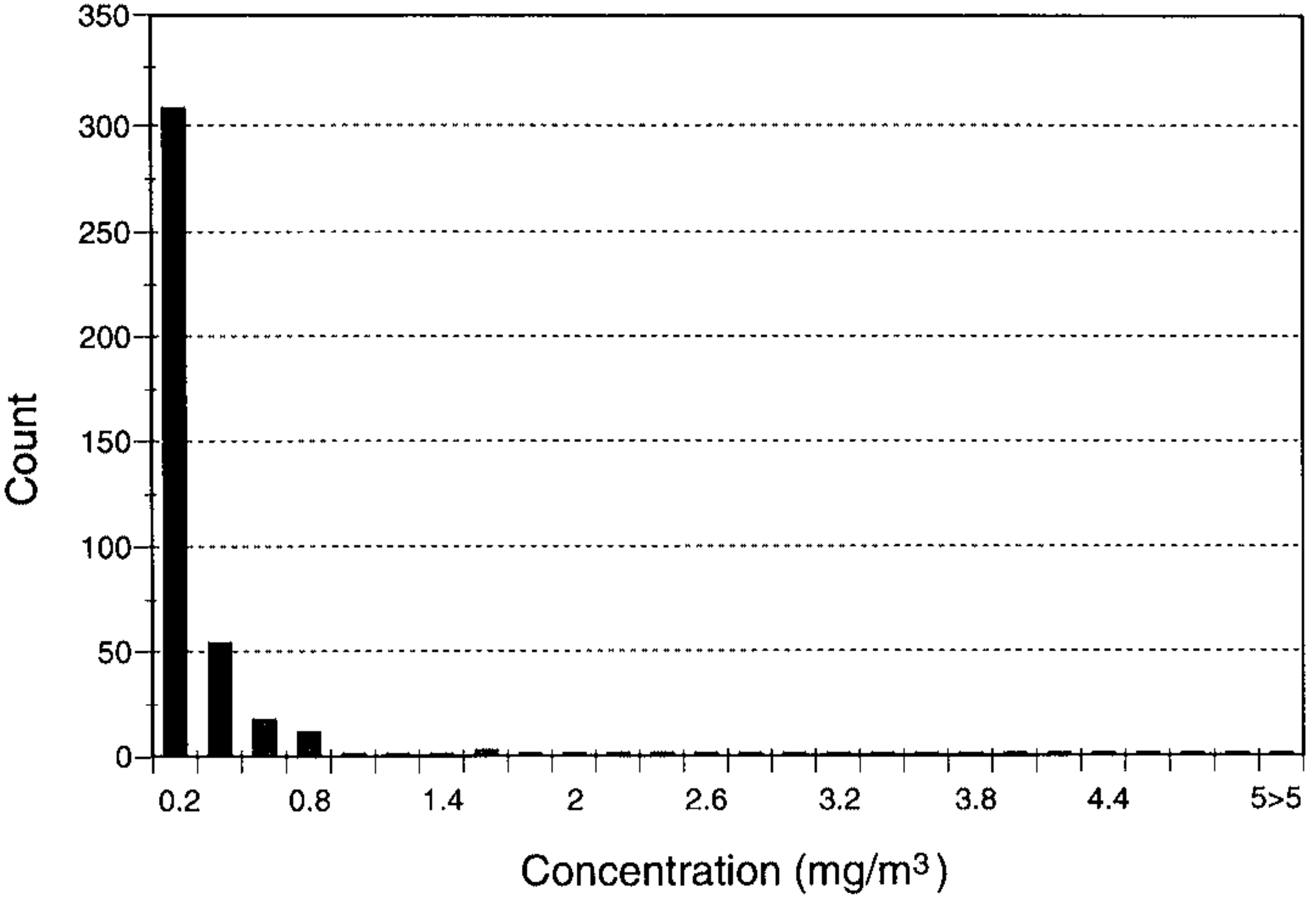

Figure K–3. Number of measurements by concentration for handloader operators (code 39) (SIP data).

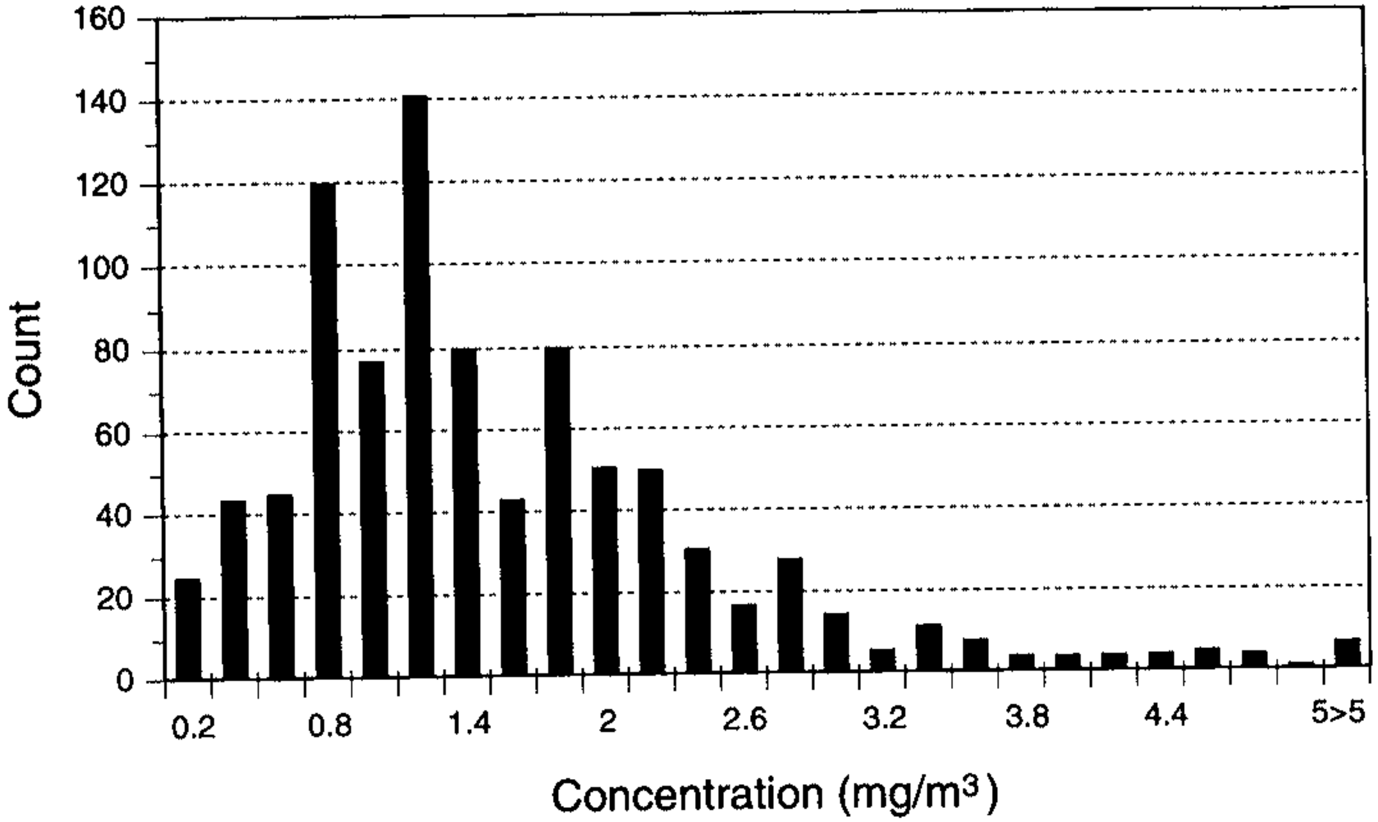

Figure K–4. Number of measurements by concentration for longwall shear operators (code 44) (SIP data).

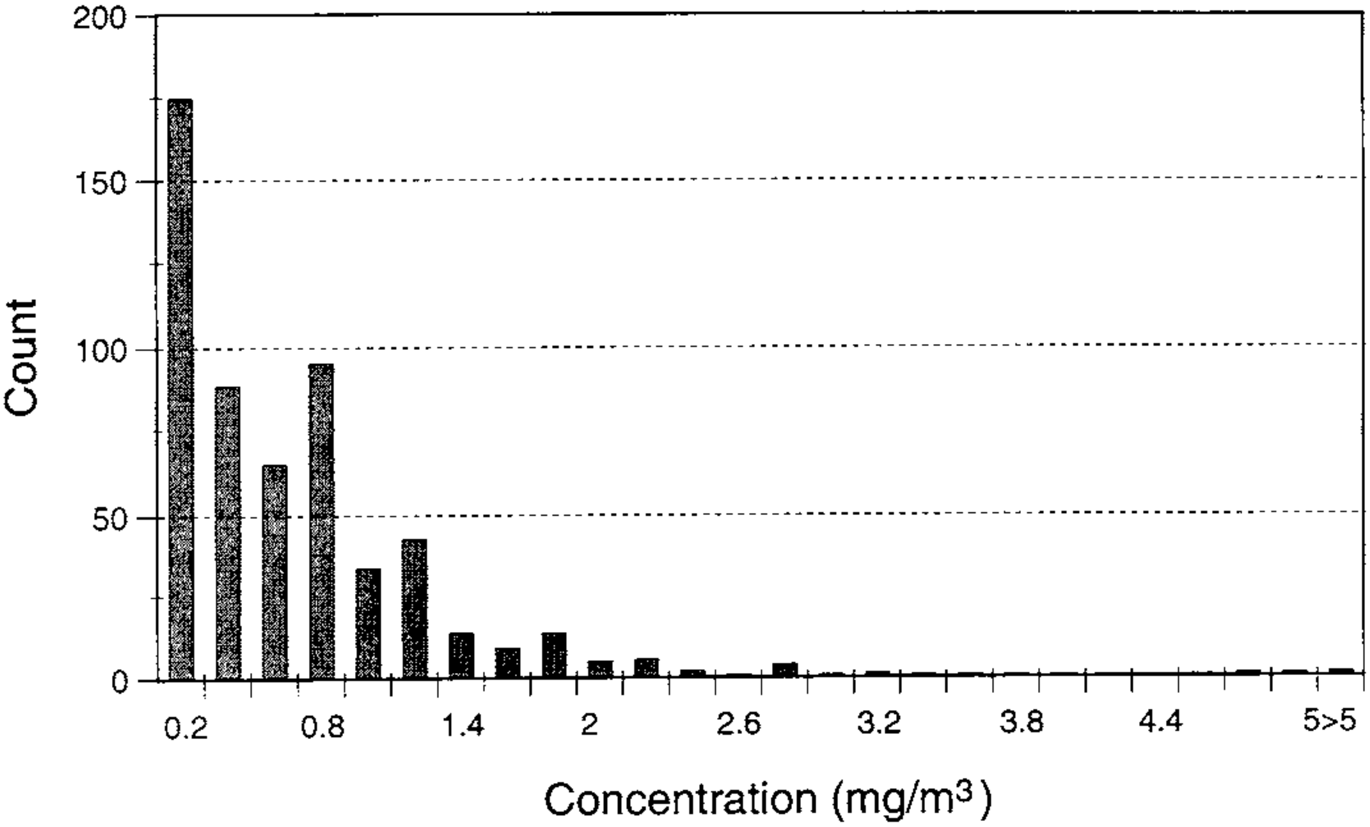

Figure K-5. Number of measurements by concentration for roof bolters (DA sample) (code 46) (SIP data).

K.4 COMMENTS

These statistics can be considered representative of the exposures that occurred *during sample days spanning roughly a 1-year period ending on October 31, 1991*. Analysis of data sets from earlier or later periods may lead to different estimates. The best estimates of the within-occupation GSD are marked with a double dagger (‡) in Table K-1.

Note that the GSD estimates, after accounting for variability due to mine and section (within mine) are not excessive, even when the LWG measurements are left in the data set. This was unexpected considering that the underground mining environment is typically characterized as being highly variable.

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Table K-1. Estimates of the within-occupation GSDs for the five occupations in the SIP data set with the greatest number of samples

		All data			LWGs excluded		
MSHA occupation code	**Occupation**	**Number of samples**	**GSD**[*]	**Estimated mean mg/m^3 (θ=0.05)**[†]	**Number of samples**	**GSD**	**Estimated mean mg/m^3 (θ=0.05)**
36	Continuous miner operator	6,818	2.36	0.35	5,172	1.79[‡]	0.45
38	Cutting machine operator	885	2.19	0.37	625	1.75[‡]	0.47
39	Handloader operator	392	1.68[‡]	0.49	85	1.81	0.45
44	Longwall shear operator	897	1.82[‡]	0.45	872	1.67	0.49
46	Roofbolter (DA samples)	559	2.34	0.35	384	1.70[‡]	0.48

[*] GSDs were estimated using the SAS PROC VARCOMP procedure both with and without LWG measurements after adjusting variability due to mine and section within a mine. The long-term mean exposure for a section with no more than 5% overexposures is given for each GSD.

[†] =P(c>REL)=P(c>1 mg/m^3).

[‡] Indicates the best estimates of the within-occupation GSDs.

Table K-2. Descriptive statistics for the SIP data set for five occupations, unadjusted for between-mine or between-section differences (includes LWG measurements)

MSHA occupation code	**Occupation**	**Number of samples**	**Arithmetic mean (mg/m^3)**	**Standard deviation (mg/m^3)**	**Geometric mean (mg/m^3)**	**GSD**
36	Continuous miner operator	6,818	0.97	1.03	0.60	2.81
38	Cutting machine operator	885	0.89	1.05	0.52	2.95
39	Handloader operator	392	0.23	0.90	0.14	1.96
44	Longwall shear operator	897	1.50	0.94	1.23	1.96
46	Roof bolter (DA samples)	559	0.65	0.66	0.44	2.54

Table K–3. Descriptive statistics for the SIP data set for five occupations, unadjusted for between-mine or between-section differences (excludes all LWG measurements)

MSHA occupation code	Occupation	Number of samples	Arithmetic mean (mg/m^3)	Standard deviation (mg/m^3)	Geometric mean (mg/m^3)	GSD
36	Continuous miner operator	5,172	1.23	1.06	0.97	1.92
38	Cutting machine operator	625	1.20	1.11	0.92	1.97
39	Handloader operator	85	0.68	1.87	0.45	1.79
44	Longwall shear operator	872	1.54	0.92	1.31	1.77
46	Roof bolter DA samples)	384	0.89	0.68	0.75	1.73

APPENDIX L

VALIDATION OF PREDICTIONS OF SMALL ROUNDED OPACITY PREVALENCE FROM ATTFIELD AND MORRING [1992]

L.1 INTRODUCTION

During review of the draft coal criteria document, a question was asked about the validity of the predictions of CWP prevalence made in Attfield and Morring [1992]. Specifically, was there any evidence from existing information about prevalence to confirm those predictions? To answer that question, data were tabulated from the Coal Workers' X-ray Surveillance Program for miners who worked for at least 10 years under dust conditions mandated by the 1969 Federal Coal Mine Health and Safety Act (Public Law 91-173). These data were then compared with the Attfield and Morring predictions.

L.2 METHODS

Data from the Coal Workers' X-ray Surveillance Program were used for verification, since they were not included in the study that developed the predictions. The requirement of 10 years or more of work in coal mining was imposed because CWP is usually a disease that develops slowly. See Attfield and Althouse [1992] for background information about the Coal Workers' X-ray Surveillance Program.

Data from rounds 3 and 4 of the Coal Workers' X-ray Surveillance Program were used (previous rounds were too close to 1969 to satisfy the 10-year tenure requirement). Prevalence of small rounded opacities was derived separately for the first and second readers, and the mean age for each tenure group was calculated. Although coal mine dust exposure has been associated with the development of both small rounded and small irregular opacities, small rounded opacities were used. For round 4, which used the 1980 ILO system [ILO 1980], small rounded opacity readings are not available specifically. To get around this problem, the following procedure was used. If the primary type was said to be rounded (p, q, r), the profusion category reported was taken to apply to rounded opacities. If, however, the primary type was said to be irregular (s, t, u), the rounded profusion was taken to be 0/0. Tenure was based on total years underground, that being the only record of work in mining available in the program.

Predictions were derived from the equations published in Attfield and Morring [1992] for category 1 or greater (1+) and for category 2 or greater (2+) (PMF was not investigated, as it was considered too subject to selection effects related to ill health). Since dust exposure information was not easily obtainable, rough estimates were made by multiplying the tenure for each group by 2 mg/m^3. Justification for this approach is given later. Predictions are given for high-volatile bituminous coals such as those mined in the western Appalachian region. These provide a reasonable overall estimate for the country since they represent most miners and fall between the higher predictions applicable to the small number of low-volatile miners and the somewhat lower predictions for the midwestern and western miners.

L.3 RESULTS

L.3.1 Round 3

Information was available for just two tenure groups: 10 and 11 years. The average number of miners, mean age, and observed and predicted prevalences by reader are listed in Table L-1. The first and second readers classified a slightly different number of chest X-rays. The mean observed prevalence from the first and second readers is also listed.

About 921 miners were in the 10-year tenure group (mean age 34). As can be seen, both sets of readers showed observed prevalences that were about twice those predicted. Basically, the same observation applies to the 11-year tenure group, which dealt with about 187 miners.

Round 3 information on category 2+ is given in Table L-2. For the 10-year tenure group, the predicted prevalence is again about twice that predicted. No category 2+ films were observed in the 11-year group, although this could be due to the small size of the group.

L.3.2 Round 4

For round 4, information was available for 9 tenure groups ranging from 10 to 18 years. Table L-3 provides the information pertinent to category 1+. The mean age increases with tenure from 35 to 43 years, and the number of miners (and thus chest X-rays) is generally much larger than that for round 3. Overall, prevalences based on the first readers are about twice those predicted from the model. In contrast, the reader-2 prevalences are generally similar to or slightly smaller than those predicted.

Table L-1. Observed and predicted prevalences of category 1+ from round 3 of the Coal Workers' X-ray Surveillance Program

			Observed prevalence			
Tenure (years)	Average number of miners	Mean age	1st readers	2nd readers	Mean	Predicted prevalence
10	921	34	5.5	5.2	5.4	2.4
11	187	34	5.3	7.1	6.2	2.4

Table L–2. Observed and predicted prevalences of category 2+ from round 3 of the Coal Workers' X-ray Surveillance Program

			Observed prevalence			
Tenure (years)	Average number of miners	Mean age	1st readers	2nd readers	Mean	Predicted prevalence
10	921	34	0.3	0.1	0.2	0.5
11	187	34	0.0	0.0	0.0	0.6

Table L–3. Observed and predicted prevalences of category 1+ from round 4 of the Coal Workers' X-ray Surveillance Program

			Observed prevalence			
Tenure (years)	Average number of miners	Mean age	1st readers	2nd readers	Mean	Predicted prevalence
10	3,058	35	4.3	1.5	2.9	2.5
11	2,182	36	4.6	2.1	3.4	2.7
12	2,159	37	6.0	1.5	3.8	2.9
13	1,755	38	6.6	1.9	4.3	3.0
14	1,312	39	6.4	2.3	4.4	3.2
15	866	40	8.7	3.5	6.1	3.3
16	536	40	9.4	3.3	6.4	3.5
17	394	41	8.5	4.2	6.4	3.7
18	266	43	10.7	6.3	8.5	4.0

The final table in this series presents the information on category 2+ (Table L–4). In this case, it is the classifications from the first readers that are most similar to those predicted, with the reader-2 prevalences being considerably lower in general.

L.4 DISCUSSION

A model is correctly and properly verified by using an external observed data set whenever possible. However, the usefulness of the exercise depends on how similar the external data set is to the predictor data set. In the present case, there are many points of difference, and hence the validity of the comparison can be questioned. These differences include the following: different X-ray readers, different ILO systems, very different miner participation rates, and different mines. Another

Table L–4. Observed and predicted prevalences of category 2+ from round 4 of the Coal Workers' X-ray Surveillance Program

Tenure (years)	Average number of miners	Mean age	Observed prevalences			Predicted prevalence
			1st readers	2nd readers	Mean	
10	3058	35	0.6	0.1	0.4	0.7
11	2182	36	1.0	0.1	0.6	0.7
12	3159	37	0.9	0.1	0.5	0.8
13	1755	38	0.9	0.0	0.5	0.8
14	1312	39	0.7	0.2	0.5	0.9
15	866	40	1.2	0.3	0.8	0.9
16	536	40	1.3	0.2	0.8	1.0
17	394	41	1.0	0.3	0.7	1.0
18	266	43	1.9	1.5	1.7	1.2

Another difficulty is that the actual degree of dust exposure experienced by these coal miners is problematic. Each of these topics will be considered in turn.

The predictions are based on the classifications of a solitary (though very experienced) reader. The classifications for the verification data sets, on the other hand, are based on readings by many readers of variable experience. It is not known whether there are systematic differences between the single reader and the readers from the Coal Workers' X-ray Surveillance Program; but it is to be expected since the first and second readers from the Coal Workers' X-ray Surveillance Program appeared to be systematically different from each other. Which of the two sets of readings from the Coal Workers' X-ray Surveillance Program is to be preferred? There is no certain answer to this, but the second readers (being all B readers) demonstrated better reading competence than the first readers (some of whom were NIOSH A readers).

Some differences between the prediction and verification data might be expected to arise from the use of different ILO systems. The prediction data set was based on the 1968 UICC/Cincinnati scheme [Bohlig et al. 1970]; whereas, the data from rounds 3 and 4 were derived using the 1971 and 1980 ILO classifications [ILO 1980, 1972], respectively. Some readers have suggested that the standard films included in the 1971 set included one for category 1 that resulted in more positive films being recorded than with previous versions. Obvious problems are involved with the round 4 classifications, for the 1980 ILO procedure for classifying small opacities was substantially different from previous versions. In this, the rounded and irregular opacities were no longer classified separately: they were read in combination. As a consequence, there is no way with the 1980 system to get readings of small rounded opacities that are identical in concept to those for the 1971 and earlier versions of the ILO system. The procedure adopted in this report derives what might be called pseudo-small rounded opacity classifications, and they may or may not reflect what would be read if separate readings of rounded opacities were actually made.

Another point of difference relates to participation rates. Until recently, participation in the Coal Workers' X-ray Surveillance Program has been very high. Unfortunately, no information existed to assess whether those who participated were typical of the complete mining workforce or were biased in some respect. In contrast, the participation rate in the predictor data set was >90%. The effect of worker selection should therefore be borne in mind in this comparison.

The last point of difference concerns mine selection. The prediction study was based on larger mines. However, since the Coal Workers' X-ray Surveillance Program is open to all underground miners, it is likely that the verification data set includes many miners from small mines. If work practices and dust conditions were systematically different in smaller mines and larger mines (which seems quite possible), this difference would be reflected in different levels of CWP.

Finally, the problem of assigning an exposure to the miners in the verification data set (Coal Workers' X-ray Surveillance Program) will be considered. Dust exposure measurements are available for virtually all miners by social security number from 1970 to 1979. However, calculation of mean exposure for each miner was rejected because of the massive effort it would require. Millions of dust exposure records are spread over about 20 computer tapes. To search them and calculate exposures would have taken too long for the result to be useful. In any case, the exposures would have accounted for only part of the miners' tenure in mining, especially for round 4.

Instead, another approach was adopted. This approach assigned a constant dust concentration to each miner (2 mg/m^3). Choice of a common concentration is not a serious problem, as the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) led to a substantial narrowing of the range of dust concentrations experienced. If 2 mg/m^3 seems too high, remember that the standard was 3 mg/m^3 from 1970 to late 1972 and that there have been persistent reports of dust sample tampering. In view of these considerations, 2 mg/m^3 was thought to be a reasonable exposure. (In any event, the results presented here are not too different if 1.5 mg/m^3 is used in place of 2 mg/m^3.)

L.5 CONCLUSIONS

The results of this exercise suggest that the predictions from the Attfield and Morring [1992] paper are not excessive. Rather, there is some indication that these predictions may underestimate the actual prevalence of small rounded opacities.

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