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.

*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).

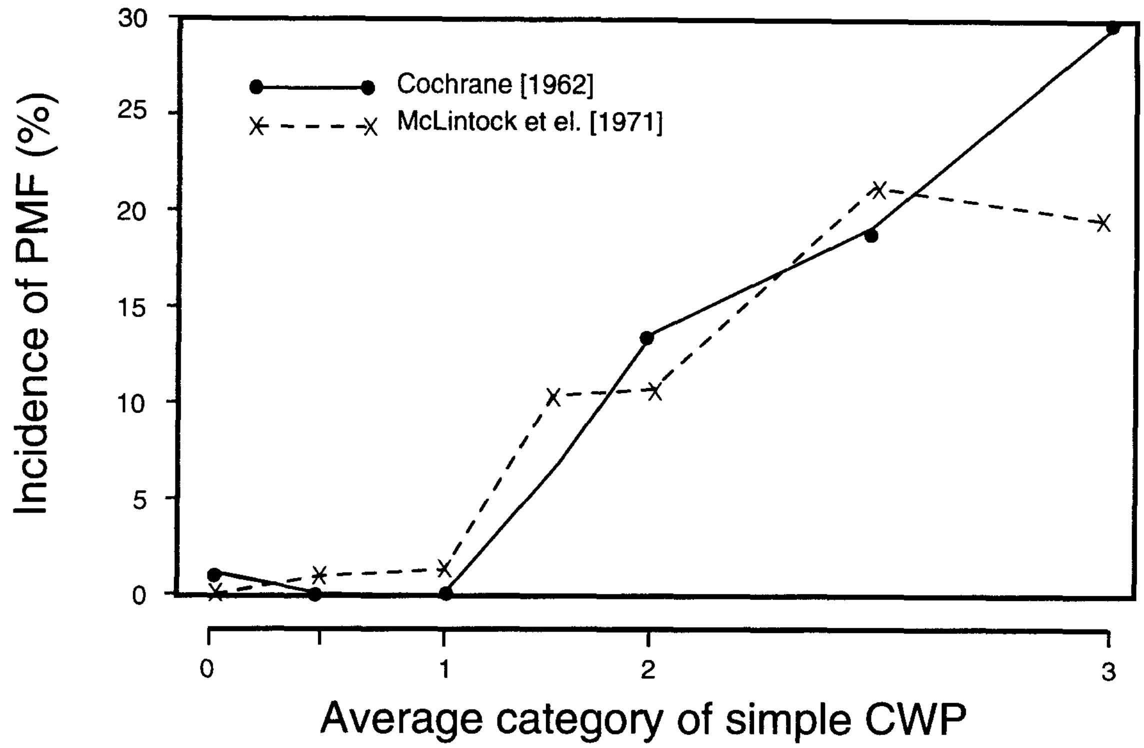

Figure 7–1. Incidence of PMF among U.K. coal miners during an 8-year period by average category of simple CWP. Adapted from McLintock et al. [1971].

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.

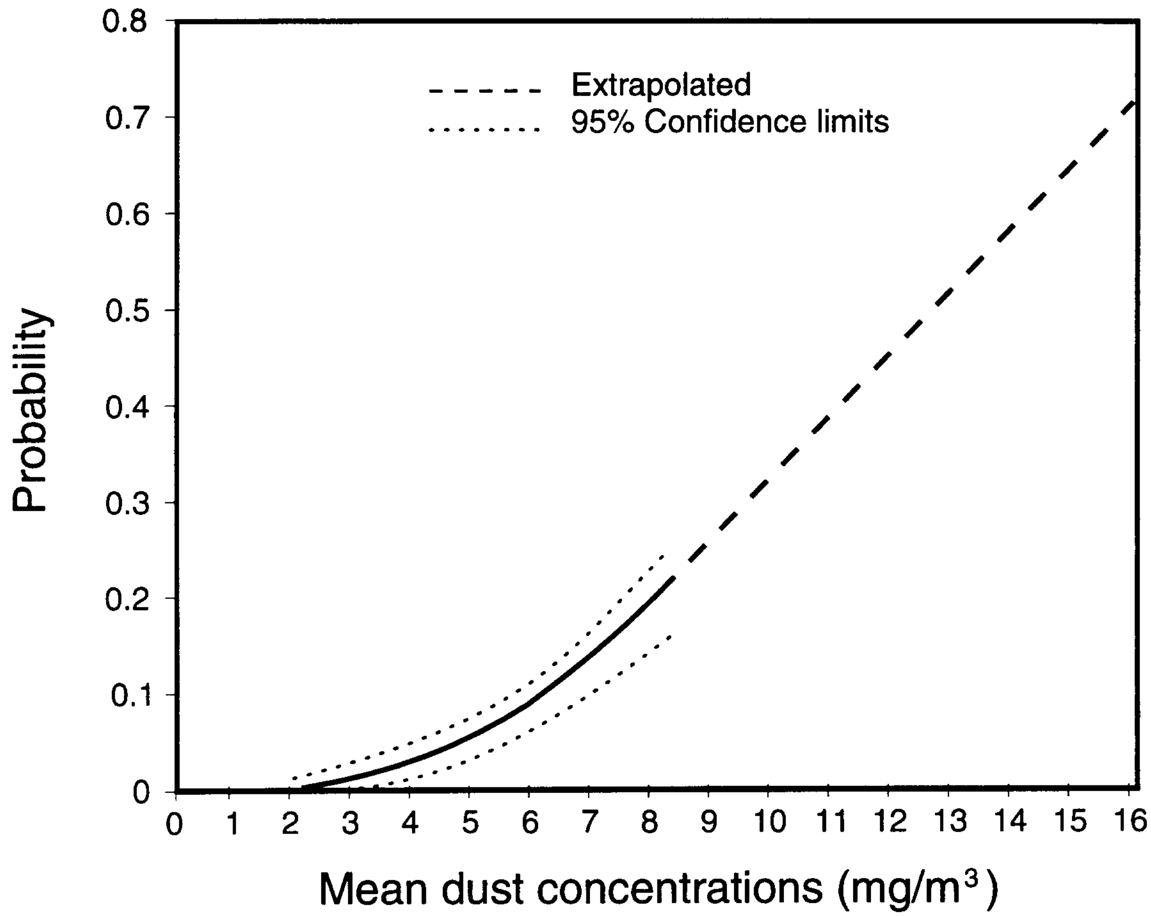

Figure 7-2. Probability that a man starting with no pneumoconiosis (category 0/0) will be classified as category 2 or higher after 35 years of exposure to various concentrations of coal mine dust. (Source: Jacobsen et al. [1971].)

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'

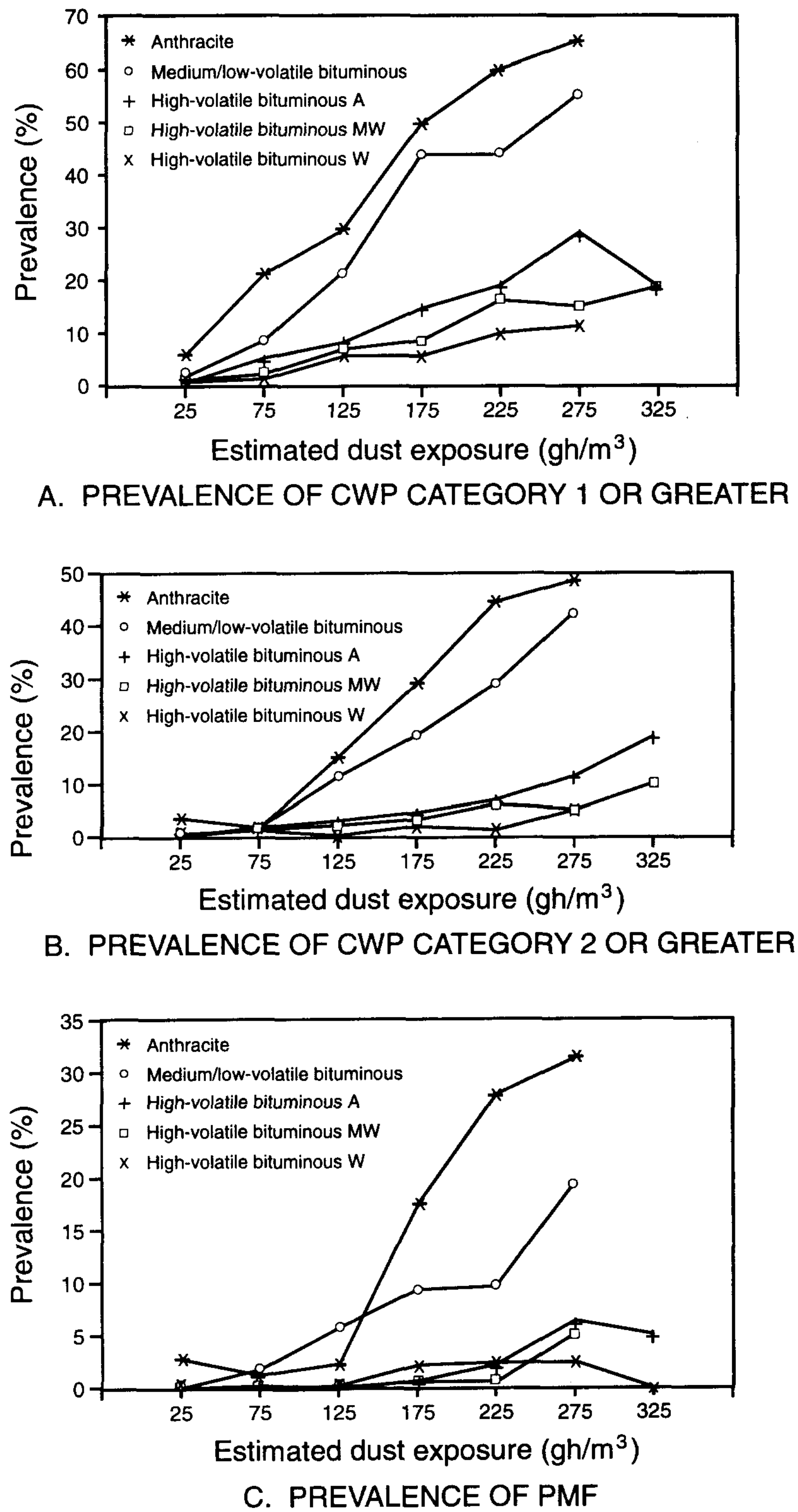

Figure 7-3. Prevalence of simple CWP and PMF among U.S. coal miners by estimated cumulative exposure and coal rank. Note: Exposure to 2 mg/m^3 for 45 years (i.e., 90 mg-years/m^3) is equivalent to 180 gh/m^3 (based on 2,000 hr/year). (Source: Attfield and Morring [1992b].)

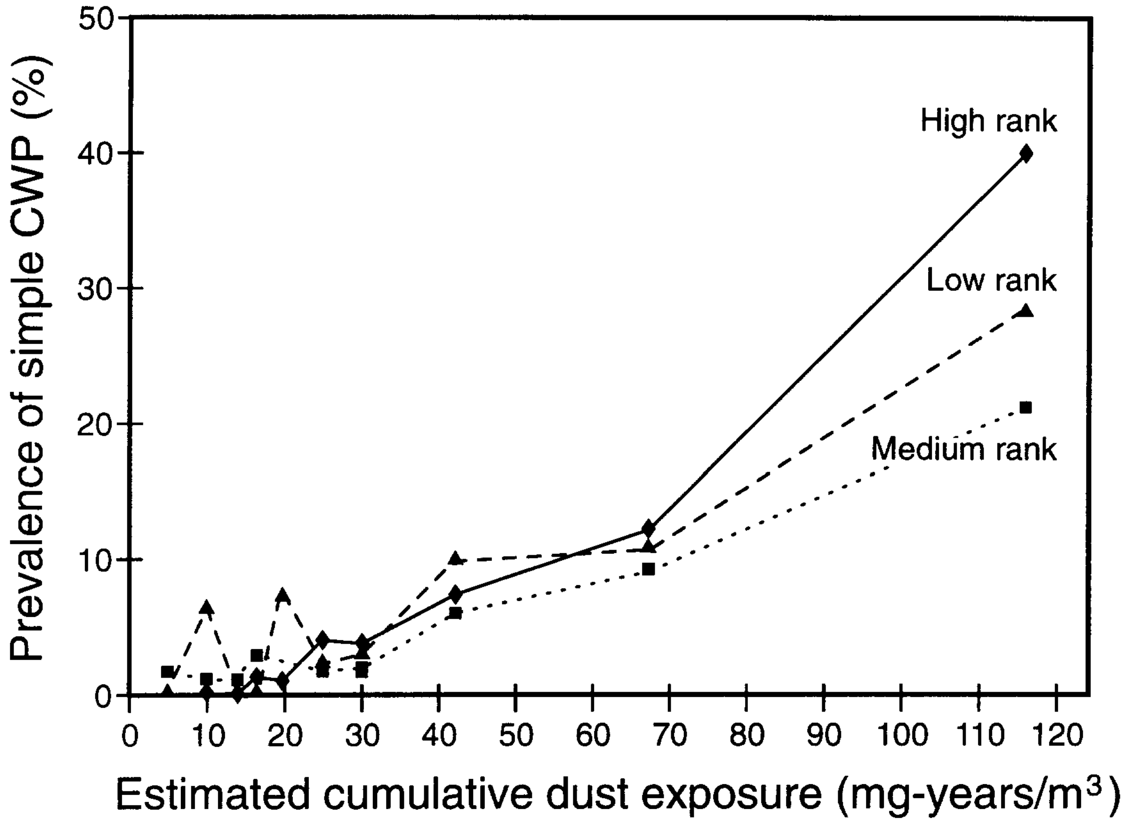

Figure 7–4. Prevalence of simple CWP category 1 or greater among U.S. coal miners by estimated cumulative dust exposure and coal rank (median reading of three X-ray readers). Note: Exposure to 2 mg/m^3 for 45 years is equivalent to 90 $mg\text{-}yr/m^3$. (Source: Attfield and Seixas [1995].)

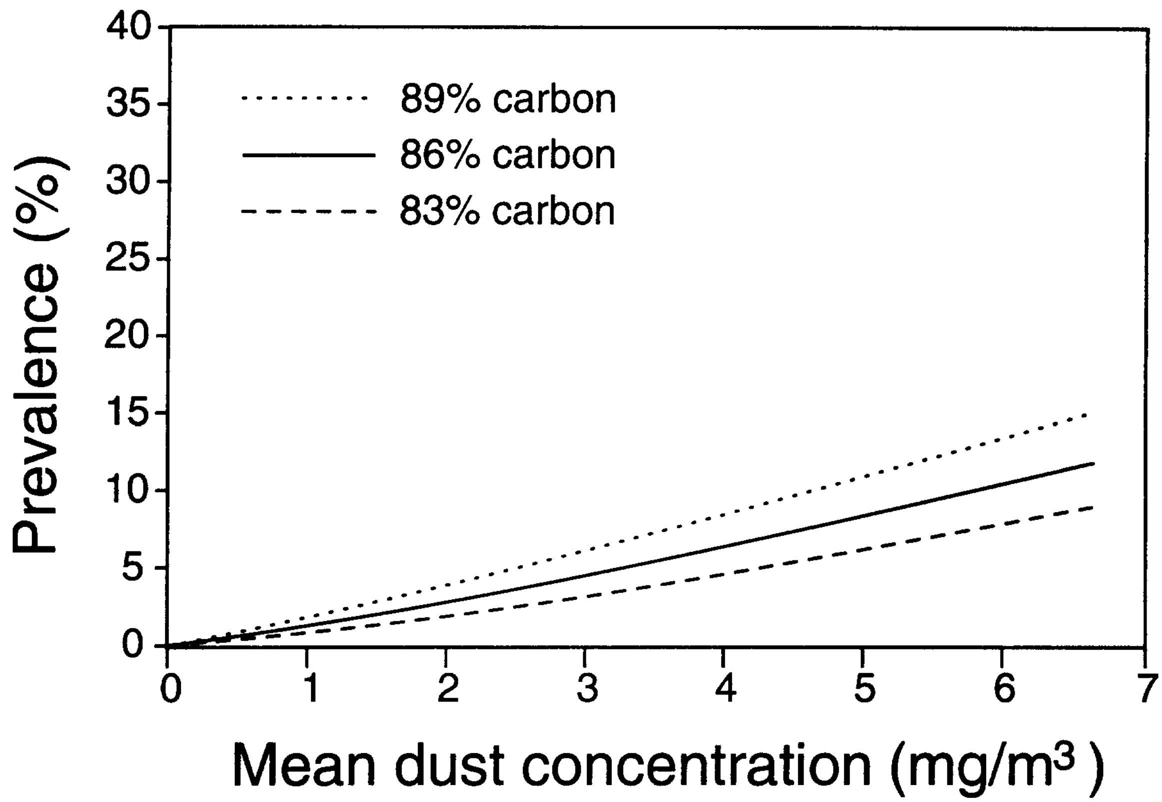

Figure 7-5. Predicted prevalence of simple CWP category 2 or higher among U.K. coal miners after a 35-year working lifetime (1,631 hr/year), by mean concentration of respirable coal mine dust and coal rank (expressed as percentage of carbon). (Source: Hurley and Maclaren [1987].)

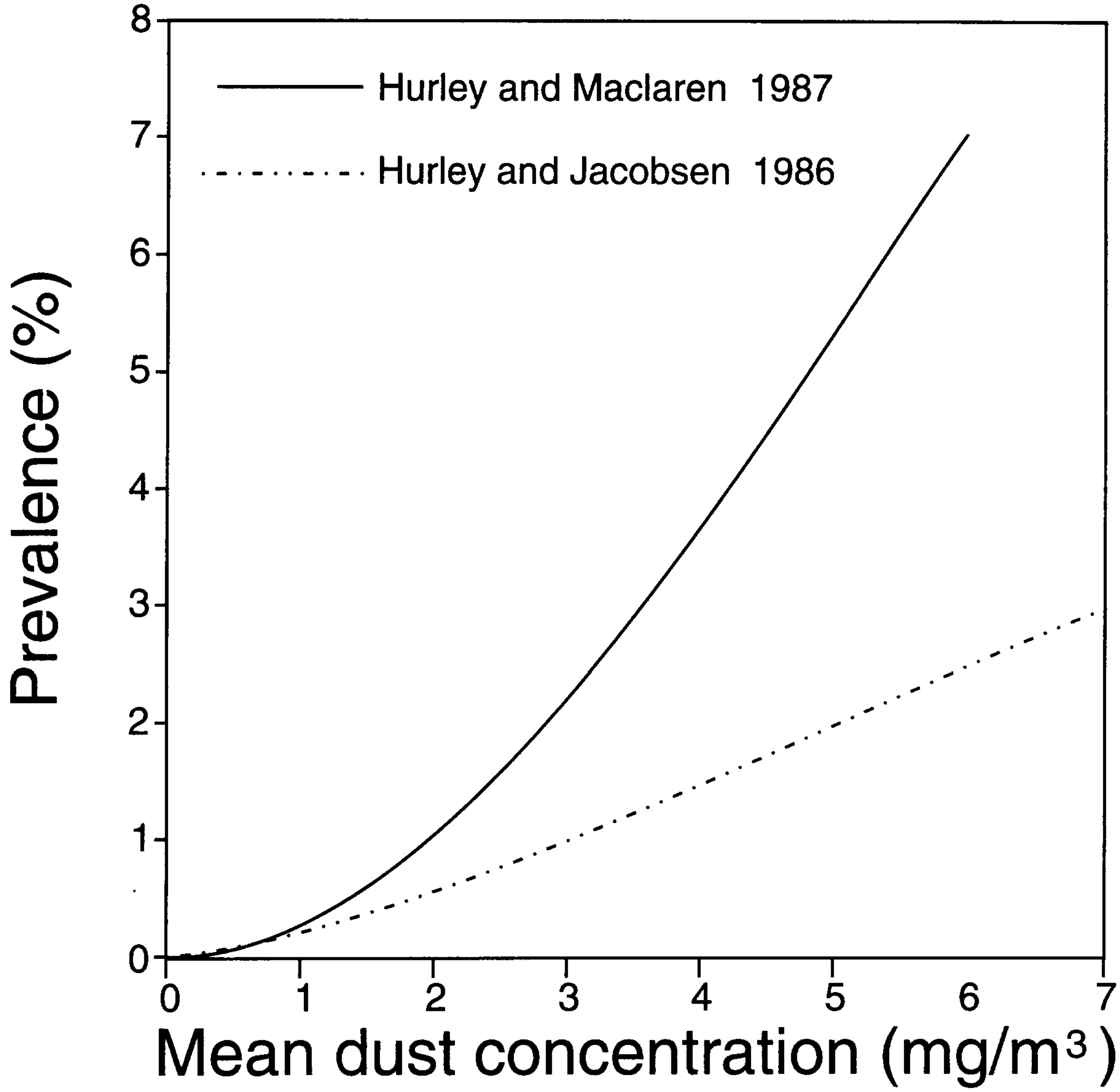

Figure 7–6. Predicted prevalence of PMF among U.K. coal miners after a 35-year working lifetime (1,631 hr/year), by mean concentration of respirable coal mine dust. (Source: Hurley and Maclaren [1987].)

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.

Study and coal rank	Disease category	Cases/1,000 at various mean dust concentrations 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.

Study and region	Lung function decrement	Smoking status	Cases/1,000 at various mean dust concentrations		
			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.

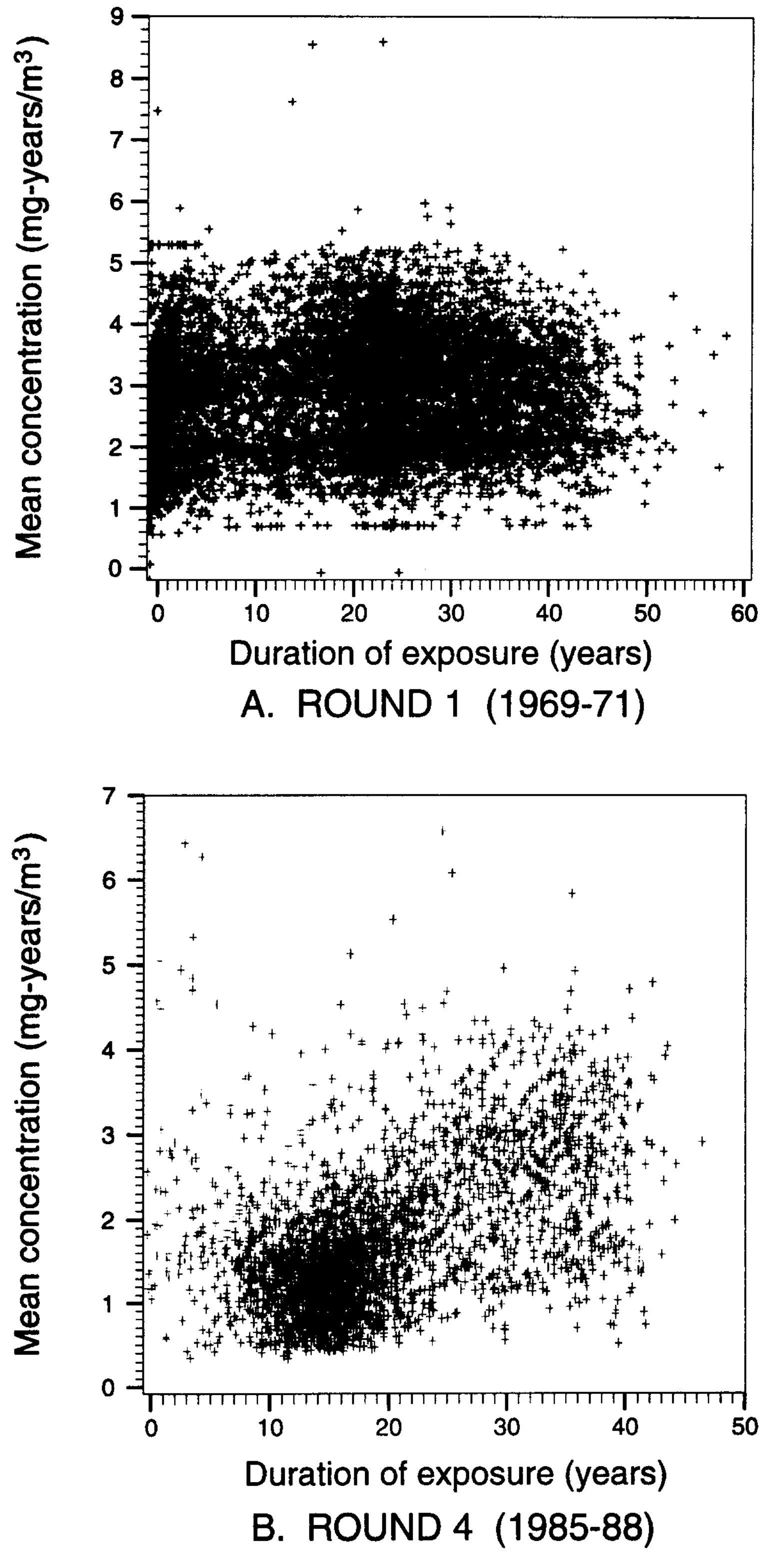

Figure 7–7. Exposures of miners participating in rounds 1 and 4 of the National Study of Coal Workers' Pneumoconiosis.

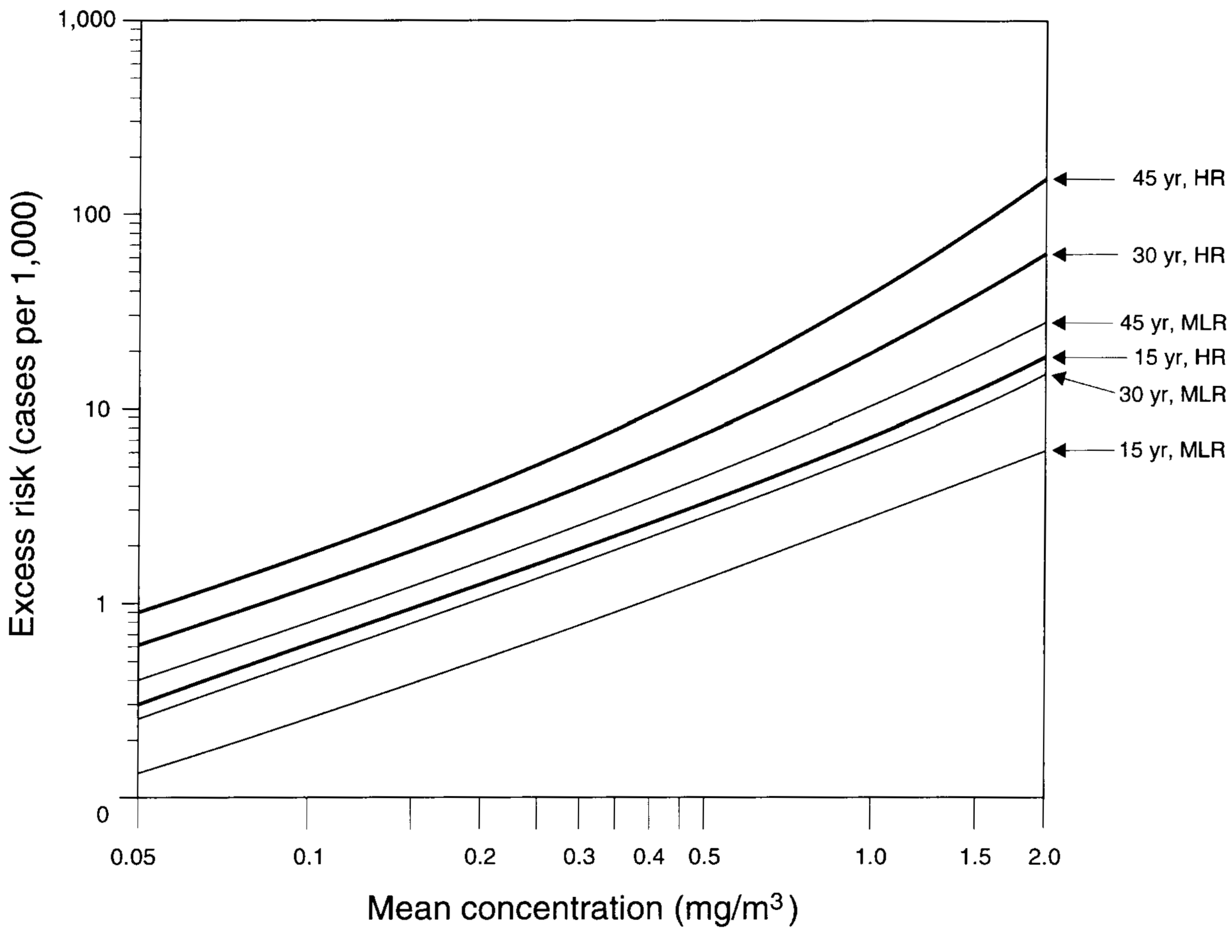

Figure 7–8. Excess risk of PMF in U.S. miners at age 65 by intensity (concentration) and duration (years) of exposure to high-rank coal (HR) or medium/low-rank coal (MLR). (Based on data from Attfield and Seixas [1995].)

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

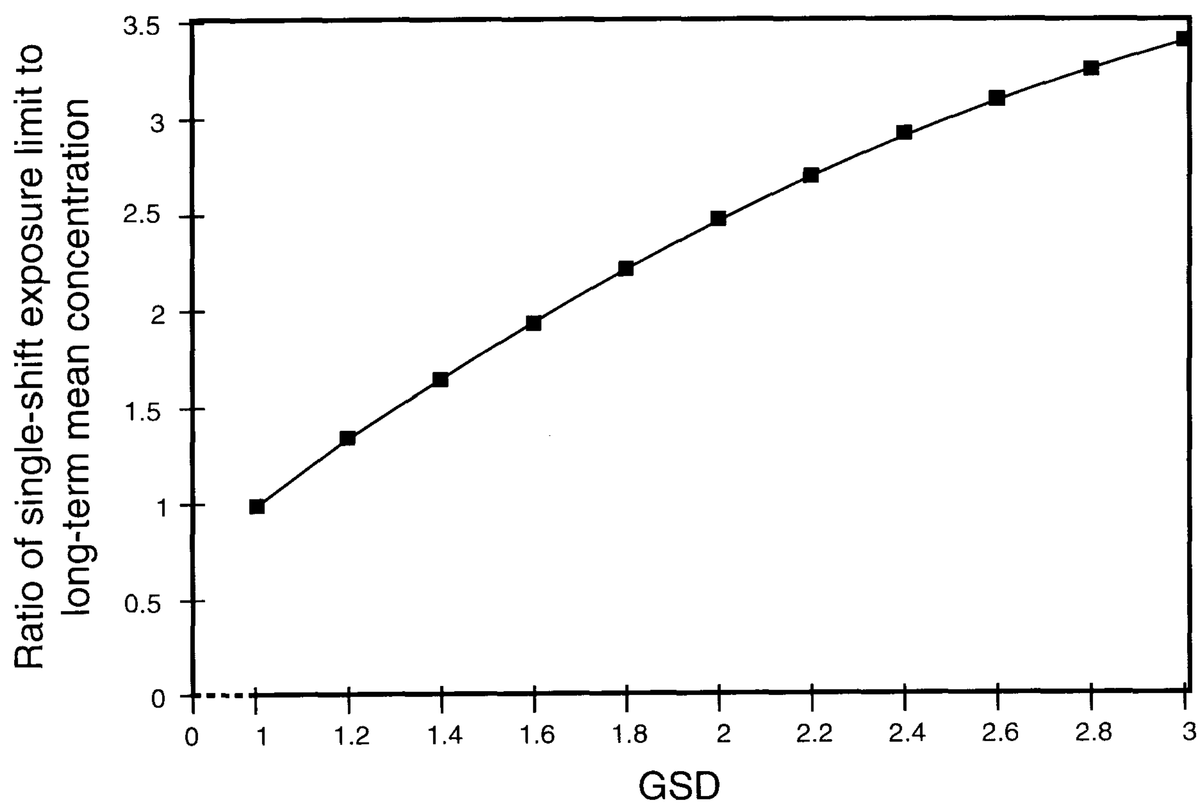

Figure 7-9. Relationship between the ratio of the single-shift exposure limit to the long-term average exposure (mean) and the variability in exposures (GSD), assuming that the probability of any measured single-shift concentration (C) exceeding the REL is 5% (i.e., probability [C>REL] = 0.05).

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-yr/m^3) and for miners exposed to 1 mg/m^3 for 40 years (also 40 mg-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

[††]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].