British Data on Coal Miners' Pneumoconiosis and Relevance to US Conditions

ABSTRACT

Objectives. The current primary federal dust standard for US underground coal miners of 2 mg/m^3 respirable dust is based on British epidemiological information on exposure-response derived in 1969. Since then, much new information has become available. This paper reviews and compares the available information as it relates to the US mining situation.

Methods. Recent exposure–response information on pneumoconiosis and dust exposure derived by British researchers was employed to estimate working-life risks of pneumoconiosis for miners exposed to 2 mg/m^3.

Results. It is estimated that close to 9% of underground coal miners who work for 40 years in a 2 mg/m^3 environment would develop pneumoconiosis (category 1 or greater). Progressive massive fibrosis would develop in 0.7%.

Conclusions. There are unresolved questions relating to the validity of extrapolating findings on British mines and miners to the US and also in predicting disease levels at the low end of the dust exposure spectrum. Given the data available, current information suggests miners who are employed for a working lifetime at the current federal dust limit of 2 mg/m^3 are still at risk of developing pneumoconiosis. (*Am J Public Health.* 1992;82:978–983)

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Introduction

It was not until 1969 that a nationwide limit was set on the level of dust to which US underground coal miners could be exposed. In that year, the Federal Coal Mine Health and Safety Act was passed.[1] This mandated that a dust standard of 3 mg/m^3 be imposed, with a reduction to 2 mg/m^3 to come into force in December 1972. (There is currently a requirement that dust levels be reduced further if the mine dust contains more than 5% quartz.) The intention was to prevent premature death and disability associated with coal workers' pneumoconiosis (CWP).

Owing to the lack of adequate epidemiological information on US underground coal miners at the time, those responsible for the law relied heavily on findings from overseas studies, primarily some interim results from Britain. Over the 23 years that have elapsed since the passage of the act, the British researchers have pursued their analyses further and developed more refined analyses. The purpose of this paper is to review both the initial and later results from Britain, and to discuss their applicability to the US underground coal mining situation.

After some preliminary background information, the paper outlines the scientific basis of the current federal 2 mg/m^3 standard. It then reviews the epidemiological findings that have been published since 1969 on British miners. Finally, it discusses some issues that involve the application of these results to US coal miners.

Note that this report is concerned only with CWP as determined through examination of chest x-rays; it does not deal with questions relating to the utility of the current dust standard in preventing other diseases, such as bronchitis and emphysema. Furthermore, no attempt has been made here to assess the efficacy of current disease-prevention measures through examination of CWP prevalence rates in US coal miners observed since 1969. Prevalence information is available in two reports: one on data from a national x-ray screening program known as the Coal Workers' X-ray Surveillance Program,[2] and one on results from a large continuing epidemiological study called the National Study of Coal Workers' Pneumoconiosis.[3]

Background

Coal mining existed in the United States for many years before it was accepted that many coal miners were suffering from occupational lung disease; and although silicosis was known to occur in some miners, the inhalation of coal dust with a low silica component was often thought to be harmless or even beneficial.[4] However, the accumulation of medical evidence to the contrary eventually led in 1969 to the enactment of federal regulations for the control of coal mine dust.

CWP is divided into two disease states: simple CWP and complicated pneumoconiosis (also called progressive massive fibrosis, or PMF).[5] In living coal miners, simple and complicated CWP are both almost always detected through examination of chest x-rays. The severity of simple CWP is measured in terms of the profusion of opacities seen on the x-ray

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and is recorded according to major categories (0, 1, 2, or 3), with each category being divided into three subcategories depending on the adjacent major category (e.g., major category 2 is divided into 2/1, 2/2, and 2/3). In this report, the emphasis is on rounded opacities (types p, q, and r), although recent evidence also suggests a relationship between irregular-shaped opacities (types s, t, and u) and coal dust exposure.[6] PMF is defined by the presence of one or more pneumoconiotic opacities of at least 1 cm in diameter. Miners who have simple CWP are at greatly increased risk of developing PMF, and this risk increases with category of simple CWP.[7]

In addition to the imposition of a dust limit, the federal act provided for a complementary radiographic screening program to identify miners who, for reasons of overexposure or individual susceptibility to dust, showed signs of CWP. Such miners are given the option of working in a low-dust (1 mg/m^3) environment while retaining their pay and benefits.

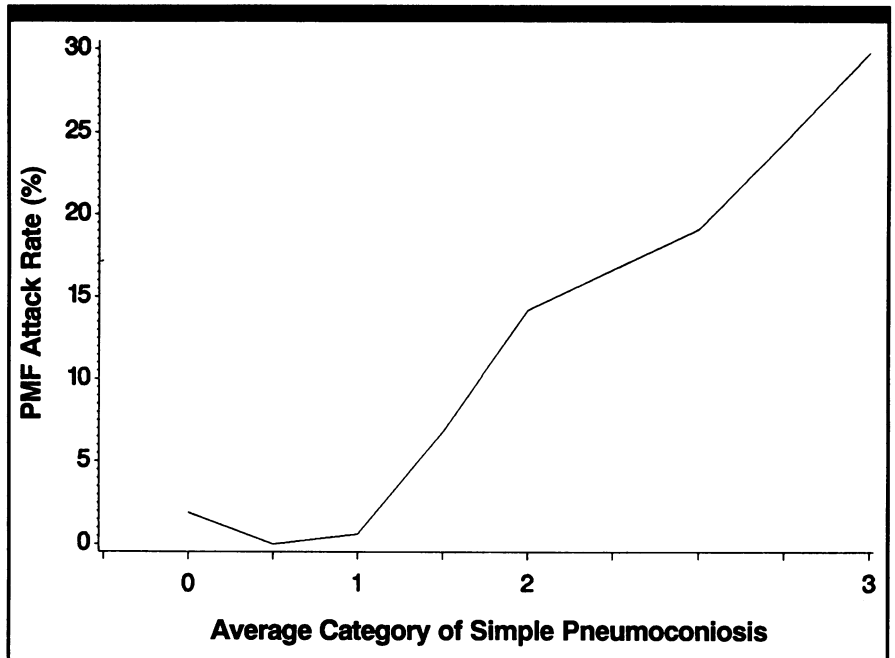

FIGURE 1—Relationship between category of simple coal workers' pneumoconiosis and progressive massive fibrosis (PMF) incidence over 8 years. Adapted from Cochrane.[7]

British Studies of CWP and Dust Exposure

British studies of CWP and other lung diseases associated with coal mining began in 1952. The principal program of investigation was the Pneumoconiosis Field Research (PFR).[8] In the PFR, coal miners working at mines located in all of Great Britain's major coalfields were medically examined at roughly 5-year intervals until the 1980s. Moreover, industrial hygienists were stationed at all the mines, their purpose being to assess the dust exposures of all miners prospectively as the study progressed. A systematic and intensive program of dust sampling was undertaken on all occupational groups, and the resulting mean dust concentrations were eventually linked with job tenure information gathered on each miner. Finally, respirable dust exposures that were developed for each miner were correlated with indices of lung disease in various studies, some of which are the subject of the following discussion.

The PFR must rank as one of the best conceived and managed epidemiological studies. Its features are a large number of subjects studied (initially 35 000 in 25 mines); continuous efforts to standardize data collection techniques and to minimize all sources of variability; a prospectively based program of dust exposure assessment, which was undertaken independently of any compliance sampling and was operated according to a scientifically designed plan of dust sampling; the collection of detailed time records of work performed by each miner; and excellent participation by miners in the study.

Basis for the Current Federal Dust Standard

In 1969, when the Federal Coal Mine Health and Safety Act was enacted in the United States, prevention of the disabling disease PMF was naturally one of its principal objectives. However, no information existed at that time that directly linked the degree of dust exposure to the risk of developing the disease. Nevertheless, two other important pieces of knowledge of relevance to this problem were available.

First, it was known that the risk of developing PMF was considerably greater among miners who had advanced simple CWP, such as category 2 or 3 (see Figure 1).[7] The abrupt rise in PMF risk associated with the higher categories of simple CWP suggested that PMF could be largely eliminated if progression to those categories could be prevented. Hence, it appeared desirable to limit the dust to a level where progression of miners to category 2 or greater simple CWP did not occur.

Second, based on data from the PFR, a curve had recently been developed, which related the risk of developing simple CWP category 2 or greater over 35 years to average dust concentration (Figure 2).[9] This curve was not derived from observation of incidence over that period but was actually extrapolated from results of a 10-year study, the Interim Standards Study (ISS).[10] From the 35-year curve, it was possible to identify the level of dust that would lead to any given degree of incidence of category 2 simple CWP or greater. Examination of the curve indicated that an exposure to 2 mg/m^3 coal mine dust would lead to zero incidence. Hence, it was argued, if exposures were kept to 2 mg/m^3 or below, miners would not progress to category 2 and thus would never get to be at high risk of developing PMF. It was on this basis that the federal standard was set at 2 mg/m^3. The Coal Workers' X-ray Surveillance Program was intended as a backup prevention strategy to identify those workers who might develop CWP despite dust control, and to enable such workers to work from then on in a low-dust environment.

Recent Information from the PFR on Exposure-Response for CWP

Although the strategy of preventing PMF through prevention of severe simple CWP was a reasonable course of action in 1969, given the lack of information that existed then on a direct relationship between PMF and dust exposure, it has a basic weakness. This was revealed in a

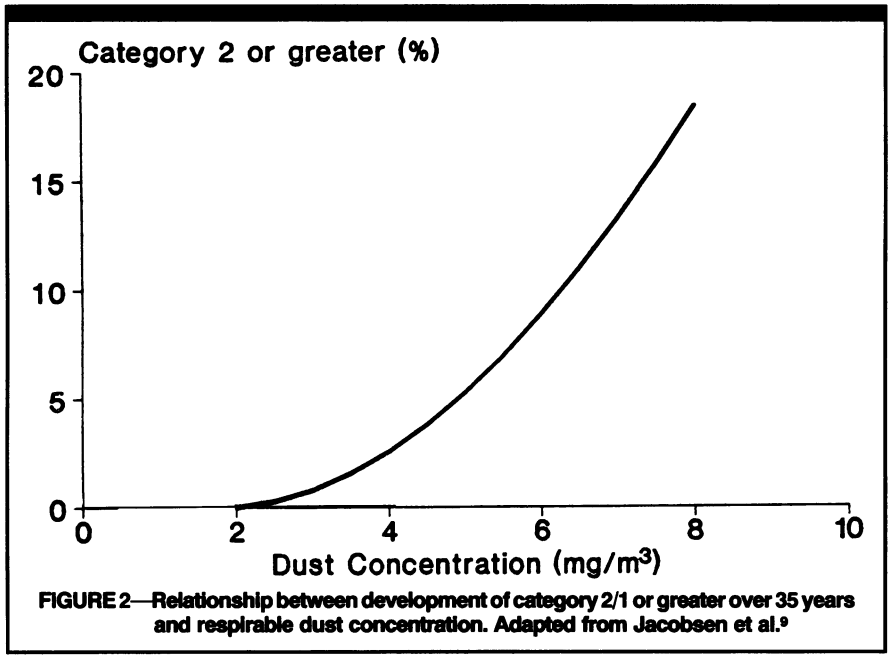

FIGURE 2—Relationship between development of category 2/1 or greater over 35 years and respirable dust concentration. Adapted from Jacobsen et al.[9]

series of articles that examined factors connected with the incidence of PMF.[11–14] The reports indicated that, contrary to Cochrane's findings,[7] the risk of PMF appeared somewhat lower for miners with categories 2 and 3 simple CWP but was rather higher for those with category 1. Because many more miners get category 1 CWP compared with those who get category 2 or 3, this implies that prevention of category 2 or greater would not eliminate the risk of getting PMF. In this respect, Shennan et al.[12] found that half the cases of PMF occurring in British miners over a 4- to 5-year period in the late 1970s were seen in miners who had category 0 or 1 at the initial examination. These findings suggested the need for an alternative approach to the prevention of PMF.

This new strategy was provided in the form of a curve linking PMF incidence directly to levels of dust exposure reported in 1985.[15] This curve was derived from data collected from 1959 to 1977 on over 30 000 British coal miners. Five-year estimates of the risk of PMF attack were obtained based on age and dust exposure; these were then compounded into 35-year predictions for various dust levels. The resulting curve indicated that an exposure to 2 mg/m^3 dust was associated with about a 1% risk of PMF. That is, 1 out of every 100 miners who worked for 35 years in an atmosphere containing 2 mg/m^3 of coal mine dust would be expected to develop PMF.

Although the above results suggest that coal miners who work for 35 years in a 2 mg/m^3 environment may be at risk of PMF, it should be noted that the analysis did not take into account the effect of secondary preventive measures—namely, x-ray surveillance and job transfer. In theory, people who exhibit early signs of CWP and then transfer to a low-dust environment should reduce their risk of progressing to a higher category of simple CWP and thus lower their chance of contracting PMF. To explore the effect of both primary and secondary measures on disease incidence in US coal miners, PFR researchers prepared a special analysis.[16] Their object was to determine what the incidence of PMF would be if a miner were to start work at age 18 and work until age 58 (a typical retirement age in US coal miners) in an atmosphere containing 2 mg/m^3 of coal mine dust, with transfer to a 1 mg/m^3 environment for those miners who were found by x-ray surveillance to have CWP category 1 or greater.

Latest Predictions of CWP Risk

Full details of the data and methods used to derive these predictions are provided by Hurley and Maclaren.[16] In brief, the results are based on virtually the same set of data used by Hurley and Jacobsen[15] and also described elsewhere,[13,14] but they included coal rank (percent carbon) as a predictor variable and used a refined method to extrapolate for lifetime risk. Results were obtained from observation of 52 264 approximate 5-year man-intervals of risk for 30 500 miners having reliable dust exposure records and x-ray readings over the period of 1953 to 1977.

Each man-interval of risk gave rise to four responses based on radiographic status at the end of the interval (category 1, 2, or 3, and PMF, category 0 being obtained by subtraction). These responses were modeled using logistic methods against initial category, age, dust exposure up to the initial survey, and coal rank (percent carbon). Support for the inclusion of this variable as well as the others can be found in earlier analyses of these data.[13] Predicted probabilities of x-ray change for 5-year age groups based on these models were then obtained by substituting various levels of dust exposure and percent carbon. (For example, 83% is an average value for the common US type "A" high volatile bituminous coal.) These 5-year probabilities could then be compounded into predictions for various ages up to age 58, assuming that every miner started in category 0 at age 18 (see Hurley and Maclaren[16] for the exact details). The effect of secondary preventive measures was allowed for by assuming that all those who were found to have category 1/0 or greater immediately worked from then on in a 1 mg/m^3 environment, as allowed for by the 1969 act.

Predictions of PMF and simple CWP levels for US miners obtained using these methods for a dust concentration of 2 mg/m^3 with 83% carbon are shown in Table 1 by age and category of CWP. They indicate that 0.7% of miners who worked their full working lives in coal mining at the present maximum of 2 mg/m^3 dust (1 mg/m^3 after contracting CWP) would have PMF at age 58, while close to 2.4% would have category 2 or higher (including PMF). Figure 3 shows two curves, one for PMF and one indicating the percentage of miners predicted to have category 2 or greater simple CWP at age 58 after 40 years of mining at dust levels ranging from 1 to 8 mg/m^3 at 83% carbon. (I computed the predicted values in Table 1 and Figure 3 from the results of Hurley and Maclaren, because they presented predictions only for 2 mg/m^3.)

The above predictions apply only to type "A" high volatile bituminous coal, a type of coal that is mined generally west of the eastern divide of the United States. They do not apply to the anthracite region in eastern Pennsylvania and to certain other areas, such as central Pennsylvania and counties in the southeast of West Virginia, where low volatile bituminous coal is mined. In both of those regions, the coal rank is higher, attaining levels of 89% or greater; and the risk of PMF according to the model is correspondingly higher, being estimated at about 1.8% for miners with 40 years of tenure at 2 mg/m^3 dust in

low volatile coals. The risk of category 2 or greater is estimated to be close to 5% in such miners. The predicted risks for anthracite workers are higher still.

Differences between Predictions

The predictions for category 2 or greater simple CWP that were derived from the various exposure-response curves show broad agreement. For 35 years' exposure, the predictions range from 0% for the ISS analysis to between 1.24% and 1.61% for the results derived by Hurley and Maclaren[16] and summarized in Table 1 (interpolated at age 53 for this comparison), depending on whether PMF is included (the ISS analysis did not take PMF into account). For the two studies involving PMF, the agreement is closer, the estimated prevalences at 2 mg/m^3 being about 1%, from Hurley and Jacobsen,[15] and 0.7% from Hurley and Maclaren.[16]

The differences seen between the curves from the various studies could have been due to a multitude of factors apart from random variation. These factors include the nature of the study group (longitudinal/cross-sectional), the period of study, the presence of miner selection effects, the type of x-ray reading performed, the x-ray readers, the x-ray classification used, and the methods of model fitting and extrapolation. Considering the potential for variation, the agreement between the various studies is noteworthy.

Each study has its stronger and weaker features in relation to the others. For instance, the latest analysis, by Hurley and Maclaren,[16] is based on the study of a very large group of coal miners for whom health-related selection effects were probably small. However, the very size of the group precluded the rereading of the films using a tightly controlled protocol. For the ISS group, the opposite was true: the miners were probably fairly highly selected, having to be predominantly face workers over a 10-year period to be included in the study, but the quality of the x-ray readings was high because the x-rays were all specially reread by eight readers.

Results from successive British analyses have suggested an increasing risk of CWP over that which seemed apparent when the 1969 federal law was enacted. Among the many possible factors that could be responsible for this increase, two are discussed further. The first involves the choice of models. This applies to the ISS analysis compared with the later studies. That initial investigation used a form of model that permitted the estimation of a threshold. In contrast, all later analyses have assumed a continuum of response down to zero dust exposure.

TABLE 1—Predicted Percentages of Miners with CWP by Age

CWP Category	Age at Start of 5-Year Interval							
	23	28	33	38	43	48	53	58
0	99.96	99.71	99.15	98.27	97.05	95.46	93.49	91.15
1	0.04	0.27	0.75	1.46	2.40	3.55	4.89	6.41
2	0.00	0.02	0.09	0.22	0.45	0.76	1.15	1.60
3	0.00	0.00	0.00	0.01	0.02	0.05	0.09	0.14
PMF	0.00	0.00	0.01	0.03	0.08	0.18	0.37	0.70

Note. These predictions assume miner starts work at 18, works continually in a 2 mg/m^3 environment, obtains an x-ray every 5 years, and transfers to a low-dust (1 mg/m^3) job immediately after category 1/0 or greater is seen. Predictions are derived from results of Hurley and MacLaren.[16]

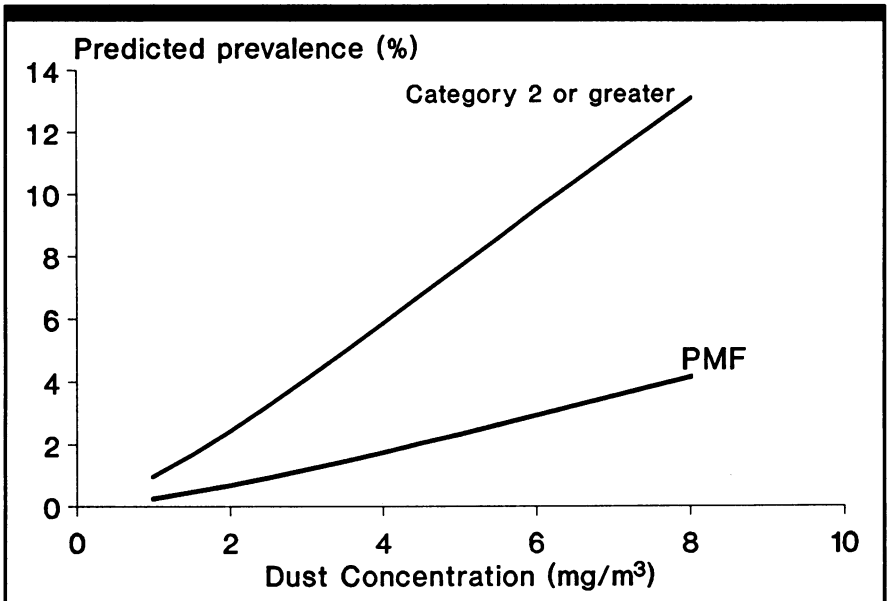

FIGURE 3—Relationships between dust concentration (83% carbon) and (1) development of category 2 or greater simple coal workers' pneumoconiosis, and (2) progressive massive fibrosis over 40 years (derived by using results given in Hurley and Maclaren[16]).

The second factor, which relates only to PMF, lies in the incorporation of information in the later studies that was ignored in the setting of the federal level: that is, incidence of PMF from simple CWP categories 0 and 1. In an early influential study of PMF incidence,[7] the risk of PMF from categories 0 and 1 appeared low compared with the obviously greater risk from the higher categories of simple CWP. For this reason, emphasis on prevention of category 2 became the major focus of the strategy for prevention of PMF. However, results from later studies of PMF incidence show a much lower gradient in risk across the categories of simple CWP, with increased risks for categories 0 and 1, and smaller risks for categories 2 and 3.[11–13] Furthermore, as exemplified in the findings of Shennan et al.,[12] the fact that most miners have category 0 or 1 simple CWP implies that a substantial fraction of the total number of PMF cases would arise from those categories, even though the risk for an individual miner might be small in that area. The later exposure-response studies with PMF as a response variable took into account this route of contracting PMF and, as a consequence, imply a higher overall risk.

Random variation obviously played a role in causing differences between the results from the various studies. However, only one of the studies provides estimates of uncertainty in the predictions. This was the ISS analysis, for which approximate confidence bounds for the 35-year predictions of risk were given. These actually indicate a range quite similar to that seen between the various PFR studies noted above.

Although the methods and models used in the PFR analysis have varied, the initial and latest studies used similar approaches to estimate the risks of CWP over a working life. In the recent Hurley and Maclaren analysis,[16] 5-year incidence and progression data were compounded into 40-year predictions. This technique is very similar to that used in the ISS, in which 10-year probabilities were compounded into 35-year estimated risks. Evidence that the ISS approach was reasonable was seen in the analysis of Hurley et al.,[17] which derived 35-year estimates of incidence directly without compounding and obtained very similar predictions to those of the ISS study (Figure 2). Hurley and Maclaren[16] expressed preference for the compounding method, since it employs the most important factor (initial category) for prediction of category 5 years later. They considered that the predictions derived using the compounding method[16] were more reliable than earlier results obtained using other methods.[15]

Application of British Results to US Mines and Miners

The validity of extrapolating results from previous studies of British mines and miners to the US situation is not known. Moreover, it may never be possible to determine exactly how valid the British findings are for the United States, given that such an evaluation would require knowledge that is now unavailable (such as that on particle-size distributions or composition for mines that are now closed). However, the following text discusses some of the more important aspects that should be considered.

Environmental factors of relevance encompass the nature of the coal mined and its surrounding or intermixed rock, coal mining practices, and other mine-specific variables. Hurley and colleagues have cautioned against indiscriminate use of their results in this respect: "There are several reasons, however, why the estimates might be inexact or misleading when applied to other conditions. . . . It is clear that at some collieries risks are far lower, or far higher, than the average values. This implies that our probability estimates will not necessarily reflect the risks to coal miners generally (in Britain or elsewhere) unless the dust concentrations and sources of unexplained colliery variability occur in a pattern broadly similar to that observed in this study."[17]

There are, however, several points of similarity between British and US mining conditions. The rank of coal mined in the two countries appears to vary over a similar range, from anthracite to high volatile bituminous.[18,19] Moreover, the average level of quartz in US mines currently also appears to be similar to that seen in British mines. Data from a recent analysis of quartz in US mines suggest that the overall mean quartz level is around 5%.[20] This compares with a mean mine average of about 4% reported for the PFR mines,[18] although this comparison does not take into account differences in the methodology used to estimate quartz levels.

Although the coals may be similar in general, there are some important differences in mining methods. Coal has been mined for many years in Britain using the longwall extraction system, a method that is relatively new to the United States. Mine operators in this country have relied on continuous miners and other coal-getting methods. Because the various methods may give rise to different particle-size distributions and involve cutting into roof, floor, or dirt band rock to differing degrees, the resulting dust clouds may vary considerably in type and composition and thus may have differing fibrogenic potential.

Another factor that needs to be considered relates to dust level estimation methods and procedures. Currently, these are different in the United States compared with those used in the British exposure-response studies. The latter involved the collection of dust concentration information, first using the thermal precipitator and then using gravimetric methods based on an instrument with a horizontal elutriator (the British Mining Research Establishment [MRE] dust sampler).[21] Later, the thermal precipitator data were converted into gravimetric equivalents using the results of comparative side-by-side sampling exercises. Furthermore, the British data were gathered according to a strategy designed specifically for epidemiological research. US procedures, in contrast, are somewhat different, being designed to assess compliance with the dust standards. Moreover, the samples are obtained using a cyclone instrument, the results of which are multiplied by a factor of 1.38 to make them equivalent to dust concentrations obtained using the MRE sampler. The uncertainties inherent in these different methods and procedures need to be considered when interpolating British exposure-response curves for application to the US coal mining situation.

Certain factors related to x-ray reading also need to be considered. First, there is evidence that US readers have tended to report more abnormality than their British colleagues in the past.[22] If this tendency still exists, prevalences of CWP estimated for US coal miners based on x-ray interpretations by US readers will be greater than those expected from the British exposure-response curves. Second, the results from the British studies summarized here were based on x-ray readings from international classification standards for pneumoconiosis that are no longer current. Because the classification is revised periodically with the introduction of different reference films, this change could easily affect the amount of abnormality reported in the future. Third, it must be noted that virtually all the PFR analyses have concentrated on small rounded opacities, whereas general US practice is to refer to combined opacity scores (rounded plus irregular opacity profusions). Moreover, the latest international classification[23] does not permit the independent assessment of rounded opacities in the same manner as past classifications. These factors imply that care will have to be taken in comparing future observed prevalences for US miners with predicted levels derived from studies using British readers and based on differing x-ray classification schemes and reference films.

Because conditions other than CWP can lead to the presence of x-ray markings that mimic simple CWP, it might be expected that a non-zero prevalence of abnormality would be seen in any cohort of subjects, including nonexposed workers. Moreover, this baseline prevalence would increase with age. Even though age is included in some of the British analyses, the form of the model forces the predictions to zero at zero dust. Hence, to date, this phenomenon has not been fully explored or incorporated into any existing analyses.

By law, current dust exposures for US underground coal miners must be less than 2 mg/m^3. This range of dust levels is actually at the extreme lower end of the range studied in the ISS analysis and other PFR analyses. Moreover, no systematic exploration of the form of the exposure-response curve in this region of dust exposure has been undertaken; hence, the proper form of this curve has not been established exactly. In particular, the existence of a threshold level of dust exposure below which no disease will occur cannot be ruled out.

As noted earlier, only the ISS analysis permitted a threshold to be estimated. There, an arc-sine transformation was fitted to the proportion of miners with cat-

egory 2 or greater simple CWP. This form of exposure-response curve is sigmoid shaped and resembles the probit and logistic transforms. It differs from them, however, in that the curve can touch the exposure axis at any point. In fact, the curve did touch the axis at dust concentration close to 2 mg/m^3, which may indicate that a threshold exists at that point. However, because no other form of model was fitted, it is not possible to determine whether the arc-sine curve was the most appropriate.

Although caution should be used in applying the British findings to the US situation, some evidence exists supporting their use. In 1984, results of a 9-year study of incidence of CWP in US coal miners were published.[24] These showed that the amount of incidence and progression of the disease was consistent with predicted levels from the initial British investigation,[9] given dust exposures mandated by federal law over the study period. These findings were supported by a study of new miners over a similar period.[25] However, these two studies covered too short a period for reliable long-term indications; further study is planned and in progress.

Evidence of a continuing trend toward lower prevalences of CWP in US miners has been reported recently.[2,3] Will the current federal disease prevention measures ensure that this trend continues until CWP is eventually eliminated from the industry? Evidence from the British studies suggests not, although the uncertainties inherent in extrapolation make it difficult to be sure as to the exact level and severity of disease to be expected. It should also be borne in mind that many miners do not transfer to a low-dust job after having an x-ray positive for CWP,[26] and that overexposure may be occurring.[27] Both phenomena suggest that observed levels of CWP incidence will be higher than those predicted. Finally, it should be noted that the results presented here are restricted to CWP; the potential for nonpneumoconiotic occupational lung diseases in coal miners should not be overlooked. □

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