The Derivation of Estimated Dust Exposures for U.S. Coal Miners Working before 1970

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A number of reports on the prevalence of coal workers' pneumoconiosis in U.S. coal miners have been published, yet very little is known about the relationship between dust exposure and pneumoconiosis levels in the U.S. This report describes the derivation of cumulative dust exposure estimates by back-extrapolation of data processed by the Mine Safety and Health Administration after 1970 by using a ratio of dust concentrations based on information collected during environmental surveys at certain U.S. mines by the Bureau of Mines between 1968 and 1969. Cumulative personal dust exposure estimates were calculated by using occupational histories obtained from the miners and job-specific estimates of dust concentration. In other reports, the resulting estimated exposures have been shown to correlate well with various measures of respiratory morbidity.

The current federally mandated limit of respirable coal mine dust to which U.S. underground miners may be exposed is 2 mg/m^3 (the 2 mg/m^3 limit is reduced if more than 5% silica is present in the dust). This limitation of coal mine dust concentrations became effective in October 1972 as a consequence of the 1969 federal Coal Mine Health and Safety Act (CMHSA).[1] The basis for this dust limit lay largely in British epidemiologic data,[2] as little information pertinent to exposure-response existed for U.S. miners when the Act was passed. Because it has yet to be established that the British data are applicable to the U.S. mining situation, one of the main objectives of studies undertaken on U.S. coal miners by the National Institute for Occupational Safety and Health (NIOSH) has been to determine the validity and effectiveness of this standard in protecting miners' health.

In this respect, a large amount of information has been reported by NIOSH concerning the prevalence and incidence of coal workers' pneumoconiosis (CWP).[3–6] These reports reveal a steady decline in CWP prevalence over the last 20 yr. However, because no information on exposure-response is given in those analyses, it is not possible to predict from them what future levels of CWP might be expected given exposure to dust at the current 2 mg/m^3 limit, or any other dust level.

This report describes the derivation of cumulative exposure estimates for a large group of coal miners by using environmental data collected at many of the mines at which they worked. These cumulative exposure estimates have been shown to correlate with respiratory health outcomes, as assessed by radiography[7] and by spirometry.[8]

BACKGROUND

Cumulative coal mine dust exposure estimates were generated for underground coal miners who had been examined as part of the National Study of Coalworkers' Pneumoconiosis (NSCWP), a nationally based, continuing epidemiologic study. The study began in late 1969 (shortly before imposition of dust control as mandated by the CMHSA) with medical surveys at 31 coal mines located from eastern Pennsylvania to Utah. During each mine survey, demographic data were collected from each participant, chest x-rays taken, ventilatory function measured, smoking and occupational histories recorded, and information on respiratory symptoms collected. The data used in this paper are drawn from the first round of medical surveys, which lasted from late 1969 until May 1971. The cumulative dust exposures generated pertain to the period from starting work until the medical examinations at the first round.

Three data sets were used to derive the cumulative exposure estimates for the group of miners studied in this paper. The first consisted of the work history data collected during the first round of the NSCWP.[3] The remaining two data sets consisted of large bodies of environmental data collected by using gravimetric instruments. The first of these resulted from certain surveys undertaken by the U.S. Bureau of Mines (BOM) between 1968 and 1969.[9] Over 4300 samples were taken in underground coal mines, 17 of which were later included in the first round of the NSCWP. The second environmental data set consisted of dust samples collected after 1969 by coal mine operators under mandate of the CMHSA and processed by the Mine Safety and Health Administration (MSHA), formerly the Mine Enforcement Safety Administration (MESA).

National Study of Coalworkers' Pneumoconiosis (NSCWP) Data

In the NSCWP, information on work history was elicited from miners by interview, including the dates of starting and stopping work in each job. Because the NSCWP until recently used the job coding scheme given in Lainhart[10] and the BOM data were coded by using the MSHA system, a conversion scheme was drawn up that related the MSHA jobs to those of the NSCWP. The scheme was prepared by NIOSH industrial hygienists familiar with coal mining with the assistance of MSHA personnel. A list of the most frequently reported jobs based on the Lainhart job categories is given in the Results section of this paper. The mean tenure in each job is also given.

U.S. Bureau of Mines (BOM) Data

The BOM data have been described in full by Doyle,[11] with a subsequent review by Jacobson.[9] Between 1968 and 1969, the BOM performed environmental surveys at 29 large mines, 17 of which subsequently became part of the NSCWP (NSCWP subset). A number of small mines were also visited. This appears to have been the first extensive use of gravimetric samplers in U.S. coal mines.

At each mine, airborne dust concentrations experienced by face and other workers were evaluated intensively over at least 10 shifts. Measurements were made by using packages of equipment including personal cyclone samplers[12] and some (British) Mining Research Establishment (MRE) samplers (see Dunmore et al.[13]). As the object was to obtain MRE equivalent concentrations for comparison with British data, the personal sample values were converted to MRE equivalents by using a factor of 1.6 derived from a comparison of cyclone and MRE dust concentrations obtained from side-by-side measurement.[9]

Data for some jobs were drawn from area samples. Overall, the area and personal data did not appear systematically different and were combined to form pooled estimates for the purpose of calculating exposures (see Discussion).

Mine Safety and Health Administration (MSHA) Data

The 1969 CMHSA imposed an interim dust standard of 3 mg/m^3 with a reduction to 2 mg/m^3 in 1972. Under the regulations arising from the Act, mine operators were required to perform frequent periodic sampling on so-called "high-risk" jobs. In addition, dust exposures of all underground workers, depending on the area of the mine they worked and on their health status,[14] had to be sampled at various intervals. These dust samples were required to be sent to MSHA for processing, the results being accumulated in a database. This database therefore contains thousands of records of dust concentrations for underground coal mining jobs. Data on surface occupations were also collected. Tabulation of dust concentrations from this database has revealed the downward trend in dust levels over the period 1970–1977 reported elsewhere.[15]

EXPERIMENTAL MATERIALS AND METHODS

Basic Approach

Although the BOM data set has a large amount of information for certain face jobs, little or no data exist for most other underground jobs and for all surface jobs. Hence, BOM data alone are not sufficient for the estimation of dust exposures for the entire cohort of miners.

The approach chosen to circumvent this problem was to back-extrapolate job-specific mean concentrations for the pre-1970 period by multiplying 1970–1972 MSHA job-specific mean dust levels by a factor of 2.3. The factor was obtained by averaging ratios of job-specific BOM dust means to 1970–1972 MSHA concentrations for every occupation where there were sufficient BOM data ($n > 10$ samples). Post-1970 concentrations were estimated directly from the MSHA data by job and year. Because the compliance sampling program was not fully operational during 1970, missing data for jobs for that year were extrapolated from 1971 data by using the same method as that used for the pre-1970 period (ratio = 1.26).

The validity of this basic approach is discussed later in this report. It is clearly not the only method that could be applied to these data. In order to be sure that other approaches did not lead to very different estimates and conclusions, other methods were explored (see Discussion). As described elsewhere, the other methods were not found to lead to very different findings nor to give rise to superior correlations when related to certain indexes of respiratory morbidity.[7,8]

Calculation of Dust Exposures

Once estimates of dust concentrations for the pre- and post-1970 periods had been derived for each MSHA job code, and after the data had been summarized into the NSCWP job categories, cumulative dust exposure estimates were calculated for each miner. The calculations took into account both the time worked before 1970 and the small interval between 1970 and the date of the miner's examination in the NSCWP. Accordingly, the formula used for this was as follows, where E_i refers to the cumulative exposure for miner i; C_{1j}, C_{2j}, and C_{3j} are the dust concentrations (mg/m^3) for job j prior to 1970, for 1970, and for 1971, respectively. T_{1ij}, T_{2ij}, and T_{3ij} are the respective times spent in job j before 1970, during 1970, and during 1971 for miner i:

$$E_i = \sum_j C_{1j}T_{1ij} + \sum_j C_{2j}T_{2ij} + \sum_j C_{3j}T_{3ij}$$

The summations in this expression are over all coal mining jobs worked by the miner. As an example, suppose a miner who was examined in 1971 had worked 20 yr in his current job for which the pre-1970, 1970, and 1971 concentrations were 1.20, 0.78, and 0.52 mg/m^3, respectively, and before that had worked 8 yr at a face job where the concentration was 4.22 mg/m^3. His cumulative exposure would be estimated by:

$$\begin{aligned} E &= (8 \times 4.22) + (18 \times 1.20) + (1 \times 0.78) + (1 \times 0.52) \\ &= 56.66 \text{ mg-yr/m}^3 \end{aligned}$$

or a weighted average concentration of 56.66/28 = 2.02 mg/m^3. The cumulative exposure estimates were converted into units of gram-hours per cubic meter (g-hr/m^3) by multiplication by a factor of 1740/1000 = 1.74. The figure of 1740 hr/yr was estimated from data on British miners[16] because information on U.S. miners was unavailable.

Allowance for Mine Effects

The above estimation method did not take into account possible systematic differences in dust exposures from mine to mine. In an attempt to derive mine-adjusted cumulative exposure estimates, each miner's unadjusted cumulative exposure was multiplied by a factor based on the ratio of the 1971 MSHA mine mean for the mine at which he was working at time of examination to the overall mean for all mines. Owing to limitations in the data (discussed later), these mine-specific exposures are not felt to be particularly reliable.

RESULTS

Table I gives a summary of the BOM data for the NSCWP subset and for the complete set organized according to relative dustiness based on the 1970–1972 MSHA data. The number of samples per occupation varied considerably with jobs associated with coal cutting (e.g., continuous miner operators and helpers, cutting machine operators and helpers, loading machine operators, roof bolters, section foremen, and shuttle car operators) being sampled most frequently.

Table I also shows the mean dust concentrations derived from the MSHA database for 1970, 1971, and the period 1970–1972. These means are based on large numbers of samples (usually thousands) and reveal a drop in dust levels from 1970 to 1971. Moreover, the means are usually substantially less than the BOM means based on a job-specific comparison.

Figure 1 illustrates the relationship between the BOM data and MSHA data for the five most sampled jobs in the BOM data set. The initial points are the mean concentrations based on the BOM survey data; the succeeding points are those derived from MSHA data collected between 1970 and 1974. The ranking of the five jobs according to BOM dust levels is almost the same as for the MSHA data in 1970, and very similar thereafter. Moreover, the data exhibit a reasonably consistent trend for each job from the BOM survey until 1974, when the declines in dust level flatten off. The obvious similarity in ranking between the BOM and MSHA data, coupled with the continuous nature of the trend, therefore supports the application of BOM data for estimation of dust concentrations prior to 1969.

Validity of Method Used

The validity of the back-extrapolation approach can be assessed in two ways. First, the data shown in Figure 1 reveal a consistent trend between BOM and MSHA data. Second, for surface jobs, where there are no BOM data, support for the concept of back-extrapolation can be obtained by consideration

TABLE I. Mean Dust Concentrations (mg/m^3) for the NSCWP Subset of the BOM Data, of the Complete Set of BOM Data, and of MSHA Data for 1970, 1971, and 1970–1972[A]

	NSCWP Subset Samples		*All BOM Samples*		*MSHA Data*		
MSHA Job Category	*Number of Samples*	*Mean Conc.*	*Number of Samples*	*Mean Conc.*	*1970 Mean*	*1971 Mean*	*1970–1972 Mean*
Continuous miner operator	200	6.0	486	6.8	3.7	2.8	2.4
Auger jack setter (intake)	31	3.4	73	5.7	2.3	2.2	2.2
Jack setter (longwall)	—	—	25	7.7	1.9	2.3	2.2
Rock duster	—	—	15	6.6	2.3	2.4	2.2
Cutting machine helper	19	7.9	68	6.4	2.7	2.1	2.1
Roof bolters	286	3.3	603	3.0	2.6	2.4	2.1
Cutting machine operator	95	6.2	363	5.1	3.5	2.4	2.0
Continuous miner helper	64	3.6	165	5.4	2.5	2.2	2.0
Loading machine operator	63	6.2	225	4.7	2.6	2.1	1.9
Blaster	43	6.0	134	4.8	2.4	2.2	1.9
Brattice men	13	1.6	34	2.4	2.0	2.2	1.9
Loading machine helper	12	6.0	44	4.5	—	2.1	1.9
Roof bolter helper	17	12.4	30	8.4	—	2.3	1.9
Supply men	13	1.6	20	2.1	2.1	2.0	1.9
Face beltmen, conveyor men	20	2.4	75	3.0	1.8	1.7	1.7
Nonface beltmen, conveyor men	35	3.0	60	2.8	2.0	1.9	1.7
Utility men	10	1.2	26	2.0	—	2.3	1.7
Laborer	—	—	19	3.0	2.0	1.7	1.6
Shuttle car operator	278	2.2	632	2.1	1.6	1.6	1.5
Coal drill operator	33	4.0	127	5.7	—	1.7	1.5
Section foremen	145	2.0	339	2.2	1.6	1.3	1.2
Electrician	—	—	11	0.9	1.5	1.3	1.2
Face mechanics	72	1.4	171	1.7	1.3	1.2	1.1
Motormen	—	—	19	1.8	1.0	1.0	0.9
Hand loaders	—	—	93	2.6	—	0.9	0.7

[A]Note: Data for jobs where the number of observations was less than 10 are omitted. The 1970–1972 MSHA means are based on a minimum of 533 samples, the average being over 20 000 per job.

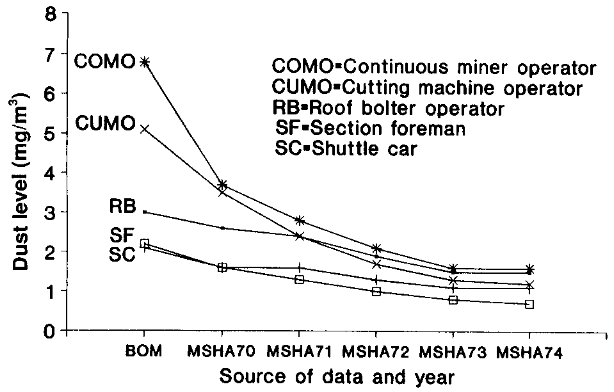

FIGURE 1. Comparison of mean dust concentrations for five heavily sampled jobs for the Bureau of Mines survey data and MSHA data collected 1970–1974

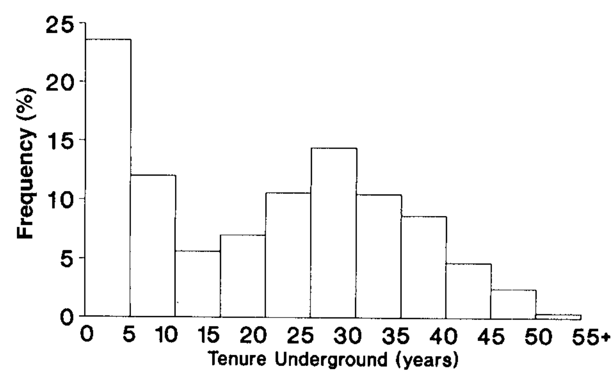

FIGURE 2. Distribution of reported tenure in mining for the 9071 NSCWP miners with work history information

of data relating to the effects of the reduction in the federal dust limit from 3 mg/m^3 to 2 mg/m^3, which took place in 1972. As might be expected, this drop in the dust limit was accompanied by a reduction in measured concentrations for underground jobs, the actual ratio being 1.47 for 1970–1972 relative to 1973–1979. Importantly, surface job dust levels also experienced a parallel decline (ratio = 1.69). This similarity of the surface job ratio to the underground job ratio for the 1970–1972 to 1973–1979 periods supports the assumption that a parallel phenomenon may have occurred for the two periods: pre-1970 to 1970–1972. Accordingly, in view of the above information, it appears reasonable to apply the ratio of the BOM to MSHA 1970–1972 data to that of the job-specific MSHA 1970–1972 data to derive reliable exposure estimates for jobs worked before 1970.

Description of Tenure Data

Tenure information was available for 9071 miners, the average job tenure being 8.7 yr (with average total tenure in mining being about 21 yr for a mean age of 44 yr). The overall distribution of tenure in mining, shown in Figure 2, reveals a bimodal dispersion with about 25% of the miners having worked less than 5 yr in mining. In contrast, the remainder of the distribution is fairly symmetrical, centered around 25–30 yr of tenure.

Table II gives information on those jobs reported most frequently (1% or greater of all reports) as grouped by the Lainhart occupational scheme, together with the mean tenure for each group. Because the MSHA job coding scheme is based on single distinct occupations, the correspondence between the Lainhart and MSHA schemes is obvious for most groups. Data for multiple MSHA jobs were pooled for those groups denoted miscellaneous in the Lainhart system. Note that Table II includes 83% of all the jobs reported by the studied miners.

Description of the Exposure Estimates

Figure 3 shows the distribution of the estimated exposures (dust concentrations) for the 9054 miners for whom they could be derived. The exposures were derived by dividing the cumulative exposure by the total tenure in mining for each miner. The mean estimated exposure was 3.0 mg/m^3 with a range from 0.1 to 8.7 mg/m^3; 95% of the exposures lay between 1.5 and 4.5 mg/m^3. The mean estimated cumulative exposure unadjusted for mine variations was 112 g-hr/m^3 (standard deviation of 81 g-hr/m^3) with 95% of the distribution lying between 4 and 250 g-hr/m^3. As might be expected, the estimated exposures were correlated with tenure underground (Pearson correlation coefficient = 0.85), although there is a wide spread of exposures among the older miners (Figure 4 shows a sample of the cohort obtained by taking every tenth miner).

TABLE II. Most Common Jobs Reported by the Miners as Coded by the Lainhart Scheme with Average Tenure Spent in Each Job

Lainhart Job Group	*Frequency (%)*	*Average Tenure (yr)*
Hand loaders, coal diggers, general miners	13	5.9
Shuttle car operators	7	7.9
Miscellaneous work at face	6	10.2
Motormen and brakemen	6	12.0
Roof bolters and helpers	5	6.2
Loading machine operators	5	10.1
Miscellaneous drillers and helpers, shotfirers and blasters, conveyor men, and helpers at face	5	7.8
Continuous miners and helpers	5	7.1
Miscellaneous work underground	4	7.6
Cutting machine operators and helpers	4	10.5
Section foremen and general supervisory	4	12.2
Miscellaneous underground maintenance	3	7.5
Timbermen	2	5.3
Bonders, trackmen, and helpers	2	6.2
Nonface beltmen	2	6.2
Miscellaneous surface activities	1	8.0
Ventilation men, brattice men, masons	1	8.5
Surface mechanics, general repairmen	1	12.2
Miscellaneous tipple activities	1	7.6

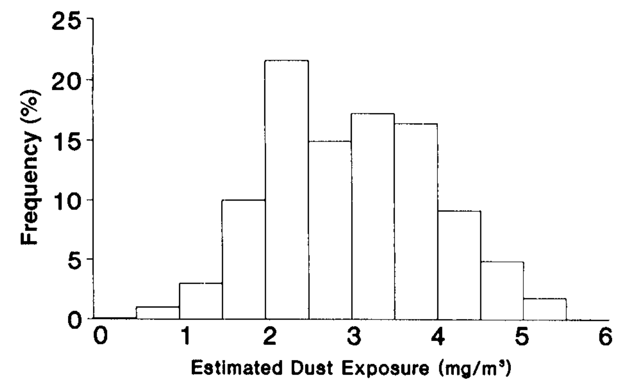

FIGURE 3. Distribution of estimated dust exposures

The mine adjustment factors ranged from 0.4 to 1.4. As would be expected, use of these factors led to cumulative exposure estimates having wider dispersion than the unadjusted estimates, the standard deviation being 96 compared to 81 g-hr/m^3. The Pearson correlation between the mine-adjusted estimates and the unadjusted exposures was 0.81; Figure 5 shows the mine-adjusted cumulative exposures plotted against the unadjusted estimates for a 10% sample of the data.

DISCUSSION

Personal cumulative respirable dust exposure estimates have been derived for a large group of underground coal miners. Although this group was studied about 20 yr ago, these exposure estimates are important and relevant for the following reasons. First, the study comprises a nationally distributed sample of coal miners who were medically examined over a relatively short period of time by using consistent methods and the same technicians. Second, because participation in the study was excellent (over 90%), the problem of selection bias is potentially less than for later rounds of the study (where participation has been lower). Last, the miners had worked in conditions where a much larger range of dust concentrations existed than apply today. This has facilitated the detection of exposure-response relationships, as is evident from the results of correlating these exposures with medical indexes.[7,8]

Although the estimated dust exposures (concentrations) for miners ranged from 0.1 to 8.7 mg/m^3, most of the exposures lay between 1.5 and 4.5 mg/m^3, a rather smaller range of variation than is suggested from the BOM data in Table I. It should be borne in mind, however, that the BOM dust concentrations were subject to two averaging processes in the creation of miner exposures: first, the combination of data by MSHA jobs into the broader Lainhart occupational groups and then a time-weighted averaging dependent on each miner's work history. These steps would be expected to reduce the range of variation in the observed individual exposures. In the first case, for example, the Lainhart scheme pools data for continuous miner operators, who had a BOM estimated exposure of 6.8 mg/m^3, with that for continuous miner helpers, whose dust level was rather lower at 5.4 mg/m^3. With regard to the time-weighted averaging, few miners spent all of their working life in the dustiest jobs, hence heavy exposures received while performing those jobs were usually diluted by the exposures caused by work in less dusty jobs.

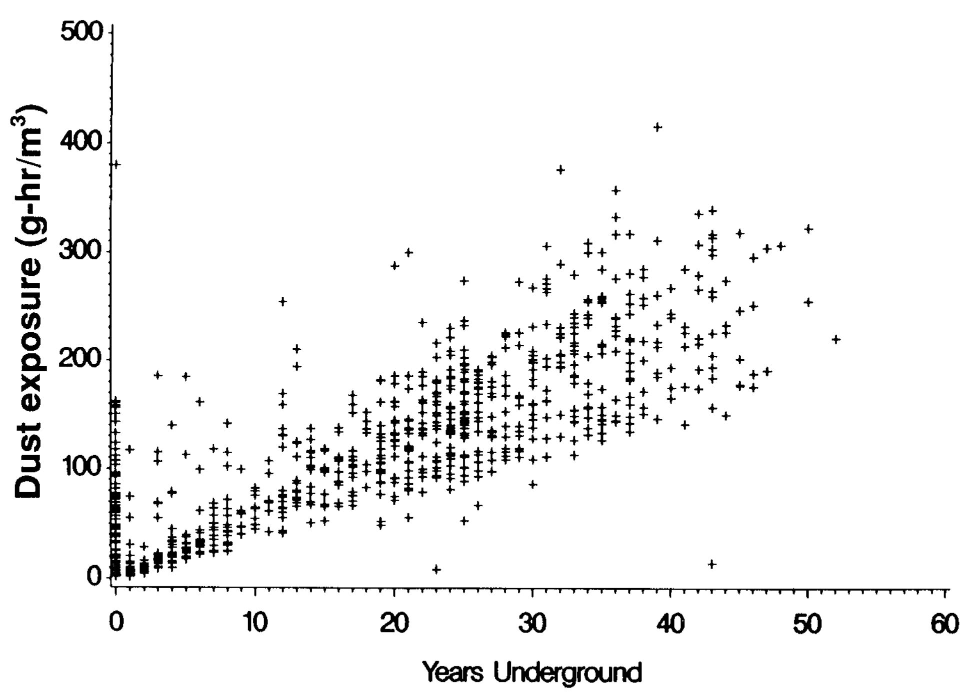

FIGURE 4. Relationship between estimated unadjusted cumulative dust exposures and tenure underground in a 10% systematic sample of miners from the NSCWP study group

The statistical precision of these dust exposure estimates should be excellent because they were based upon thousands of samples. However, accuracy must be considered also. One important factor that impinges on accuracy relates to temporal changes in dust levels before 1970. However, apart from the BOM data, very little reliable quantitative information on dust concentrations prior to 1970 exists. The general consensus of opinion is that dust levels rose with mechanization in the early 1950s and then remained stationary until the passage of the CMHSA.

Data collected prior to 1961 at 14 central Pennsylvania mines[17] indicate that average dust concentrations were not dissimilar to those shown in Table I of this report. The mean dust levels at the 14 mines for nine jobs, mostly at the face, was 3.7 mg/m^3 overall (using the rough conversion factor of 0.1 given by Peluso[18] to

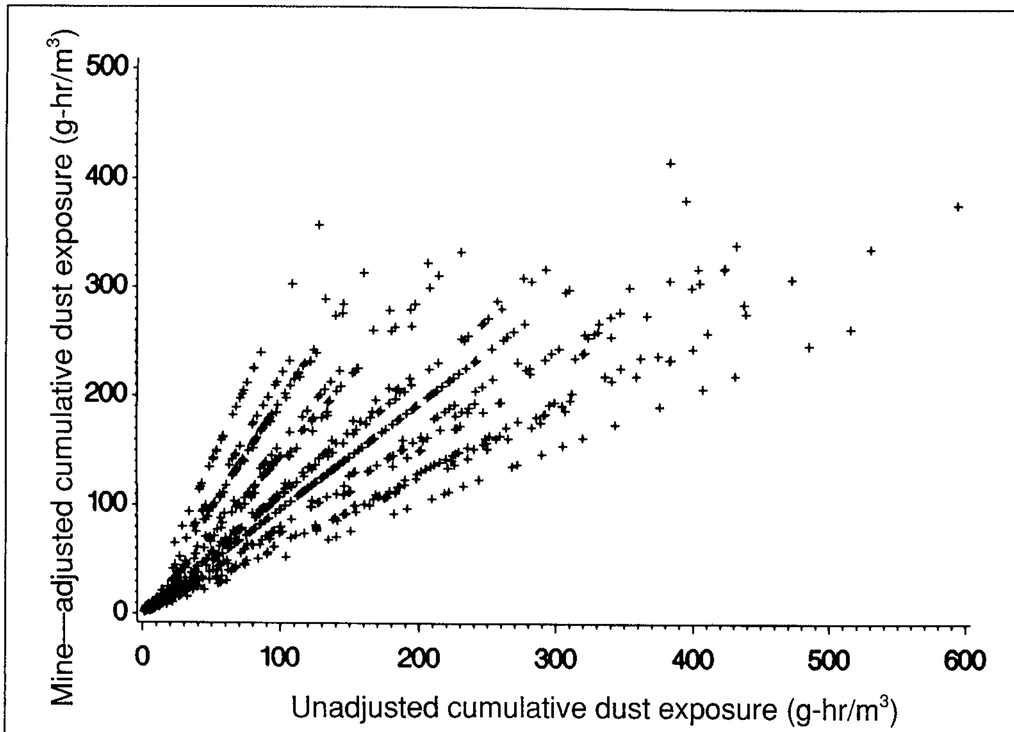

FIGURE 5. Relationship between estimated unadjusted cumulative dust exposures and mine-adjusted cumulative exposures in a 10% systematic sample

derive gravimetric concentrations from million particles per cubic foot), compared to an estimate from the BOM data of 4.4 mg/m^3 for the same group of jobs.

Another factor that impinges on accuracy is mine-to-mine variation in dust level. Various procedures were explored to allow for mine effects, but all had defects, and none were thought to be particularly reliable. The strategy adopted was to multiply the overall personal exposure estimates by factors derived from mean dust levels at the mines. Mine means from the BOM data and from the 1970 and 1971 MSHA data were considered. Each set had its limitations, the former having only 17 mines in common to the BOM data and NSCWP and generally sparse data per mine. The 1970 MSHA data for the NSCWP mines were also quite sparse and missing for some mines. For these reasons, these data were not considered further. Because data for 1971 were plentiful and were reasonably correlated with BOM mine means (Pearson correlation coefficient = 0.63), they were used for mine adjustment. However, the introduction of dust control measures after 1969 may have by 1971 substantially reduced the intermine differences to such an extent that they no longer accurately reflected the pre-1970 relative mine-to-mine variations in dust level. Overall, based on results obtained from correlation with various medical indexes, it appears that the attempt to derive mine-adjusted cumulative exposure estimates did not provide superior estimates to the unadjusted exposures.

One debatable issue in the derivation of these estimated exposures concerns the use of a common factor for back-extrapolation of the MSHA 1970–1972 data. Examination of the data given in Figure 1 and Table I leads to the impression that the ratios of the BOM data to the MSHA 1970–1972 data may differ systematically across jobs. There is also the suggestion that the ratios increase with the general dust level. In defense of the chosen strategy, four factors should be considered. First, it should be noted that a large part of the variation apparent in Table I is probably of random origin, particularly with regard to the jobs with relatively few BOM samples (e.g., the electricians). On the basis of standard errors for the numerators of the ratios, 95% confidence limits for 13 of the 25 ratios for the jobs given in Table I included the value 2.3 (variation in the denominators of the ratios can be ignored because of the large number of samples).

Second, for some of the remaining jobs, the ratio 2.3 was believed to be more valid than the actual, observed, job-specific ratios. For example, on the basis of the BOM data, pre-1970 dust levels were less than or equal to the MSHA 1970 and 1971 data for the supply man and utility man jobs. This does not seem reasonable. (Two other jobs for which use of the common ratio of 2.3 may be more appropriate are continuous miner operator and roof bolter—see the discussion below on combination of personal and area sample data.)

Third, the necessity of pooling the individual MSHA jobs into the broader Lainhart categories for matching with the work histories results in a reduction in variation in dust levels across Lainhart job groups compared to that across individual MSHA jobs. This tends to bring the pre-1970 to MSHA 1970–1972 ratios based on Lainhart job groups (which are of more practical relevance than the individual MSHA job ratios in Table I) closer to the mean of 2.3 used in the exposure derivation. For example, the Lainhart job scheme pooled coal drill operators, who had one of the largest ratios of the BOM to MSHA 1970–1972 data (3.8), with blasters and face conveyor men, who had ratios of 2.5 and 1.8, respectively (Table I). The lower ratios for these two groups counterbalanced that for drillers and led to a pooled value of 2.5, not far from the average of 2.3.

The last of the four factors for consideration concerns the results of attempting to derive exposure estimates based on variable ratios. In the first of these, the actual BOM job means were used directly to estimate the exposures, with MSHA data being used only to fill the gaps. The resulting exposure estimates had a mean and standard deviation of 100 and 79 g-hr/m^3, respectively, and were highly correlated with those developed by using the common ratio (Pearson correlation = 0.95). Use of these data in exposure-response analyses did not realize any advantages. In another attempt, a set of dust exposure estimates was generated by using variable ratios derived from a nonlinear model of the form

$$\text{BOM dust concentration} = \alpha(\text{MSHA 1970–1972 concentration})^{\beta}$$

in place of the form used for the other exposures, i.e.,

$$\text{BOM dust concentration} = \alpha(\text{MSHA 1970–1972 concentration})$$

Again, the resulting exposures did not correlate better with medical indexes in analyses of exposure-response.

Both personal and area sample data were used in the derivation of these exposure estimates. Inclusion of the area samples made little difference to the final results, the ratio of pre-1970 to 1970–1972 MSHA data rising slightly to 2.39 from 2.3 if they were omitted. Of the 760 area samples used in this study, 82% were taken in three jobs: continuous miner operator (232), cutting machine operator (177), and roof bolter (213). The mean area dust concentration for these three jobs was 4.9 mg/m^3 compared to a mean of 4.8 mg/m^3 for the personal samples for those jobs. Of these three jobs, the mean area and personal sample dust concentrations for the cutting machine operator were virtually identical, but the area samples indicated higher levels of dust for the continuous miner operator and lower levels for roof bolters. Interestingly, the latter two jobs had higher-than-average and lower-than-average ratios, respectively, in Table I.

Evidence exists that suggests that MSHA compliance data may be biased downwards.[19–21] In particular, Boden[19] noted that mine- and job-specific distributions of MSHA operator compliance data revealed greater than expected numbers of low samples compared to fitted lognormal distributions. These findings and reports may be relevant to the exposures described in this paper, because examination of the MSHA data used revealed the same general tendency found by Boden. In the main, this phenomenon is expected to have the greatest effect on those portions of a miner's cumulative exposure experienced after 1970. For most miners, this was only a small component of their total cumulative exposure. Any underestimation (or overestimation) in the MSHA data would have little effect on the pre-1970 portion of the exposures because the method adopted here is essentially self-correcting. For example, suppose the MSHA data used in this analysis were subject to a 50% downward bias. The true pre-1970 to MSHA 1970–1972 ratio would clearly be 1.15 instead of 2.3. However, because the true job-specific MSHA dust concentrations would be twice the observed values shown in Table I, the back-extrapolated, job-specific mean concentrations estimated by the chosen method would be unchanged.

Only 17 of the BOM mines were also NSCWP mines. Hence, it may be thought that the dust exposures should be derived by using only the data from those mines. If this is done, following the approach outlined earlier and using the means for the NSCWP mines shown in the left-most column of Table I, the back-extrapolation factor rises to 2.37, which is 3% greater than the figure for all BOM data of 2.30.

The figure of 1740 hr worked per year used in these exposure derivations was borrowed from similar British calculations. If a figure such as 2000 hr (i.e., 40 hr per week for 50 weeks) is thought more realistic for U.S. miners, the estimated exposures should be multiplied by a factor of 2000/1740 = 1.15. However, the hours worked per year may well be less than an average of 2000 owing to the effect of strikes and layoffs, which have periodically affected the industry. This factor would clearly be counterbalanced by any overtime worked. In one sense, the exact magnitude of this factor is immaterial, for if the same figure is used in interpolation of a fitted model as was used in the generation of that model, the prediction would be the same whatever size of factor was used.

The dust levels reported here appear to be quite similar to those experienced by British coal miners over roughly the same time period (1953–1973). For example, the group of miners studied by Hurley et al.[22] had a cumulative exposure of 183 g-hr/m^3 and a mean tenure in mining of 33 yr. This translates to a mean dust concentration over that period of about 3.2 mg/m^3, slightly higher than the estimated mean concentration of 3.0 mg/m^3 for the U.S. miners.

In summary, dust exposure estimates have been derived for a large group of underground coal miners. Application of these exposures to studies of exposure-response has led to detection of relationships between dust exposure and prevalence of CWP[7] and between dust exposure and ventilatory function.[8] These relationships were stronger than those obtained by using surrogate measures of exposure, such as tenure underground.

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