APPENDIX J

VARIABILITY IN SAMPLING AND ANALYTICAL METHODS*

J.1 MSHA GRAVIMETRIC METHOD FOR RESPIRABLE COAL MINE DUST

The current procedure for measuring the concentration of respirable coal mine dust is as follows. Each filter is preweighed by the filter manufacturer to ±0.1 mg. Following sampling with the Coal Mine Dust Personal Sample Unit (CPSU) at 2.0 L/min, the filter with coal mine dust is sent to MSHA for weighing. The current MSHA procedure for weighing respirable dust samples uses a Mettler Model AE163 analytical balance in conjunction with an automatic weighing system with a precision of ±0.02 mg [Tomb 1990]. Each balance is calibrated twice per day.

Quality control for the automatic weighing system includes the systematic weighing of one in eight filters on a second Mettler AE163 balance. Tolerance is set at ±0.1 mg between the two weighings of the same sample. Weights are truncated at the 0.1 mg level (e.g., 3.457 mg is truncated to 3.4 mg) [Bowman et al. 1985]. The difference of the two truncated weights is then recorded as the weight of coal dust deposited. The respirable concentration (mg/m^3) is computed by multiplying by a correction equal to 1.38 and dividing by the volume of air sampled (2.0 L/min × sampling time [min]).

J.2 WEIGHING IMPRECISION

The weighing inaccuracy corresponding to the MSHA weighing procedure has been estimated and is documented in Parobeck et al. [1981] and Bowman et al. [1985]. Including both the above truncation on the weights prior to subtraction and analytical errors (for example, due to balance inaccuracy or to filter mass instability), the estimated standard deviation σ_{weigh} in the measured deposited mass has been reported as:

$$\sigma_{weigh} = 0.081 \text{ mg}$$

The relative standard deviation (rsd)* in the respirable dust concentration estimates due to a weighing error (rsd_{weigh}) can be estimated, as illustrated in the following examples:

*Rsd may be approximated by the coefficient of variation (CV).

Example 1: The following conditions represent sampling at the current PEL for respirable coal mine dust (using the 10-mm nylon cyclone): sampling time, 8 hr; sampler flow rate, 2.0 L/min; respirable dust concentration, 2.0 mg/m^3. The rsd_{weigh} is given by the following equation:

$$rsd_{weigh} = [(0.081 \text{ mg} \times 1.38)/(2.0 \times 10^{-3} \text{ m}^3/\text{min} \times 8 \text{ hr} \times 60 \text{ min/hr})]/2 \text{ mg/m}^3$$
$$= 5.8\%$$

Example 2: The conditions corresponding to sampling at the REL (again using the CPSU): sampling time, 8 hr; sampler flow rate, 1.7 L/min; respirable dust concentration, 0.9 mg/m^3. Note that a correction factor (e.g., 1.38) is not required for the REL. The rsd_{weigh} is given by the following:

$$rsd_{weigh} = [(0.081 \text{ mg})/(1.7 \times 10^{-3} \text{ m}^3/\text{min} \times 8 \text{ hr} \times 60 \text{ min/hr})]/0.9 \text{ mg/m}^3$$
$$= 11.0\%.$$

Example 3: Similarly using the HD cyclone, the following conditions correspond to sampling at the REL: sampling time, 8 hr; sampler flow rate, 2.2 L/min; respirable dust concentration, 0.9 mg/m^3. Then, rsd_{weigh} is given by the following:

$$rsd_{weigh} = [(0.081 \text{ mg})/(2.2 \times 10^{-3} \text{ m}^3/\text{min} \times 8 \text{ hr} \times 60 \text{ min/hr})]/0.9 \text{ mg/m}^3$$
$$= 8.5\%$$

Note that the value rsd_{weigh} for sampling at the REL, using either the CPSU or the HD cyclone, is larger than rsd_{weigh} for sampling at the current PEL and sampling criteria. The NIOSH accuracy criteria for determining the acceptability of sampling and analytical methods are the following: 95% of a method's concentration estimates should be within 25% of the true concentration [Busch and Taylor 1981]. Translated to the method inaccuracy rsd, this means that rsd (or CV) must be less than 12.8% (even if the method has no systematic error) [Gunderson and Anderson 1980].

J.3 FEASIBILITY OF REDUCING WEIGHING IMPRESSION

For respirable dust samplers, rsd is composed of rsd_{weigh} as well as 5% from the sampling pump uncertainty [30 CFR Part 74 (1988)] and 5% from intersampler variability [Bartley et al. 1994]. With rsd_{weigh} as large as 11.0% or 8.5%, the weighing errors dominate the method inaccuracy. Thus, the total rsd can be significantly reduced by lowering the true uncertainty in weighing (σ_{weigh}).

σ_{weigh} itself is comprised of two parts:

$$(\sigma_{weigh})^2 = (\sigma_{trunc})^2 + (\sigma_{analy})^2,$$

where σ_{trunc} refers to the truncation procedure and σ_{analy} to the variability in the analysis itself. Truncation errors are analyzed as follows: Define the function $x_{trunc}(x)$ of a random variable x by dropping the decimal part of x. The error $\Delta = x_{trunc}(x) - x$ looks like a saw-tooth, falling from 0 to -1 between each integer. The mean or expected error $E(\Delta)$ is thus -1/2 (i.e., truncation is negatively biased). Similarly, $E(\Delta^2) = 1/3$, which means the variance σ^2 is

$$\sigma^2 = E(\Delta^2) - E(\Delta)^2 = 1/12$$

The bias cancels the *difference* between two such independent truncated numbers, but the variance is doubled. Thus, the standard deviation in the difference σ_{diff} is

$$\sigma_{diff} = 1/Sqrt[6]$$

With dust mass equal to the difference of two weights truncated at the 0.1 mg level, the standard deviation σ_{trunc} is 0.1 mg/Sqrt[6] or about 0.41 × 0.1 mg.

Thus, the two truncations lead to the following:

$$\sigma_{trunc} = 0.41 \times 0.1 \text{ mg}$$

where mass is the sampled mass. Therefore, σ_{weigh} = 0.081 mg implies that σ_{anal} = 0.070 mg.

For example, after 8 hr of sampling 0.9 mg/m^3 at 1.7 L/min,

$$\text{mass} = 0.734$$

and therefore,

$$rsd_{trunc} = 5.6\%$$

At rsd_{weigh} = 11.0%, this corresponds to

$$rsd_{analy} = 9.5\%$$

Thus, to reduce rsd_{weigh}, NIOSH recommends the following:

(1) Reduce rsd_{analy} by improving quality control of the weighing procedure itself. The figure 0.081 mg quoted above for the weighing precision is based on an early study [Parobeck et al. 1981] of weighing procedures employed in the past by MSHA in which filters are preweighed by the filter manufacturer and postweighed by MSHA using balances readable to 0.010 mg. MSHA has recently completed a study of the accuracy of weighing new "tamper-resistant" capsules using a 0.001 mg balance for the post-weighing, indicating imprecision equal to 0.029 mg [Kogut 1994]. The precision can probably be improved further. Bowman et al. [1985] reported imprecision equal to 0.010 mg using a single 0.001-mg balance for both preweighing and postweighing. This value is consistent with a study of Vaughan et al. [1989] of repeat filter weighings, although the actual attainable precision may depend strongly on the specific environment to which the filters are exposed between the two weighings.

(2) Essentially eliminate rsd_{trunc} by using scientific rounding (at no greater than the 0.01-mg level) instead of the current MSHA method of truncating measured weights at the 0.1-mg level.

J.4 DETERMINATION OF VARIABILITY IN SAMPLING RESPIRABLE COAL MINE DUST: ADJUSTMENT FOR BIASED METHODS

The statistical evaluation of workplace exposures as measured by unbiased sampling methods is described by Leidel et al. [1977]. However, when the sampling method includes bias, adjustment for that bias is made by adding the estimated value of that bias to the quantity 1.645*CV. Such bias adjustment is required when using performance-based sampling criteria. Performance-based sampling criteria enable the certification of any sampler meeting specified criteria to be used for sampling in accordance with the international definition of respirable dust. This bias associated with performance-based sampling results from the differences in the collection characteristics of an ideal laboratory sampler relative to those of a prospective sampler.

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APPENDIX K

ESTIMATES OF EXPOSURE VARIABILITY AND EXPOSURE PARAMETERS FOR SELECTED DESIGNATED OCCUPATIONS

K.1 INTRODUCTION

The primary purpose of this analysis was to derive the best possible estimates of the *within-occupation* geometric standard deviations (GSDs), using the Spot Inspection Program (SIP) data set [MSHA 1993]. Accurate estimates of the within-occupation GSDs are necessary in order to estimate the true long-term mean for a section that is, at given confidence (e.g., 95%), in compliance with the NIOSH REL for coal mine dust where the REL is defined as the maximum average exposure across a single shift.*

The SIP data set was chosen because it contains fairly recent data and therefore is likely to represent current conditions. Furthermore, the SIP data set is readily available; thus, the results reported here could be easily duplicated by any interested party.

The secondary purpose was to derive estimates of the exposure parameters (mean, standard deviation, geometric mean, and geometric standard deviation) for selected designated occupations. Such parameter estimates are useful for estimating the fraction of measured exposures that exceed the REL or any other value.

K.2 METHODS

A complete description of the SIP data set is provided in an MSHA report [MSHA 1993]. Briefly, the SIP consists of the operator-submitted exposure monitoring data for the three cycles (bimonthly sampling periods) preceding the "spot inspection" by an MSHA inspector. These spot inspections ended on October 31, 1991.

The SIP data set was analyzed using the SAS procedure PROC MEANS to derive estimates of the exposure parameters and SAS procedure PROC VARCOMP to derive estimates of the within-occupation GSD after accounting for variability due to mine and section within a mine.

*A section that is "in compliance" with the NIOSH REL is one in which single-shift exposures exceed the REL infrequently if at all.

The within-occupation GSDs for roof bolters (occupation code 46) were estimated after accounting only for variability due to mine because the MMU (section) number was not reported with the data.

Five occupations were included in this analysis: continuous miner operator, cutting machine operator, handloader operator, longwall shear operator, and roof bolter. These occupations primarily represent designated occupations, which are those occupations with the highest exposures and the most frequent sampling. The number of samples for these five occupations ranged from 392 to 6,818 (summed across all mines). Other occupations sampled had less than 30 measurements (summed across all mines), and these were excluded from this analysis.

Low-weight-gain (LWG) measurements (i.e., all measurements of 0.1 and 0.2 mg/m^3)† were removed from the data set, and the analyses were repeated. Thus, two sets of results were generated: those calculated with the LWG measurements and those without. The distributions of exposure for each occupation were examined to determine which set of results are likely to be the most representative of the true exposures. Justification for excluding LWG measurements was presumed to exist if the number of 0.1 to 0.2 mg/m^3 measurements was inconsistent with the remainder of the distribution.

K.3 RESULTS

The results of the components of variance analysis are given in Table K-1. Descriptive statistics for each of the occupations are given in Table K-2. Table K-3 contains descriptive statistics for the same data, but minus the LWG measurements. The GSDs in Tables K-2 and K-3 are greater than those given in Table K-1 because they were calculated directly from the data; thus, they include the extra variability due to between-mine differences and between-section differences within mines.

The number of measurements by concentration are provided in Figures K-1 through K-5 for each of the five occupations analyzed. The histograms for continuous miner operators (code 36), cutting machine operators (code 38), and roof bolters (code 46) suggest an overabundance of LWG measurements that may not be representative of the true distributions. Thus the estimates of the within-occupation GSD for these occupations (which was derived after excluding LWG measurements [column 7, Table K-1]) are most likely closer to the true values.

The handloader operators (code 39) apparently experienced much lower exposures than other designated occupations so that exposures of 0.1 and 0.2 mg/m^3 were common. The longwall shear operators (code 44) experienced generally greater exposures than the other designated occupations. The number of 0.1 and 0.2 mg/m^3 measurements appeared to be consistent with the overall shape of the exposure distribution. Thus, for both these occupations the GSDs derived using all the data are probably the best estimates of the true GSDs (column 4, Table K-1).

†MSHA defines low weight gain measurements as any calculated concentration of 0.1 and 0.2 mg/m^3 [MSHA 1993]. Such measurements, in principle, occur with any exposure distribution for coal mine dust, but an overabundance when compared with the rest of the exposure distribution suggests that some manipulation of the environment or sampling process may have occurred. Evidence of an overabundance of measurements below 0.3 mg/m^3 in mine operator-collected data was reported by Boden and Gold [1984].

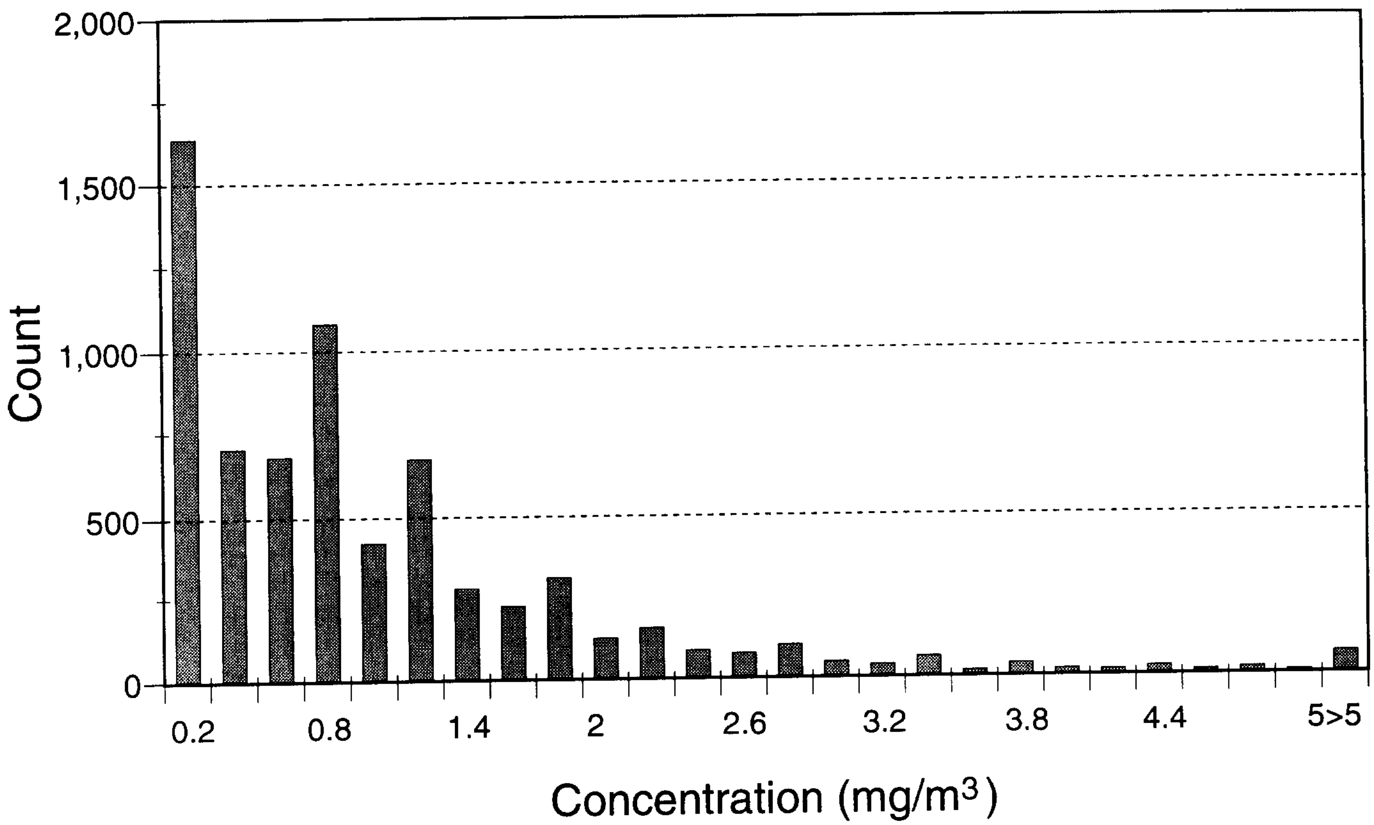

Figure K–1. Number of measurements by concentration for continuous miner operators (code 36) (SIP data).

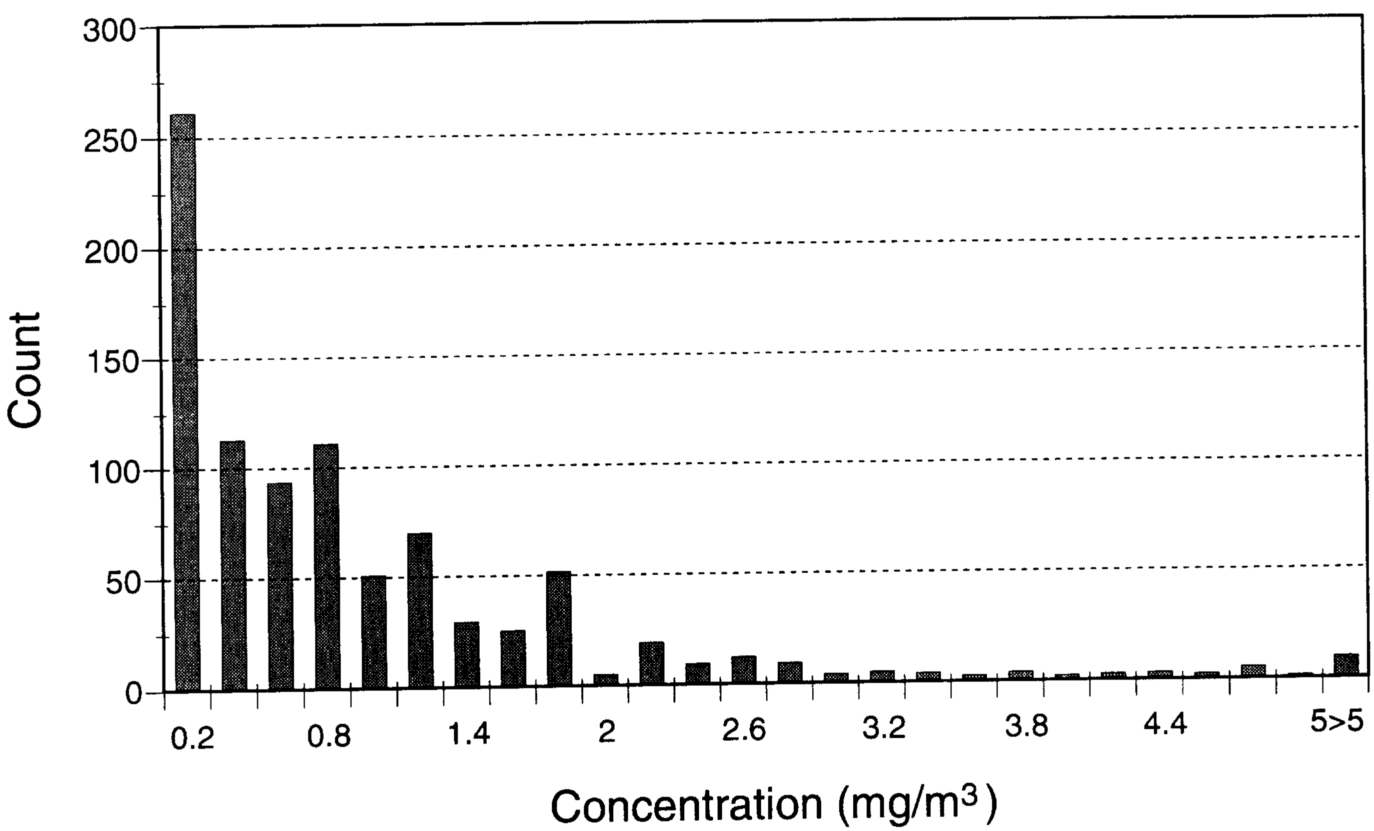

Figure K–2. Number of measurements by concentration for cutting machine operators (code 38) (SIP data).

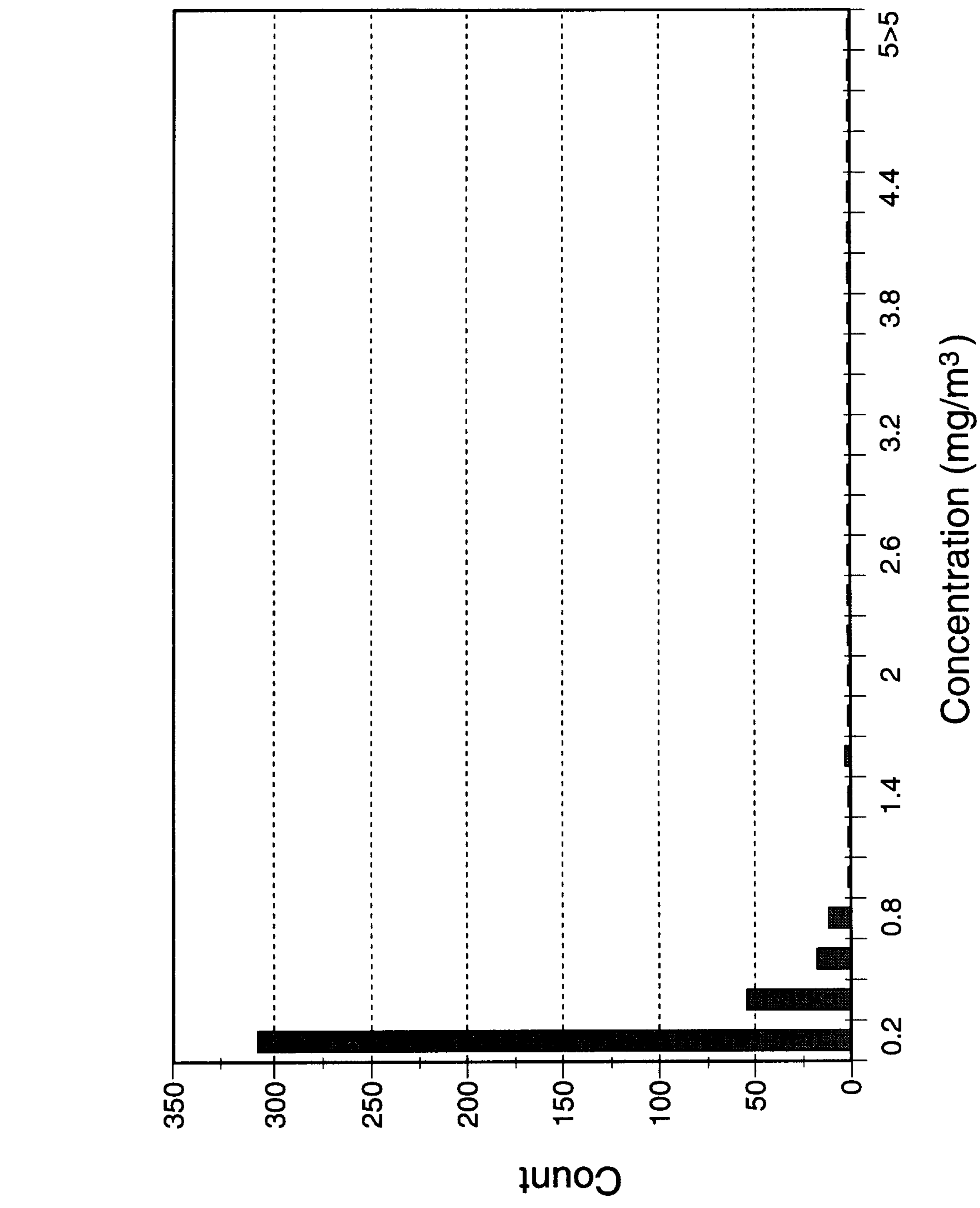

Figure K–3. Number of measurements by concentration for handloader operators (code 39) (SIP data).

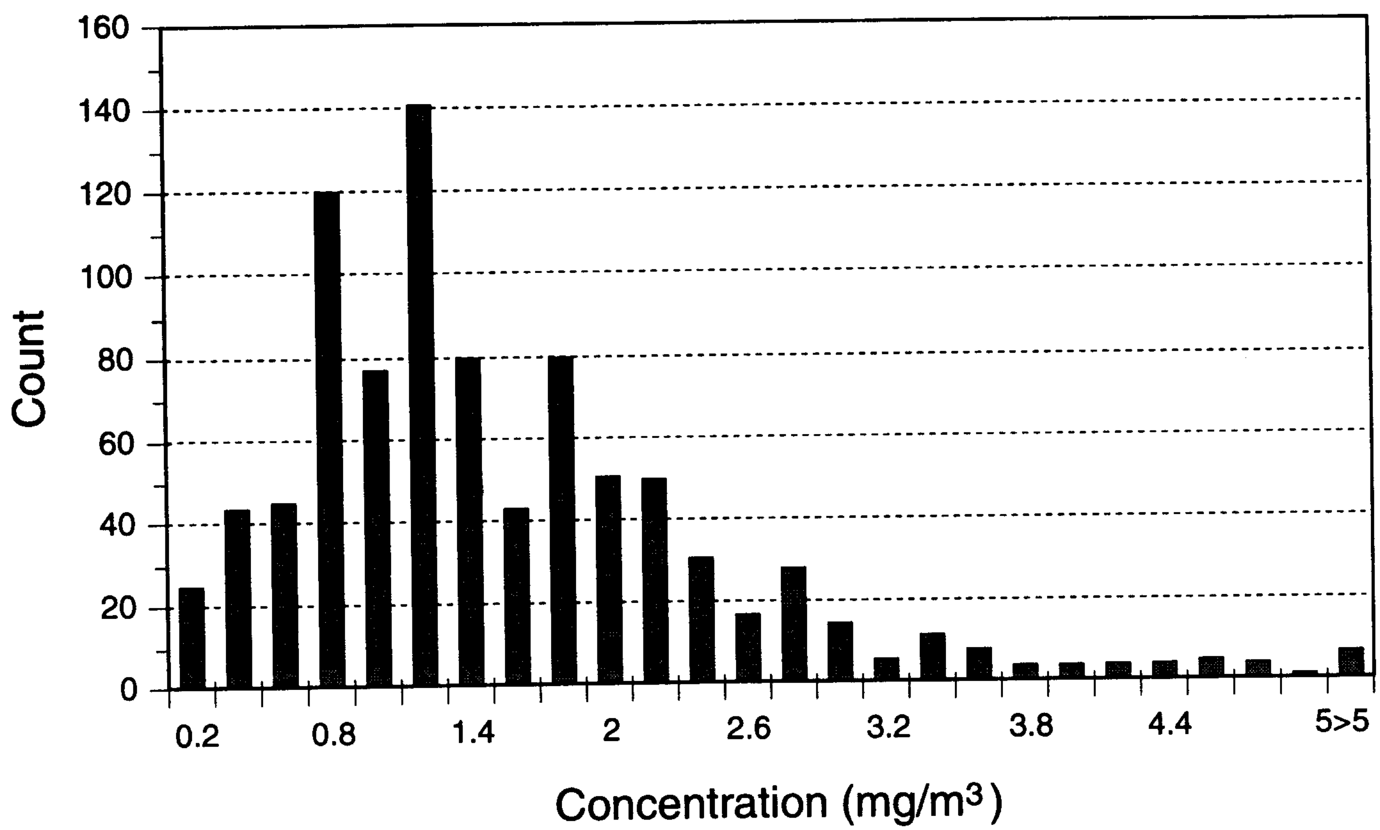

Figure K–4. Number of measurements by concentration for longwall shear operators (code 44) (SIP data).

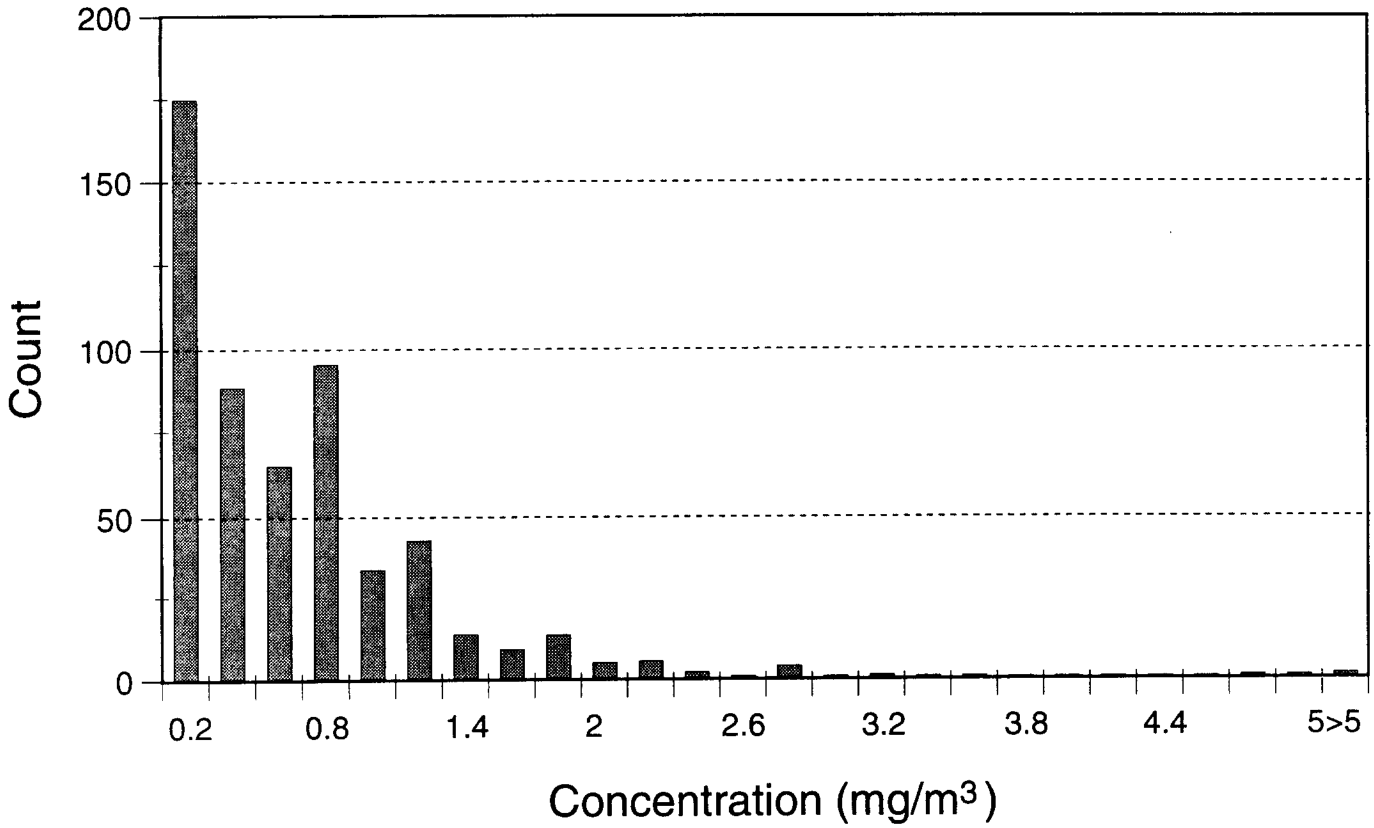

Figure K-5. Number of measurements by concentration for roof bolters (DA sample) (code 46) (SIP data).

K.4 COMMENTS

These statistics can be considered representative of the exposures that occurred *during sample days spanning roughly a 1-year period ending on October 31, 1991*. Analysis of data sets from earlier or later periods may lead to different estimates. The best estimates of the within-occupation GSD are marked with a double dagger (‡) in Table K-1.

Note that the GSD estimates, after accounting for variability due to mine and section (within mine) are not excessive, even when the LWG measurements are left in the data set. This was unexpected considering that the underground mining environment is typically characterized as being highly variable.

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Table K-1. Estimates of the within-occupation GSDs for the five occupations in the SIP data set with the greatest number of samples

		All data			LWGs excluded		
MSHA occupation code	Occupation	Number of samples	GSD*	Estimated mean mg/m^3 (θ=0.05)†	Number of samples	GSD	Estimated mean mg/m^3 (θ=0.05)
36	Continuous miner operator	6,818	2.36	0.35	5,172	1.79‡	0.45
38	Cutting machine operator	885	2.19	0.37	625	1.75‡	0.47
39	Handloader operator	392	1.68‡	0.49	85	1.81	0.45
44	Longwall shear operator	897	1.82‡	0.45	872	1.67	0.49
46	Roofbolter (DA samples)	559	2.34	0.35	384	1.70‡	0.48

*GSDs were estimated using the SAS PROC VARCOMP procedure both with and without LWG measurements after adjusting variability due to mine and section within a mine. The long-term mean exposure for a section with no more than 5% overexposures is given for each GSD.

†=P(c>REL)=P(c>1 mg/m^3).

‡Indicates the best estimates of the within-occupation GSDs.

Table K-2. Descriptive statistics for the SIP data set for five occupations, unadjusted for between-mine or between-section differences (includes LWG measurements)

MSHA occupation code	Occupation	Number of samples	Arithmetic mean (mg/m^3)	Standard deviation (mg/m^3)	Geometric mean (mg/m^3)	GSD
36	Continuous miner operator	6,818	0.97	1.03	0.60	2.81
38	Cutting machine operator	885	0.89	1.05	0.52	2.95
39	Handloader operator	392	0.23	0.90	0.14	1.96
44	Longwall shear operator	897	1.50	0.94	1.23	1.96
46	Roof bolter (DA samples)	559	0.65	0.66	0.44	2.54

Table K-3. Descriptive statistics for the SIP data set for five occupations, unadjusted for between-mine or between-section differences (excludes all LWG measurements)

MSHA occupation code	Occupation	Number of samples	Arithmetic mean (mg/m^3)	Standard deviation (mg/m^3)	Geometric mean (mg/m^3)	GSD
36	Continuous miner operator	5,172	1.23	1.06	0.97	1.92
38	Cutting machine operator	625	1.20	1.11	0.92	1.97
39	Handloader operator	85	0.68	1.87	0.45	1.79
44	Longwall shear operator	872	1.54	0.92	1.31	1.77
46	Roof bolter DA samples)	384	0.89	0.68	0.75	1.73

APPENDIX L

VALIDATION OF PREDICTIONS OF SMALL ROUNDED OPACITY PREVALENCE FROM ATTFIELD AND MORRING [1992]

L.1 INTRODUCTION

During review of the draft coal criteria document, a question was asked about the validity of the predictions of CWP prevalence made in Attfield and Morring [1992]. Specifically, was there any evidence from existing information about prevalence to confirm those predictions? To answer that question, data were tabulated from the Coal Workers' X-ray Surveillance Program for miners who worked for at least 10 years under dust conditions mandated by the 1969 Federal Coal Mine Health and Safety Act (Public Law 91-173). These data were then compared with the Attfield and Morring predictions.

L.2 METHODS

Data from the Coal Workers' X-ray Surveillance Program were used for verification, since they were not included in the study that developed the predictions. The requirement of 10 years or more of work in coal mining was imposed because CWP is usually a disease that develops slowly. See Attfield and Althouse [1992] for background information about the Coal Workers' X-ray Surveillance Program.

Data from rounds 3 and 4 of the Coal Workers' X-ray Surveillance Program were used (previous rounds were too close to 1969 to satisfy the 10-year tenure requirement). Prevalence of small rounded opacities was derived separately for the first and second readers, and the mean age for each tenure group was calculated. Although coal mine dust exposure has been associated with the development of both small rounded and small irregular opacities, small rounded opacities were used. For round 4, which used the 1980 ILO system [ILO 1980], small rounded opacity readings are not available specifically. To get around this problem, the following procedure was used. If the primary type was said to be rounded (p, q, r), the profusion category reported was taken to apply to rounded opacities. If, however, the primary type was said to be irregular (s, t, u), the rounded profusion was taken to be 0/0. Tenure was based on total years underground, that being the only record of work in mining available in the program.

Predictions were derived from the equations published in Attfield and Morring [1992] for category 1 or greater (1+) and for category 2 or greater (2+) (PMF was not investigated, as it was considered too subject to selection effects related to ill health). Since dust exposure information was not easily obtainable, rough estimates were made by multiplying the tenure for each group by 2 mg/m^3. Justification for this approach is given later. Predictions are given for high-volatile bituminous coals such as those mined in the western Appalachian region. These provide a reasonable overall estimate for the country since they represent most miners and fall between the higher predictions applicable to the small number of low-volatile miners and the somewhat lower predictions for the midwestern and western miners.

L.3 RESULTS

L.3.1 Round 3

Information was available for just two tenure groups: 10 and 11 years. The average number of miners, mean age, and observed and predicted prevalences by reader are listed in Table L-1. The first and second readers classified a slightly different number of chest X-rays. The mean observed prevalence from the first and second readers is also listed.

About 921 miners were in the 10-year tenure group (mean age 34). As can be seen, both sets of readers showed observed prevalences that were about twice those predicted. Basically, the same observation applies to the 11-year tenure group, which dealt with about 187 miners.

Round 3 information on category 2+ is given in Table L-2. For the 10-year tenure group, the predicted prevalence is again about twice that predicted. No category 2+ films were observed in the 11-year group, although this could be due to the small size of the group.

L.3.2 Round 4

For round 4, information was available for 9 tenure groups ranging from 10 to 18 years. Table L-3 provides the information pertinent to category 1+. The mean age increases with tenure from 35 to 43 years, and the number of miners (and thus chest X-rays) is generally much larger than that for round 3. Overall, prevalences based on the first readers are about twice those predicted from the model. In contrast, the reader-2 prevalences are generally similar to or slightly smaller than those predicted.

Table L-1. Observed and predicted prevalences of category 1+ from round 3 of the Coal Workers' X-ray Surveillance Program

Tenure (years)	Average number of miners	Mean age	Observed prevalence: 1st readers	Observed prevalence: 2nd readers	Observed prevalence: Mean	Predicted prevalence
10	921	34	5.5	5.2	5.4	2.4
11	187	34	5.3	7.1	6.2	2.4

Table L–2. Observed and predicted prevalences of category 2+ from round 3 of the Coal Workers' X-ray Surveillance Program

Tenure (years)	Average number of miners	Mean age	Observed prevalence			Predicted prevalence
			1st readers	2nd readers	Mean	
10	921	34	0.3	0.1	0.2	0.5
11	187	34	0.0	0.0	0.0	0.6

Table L–3. Observed and predicted prevalences of category 1+ from round 4 of the Coal Workers' X-ray Surveillance Program

Tenure (years)	Average number of miners	Mean age	Observed prevalence			Predicted prevalence
			1st readers	2nd readers	Mean	
10	3,058	35	4.3	1.5	2.9	2.5
11	2,182	36	4.6	2.1	3.4	2.7
12	2,159	37	6.0	1.5	3.8	2.9
13	1,755	38	6.6	1.9	4.3	3.0
14	1,312	39	6.4	2.3	4.4	3.2
15	866	40	8.7	3.5	6.1	3.3
16	536	40	9.4	3.3	6.4	3.5
17	394	41	8.5	4.2	6.4	3.7
18	266	43	10.7	6.3	8.5	4.0

The final table in this series presents the information on category 2+ (Table L–4). In this case, it is the classifications from the first readers that are most similar to those predicted, with the reader-2 prevalences being considerably lower in general.

L.4 DISCUSSION

A model is correctly and properly verified by using an external observed data set whenever possible. However, the usefulness of the exercise depends on how similar the external data set is to the predictor data set. In the present case, there are many points of difference, and hence the validity of the comparison can be questioned. These differences include the following: different X-ray readers, different ILO systems, very different miner participation rates, and different mines. Another

Table L–4. Observed and predicted prevalences of category 2+ from round 4 of the Coal Workers' X-ray Surveillance Program

			Observed prevalences			
Tenure (years)	Average number of miners	Mean age	1st readers	2nd readers	Mean	Predicted prevalence
10	3058	35	0.6	0.1	0.4	0.7
11	2182	36	1.0	0.1	0.6	0.7
12	3159	37	0.9	0.1	0.5	0.8
13	1755	38	0.9	0.0	0.5	0.8
14	1312	39	0.7	0.2	0.5	0.9
15	866	40	1.2	0.3	0.8	0.9
16	536	40	1.3	0.2	0.8	1.0
17	394	41	1.0	0.3	0.7	1.0
18	266	43	1.9	1.5	1.7	1.2

Another difficulty is that the actual degree of dust exposure experienced by these coal miners is problematic. Each of these topics will be considered in turn.

The predictions are based on the classifications of a solitary (though very experienced) reader. The classifications for the verification data sets, on the other hand, are based on readings by many readers of variable experience. It is not known whether there are systematic differences between the single reader and the readers from the Coal Workers' X-ray Surveillance Program; but it is to be expected since the first and second readers from the Coal Workers' X-ray Surveillance Program appeared to be systematically different from each other. Which of the two sets of readings from the Coal Workers' X-ray Surveillance Program is to be preferred? There is no certain answer to this, but the second readers (being all B readers) demonstrated better reading competence than the first readers (some of whom were NIOSH A readers).

Some differences between the prediction and verification data might be expected to arise from the use of different ILO systems. The prediction data set was based on the 1968 UICC/Cincinnati scheme [Bohlig et al. 1970]; whereas, the data from rounds 3 and 4 were derived using the 1971 and 1980 ILO classifications [ILO 1980, 1972], respectively. Some readers have suggested that the standard films included in the 1971 set included one for category 1 that resulted in more positive films being recorded than with previous versions. Obvious problems are involved with the round 4 classifications, for the 1980 ILO procedure for classifying small opacities was substantially different from previous versions. In this, the rounded and irregular opacities were no longer classified separately: they were read in combination. As a consequence, there is no way with the 1980 system to get readings of small rounded opacities that are identical in concept to those for the 1971 and earlier versions of the ILO system. The procedure adopted in this report derives what might be called pseudo-small rounded opacity classifications, and they may or may not reflect what would be read if separate readings of rounded opacities were actually made.

Another point of difference relates to participation rates. Until recently, participation in the Coal Workers' X-ray Surveillance Program has been very high. Unfortunately, no information existed to assess whether those who participated were typical of the complete mining workforce or were biased in some respect. In contrast, the participation rate in the predictor data set was >90%. The effect of worker selection should therefore be borne in mind in this comparison.

The last point of difference concerns mine selection. The prediction study was based on larger mines. However, since the Coal Workers' X-ray Surveillance Program is open to all underground miners, it is likely that the verification data set includes many miners from small mines. If work practices and dust conditions were systematically different in smaller mines and larger mines (which seems quite possible), this difference would be reflected in different levels of CWP.

Finally, the problem of assigning an exposure to the miners in the verification data set (Coal Workers' X-ray Surveillance Program) will be considered. Dust exposure measurements are available for virtually all miners by social security number from 1970 to 1979. However, calculation of mean exposure for each miner was rejected because of the massive effort it would require. Millions of dust exposure records are spread over about 20 computer tapes. To search them and calculate exposures would have taken too long for the result to be useful. In any case, the exposures would have accounted for only part of the miners' tenure in mining, especially for round 4.

Instead, another approach was adopted. This approach assigned a constant dust concentration to each miner (2 mg/m^3). Choice of a common concentration is not a serious problem, as the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) led to a substantial narrowing of the range of dust concentrations experienced. If 2 mg/m^3 seems too high, remember that the standard was 3 mg/m^3 from 1970 to late 1972 and that there have been persistent reports of dust sample tampering. In view of these considerations, 2 mg/m^3 was thought to be a reasonable exposure. (In any event, the results presented here are not too different if 1.5 mg/m^3 is used in place of 2 mg/m^3.)

L.5 CONCLUSIONS

The results of this exercise suggest that the predictions from the Attfield and Morring [1992] paper are not excessive. Rather, there is some indication that these predictions may underestimate the actual prevalence of small rounded opacities.

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