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Assessment of Historical Exposures to Talc at a Mining and Milling Facility

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The purpose of this study was to develop an estimate of exposure to respirable dust for all job categories and all years in a retrospective follow-up study of worker mortality in a talc mining and milling facility. All jobs were assigned to work areas that were considered to have similar exposure profiles. Uniform exposure time periods during which non-random, deterministic variables were thought to be constant were identified and an experienced rater assigned categorical exposure scores to each work area/time period. These scores and measured baseline respirable dust concentrations were used to calculate the estimated job area/year concentrations for each work area/time period. Estimates were compared to available historical measurements. The estimated exposures ranged from 1.7 to 0.1 mg/m^3 and displayed a decreasing trend over time. When compared with measured exposures, the estimated exposures had a correlation coefficient of 0.55 with an average difference of 0.01 mg/m^3 and a range of 0.60 to –0.48 mg/m^3. The estimates were considered to be acceptable for determining relative ranking of subjects according to cumulative exposure.

Keywords: exposure estimation; occupational exposure; talc

INTRODUCTION

The purpose of this investigation was to develop a job–exposure matrix for respirable dust, covering all work areas in an industrial grade (tremolitic) talc mining and milling facility in upstate New York as part of a retrospective follow-up study of mortality among workers at this facility (Honda *et al.*, 2002). The facility started operating in 1948 with the opening of an underground mine (mine 1) and a mill (mill 1). An open pit mine (mine 2) opened in 1974. Talc from the facility was used predominantly for paint and ceramic tiles.

The job–exposure matrix consisted of an estimate of the average respirable dust concentration in each work area and each calendar year from 1948 to 1989. The estimated dust concentrations were derived from exposure scores, ranging from 1 (low) to 10 (high), for each work area and year, and from reference dust concentrations measured in surveys in 1991 to determine average concentrations under current operating conditions. The matrix was linked with employees' work histories to estimate the cumulative exposure to respirable dust of each subject in the companion retrospective follow-up study (Honda *et al.*, 2002).

MATERIALS AND METHODS

Overview of exposure estimation procedures

As with most retrospective follow-up studies, the utility of historical exposure data that were available for the assessment of exposures was limited (Stewart *et al.*, 1996). A total of 1322 historical exposure measurements collected over the 42 yr of the study period were identified. The utility of these data was limited because a variety of methods were used over the study period to measure exposures to talc. The

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methods included dust counts (n = 428), fiber counts (n = 442), respirable dust measurements (n = 206) and total dust measurements (n = 246). There were questions about the validity of much of the data because of uncertainty regarding the source, type or location of the samples (Stewart, 1999). Also, measurements were not available for many of the work area/year combinations in the study period.

Because of the sparseness and uncertain quality of the historical data, cumulative respirable dust exposure estimation for individual subjects could not be based exclusively on existing dust measurements. Rather, a job–exposure matrix consisting of estimates of respirable dust concentrations for various work area and calendar year combinations was developed. The process of developing this matrix included: (i) specifying work areas and associated jobs; (ii) defining time periods during which exposure levels could be considered uniform within the work areas and assigning an exposure score to each work area/time period; (iii) conducting baseline surveys to determine current exposure conditions in the work areas and to develop a factor to convert historical dust count data to respirable dust concentrations; (iv) estimating historical respirable dust concentrations for each work area/calendar year category; (v) comparing the job–exposure matrix concentration estimates with available historical measurements. Respirable talc dust, rather than dust count, data were used as the basis of cumulative exposure estimates because of the better precision of respirable mass sampling and analytical methods compared to the other sampling methods employed (Ayer, 1969) and the necessity of pooling historical data collected by several agencies (Ulfvarson, 1983; Seixas *et al.*, 1990). In addition, respirable mass is a more appropriate measure of exposure because of the relevance of the physiological region of respiratory deposition of that size fraction to occupational respiratory diseases. These exposures would be comparable to the threshold limit value (TLV) of 2 mg/m^3 for talc containing no asbestos fibers [American Conference of Governmental Industrial Hygienists (ACGIH, 2001)].

Work area specification

Each job title included in the work histories of employees was assigned to a work area, defined as a group of jobs having a similar exposure profile based on similar processes, tasks, engineering controls (e.g. ventilation) and exposures to airborne talc (Corn and Esman, 1979; Stewart *et al.*, 1996). The initial work area/job groups were based on a preliminary classification developed by the National Institute for Occupational Safety and Health (NIOSH) (Dement *et al.*, 1980). The designated areas and each area's component jobs were refined by one of the authors (K.O.), a certified industrial hygienist, by observing current operations, consulting long-term supervisory personnel familiar with operating conditions at the facility and reviewing historical exposure measurements. Jobs comprising a given work area were assumed to be reasonably homogeneous with respect to exposure within the specified time periods.

Table 1 shows the final 13 work areas and typical job activities within each area. The 'mill average' work area consists of laborers who worked in unspecified areas within the mills, the 'no exposure' work area consists of office employees and outside laborers and the unknown work area was assigned to work history entries for which activities were not specified and for which exposure estimates could not be developed.

Specification of uniform exposure time periods

Work area-specific uniform exposure time periods were defined as calendar periods during which non-random, deterministic variables, such as operating processes and control technology, were constant and during which the average exposure level probably did not change over time (Yu *et al.*, 1990). These time periods were specified by a panel of three knowledgeable supervisory personnel, using production and engineering records, dust control information and past industrial hygiene reports. These personnel included: rater 1, hired in 1953 and familiar with both the mines and the mills; rater 2, hired in 1948 and familiar with the mills; rater 3, hired in 1971 and familiar with the mines. One of us (K.O.) reviewed the periods identified by the panel and judged their specifications to be adequate.

Development of exposure scores

The supervisory panel and five additional hourly employees were asked to assign an exposure score, ranging from 0 for no exposure to 10 for highest exposure, within each time period to the most commonly held jobs in a given work area. The additional employees included: rater 4, hired in 1951 and familiar with the mills; rater 5, hired in 1954 and familiar with the mills; rater 6, hired in 1957 and familiar with the mills; rater 7, hired in 1950 and familiar with the mines; rater 8, hired in 1959 and familiar with the mines.

Rater 1 assigned scores to all jobs and years. Because of their different hire dates and different work experiences, all the other raters assigned scores only to jobs, work areas, locations (e.g. mill, mine 1 or mine 2) and years for which they had knowledge and experience. Rater 6 provided extremely incomplete information and his scores were discarded.

Inter-rater agreement among these scores was evaluated by comparison of two average scores. First, all job/year-specific exposure scores were averaged over all jobs comprising a given work area to obtain a 'work area/year' score. Second, work area/year-specific scores were averaged over all work areas

Table 1. Work areas and typical job activities

1. Mill, average	Mill laborer, unspecified	7. Mine 1, surface crushing	Surface crusher operators
2. Mill, milling	Crusher/dryer operators	8. Mine 2, surface equipment operators	Truck drivers
	Wheeler operators		Loader operators
	Hardinge operators		Drillers
	Air process operators		Tractor operators
	Cal process operators	9. Mine 2, crusher	Crusher operators
	Foremen/supervisors/managers	10. Maintenance	Mobile mechanics
3. Mill, palletizing/packing	Packers		Maintenance workers
	Palletizers		Supervisors
4. Mill, packhouse support	Utility men/pumpmen/laborers	11. General, minimal exposure	Laboratory workers
	Fork lift operators		Mine managers
	Bulk loaders		Construction workers
	Foremen/supervisors		Engineers
	Car liners		Janitors
5. Mill, maintenance	Millwrights		Masons
	Machinists/oilers		Powerline workers
	Electricians		Quality control
	Sheet metal workers/welders		Stock clerks
	Laborer, maintenance		Store keepers
	Instrument repairmen		Surveyors
6. Mine 1, underground	Driller helpers		Warehousemen
	Slushers/scrapers		Watchmen
	Trammers	12. No exposure	Inventory control supervisors
	Muckers		Mine 4 workers
	Eimco operators		Purchasing agents
	UG crusher operators		Office clerks and managers
	Pocket cagemen/hoistmen		Laborers, outside
	Repairmen	99. Unknown	
	Repairman helpers		
	Mechanic		
	Laborer		
	Mine maintenance		
	Blacksmiths/welders		
	Supervisors		

within a location and over all years within a time period to obtain a mean 'location/time period score'. Time periods were specified on the basis of the number of raters providing scores. Inter-rater agreement was evaluated for the average scores of the three major locations (i.e. the mills, mine 1 and mine 2) because of differences among the raters in the locations and time periods about which they were knowledgeable. Agreement among the absolute values of the work area/year-specific scores was poor, although raters tended to agree on trends in exposure levels over time for a given work area.

To evaluate inter-rater agreement among the trends, a 'residual' score was computed for each combination of work area, location and time period by subtracting the rater's mean location/time period score from each work area/year-specific score within that location. The effect of calendar year and work area on the entire set of residual scores available from all raters for each location and time period was evaluated by multiple linear regression.

Baseline exposure surveys

Two 1 week exposure surveys were conducted by one of us (K.O.) in 1991 to measure current respirable dust concentrations during warm (July) and cold weather (December) months and to develop a factor to convert historical dust count data to respirable dust concentrations. Personal air samples were collected and analyzed to determine 8 h time-weighted average respirable dust exposures according to NIOSH Analytical Method 0600—Nuisance Dust, Respirable (NIOSH, 1984). Impinger samples for dust counts were collected and analyzed according to the

US Public Health Service Impinger Sampling Technique (Roach, 1973). Concurrent respirable dust samples were collected using a high volume cyclone (Hering, 1989). These samples were also analyzed by NIOSH Method 0600 (NIOSH, 1984). The use of the high volume cyclone allowed identical sampling times for the impinger and respirable dust samples.

The arithmetic means of baseline survey respirable dust concentrations were used to define baseline exposures in each area and, consequently, to calculate estimated exposures for the job–exposure matrix. These values were used because the accumulated uptake of the contaminant by the human body is proportional to the arithmetic mean of the period under observation (Ulfvarson, 1983; Rappaport, 1991). The value for the mill work area 1 was the arithmetic mean of all observations in work areas 2–5. The value for the minimal exposure group was taken as the exponent of the 5th percentile of natural logarithms of exposures used to define baseline values for all work areas. In some work areas, the baseline exposures are based on very few samples ($n < 4$), so the true average could be within a relatively large range.

Coincident respirable dust and dust count samples were used to generate a factor for converting historical dust counts to respirable dust concentrations. A weighted regression equation of the natural logarithms of the respirable dust and the dust count concentrations was used to convert historical dust count data to respirable dust concentrations. Based on corresponding sample descriptive information, the historical dust concentration data were classified into the previously described work area/year matrix. The average of the historical measurements was then calculated from the data available for each work area/year category for use in the comparison of measured and estimated exposures.

Estimation of work area/time period-specific dust levels

Quantitative dust concentration estimates were developed for each work area/time period combination as follows. First, the baseline arithmetic mean respirable dust concentration for each work area was calculated from data collected in the two exposure surveys. Next, for each time period, the estimated average respirable dust concentration for the work area was computed as the product of the baseline mean concentration and the ratio of the time period-specific exposure score to the baseline exposure score. This computation is illustrated in the following conceptual equation:

$$\text{estimated dust concentration} = \text{baseline dust concentration} \times (\text{time period-specific exposure score}/\text{baseline exposure score}). \quad (1)$$

Comparison of exposure estimation procedures

Work area/year-specific exposure estimates were compared with the mean of the historical dust measurements that were available for selected work areas and years. The use of the latter data was complicated by the fact that dust samples were collected by several agencies, including the employer, environmental consultants and/or insurance carriers, State and Federal safety and health regulatory agencies and NIOSH using diverse methods. The use of pooled data collected by different agencies could produce information bias (Ulfvarson, 1983; Olsen *et al.*, 1991). Particularly, regulatory agencies tend to overestimate the average dust level by conducting compliance or 'worst case' sampling (Seixas *et al.*, 1990). This bias may also be present in data collected by insurance carriers and even in some data collected by company hygienists. Also, the precision of the historical data was limited because most of the data were converted from dust counts to respirable mass concentrations by a regression equation with a moderate coefficient of determination.

RESULTS

Exposure scores

As previously indicated, agreement among the raters' work area/year-specific absolute exposure scores was poor, but they did agree on trends in exposure levels over time for a given work area. However, regression models (Littell *et al.*, 1991) used to evaluate inter-rater agreement among the residual scores found that, for each location and time period, the scores did not significantly vary by rater. In contrast, both work area within the location and year within the time period were significantly associated with the scores. These results are shown in Table 2.

Two sets of scores were developed, one based only on the scores of rater 1 and the other based on the average adjusted scores of all raters. Differences between the two sets tended to be unremarkable. Therefore, only the scores of rater 1 were used to compute exposure scores for this study because he was considered to be the most knowledgeable rater and he provided scores for all locations, work areas and years across the study. Those scores are shown in Table 3. They indicate a gradual decrease in exposure over the study period in all work areas.

Baseline dust concentrations

The range of all respirable dust concentrations measured in the two baseline exposure surveys was 0.01–2.67 mg/m^3, with an arithmetic mean of 0.47 mg/m^3, a standard deviation of 0.49, a geometric mean of 0.28 mg/m^3 and a geometric standard deviation of 3.05. The geometric mean of the measurements made during the summer survey was

Table 2. Effects of work area, year and rater on adjusted exposure scores of seven raters

Model	Location	Raters	Time period	r^2	P value		
					Area	Year	Rater
1	Mill	1,2	1948–1953	0.87	0.00	0.01	0.98
2	Mill	1,2,5	1954–1957	0.81	0.00	0.92	1.00
3	Mill	1,2,4,5	1958–1985	0.76	0.00	0.00	1.00
4	Mine 1	1,7	1948–1958	0.96	0.00	0.84	0.96
5	Mine 1	1,7,8	1959–1970	0.69	0.00	0.06	1.00
6	Mine 1	1,3,7,8	1971–1985	0.82	0.00	0.03	1.00
7	Mine 2	1,3,8	1974–1985	0.23	0.00	0.69	1.00

0.59 mg/m^3, whereas that for the winter survey was 0.41 mg/m^3. These values were not significantly different. Therefore, no adjustment was made for seasonal differences in the subsequent data analysis or exposure estimation. The work area arithmetic and geometric mean baseline dust concentrations are shown in Table 4. Exposure levels were relatively high in mine 2, crushing (0.83 mg/m^3) and in mine 1, underground (0.73 mg/m^3), intermediate in mill 1 (0.35–0.53 mg/m^3) and mine 2, equipment operator (0.22 mg/m^3) and low in all other areas (0.06–0.14 mg/m^3).

Conversion of dust counts

Historical dust counts were converted to respirable mass concentrations by linear regression analysis of 27 paired dust count and respirable mass samples. Previous studies have reported an average ratio for this type of conversion (Jacobson and Tomb, 1967; Ayer, 1969). However, the set of ratios in this study was found to be log-normally distributed, so a regression equation using the natural logarithms of measured dust counts and respirable mass concentrations was thought to be a more appropriate method of conversion. The weighted regression equation, shown below, yielded an adjusted coefficient of determination of 0.38:

$$\ln(\text{mg/m}^3) = \ln(\text{m.p.p.c.f.}) \times 0.62 - 1.20 \qquad (2)$$

where m.p.p.c.f. is million particles per cubic foot.

A plot of the natural logarithms of the dust count and respirable mass samples with their regression line are shown in Figure 1.

Work area/year-specific dust concentration estimates

Table 5 presents work area/calendar year-specific estimates of average respirable dust concentrations, computed from the exposure scores of rater 1 (Table 3) and the baseline respirable dust concentrations (Table 4). Exposure concentrations were estimated to be slightly higher in milling than in underground mining until the early 1970s and were estimated to be similar in the two locations or slightly higher in underground mining than in milling thereafter.

Comparison of historical dust measurements and exposure estimates

The years and work areas (n = 45) for which measured and converted historical respirable dust exposure measurements were available and the corresponding predicted exposures from the estimation procedure described above are shown in Table 6. The data are also plotted in Figure 2. The Pearson's correlation coefficient for the measured and the predicted concentrations was 0.55. The average difference between all of the measured and predicted concentrations was –0.01 mg/m^3. Differences within the work areas ranged from 0.17 mg/m^3 in mine 1, surface crushing to –0.32 mg/m^3 in mine 2, crushing.

DISCUSSION

A job–exposure matrix based on work area and time period was developed to estimate historical quantitative respirable dust exposures of employees at the talc mining and milling facility under study. The procedures used measured baseline work area-specific exposure concentrations along with categorical exposure scores assigned by a long-term, salaried employee who was familiar with conditions in all locations to estimate year-specific respirable dust exposure concentrations for the years 1948–89. This approach was thought to be the most effective method of estimating exposures given the limited quantity and quality of available historical exposure data. This method is more sensitive than ordinal classification of exposures and it avoids the uncertainties of exposure prediction models (Hornung, 1991).

Initially it had been proposed to use dust count data as a parallel estimate of exposure to talc dust. However, it was decided to use respirable dust concentrations because these data were considered to be more precise than dust count measurements (Edwards *et al.*, 1966; Ayer, 1969) and less biased than some of the historical data (Ulfvarson, 1983; Olsen *et al.*, 1991). The use of baseline respirable dust concentration data reduced imprecision that would have resulted from converting historical data to dust counts by a regression equation that had a

Table 3. Work area/year-specific exposure scores by rater 1

Year	Mill					Mine 1		Mine 2			General
	1	2	3	4	5	6	7	8	9	10	11
1948	8.5	7.8	10	9.5	6.7	4.4	6.0				4.0
1949	8.5	7.8	10	9.5	6.7	4.4	6.0				4.0
1950	8.5	7.8	10	9.5	6.7	4.4	6.0				4.0
1951	8.5	7.8	10	9.5	6.7	4.4	6.0				4.0
1952	7.2	7.2	8.0	7.5	6.0	4.4	6.0				4.0
1953	7.1	7.0	8.0	7.5	6.0	4.4	6.0				4.0
1954	7.1	7.0	8.0	7.5	6.0	4.4	6.0				4.0
1955	6.8	6.5	8.0	7.5	5.3	4.4	6.0				4.0
1956	6.8	6.5	8.0	7.3	5.3	4.5	6.0				4.0
1957	6.8	6.5	8.0	7.3	5.3	4.5	6.0				4.0
1958	6.8	6.5	8.0	7.3	5.3	4.5	6.0				2.5
1959	6.7	6.0	8.0	7.3	5.3	4.5	6.0				2.5
1960	6.2	5.2	8.0	7.3	4.3	4.5	6.0				2.5
1961	6.1	4.8	8.0	7.3	4.3	4.5	6.0				2.5
1962	6.1	4.8	8.0	7.3	4.3	4.5	6.0				2.5
1963	6.1	4.8	8.0	7.3	4.3	4.5	6.0				2.5
1964	6.1	4.8	8.0	7.3	4.3	4.5	6.0				2.5
1965	6.1	4.8	8.0	7.3	4.3	4.5	6.0				2.5
1966	6.1	4.7	8.0	7.3	4.3	4.5	6.0				2.5
1967	6.0	4.3	8.0	7.3	4.3	4.5	6.0				2.5
1968	5.1	4.3	6.0	5.7	4.3	3.9	3.0				2.5
1969	4.5	4.3	6.0	4.0	3.7	3.9	3.0				2.0
1970	4.6	4.8	6.0	4.0	3.7	3.9	3.0				2.0
1971	4.6	4.8	6.0	4.0	3.7	3.9	3.0				2.0
1972	4.3	3.8	6.0	4.0	3.3	3.4	3.0				2.0
1973	4.2	3.4	6.0	4.0	3.3	3.4	3.0				2.0
1974	4.2	3.4	6.0	4.0	3.3	3.4	3.0	2.3	4.0	1.5	2.0
1975	4.1	3.2	6.0	4.0	3.3	3.4	3.0	2.3	4.0	1.5	2.0
1976	4.1	3.2	6.0	4.0	3.3	3.3	3.0	2.3	4.0	1.5	2.0
1977	4.1	3.2	6.0	4.0	3.3	3.3	3.0	2.3	4.0	1.5	2.0
1978	3.6	2.8	6.0	2.3	3.3	3.3	3.0	2.0	4.0	1.5	2.0
1979	3.1	2.8	4.0	2.3	3.3	3.3	3.0	2.0	4.0	1.5	2.0
1980	3.0	2.8	4.0	2.3	2.7	3.3	2.0	2.0	2.0	1.5	1.5
1981	2.8	2.3	4.0	2.3	2.3	3.3	2.0	2.0	2.0	1.5	1.5
1982	2.8	2.3	4.0	2.3	2.3	3.3	2.0	1.5	2.0	1.5	1.5
1983	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1984	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1985	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1986	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1987	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1988	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5
1989	2.8	2.3	4.0	2.3	2.3	3.4	2.0	1.5	2.0	1.5	1.5

coefficient of determination of 0.38. The effect of the imprecision of the conversion was limited to those respirable dust concentrations that were converted from historical dust counts and compared to exposure estimates.

No attempt was made to use available fiber count data because of inconsistencies between the regulatory and mineralogic definitions of fibers and the mineralogic composition of talc dust at this facility. According to the NIOSH analytical method for asbestos, a fiber is defined as any particle with a length-to-width aspect ratio of at least 3:1 and a length of 5 µm or more observed under phase contrast microscopy (Leidel *et al.*, 1979). However,

Table 4. Baseline respirable dust exposures

Number	Work area	n	Work area baseline exposures (mean ± SD) (mg/m^3)	
			Arithmetic	Geometric
1	Mill 1, average		0.48[a]	
2	Mill 1, milling	28	0.53 ± 0.71	0.29 ± 3.80
3	Mill 1, palletizing/packing	24	0.52 ± 0.27	0.46 ± 1.70
4	Mill 1, packhouse support	16	0.32 ± 0.21	0.24 ± 2.45
5	Mill 1, maintenance	14	0.42 ± 0.31	0.31 ± 2.42
6	Mine l, underground	11	0.70 ± 0.68	0.42 ± 2.42
7	Mine l, surface crushing	1	0.14	
8	Mine 2, equipment operators	11	0.22 ± 0.25	0.11 ± 3.36
9	Mine 2, crusher	4	0.83 ± 0.55	0.70 ± 1.96
10	Mine 2, maintenance	3	0.06 ± 0.06	0.04 ± 3.47
11	Minimal exposure		0.09[b]	

[a]Average of work areas 2–5.
[b]This concentration represents the 5th percentile of all exposure data used to determine baseline exposures in mill 1.

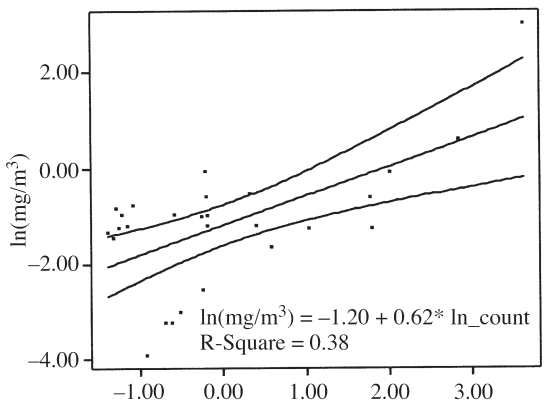

Fig. 1. Regression of dust count and respirable mass concentrations.

this definition has been criticized by mineralogists as being non-specific for true asbestiform fibers (Skinner *et al.*, 1988). Kelse and Thompson (1989) have demonstrated that airborne cleavage fragments of non-asbestiform tremolitic talc dust collected at this facility would be incorrectly classified as fibers under the 3:1 aspect ratio rule. This misclassification resulted in an overestimation of fiber counts in air samples collected at that facility. The development of the job–exposure matrix also involved assumptions and uncertainties. We had to assume that exposures in the job classifications were homogeneous when, in fact, they may not have been. However, we refined previously developed job/work area classifications (Dement *et al.*, 1980) by evaluating the operational characteristics of the work areas, utilizing respirable dust data obtained during our baseline surveys, and by analyzing exposure scores assigned to jobs in the areas. We also compared our exposure estimates, making use of historical data available for eight of the 11 work areas where exposure was judged to be more than minimal. Comparison was, however, limited to 45 (11.7%) of the 384 cells of the job–exposure matrix because historical measures tended to be clustered in specific years and work areas.

The observed correlation coefficient of 0.55 for measured and predicted exposures was considered to be good given the following characteristics of the data: (i) the inherent variability of the dust count method (Edwards *et al.*, 1966; Ayer, 1969); (ii) the relatively low coefficient of determination for the equation converting counts to respirable dust concentrations; (iii) the use of pooled data collected by several agencies using different methods (Ulfvarson, 1983); (iv) the use of averages of a small number of observations to represent exposures that are known to exhibit considerable inter- and intra-day variation (Seixas *et al.*, 1988). Given the above characteristics of the data, an average difference between measured and estimated exposures of only –0.01 mg/m^3 was considered to be remarkable. The wide range of average differences among the work areas is probably an indication of the instability of this number. A detailed statistical validation of the predicted exposures within a work area was not conducted because of the relatively small number of cells and observations in those cells. However, the average difference between measured and predicted exposures for each work area was well within a factor of 1 of the mean measured value for that area.

The estimated exposures in this study do not take into account other factors that affect the uptake of contaminants. These factors could include: (i) the effective use of respiratory protection; (ii) part-time exposures; (iii) personnel rotation not recorded in administrative work histories; (iv) unfavorable distribution of exposure periods over time; (v) unusually hard work increasing the ventilation of the exposed

Table 5. Work area/calendar year-specific estimated average respirable dust concentrations (mg/m^3) based on exposure scores of rater 1

Year	Mill 1					Mine 1		Mine 2			General
	1	2	3	4	5	6	7	8	9	10	11
1948	1.4	1.7	1.3	1.4	1.3	0.9	0.4				0.2
1949	1.4	1.7	1.3	1.4	1.3	0.9	0.4				0.2
1950	1.4	1.7	1.3	1.4	1.3	0.9	0.4				0.2
1951	1.4	1.6	1.3	1.4	1.2	0.9	0.4				0.2
1952	1.2	1.6	1.1	1.1	1.2	0.9	0.4				0.2
1953	1.2	1.5	1.1	1.1	1.2	0.9	0.4				0.2
1954	1.2	1.5	1.1	1.1	1.2	0.9	0.4				0.2
1955	1.1	1.4	1.1	1.1	1.0	0.9	0.4				0.2
1956	1.1	1.4	1.1	1.1	1.0	1.0	0.4				0.2
1957	1.1	1.4	1.1	1.1	1.0	1.0	0.4				0.2
1958	1.1	1.4	1.1	1.1	1.0	1.0	0.4				0.2
1959	1.1	1.3	1.1	1.1	1.0	1.0	0.4				0.2
1960	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1961	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1962	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1963	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1964	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1965	1.0	1.1	1.1	1.1	0.8	1.0	0.4				0.2
1966	1.0	1.0	1.1	1.1	0.8	1.0	0.4				0.2
1967	1.0	0.9	1.1	1.1	0.8	1.0	0.4				0.2
1968	0.9	0.9	0.8	0.9	0.8	0.8	0.2				0.2
1969	0.8	0.9	0.8	0.6	0.7	0.8	0.2				0.1
1970	0.8	1.0	0.8	0.6	0.7	0.8	0.2				0.1
1971	0.8	1.0	0.8	0.6	0.7	0.8	0.2				0.1
1972	0.7	0.8	0.8	0.6	0.6	0.7	0.2				0.1
1973	0.7	0.7	0.8	0.6	0.6	0.7	0.2				0.1
1974	0.7	0.7	0.8	0.6	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1975	0.7	0.7	0.8	0.6	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1976	0.7	0.7	0.8	0.6	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1977	0.7	0.7	0.8	0.6	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1978	0.6	0.6	0.8	0.4	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1979	0.5	0.6	0.5	0.4	0.6	0.7	0.2	0.3	1.7	0.1	0.1
1980	0.5	0.6	0.5	0.4	0.5	0.7	0.1	0.3	0.8	0.1	0.1
1981	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.3	0.8	0.1	0.1
1982	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1983	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1984	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1985	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1986	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1987	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1988	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1
1989	0.4	0.5	0.5	0.4	0.5	0.7	0.1	0.2	0.8	0.1	0.1

individuals. Of these, the use of respiratory protection would be the most likely uptake modifier among these workers. During the baseline surveys it was observed that there was current widespread usage of respirators, but it is not known when the use of this equipment was initiated systematically or how conscientiously and effectively respirators were used.

The highest average estimated exposure was 1.7 mg/m^3, which is below the TLV of 2 mg/m^3 for non-asbestiform talc (ACGIH, 2001). The retrospective follow-up study of workers at the facility under study found increased rates of non-malignant respiratory disease (Honda *et al.*, 2002). Thus, these results might indicate that the TLV for talc is too high

Table 6. Measured and predicted respirable concentrations by year and work area

Year	n	Work area	Measured average[a] (mg/m^3)	Predicted exposure (mg/m^3)
1985	8	2	0.84	0.51
1984	13	2	0.36	0.51
1983	15	2	0.38	0.51
1982	4	2	0.06	0.51
1979	4	2	0.32	0.62
1975	12	2	0.99	0.69
1973	2	2	0.74	0.74
1969	5	2	0.89	0.95
1958	3	2	0.73	1.42
1952	3	2	1.11	1.57
1985	5	3	0.73	0.53
1984	6	3	0.44	0.53
1983	4	3	0.50	0.53
1979	2	3	0.32	0.53
1975	6	3	0.95	0.80
1973	2	3	0.80	0.80
1969	6	3	0.78	0.80
1958	2	3	1.60	0.80
1952	1	3	1.46	1.06
1983	1	4	0.46	0.35
1979	2	4	0.28	0.35
1975	10	4	0.41	0.60
1952	3	4	0.45	1.12
1975	10	5	1.24	0.64
1973	2	5	0.71	0.64
1952	1	5	0.86	1.16
1985	7	6	0.61	0.73
1984	9	6	0.62	0.73
1983	10	6	0.92	0.73
1982	2	6	0.99	0.73
1979	12	6	0.40	0.73
1975	14	6	0.86	0.73
1969	10	6	0.78	0.84
1958	8	6	1.40	0.96
1952	8	6	0.94	0.96
1985	1	7	0.27	0.14
1984	2	7	0.11	0.14
1983	3	7	0.31	0.14
1969	1	7	0.62	0.21
1985	5	8	0.40	0.22
1984	2	8	0.06	0.22
1983	3	8	0.34	0.83
1984	3	9	0.90	0.83
1983	1	9	0.50	0.83
1982	2	9	0.14	0.83

[a]Measured respirable mass values may include data converted from historical particle counts.

to prevent the increased risk of these diseases. However, such an interpretation is limited because we did not know employees' occupational exposures outside the study facility. Despite this limitation, this observation deserves further evaluation in future studies.

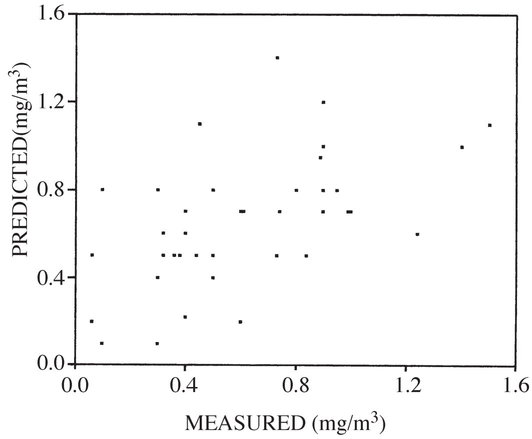

Fig. 2. Correlation of measured and predicted respirable mass concentrations.

In summary, it is expected that the concentrations in the job–exposure matrix over-estimate the actual exposures experienced by these employees. This is based on a slight average negative difference of estimated exposures when compared with historical data that are thought to represent worst case conditions (Seixas *et al.*, 1990; Ulfvarson, 1983). Also, the estimated exposures do not take into account the potential diminishing effect of the use of respiratory protection. In addition, the baseline exposure surveys were conducted 2 yr after the end of the retrospective follow-up study and exposure levels may have changed during that time. For these reasons, the absolute values of cumulative exposure estimated for subjects in the retrospective follow-up study may not be accurate. However, cumulative exposure estimates based on these values should be useful for obtaining a relative ranking of subjects according to exposure for use in an epidemiological dose–response analysis.

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