



Estimation of Historical and Current Employee Exposure to Refractory Ceramic Fibers during Manufacturing and Related Operations

Carol H. Rice , James E. Lockey , Grace K. Lemasters , Linda L. Levin , Preston Staley & Karen R. Hansen

To cite this article: Carol H. Rice , James E. Lockey , Grace K. Lemasters , Linda L. Levin , Preston Staley & Karen R. Hansen (1997) Estimation of Historical and Current Employee Exposure to Refractory Ceramic Fibers during Manufacturing and Related Operations, Applied Occupational and Environmental Hygiene, 12:1, 54-61, DOI: [10.1080/1047322X.1997.10389456](https://doi.org/10.1080/1047322X.1997.10389456)

To link to this article: <http://dx.doi.org/10.1080/1047322X.1997.10389456>



Published online: 24 Feb 2011.



Submit your article to this journal [↗](#)



Article views: 23



View related articles [↗](#)



Citing articles: 19 View citing articles [↗](#)

Estimation of Historical and Current Employee Exposure to Refractory Ceramic Fibers During Manufacturing and Related Operations

Carol H. Rice,^A James E. Lockey,^A Grace K. Lemasters,^A Linda L. Levin,^A Preston Staley,^B
and Karen R. Hansen^A

^AUniversity of Cincinnati College of Medicine, Cincinnati, Ohio 45220;
^BNational Institute for Occupational Safety and Health, Cincinnati, Ohio 45226

Refractory ceramic fibers (RCFs) have been produced in the United States since the early 1950s for use as a high temperature insulation material, or in the production of specialty products for insulation. Environmental data collected through 1991 have been assembled and used to reconstruct exposures at jobs in RCF manufacture or related operations. The algorithm incorporated consideration of the statistical distribution of the data, dates of implementation of engineering or process modifications potentially associated with a change in airborne fiber concentration, and the area in the facility (dust zone) where the sample was collected. Analysis of variance was used to test if differences between time periods within a dust zone were statistically significant. Time period was considered a fixed effect; the days of sample collection within a time period were considered a random, nested effect. Exposure estimates were constructed for 81 job titles in seven facilities for specified time periods. Overall, exposures are shown to have decreased. The maximum exposure estimated was 10 fibers/cubic centimeter (f/cc) in the 1950s for carding in a textile operation; subsequent engineering changes reduced estimated exposure to below 1 f/cc. At current operations, exposure estimates range from 0.66 f/cc to below the limit of detection. The estimates presented will be used in exposure-response analyses in an epidemiologic study of pulmonary morbidity in persons employed in these facilities. © 1997 AIH. RICE, C.H.; LOCKEY, J.E.; LEMASTERS, G.K.; LEVIN, L.L.; STALEY, P.; HANSEN, K.R.: ESTIMATION OF HISTORICAL AND CURRENT EMPLOYEE EXPOSURE TO REFRACTORY CERAMIC FIBERS DURING MANUFACTURING AND RELATED OPERATIONS. APPL. OCCUP. ENVIRON. HYG. 12(1):54-61; 1997.

The evaluation of possible relationships between workplace exposure and various chronic health endpoints such as changes in pulmonary function or chest radiographs requires an understanding of exposure over an extended period of time, from first employment to the date of determination of health status. Generally, only a few samples were collected during the early years to characterize airborne exposure; following implementation of the Occupational Safety and Health Act in 1970, more attention was devoted to measurement of airborne contaminants. Where resources have been targeted toward characterization of the environment for research or surveillance purposes, more detailed information may be available.

The focus of this report is on the construction of exposure

estimates for jobs held by persons employed in the manufacture of refractory ceramic fibers (RCFs) or related activities at facilities operated by one corporation from earliest operation through 1991. Results of analyses of exposure and response as indicated by various health outcomes are reported elsewhere.⁽¹⁾

The data were assembled as part of an industry-wide study at RCF production facilities, or where fibers are used to produce felts, boards, yarn/textiles, or other specialty items. Sand, kaolin, and/or alumina are the principal raw materials for the production of RCFs. Since 1987 exposure assessment has been conducted according to a standardized protocol; these data were merged with all identified, previously collected hygiene data. Plant processes, job functions, location of equipment within facilities, and engineering changes were described and catalogued.

Methods

Facilities

The earliest dates of operation for the seven facilities included in the study are as follows: facility 1, fiber processing (1956); facility 2, fiber production and processing (1953); facility 3, fiber production and processing (1970); facility 4, fiber processing (1979); facility 5, fiber production (1982); facility 6, research and development (1965); facility 7, fiber processing (1988).

Qualitative Information

Description of the facility, changes over time, and job descriptions were obtained from detailed questionnaires. First, all employees working during the plant visit by university personnel were interviewed to document the tasks conducted as part of the usual job assignments; each worker was asked to give the job title and describe both daily and less routine duties. Second, long-term employee interviews designed to capture information concerning previous plant operations and layout, job activities, and personnel staffing levels were conducted with three production and three nonproduction employees from each facility. Third, to determine the amount of time nonproduction employees might spend in production areas, each of these employees was asked to complete a self-report on the nature and duration of each activity conducted in a production area. These three sources provided information on the conduct of various jobs throughout the operational history of each facility.

Engineering data related to production processes and environmental controls were identified in plant records and files pertaining to plant and division monthly activity reports; capital projects; equipment function and problems; furnace and fabrication operations; environment, pollution control, or health and safety issues; and business plans. Qualitative data were used to assemble a timeline documenting changes in facility operations. Company personnel reviewed the document and provided feedback. The dates of production or engineering changes potentially affecting airborne fiber concentrations were identified.⁽²⁾

The complete listing of jobs for which an exposure estimate was needed at each facility was drawn from the occupational history interviews with the workers. Due to potential changes in job titles and functions over time, the work activities were also recorded. To reduce the results of the interviews to a manageable number of jobs to be linked with the exposure estimates, three study personnel edited the interview entries to form groups of similar activities, referred to as uniform job titles (UJTs). As a first step, the file was sorted by reported job title. Next, the descriptions of the work activities for each job title were reviewed, and assignments were made to a UJT. For example, the reported job title of B-operator at a facility included work activities such as "folding blanket," "cut and pack," and "take product and put on skids," and resulted in assignment to the end of line UJT; alternatively, where B-operator duties included "make modules," "banding, folding, pinning," or "working with fibers to make cement," the assignment was to the fab UJT. The list was then reviewed by company personnel and resolution reached where necessary.

Quantitative Historical and Current Exposure Data

Historical (pre-1987) exposure/sampling data identified in the plant records were computerized. A previous industry-wide hygiene study was a major source of early exposure data.⁽³⁾ These samples were collected on a mixed cellulose ester filter held in an open-face, 37-mm sampling cassette; fibers greater than 5 μm in length were counted. Samples collected by plant personnel or their designees were reportedly collected and analyzed in a similar fashion.⁽⁴⁾

Since 1987, environmental sampling data have been collected according to the procedures set forth in a standardized protocol incorporating National Institute for Occupational Safety and Health Method 7400.⁽⁵⁾ Originally the protocol included use of the "A" counting rules in the analysis of air samples for fiber concentration. This decision had been based upon the Occupational Safety and Health Administration requirement that airborne asbestos samples be analyzed using the "A" rules, even though there was no such specification for RCFs. After approximately 2 years of sample collection, the University of Cincinnati protocol was modified and the "B" counting rules were introduced for the analysis in order to be consistent with other evaluations of man-made mineral fiber environmental assessments. Differences between the two sets of counting rules include: (1) the requirements to be a counted fiber [entire fibers $\geq 5 \mu\text{m}$ in length (A); ends of fiber $\geq 5 \mu\text{m}$ in length and $\geq 3 \mu\text{m}$ in diameter (B)]; and (2) the treatment of fibers that are not totally enclosed by the counting area [count as one half any fiber that does not lie totally within the graticule area, and do not count a fiber crossing the graticule

boundary more than once (A); count each end within the graticule area, and count any end even if attached to another particle (B)].⁽⁵⁾ For bundles of fibers meeting the preceding criteria, the structure is counted as a single fiber using the A rules; however, up to ten free ends may be counted using the B rules. For these RCF manufacturing environments, the two counting rules have been shown to provide comparable results.⁽⁶⁾

Stationary samplers were placed at an elevation of approximately 5 ft in the center of office areas; collection media and analysis procedures were the same as for the personal samples.

The dust zone (DZ) concept developed during a previous study that included RCF facilities was applied to these plants.⁽⁷⁾ Four considerations are included in the assignment of DZ: similarity of work tasks, similarity of materials to which workers may be exposed, similarity of the process elements and control technology, and identifiability of the group of workers for exposure assessment. For plants included in the prospective exposure assessment protocol, dust zones were identified during walk-through surveys. For discontinued or relocated operations, detailed plant layout diagrams developed for each facility prior to 1987 were used to determine DZs represented by the historical exposure measurements. The location of operations and major equipment on each floor of a facility was documented on these year-by-year drawings.

Exposure Algorithm

Estimates of fiber exposure level were based on measurements obtained for a period of at least 90 minutes in facilities 1 to 5 and 7. In these facilities, 90-minute samples were believed to be of sufficient duration to reflect the exposure experienced during routine, daily operations. Plant personnel verified that sampling for this duration was considered representative, especially during the early years of monitoring; for example, a typical collection time is represented by the period between start of work and a scheduled break about 2 hours later. Also, during the early years some operations classified as a DZ were not conducted for an entire work shift; for example, at facility 2 bagging, scrap burnout, and paper burnout were not continuous operations. This decision rule allowed retention of measurements for short-duration tasks considered a DZ. For research and development (R&D) activities at facility 6, where most operations were nonroutine, a longer total sampling time of 5 hours was considered necessary to estimate representative exposures. This duration allowed inclusion of measurements in the exposure estimate which reflected both shorter- and longer-duration R&D test runs, as well as days characterized primarily by office activity. For any sample result reported below the limit of detection, exposure was estimated to be equal to the appropriate limit of detection divided by the square root of 2.⁽⁸⁾ When more than one sample was collected, the estimate of exposure during the sampling period was expressed as a time-weighted average (TWA).

To test the hypothesis that TWA values were lognormally distributed,⁽⁹⁾ the Shapiro-Wilk statistic⁽¹⁰⁾ was calculated for each DZ having sufficient data to provide a test with adequate power. The results indicated that the data followed a lognormal distribution; therefore, to satisfy underlying assumptions for statistical procedures such as analysis of variance, a loga-

rhythmic transformation was used to normalize the distribution of TWA values about the mean value.⁽¹¹⁾

A priori time periods were demarcated by the dates of implementation of process or engineering changes potentially impacting airborne fiber concentration. Changes in exposure over time were studied within each DZ. First, data were displayed graphically, with the natural log of the sampling result on the y-axis and time on the x-axis in order to identify any obvious changes in airborne fiber concentration. Heretofore undocumented changes in environmental conditions, suspected by noting a clustering of data with larger or smaller values, were identified and an additional time period was specified. The test of the hypothesis that mean exposure differed between time periods was carried out by partitioning the TWA data into between-time period, between-day within time period, and within-day (error) variability. Analysis of variance was carried out in which period within DZ was modeled as a nested fixed effect and day within time period was modeled as a nested random effect; error variance was estimated from TWAs obtained on the same day. Since there were unequal data per period, an approximate F-statistic was obtained to test the difference in mean TWA exposure between periods using the method of Satterthwaite–Cochran.⁽¹²⁾ If a significant difference was found, time periods were redefined and plotted for visual check.

After time periods were designated, a corrected maximum likelihood estimator was calculated to estimate the (untransformed) average fiber concentration.⁽¹³⁾ The corrected maximum likelihood estimator, M , was obtained from the least-squares mean of log-transformed daily TWA mean values and their standard deviation, calculated as

$$M = \exp(\bar{Y})\Psi_n(V)$$

where:

\bar{Y} = the least-squares mean of the log-transformed daily TWA mean values
 Ψ_n = a function of the squared standard deviation of the TWA means, S^2

$$\Psi_n(V) = 1 + \frac{(n-1)V}{n} + \frac{(n-1)^3 V^2}{n^2(n+1)2!} + \frac{(n-1)^5 V^3}{n^3(n+1)(n+3)3!} + \dots$$

where:

$V = 1/2S^2$
 n = the number of days on which sampling occurred

Fifteen terms in the series formulation of the estimator were used to ensure convergence. An approximation to the standard error of M was obtained from the square root of the following variance estimate:

$$\text{Var}(\text{me}\hat{\text{a}}\text{n}) = \exp(2\bar{Y} + S^2) \left\{ \frac{1}{n} \left(S^2 + \frac{S^4}{2} \right) + \frac{1}{2n} \left(S^6 + \frac{S^8}{4} \right) \right\}^{(14)}$$

Estimates of mean exposure for UJTs which included multiple DZs were obtained from the mean value estimate of the

appropriate DZ, weighted by the proportion of time in the DZ. Estimates of the standard error of these UJT mean exposures were calculated as sum of the squared time weights multiplied by the variance of the DZ mean, given by the following:

$$\text{me}\hat{\text{a}}\text{n}(\text{UJT}) = \sum W_i \text{me}\hat{\text{a}}\text{n}_i$$

$$\widehat{\text{SE}}(\text{UJT}) = \sqrt{\sum W_i^2 \text{Var}_i}$$

where:

W_i = the proportion of time spent in DZ i
 $\text{me}\hat{\text{a}}\text{n}_i$ = the mean TWA estimate for DZ i
 Var_i = the estimated variance of the mean TWA estimate for DZ i

Weights were developed from data collected in the current employee, long-term employee, nonproduction employee, and occupational history questionnaires and reviewed by company personnel.

For the early years at facility 1, one DZ exposure estimate was based on calculated fiber exposure from a sample of airborne dust using the mass-count conversion equation of Esmen *et al.*;⁽³⁾ therefore, no standard error could be calculated directly, and a coefficient of variation (CV) of 20 percent was assumed for this initial estimate, consistent with previous evaluations of the total CV for fiber sampling and analysis.⁽¹⁵⁾

Results

Uniform Job Titles

The 1820 entries recorded during the work history interviews were condensed into a smaller number of UJTs. For example, the UJT “forklift driver” at facility 3 included tasks/duties such as packaging ceramic fiber blanket, moving pallets, baling trim from insulation, supplying batch mixtures, pit cleaning, and relieving the blanket line worker. Recorded job titles from the work history classified as the forklift driver UJT included “forklift and needler,” “forklift driver,” and “forklift operator.” The number of UJTs for which exposure estimates were required for facilities 1 through 7, respectively, were 12, 21, 17, 16, 3, 6, and 4.

Industrial Hygiene Data

A companion document to the time lines described above was a pictorial representation of equipment layouts for each year of operation. Virtually all historical environmental samples could be assigned to a location on these detailed maps. For example, where only the machine was recorded as the location of the sample, the detailed information on processes and the drawings enabled location of the sample within the plant. Therefore, each sample was first associated with a machine, operation, or area within the facility; from this information, the samples could be assigned to a DZ. For three operations making up one DZ in facility 3, the process layout information confirmed that a similar configuration was used for the original setup in facility 2. Since no exposure measurements were available for these operations at facility 2, data collected in facility 3 were also assigned to the facility 2 DZ. All assignments were made without knowledge of the exposure result. The DZs for each of the seven facilities are shown in Table 1.

TABLE 1. Dust Zones Identified for Each RCF Facility

Facility	Dust Zones	
1	Stamping	
	Card/blend	Spin
	Loom	Ship
	Ship	Maintenance
	Supervisor	Quality control/office
2	Mix tank	Roto pack
	Paper burnout	Paper slitter
	Quality control	Maintenance
	Office	Shipping
	Scrap burnout	Furnace operator
3	Bagger	Arrange
	Mix area	Cement production
	Needler operation	Tanks, ball mill,
	Office	V blender, dry mix,
	Quality control	band saw, modules
4	Vacuum cast:	Maintenance/occupancy
	Wet end	Furnace
	Edge/sand	
	Shipping/warehousing	
	XPE paper	Card/blend
5	Spinner	RopeLayer/braiders/
	Specialist	Broad looms/tape looms/formers
	HSA	
	Shipping	Maintenance
	Shift supervisor	Quality control/office/ production/center/ production
6	FB 80	
	Operator/technician —downstairs	
	Operator/technician —upstairs	
7	Shipping	
	Technician	
	Senior technician	
	Master technician	
7	Office	
	Supervisor/operator- in-charge	
	Wet end	
	Dry end	
	Sanitation	
	Maintenance	
	Quality control/ office	
Shipping		

The numbers of TWAs developed to describe exposures of all employees at facilities 1 through 7 were 20, 237, 471, 129, 47, 13, and 35, respectively.

Exposure Estimates

The resulting exposure estimates for UJTs and relevant time periods are shown in Table 2. The first day of the initial year of operation is used as the earliest begin date. A number of facilities are no longer in operation, as indicated by an end date

prior to December 1991, the last month and year for which exposure estimates were formulated. For some UJTs, substantial reduction in exposure has occurred; for example, note the initial estimated exposure of 4.47 fibers/cubic centimeter (f/cc) at facility 3 for the fab B activity, which is lowered to 0.97 f/cc after July 1, 1982, and to 0.02 f/cc beginning April 19, 1989. The facility 3 data include the only two instances where estimated exposure increased from one time period to another: fab A, 2.79 f/cc (July 1, 1982, through December 31, 1984) and furnace supervisor, 0.20 f/cc (October 7, 1990, through December 31, 1991). In the first instance, the change is associated with production process changes; the exposures were later reduced by ventilation. The second instance is not associated with any of the *a priori* dates, but rather was an observation on review of the plotted data. The results could reflect altered work time near the furnaces during these months. The exposure for the last time period is approximately equal to the earlier values.

Discussion

The exposure estimates incorporate the dates for which implementation of documented engineering changes are associated with a statistically significant change in airborne concentration. In all instances, a step function is assumed; that is, the exposures change abruptly, and not gradually over some period of time during which the process change might have been introduced. Long phase-in periods would be unlikely due to reduced production during implementation.

The calculated exposure estimates presented here included the measurements from the initial plant survey and from the first two quarters of monitoring, ending in 1991. Because of the small number of samples collected during this early phase of the project, the variability within a DZ was not considered; an update of the exposure estimates through June, 1994, is currently underway and includes an assessment of variability within the *a priori* dust zones. Fewer than 50 TWA estimates were calculated from the measurement data for each of facilities 1, 5, 6, and 7. However, these were the facilities with the smallest number of UJTs as well. Additional samples being collected as part of the ongoing protocol at facilities 5 through 7 provide a larger database on which to estimate exposure in the future and to evaluate these first estimates. Since facility 1 is no longer in operation, the limited available data cannot be updated.

The development of floor diagrams and the time lines for each facility provided important sources of information. The diagrams allowed use of environmental data for two locations because of similarly configured operations. The time lines provided documentation for relating changes in production to observed changes in airborne concentration. Interviews with long-term employees and review by corporate and plant personnel were used to help assure completeness. Such detail might not be feasible in facilities with less complete retention of records or less stable production processes.

The lack of exposure data from initial years of operation at facilities did not permit evaluation of the relationship between earlier process or engineering control changes and airborne fiber levels. Of the 17 changes for which exposure estimates were available both before and after the change, seven were related to a statistically significant ($p < 0.05$) change in expo-

TABLE 2. Mean RCF Exposure Estimates (f/cc) and Standard Errors (SE) During Specified Time Periods for Uniform Job Titles at Each Facility

Facility	UJT	Mean	SE	N	Begin Date	End Date
1	Braider	2.50	0.50	0	01/01/56	12/31/73
		0.13	0.01	2	01/01/74	12/31/81
1	Card	10.00	2.00	0	01/01/56	12/31/73
		0.37	0.03	2	01/01/74	12/31/81
1	Cleaner	4.41	0.59	1	01/01/56	12/31/68
		4.03	0.47	1	01/01/69	12/31/73
		0.40	0.05	8	01/01/74	12/31/76
		0.22	0.02	7	01/01/77	12/31/81
1	Foreman	2.97	0.38	1	01/01/56	12/31/68
		2.56	0.29	1	01/01/69	12/31/73
		0.30	0.03	8	01/01/74	12/31/76
		0.13	0.03	1	01/01/77	12/31/81
1	Former operator	2.50	0.50	0	01/01/56	12/31/73
		0.13	0.01	2	01/01/74	12/31/81
1	Loom operator	2.50	0.50	0	01/01/56	12/31/73
		0.13	0.01	2	01/01/74	12/31/81
1	Maintenance	2.97	0.38	1	01/01/56	12/31/68
		2.56	0.29	1	01/01/69	12/31/73
		0.30	0.03	8	01/01/74	12/31/76
		0.19	0.02	7	01/01/77	12/31/81
1	Operator	4.41	0.59	1	01/01/56	12/31/68
		4.03	0.47	1	01/01/69	12/31/73
		0.40	0.05	8	01/01/74	12/31/76
		0.22	0.02	7	01/01/77	12/31/81
1	Shipping	1.31	0.25	1	01/01/56	12/31/68
		1.31	0.18	1	01/01/69	12/31/73
		0.38	0.06	4	01/01/74	12/31/76
		0.13	0.03	1	01/01/77	12/31/81
1	Spinner operator	5.00	1.00	0	01/01/56	12/31/73
		0.23	0.07	2	01/01/74	12/31/81
1	Super	2.97	0.38	1	01/01/56	12/31/68
		2.56	0.29	1	01/01/69	12/31/73
		0.30	0.03	8	01/01/74	12/31/76
		0.13	0.03	1	01/01/77	12/31/81
1	Technician	2.97	0.38	1	01/01/56	12/31/68
		2.56	0.29	1	01/01/69	12/31/73
		0.30	0.03	8	01/01/74	12/31/76
		0.13	0.03	1	01/01/77	12/31/81
2	A OIC	0.83	0.14	36	01/01/53	09/30/88
2	A operator	0.32	0.11	18	01/01/53	09/30/88
2	B die cutter	3.53	0.51	2	01/01/53	03/31/81
		0.99	0.39	5	04/01/81	09/30/88
2	B operator	1.43	0.47	103	01/01/53	02/28/74
		1.28	0.41	118	03/01/74	06/30/74
		1.25	0.36	156	07/01/74	08/31/75
		0.63	0.07	152	09/01/75	09/30/88
2	B pack	0.32	0.05	27	01/01/53	02/28/74
		0.34	0.04	42	03/01/74	06/30/74
		0.57	0.08	80	07/01/74	09/30/88
2	Bagger	1.02	0.26	26	01/01/53	09/30/88
2	Cleaner	1.43	0.47	103	01/01/53	02/28/74
		1.28	0.41	118	03/01/74	06/30/74
		1.25	0.36	156	07/01/74	08/31/75
		0.63	0.07	152	09/01/75	09/30/88
2	Electrician	0.20	0.05	22	01/01/53	09/30/88

(Continued)

TABLE 2. (Continued)

Facility	UJT	Mean	SE	N	Begin Date	End Date
2	Engineer	0.32	0.06	88	01/01/53	09/30/88
2	Fab	3.10	1.41	4	01/01/53	09/30/88
2	Foreman	0.26	0.20	85	01/01/53	09/30/88
2	Janitorial	0.07	0.39	4	01/01/53	09/30/88
2	Lab tech	0.19	0.10	7	01/01/53	09/30/88
2	Maintenance	0.20	0.05	22	01/01/53	09/30/88
2	Millwright	0.20	0.05	22	01/01/53	09/30/88
2	Office-plant	0.08	0.35	14	01/01/53	09/30/88
2	Office	0.07	0.39	4	01/01/53	09/30/88
2	Pipefitter	0.20	0.05	22	01/01/53	09/30/88
2	Production super	0.19	0.23	102	01/01/53	09/30/88
2	Quality control	0.19	0.10	7	01/01/53	09/30/88
2	Shipping	0.23	0.09	10	01/01/53	09/30/88
3	End of line	0.91	0.01	2	01/01/70	06/30/82
		0.79	0.13	88	07/01/82	03/05/89
		0.06	0.03	14	04/06/89	12/31/91
3	Engineer	0.85	0.28	59	01/01/70	06/30/82
		0.59	0.15	271	07/01/82	12/31/84
		0.42	0.03	354	01/01/85	12/31/87
		0.42	0.03	354	01/01/88	03/31/89
		0.37	0.03	314	04/01/89	04/05/89
		0.13	0.02	157	04/06/89	04/18/89
		0.04	0.02	48	04/19/89	10/06/90
		0.08	0.02	45	10/07/90	12/31/91
3	Fab super	2.48	1.13	8	01/01/70	06/30/82
		1.50	0.59	134	07/01/82	12/31/84
		0.82	0.06	217	01/01/85	12/31/87
		0.82	0.06	217	01/01/88	04/05/89
		0.47	0.09	134	04/06/89	04/18/89
		0.09	0.08	25	04/19/89	12/31/91
3	Fab A	1.73	0.04	3	01/01/70	06/30/82
		2.79	1.48	17	07/01/82	12/31/84
		1.07	0.12	100	01/01/85	04/05/89
		0.20	0.20	17	04/06/89	12/31/91
3	Fab B	4.47	0.89	1	01/01/70	06/30/82
		0.97	0.09	113	07/01/82	04/18/89
		0.02	0.05	4	04/19/89	12/31/91
3	Fab AB	3.10	1.41	4	01/01/70	06/30/82
		1.88	0.74	130	07/01/82	12/31/84
		1.02	0.07	213	01/01/85	04/05/89
		0.58	0.11	130	04/06/89	04/18/89
		0.11	0.10	21	04/19/89	12/31/91
3	Furnace operator	0.27	0.05	49	01/01/70	03/31/89
		0.01	0.00	9	04/01/89	10/06/90
		0.25	0.05	6	10/07/90	12/31/91
3	Furnace super	0.21	0.04	53	01/01/70	12/31/87
		0.21	0.04	53	01/01/88	03/31/89
		0.01	0.00	13	04/01/89	10/06/90
		0.20	0.04	10	10/07/90	12/31/91
3	Maintenance	0.32	0.19	3	01/01/70	12/31/87
		0.09	0.05	13	01/01/88	12/31/91
3	Mixmaker	0.00	—	0	01/01/70	12/31/91
3	Occupancy	0.32	0.19	3	01/01/70	12/31/87
		0.09	0.05	13	01/01/88	12/31/91
3	Office	0.00	0.00	4	01/01/70	12/31/91
3	Office-plant	0.21	0.07	74	01/01/70	06/30/82

(Continued)

TABLE 2. (Continued)

Facility	UJT	Mean	SE	N	Begin Date	End Date
		0.15	0.04	286	07/01/82	03/31/83
		0.16	0.04	286	04/01/83	12/31/84
		0.12	0.01	369	01/01/85	12/31/87
		0.12	0.01	363	01/01/88	03/31/89
		0.11	0.01	323	04/01/89	04/05/89
		0.05	0.01	166	04/06/89	04/18/89
		0.02	0.01	57	04/19/89	10/06/90
		0.04	0.01	54	10/07/90	12/31/91
3	Quality control	0.41	0.10	1	01/01/70	12/31/87
		0.01	0.00	3	01/01/88	12/31/91
3	Shipping	0.24	0.04	15	01/01/70	12/31/87
		0.05	0.05	9	01/01/88	12/31/91
3	Shipping super	0.19	0.04	19	01/01/70	12/31/87
		0.04	0.04	13	01/01/88	12/31/91
3	Utility outside	0.00	—	0	01/01/70	12/31/91
3	Utility	0.91	0.01	2	01/01/70	06/30/82
		0.79	0.13	88	07/01/82	04/05/89
		0.06	0.03	14	04/06/89	12/31/91
4	Braider	0.09	0.01	54	01/01/79	12/31/91
4	Card	0.20	0.04	18	01/01/79	12/31/91
4	Engineer	0.07	0.01	107	01/01/79	12/31/91
4	Foreman	0.06	0.02	8	01/01/79	12/31/91
4	Janitorial	0.01	0.00	1	01/01/79	12/31/91
4	Maintenance	0.10	0.06	11	01/01/79	12/31/91
4	Office	0.01	0.00	1	01/01/79	12/31/91
4	Operator	0.11	0.02	91	01/01/79	12/31/91
4	Production super	0.06	0.02	8	01/01/79	12/31/91
4	Quality control	0.01	0.00	1	01/01/79	12/31/91
4	Rope layer	0.09	0.01	54	01/01/79	12/31/91
4	Sewer	0.26	0.03	3	01/01/79	12/31/91
4	Shipping and receiving	0.06	0.07	8	01/01/79	12/31/91
4	Spinner operator	0.11	0.03	11	01/01/79	12/31/91
4	Tapeloom	0.09	0.01	54	01/01/79	12/31/91
4	XPE	0.17	0.04	15	01/01/79	12/31/91
5	Foreman	0.63	0.51	47	01/01/82	12/31/91
5	Operator tech	0.64	0.35	47	01/01/82	12/31/91
5	Shipping	0.66	0.27	30	01/01/82	12/31/91
6	Applications engineer	0.01	0.00	2	01/01/65	12/31/91
6	Lab technician	0.14	0.07	5	01/01/65	12/31/91
6	Master technician	0.09	0.06	6	01/01/65	12/31/91
6	Office-plant	0.03	0.01	9	01/01/65	12/31/91
6	Office	0.01	0.00	2	01/01/65	12/31/91
6	Project engineer	0.01	0.00	2	01/01/65	12/31/91
7	Office	0.00	0.00	2	01/01/88	12/31/91
7	Office-plant	0.04	0.35	28	01/01/88	12/31/91
7	Quality control	0.00	0.00	2	01/01/88	12/31/91
7	Shipping	0.04	0.04	5	01/01/88	12/31/91

sure, or a difference exceeding 1.0 f/cc.⁽²⁾ These included four instances of improved local ventilation, and one each of process change, new process introduction, and installation of make-up air heaters. Not producing a detectable impact on airborne fiber concentration were five process changes: introduction of two new processes, two improvements in general ventilation, and one improvement in local ventilation. Earlier engineering changes which could not be evaluated may have

reduced exposures in facilities 2 and 3 from higher, albeit unmeasured levels, to those reported for this study. In the absence of measurements, the exposure estimates were extrapolated back in time. Over time, as we better understand the effect of engineering controls on airborne fiber concentrations, further refinement may be made in the estimates; alternatively, we may become more confident in the validity of the estimate.

The use of the mass-to-count conversion equation to esti-

mate exposure for one DZ at facility 1 may have introduced uncertainty in the earlier estimates. The value obtained was consistent with other mineral textile processing data.⁽¹⁶⁾ The short duration of sampling accepted as representative of full-shift exposure is less than recommended in current guidelines. In early years sampling personnel were not charged with full-shift monitoring; therefore, it was assumed that samples were collected only during representative work operations.

To more fully evaluate the exposure estimates derived from the methods described, the data in Table 2 may be compared with previously reported summary data for facilities 1 and 2.⁽³⁾ While the original data were available for the current study, the sample results accounted for less than 30 percent of the total samples. In the earlier work, all textile operations were grouped and the mean exposure reported as 0.62 f/cc with range of the individual measurement results ($n = 20$) from 0.035 to 6.7 f/cc. The highest value was associated with a DZ in which no one spent more than 2 hours per day. Comparison across the UJTs listed in Table 2 for the comparable time period (after January 1974), indicates a range of exposures from 0.13 to 0.40 f/cc, all within the reported range but below the mean value. For facility 2, Esmen *et al.*⁽³⁾ defined four DZs with the following means and ranges of exposure: maintenance (combines all maintenance functions), 0.27, 0.079 to 0.84; furnace or A operator-in-charge (A OIC), 0.60, 0.40 to 0.88; process (combines other production jobs), 1.10, 0.20 to 3.4; quality control, 0.33, 0.13 to 0.74. The exposure estimates for maintenance and quality control from the current report are approximately 0.1 f/cc lower than those reported by Esmen *et al.*,⁽³⁾ but are within the range of values measured previously. The A OIC exposure estimated for this study exceeds the previous mean, but is again within the range of the earlier results. The large number of jobs included in the process groups limits direct comparison; however, the range of values estimated in this study is 0.19 to 3.10 f/cc, which compares well with the literature values. It is possible that averaging results from multiple surveys conducted over a number of years contributed to the lower estimate of mean exposure. It should also be noted that different statistical methods were used to estimate the mean exposure.

The estimated exposures may be useful for comparison with historical and current exposures to RCF in other settings. The values presented will be updated as part of an ongoing epidemiologic study of health status among persons employed in these facilities.

Acknowledgments

This work was funded by a contract from the Carborundum Corporation. The assistance of Linda Alerding and Karen Williams in manuscript preparation is gratefully acknowledged.

References

1. Lockey, J.E.; Lemasters, G.K.; Rice, C.H.; et al.: Refractory Ceramic Fiber Exposure and Pleural Plaques. *Am. J. Respir. Crit. Care Med.* (accepted for publication)
2. Rice, C.; Lockey, J.; Lemasters, G.; et al.: The Use of Employee Interviews and Facility Engineering Data to Predict and Evaluate Changes in Airborne Fiber Concentration in RCF Manufacturing. *Occup. Hyg. J.* 3:85-90 (1996).
3. Esmen, N.A.; Corn, M.; Hammad, Y.Y.; et al.: Exposure of Employees to Man-made Mineral Fibers: Ceramic Fiber Production. *Environ. Res.* 19:265-278 (1979).
4. Lipomi, C.: Personal communication (1993).
5. National Institute for Occupational Safety and Health: Method 7400, Revision #3. In: *Manual of Analytical Methods*, 3rd ed. NIOSH, Cincinnati, OH (1989).
6. Buchta, T.; Rice, C.; Lockey, J.; et al.: A Comparative Study of the NIOSH 7400 "A" and "B" Counting Rules Using Refractory Ceramic Fiber. *Appl. Occup. Environ. Hyg.* (submitted).
7. Corn, M.; Esmen, N.A.: Workplace Exposure Zones for Classification of Employee Exposures to Physical and Chemical Agents. *Am. Ind. Hyg. Assoc. J.* 40:47-57 (1979).
8. Hornung, R.W.; Reed, L.D.: Estimation of Average Concentration in the Presence of Nondetectable Values. *Appl. Occup. Environ. Hyg.* 5:46-51 (1990).
9. Esmen, N.A.; Hammad, Y.Y.: Log-Normality of Environmental Sampling Data. *J. Environ. Sci. Health* 29:29-42 (1977).
10. Shapiro, S.S.; Wilk, M.B.: An Analysis of Variance Test for Normality (Complete Samples). *Biometrika* 52:591-611 (1965).
11. Kleinbaum, D.G.; Kupper, L.L.: *Applied Regression Analysis and Other Multivariable Methods*. Duxbury Press, North Scituate (1978).
12. Bancroft, T.A.: *Topics in Intermediate Statistical Methods*. The Iowa State University Press, Ames, IA (1968).
13. Aitchison, J.; Brown, J.A.C.: *The Lognormal Distribution*. Cambridge University Press, Cambridge, UK (1957).
14. Attfield, M.D.; Hewitt, P.: Exact Expressions for the Bias and Variance of Estimators of the Mean of a Lognormal Distribution. *Am. Ind. Hyg. Assoc. J.* 53:432-435 (1992).
15. Leidel, A.L.; Bayer, S.G.; Zumwalde, R.D.: UPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers. National Institute for Occupational Safety and Health, Cincinnati, OH (1975).
16. Dement, J.M.; Harris, R.L.; Symons, M.J.; Shy, C.M.: Exposures and Mortality Among Chrysotile Asbestos Workers. Part 1: Exposure Estimates. *Am. J. Ind. Med.* 4:399-419 (1983).