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A COMPARISON OF EXPOSURES TO REFRACTORY CERAMIC FIBRES OVER MULTIPLE WORK SHIFTS

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Abstract—As part of an ongoing, industry-wide study in the manufacture of refractory ceramic fibres (RCF), time weighted average (TWA) exposures have been collected at five facilities according to a standardised protocol. Work activities were grouped into dust zones (DZs). Persons to be sampled were randomly selected according to a protocol designed to assure that at least one sample was collected annually from each DZ; each work shift is also sampled at least annually. TWA exposures calculated over a sampling period of at least 360 min were included in the data set. DZs were combined into one of three groups (DZGs): fibre production; vacuum processes; other. The data were analysed to identify any differences by DZG between airborne fibre exposures, by the shift worked at each facility, and across all facilities. There were no statistically significant shift-related differences detected between airborne fibre exposures across the five RCF facilities when analysed as a group. Within four of the facilities, no shift-related differences were detected between airborne fibre exposures; however, at one facility, first and third shift exposures were statistically different. No documentation related to job activities was found to account for the observation. The data generally support the use of a single exposure estimate for each DZG in each of these facilities, regardless of shift worked. Researchers reconstructing exposure and not able to determine the shift worked by study subjects may find these results useful, but are cautioned that substantial differences in exposure across shifts may exist in other types of manufacturing. © 1997 Published by Elsevier Science Ltd.

INTRODUCTION

Refractory ceramic fibres (RCF) are a type of man-made vitreous fibre (MMVF) which are used in many industrial applications requiring heat-resistant insulation material. As production and use of asbestos has decreased throughout the years, the world production of MMVF has increased steadily (WHO, 1988). Raw materials used in the manufacture of RCF include kaolin, silica and alumina (EPA, 1993). Any potential health problems which may be associated with RCF will likely result from inhalation.

The RCF production process involves melting the raw material in a furnace. Raw materials are transferred from the storage or batching area to the furnace manually or pneumatically and melted into a molten slurry. The molten material then flows into a fibreization chamber where fibres are formed either by blowing or spinning. These fibres may be bagged and shipped as a final product or converted at the manufacturing site into one of several commercial products. Commercial RCF products include blankets, vacuum-formed shapes, felts, modules, bulk fibres and textiles. Furnace operations are continuous, 24-h operations; other processes run either one or two shifts.

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The University of Cincinnati (UC) has concluded a 6-year, industry-wide epidemiologic study of exposure in the manufacture of refractory ceramic fibre. The purpose of the study was to assess the exposures and health status of workers, to determine if there was an increased risk of adverse pulmonary effects. Located in five states across the United States, personnel at each facility were trained to conduct air sampling on a quarterly basis to evaluate exposure of workers to RCF. Some workers rotated shifts, moving according to a defined schedule from first (day shift) to second (afternoon/evening shift) to third (night shift), while others routinely worked the same shift each day. Specific start and stop time for the 8-h shifts varied; for example, first shift is from 7 a.m. to 3 p.m. at one facility, and is from 8 a.m. to 4 p.m. at another.

Changes in work practices during the second and third shift such as production schedules, number of supervisory personnel, type of product manufactured, and maintenance including 'blow-down' of a production line can all influence exposure levels. Therefore, it was decided that we should investigate whether all the measurements for a job could be pooled to calculate an estimate of exposure, or whether an estimate was needed for each shift in order to adequately describe a worker's exposure. The goal of the work presented was to evaluate whether exposure varied significantly across work shift for jobs in the RCF facilities studied.

METHODS

Initially, a detailed walk-through was conducted to identify *a priori* dust zones (DZ). The jobs included in each DZ shared four characteristics: similar work tasks, similar materials to which workers were potentially exposed, similar types of process and control technology, and an identifiable group of workers who conducted the jobs (Corn and Esmen, 1979). Specific DZs identified in some RCF facilities have been reported elsewhere (Rice *et al.*, 1997). Briefly, the DZ system results in separate DZs for wet and dry operations (for example mix tanks and bagging) because of differences in process; similarly, raw material mixers and baggers are in different DZs because of the types of potential exposures to workers (for example silica compared with fibres). Workers conducting various dry operations such as finishing and cutting may be included in the same DZ, because the types of exposures, processes and controls are similar. At each facility, at least one operation was conducted over three shifts.

Facility personnel were trained in sample collection, documentation, and shipping. Quarterly sampling of 10% of the workers across all shifts was conducted at each facility according to a standardised protocol. Adherence to the protocol was reviewed quarterly and during an annual audit. A list of all workers assigned to specific job titles was provided to the University prior to each sampling period. A list of random numbers associated with each worker was generated based on job titles within assigned dust zones. Workers to be sampled were selected randomly by an algorithm which ensured that each dust zone was represented at least once annually. Collection media was supplied to facility personnel, including nickel-plated aluminum extension cowls with 0.8- μm mixed cellulose ester filters held in a 25-mm base (Breysse *et al.*, 1990). The samples were collected using personal sampling pumps calibrated at approximately 2 l. min⁻¹. Pumps were calibrated before and

after sampling. Sample collection personnel were instructed to make detailed notes of nearby operations, clean-up activities, production data, and pump calibration. Cassettes were sealed and returned to the University with a chain of custody form. Samples were analysed according to National Institute for Occupational Safety and Health (NIOSH) method 7400, counting rules B (NIOSH, 1989). Fibre concentration was determined for each cassette and time-weighted average (TWA) estimates of exposure were calculated and reported to management.

Work location and job title entered on the data forms were standardized to allow for comparison of exposure at similar operations between facilities. Information from the data sheet and the analytical report was entered into a main database. Resolution of any inconsistencies identified from a comparison of initial and duplicate entry ensured that the data were cleaned and ready for analysis (SAS, 1982).

Exposure estimates for DZs in each facility were grouped into one of three major facility operations: fibre production, vacuum processing; and other. The fibre production dust zone group (DZG) included those DZs which involved dry production or finishing operations, specifically furnacing, blanket line, machine tender, slit/cut/pack, end-of-line and board finishing. Vacuum processing included wet processes, specifically board forming and vacuum casting. Other included operations with both wet and dry exposures, specifically maintenance, quality control and module operations or operations not directly related to production such as shipping, office and forklift. Three facilities (A, B and C) were involved with fibre production and processing; at facilities D and E fibres were processed only. The use of DZGs provided consistency for comparing exposures across facilities.

All statistical analyses were performed using SAS® software (SAS, 1982). Arithmetic and geometric mean TWA and standard deviations were determined for each shift in each DZG for each facility and across all facilities. A two-way analysis of variance (ANOVA) was used to determine if there were any differences between shifts and between DZ Groups across all five facilities (SAS, 1982). Multiple comparisons were used to determine differences among shifts and DZGs for each facility (SAS, 1982). For the ANOVA and multiple comparison analyses, the data were log-transformed, since fibre counts from these facilities have been demonstrated to be log-normally distributed (Buchta, 1991), consistent with observations of others conducting surveys in the man-made mineral fibre industries (Esmen *et al.*, 1979; Schneider, 1978).

The total number of TWAs calculated for the duration of the sampling period within the 8-h shift from this study was 594. However, 90 TWAs were eliminated from the analysis because they did not have a total sample time of at least 360 min (6 h). These shorter duration samples were excluded in order to assure comparisons reflected exposure throughout a shift. The cut-off time of 360 min resulted in elimination of approximately 18 samples at each facility. Reasons for total sampling time being below 360 minutes were most often a short duration clean-up activity, pump failure or the worker being sampled leaving the work-place early.

RESULTS

The numbers of TWA estimates for each facility were: Facility A, 111; Facility B, 112; Facility C, 104; Facility D, 53; Facility E, 124. The number of workers at

Table 1. Numbers (and fractions) of measured TWA concentration ranges for each DZG, by shift ($f\text{ cm}^{-1}$)

DZG	Shift	< 0.10	0.10–0.49	≥ 0.50
Fibre production	1	56 (0.46)	31 (0.44)	8 (0.38)
	2	40 (0.33)	26 (0.37)	6 (0.29)
	3	26 (0.21)	13 (0.19)	7 (0.33)
Vacuum production	1	22 (0.60)	22 (0.71)	11 (0.58)
	2	9 (0.24)	8 (0.26)	8 (0.42)
	3	6 (0.16)	1 (0.03)	–
Other	1	87 (0.75)	46 (0.63)	8 (0.53)
	2	25 (0.22)	14 (0.19)	3 (0.20)
	3	4 (0.03)	13 (0.18)	4 (0.27)
All DZ groups	1	168 (0.60)	99 (0.57)	27 (0.49)
	2	74 (0.27)	48 (0.27)	17 (0.31)
	3	36 (0.13)	27 (0.16)	11 (0.20)

Facility D allowed sampling of only approximately five workers per quarter, resulting in a lower accumulation of samples compared to the other facilities.

Table 1 is a display of actual TWA concentration ranges by shift for each of the DZ Groups, and for all samples collected across the five facilities. The lower bound of the group designated as $< 0.1 f\text{ cm}^{-1}$ is $0.01 f\text{ cm}^{-1}$, or the limit of detection for the method. No measured concentration exceeded $2.0 f\text{ cm}^{-1}$. Geometric mean TWA results across all facilities are presented in Table 2. A two-way ANOVA was performed on each shift *versus* each dust zone group (SAS, 1982). The resulting F-statistic of 0.43, $P=0.65$ for the shift variable, was not significant. A two-way ANOVA was performed on the data set of 594 TWA concentrations and on each facility to determine if the elimination of shorter duration samples would change the results. The F-statistic of 0.25 for the shift variable was not statistically significant, $P=0.78$.

Differences among shifts were tested statistically and did not show significance ($P < 0.05$) within the five facilities separately or for the shifts combined into one data set. A statistically significant difference between geometric mean TWAs was observed between the first and the third shift at Facility A; the least squares means value for shift 1 *versus* shift 3 was -0.75 , $P=0.04$ ($N=111$). The results for this facility are shown in Table 3. The TWA measurements indicate that exposures are higher during third shift in both the fibre production DZG and the other DZG at Facility A. No documentation related to different job duties was found on the data forms or as a result of annual audits to account for the higher TWA values during

Table 2. Geometric mean (geometric standard deviation) of TWA measurements ($f\text{ cm}^{-1}$) of at least 360 min duration across all facilities by DZG and shift

DZGs	Shift 1	Shift 2	Shift 3	All shifts combined
Fibre production ($N=213$)	0.09 (3.32)	0.08 (4.48)	0.08 (4.48)	0.08 (1.08)
Vacuum process ($N=87$)	0.13 (4.57)	0.15 (6.30)	0.04 (2.75)	0.09 (2.16)
Other ($N=204$)	0.06 (4.22)	0.05 (6.23)	0.18 (3.25)	0.08 (2.01)
All DZGs combined ($N=504$)	0.09 (1.54)	0.09 (1.73)	0.08 (2.18)	0.35 (1.43)

Table 3. Geometric mean (geometric standard deviation) of TWA measurements of at least 360 min duration ($f\text{ cm}^{-1}$) for Facility A by DZG and shift

DZG	Shift 1	Shift 2	Shift 3	All shifts combined
Fibre production ($N=40$)	0.26 (2.54)	0.27 (2.72)	0.48 (2.92)	0.32 (1.41)
Vacuum process ($N=37$)	0.26 (4.06)	0.38 (2.56)	–	0.31 (1.28)
Other ($N=34$)	0.24 (2.86)	0.26 (2.20)	0.41 (1.80)	0.32 (1.26)
All DZGs combined ($N=111$)	0.25 (1.49)	0.30 (1.22)	0.52 (1.42)	0.71 (1.35)

third shift operations. There are no vacuum process operations during the third shift at Facility A. When noted, clean-up activities were generally conducted by workers during both the first and third shifts.

DISCUSSION

The result of the comparison of TWA concentrations over multiple shifts showed no significant differences in the entire data set. The combination of dust zones into DZGs was done primarily to increase the number of samples and increase the power of the statistics. This grouping scheme worked well in the entire data set; all DZGs were represented across all shifts. The number of samples divided among the three DZGs at individual facilities was not equal: Facility A did not operate wet processes during the third shift, Facility B did not operate wet processes during the second and third shifts and Facility D was not involved with any wet process applications.

Exposures were higher during third shift operations at Facility A, even though not as many production operations occurred. Collection of additional samples over time may further clarify any differences in TWA concentration by shift at this facility. There were no outlying values in the data set for Facility A that could have contributed to the finding.

The data set of samples with sampling duration of at least 360 min was chosen to represent an average working day. Sample results excluded from the analysis generally followed the same distribution as those included in the analyses. The number of sample results eliminated was small (15%) compared to the overall number of samples. Therefore, there is no evidence that elimination of shorter-duration samples altered the overall results reported.

This initial investigation assessed whether there was a difference in TWA concentrations for three DZGs of work activities over operating shifts. As additional samples are collected, further analysis should be conducted of specific job titles to determine the relationship between job title, shift, and exposure. Continued documentation of work activities during the sample period will provide the detailed job descriptions needed to interpret any observed trends. For example, exposures at the end of the furnace production line, which runs three shifts per day may be lower during the second and third shifts, as forklift and other traffic related to nearby single or double shift operations is reduced. Grouping of the TWA concentrations by DZGs did not allow evaluation of differences exposure by job title at the individual facilities.

CONCLUSION

There were no statistically significant shift-related differences detected between airborne fibre exposures in DZGs across the five RCF facilities when the data were analysed in a single analysis. When analysed by facility, within four of the facilities, no shift-related differences were detected in airborne fibre exposures. However, third-shift exposures at Facility A were statistically different from first-shift exposures. No documentation related to job activities was found to account for the higher TWA values during third-shift operations.

Since exposure data are still being collected in these facilities, future analyses will be conducted with a larger data set to determine if the apparent difference in Facility A persists. In addition, an analysis by dust zone will be possible with a larger data set.

The data generally support the use of a single exposure estimate for each DZG in each of these facilities, regardless of shift worked. Researchers reconstructing exposure and not able to determine the shift worked by study subjects may find these results useful and encouraging, but are cautioned that substantial differences in exposure across shifts may exist in other types of manufacturing.

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REFERENCES

- Breyse, P. N., Rice, C., Aubroug, A., Komoroski, M. F., Kalinowski, M., Versen, R., Goodson, J., Carlton, R. and Lees, P. S. J. (1990) Cowl rinsing procedure for airborne fiber sampling. *Applied Occupational and Environmental Hygiene* **5**, 619–622.
- Buchta, T. M. (1991) *A Comparison Study of the NIOSH 'A' and 'B' Counting Methods Using Refractory Ceramic Fibers*. Masters Thesis. University of Cincinnati, Cincinnati, OH.
- Corn, M. and Esmen, N. A. (1979) Workplace exposure zones for classification of employee exposures to physical and chemical agents. *American Industrial Hygiene Association Journal* **40**, 47–57.
- EPA (1993) *Federal Register*. Vol. 58, No. 92, p. 28517. Government Printing Office, Washington, DC.
- Esmen, N. A., Corn, M., Hammad, Y. Y., Whittier, D., Kotsko, N., Haller, M. and Kahn, R. A. (1979) Exposure of employees to man-made mineral fibers: ceramic fiber production. *Environmental Research* **19**, 265–278.
- NIOSH (1989) NIOSH method 7400, revision #3. In *NIOSH Manual of Analytical Methods*, 3rd Ed. U.S. Dept of Health and Human Services, NIOSH, Cincinnati.
- Rice, C. H., Lockey, J. E., Lemasters, G. K., Levin, L. L., Staley, P. and Hansen, K. R. (1997) Estimation of historical and current employee exposure to refractory ceramic fibers during manufacturing and related operations. *Applied Occupational and Environmental Hygiene* **12**, 54–61.
- SAS (1982) *SAS User's Guide: Statistics, 1982 Edition*, ed. A. A. Ray. SAS Institute Inc., Cary, NC.
- Schneider, T. (1978) Exposures to man-made mineral fibres in user industries in Scandinavia. *Annals of Occupational Hygiene* **22**, 153–162.
- WHO (1988) *International Agency for Research on Cancer Monographs on the Evaluation of Carcinogenic Risks to Humans, Man-made Mineral Fibers and Radon*, Vol. 43, UK/IARC.