Study of the respiratory health of employees in seven European plants that manufacture ceramic fibres

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Abstract

Objectives—To study the relation between occupational exposure to ceramic fibres during manufacture and respiratory health.

Methods—The respiratory health of 628 current employees in the manufacture of ceramic fibres in seven European plants in three countries was studied with a respiratory questionnaire, lung function tests, and chest radiography. Simultaneous plant hygiene surveys measured subjects' current exposure to airborne ceramic fibres from personal samples with optical microscopy fibre counts. The measured exposures were combined with occupational histories to derive estimates of each subject's cumulative exposure to respirable fibres. Symptoms were related to current and cumulative exposure to ceramic fibres and lung function and findings from chest radiographs were related to cumulative exposure.

Results—The mean duration of employment was 10.2 years and mean (range) cumulative exposure was 3.84 (0–22.94) (f.ml⁻¹.y). Eye and skin symptoms were frequent in all plants and increased significantly, as did breathlessness and wheeze, with increasing current exposure. Dry cough and stuffy nose were less common in the least exposed group but did not increase with increasing exposure. After adjustment for the effects of age, sex, height, smoking, and past occupational exposures to respiratory hazards, there was a significant decrease in both forced expiratory volume in one second (FEV₁) and forced midexpiratory flow related to cumulative exposure in current smokers ($P < 0.05$) and in FEV₁ in ex-smokers ($P < 0.05$). Small opacities were found in 13% of the chest radiographs; their prevalence was not related to cumulative exposure to ceramic fibres. **Conclusions**—It is concluded that exposure to ceramic fibres is associated with irritant symptoms similar to those seen in other exposures to man made mineral fibres (MMMFs) and that cumulative exposure to respirable ceramic fibres may cause airways obstruction by promoting the effects of cigarette smoke.

Ceramic fibres are heat resistant amorphous man made mineral fibres (MMMFs) produced from alumino-silicate glass by blowing or spinning methods similar to those used in the manufacture of insulating wool. They are capable of withstanding higher temperatures than other MMMFs and have better heat insulation properties. Because of their greater production cost, they have until recently been used mainly for industrial applications such as special purpose heat insulation and refractory linings. Now they are also being used increasingly in fire protection of buildings and in the heat insulation of domestic appliances.

The production of ceramic fibres began in Europe 27 years ago and by 1989 output had reached about 90 000 tonnes a year. When our study began in 1986 there was a total of seven plants manufacturing ceramic fibre products in France, Germany, and the United Kingdom and all of these have been included in our study.

Although exposures to other forms of MMMF have been extensively studied in the production industries in the United States and Europe, there have so far been very few environmental surveys of the production of ceramic fibres. Average exposures to respirable fibres in the production of insulating wool, special purpose glass fibres, and continuous glass filament in Europe have been shown to be generally low (0.004 to 0.45 f.ml⁻¹) and substantially lower than those found historically in asbestos factories.¹ In contrast to these results a study of three plants that produced ceramic fibres in the United States found group mean airborne fibre concentrations that ranged between 0.02 and 6.9 f.ml⁻¹ and in one plant individual exposures of ≥ 10 f.ml⁻¹ were not unusual in unventilated manufacturing areas with up to 40% of fibres classified as Stanton type fibres (<1.5 mm diameter and >8 μ m length).² These results indicate a potential exposure to higher concentrations of respirable fibres in the production of ceramic fibres than in other branches of the MMMF industry.

At the present time no conclusion can be reached about the health effects to humans of exposure to ceramic fibres. For other MMMFs, investigations into the effects in humans from exposure to airborne dusts and fibres during production have included studies of employees who manufacture insulation wool, special purpose glass fibres, and continuous glass filaments. The studies have included both the morbidity and mortality of workers employed in these industries, the

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results of which have been critically reviewed in the scientific literature on several occasions.³⁻⁶ Only one of the morbidity studies has produced evidence of a causal effect of exposure to MMMFs. In that study an association between the prevalence of small opacities on chest radiographs and duration of exposure to MMMFs was found in smokers only but a second phase of the study has not reproduced these results.^{7,8} Not all of the remaining studies are negative. In some there are inadequate data on respiratory effects, on exposure to MMMFs, on smoking habits, or on previous hazardous exposures that might have influenced the final outcome. On the other hand the mortality studies are among the most statistically powerful conducted in any industry with 90% power to detect a standardised mortality ratio (SMR) for lung cancer of only 115%. These studies have shown an excess of lung cancer in those first employed 30 or more years ago in the rock and slag wool production industries but there is uncertainty about past fibre counts and the extent of exposure to other carcinogens in these parts of the industry. What is now clear from all these studies is that no chronic pathological effects have been seen in the first 20 years after first exposure in the industry and that recent exposures to respirable fibres are low but may have been higher in the past.⁶ Although there has been considerable research effort, no firm conclusions can yet be reached about the human health effects of exposure to insulation wool, special purpose glass fibres, or continuous glass filament.

Present knowledge of potential health effects of ceramic fibres is based upon experimental work with rats and hamsters. Ceramic fibres have been shown to be more durable and persistent in rat lung tissue^{9,10} and less soluble in physiological fluids than other MMMFs.^{11,12} They have similar carcinogenic potential to other MMMFs when directly deposited into the peritoneal cavity of rats and hamsters.¹³ Also, unlike other forms of MMMF, ceramic fibres have produced pulmonary fibrosis, lung tumours, and mesothelioma in these animals when inhaled in high concentrations.¹³⁻¹⁵

Thus, from what little is already known about the biological activity of ceramic fibres and the potential exposure to them in

the manufacturing environment, there is an important need to undertake similar morbidity and mortality studies among those with current and past exposure to ceramic fibres as has been done in other branches of the MMMF industry.

Our study was undertaken with the aim of determining respiratory morbidity in current employees in the European ceramic fibre production industry. The study was a cross sectional respiratory morbidity survey combined with simultaneous measurements of exposure to dust and fibres. The aims were to investigate lung function and the prevalence of various respiratory, nasal, eye, and skin symptoms in an exposed population, and to relate these findings to estimates of current and cumulative exposure to ceramic fibres. The study was commissioned by the European Ceramic Fibres Industry Association (ECFIA) and included all of the seven European manufacturing plants that belong to its member companies. The plants were operating in three European countries.

We present the findings of the investigation of symptoms and lung function in relation to exposure to ceramic fibres in the study population. The sampling methods and results from the plant hygiene surveys have been fully reported elsewhere,¹⁶ and only brief details are included in this paper.

Materials and methods

PLANTS

The seven plants studied were situated in three countries; two in the United Kingdom; four in France; and one in Germany (table 1). Six plants manufactured ceramic fibres in bulk or blanket form with similar raw materials that consist of roughly a 50:50 mixture of alumina (Al_2O_3) and silica (SiO_2) to which elements such as zirconium, chromium, calcium, and magnesium may be added to alter the refractory properties of the fibres. After heating the raw materials in an electric furnace, fibres were produced from the molten mixture by blowing or spinning methods. In all plants ceramic fibres were used as the main constituent in various wet and dry secondary production processes to make refractory and insulation products—for example, laminated blocks or modules, ropes

Table 1 Details of the plants and workers included in the study

Plant	Country	Start	Employees (n)	Participation (%)	Mean age (y)	Women (%)	Current smokers (%)	Mean years employed	Exposures to other refractory fibres
1	UK	1971*	137	93	40.0	0	39	10.8	Bricks, silicon carbide elements
2	UK	1967	175	80	37.7	6	52	7.7	Bricks until 1979
3	F	1967	46	91	38.1	24	21	13.8	Bricks only
4	F	1968†	56	93	35.0	12	50	9.3	Nil
5	F	1969‡	70	90	38.5	24	38	11.3	Bricks until 1974
6	F	1965	147	92	37.0	8	37	11.5	Bricks until 1974
7	G	1977	77	87	36.2	7	62	8.5	Bricks and abrasives
All	3	1965	708	89	37.7	9	44	10.2	

*Secondary production only until 1976 used imported ceramic fibres from USA; †used ceramic fibres from plants 3 and 5; ‡until 1974 used ceramic fibres from plant 3.
UK = United Kingdom; F = France; G = Germany.

and textiles, paper, boards and moulded shapes, cements, and mastics. Most plants started producing ceramic fibres in some form before 1970 although in plants 1 and 5 early production used ceramic fibres manufactured in other plants before their own fibre production started.

At the time of the survey a total of 708 employees were engaged in these plants. The plants varied considerably in size and numbers of employees. Except for plant 4, all had developed alongside an existing refractory brick manufacturing industry, which was still functioning at three sites (plants 1, 3, and 7). A small proportion of the current workforce had transferred from employment with bricks to manufacture of ceramic fibres.

STUDY POPULATION

The study population was identified from plant employee records and included all current employees working full time on the site regardless of the degree of exposure or duration of employment. In a pilot survey (plant 1), women were excluded because of their very low numbers and employment in areas with little or no exposure to ceramic fibres. In the remaining plants all women were included because they were more numerous and higher proportions were employed in production work. Contract and temporary employees were excluded. A small proportion of employees who worked in the three plants with an associated refractory brick manufacturing facility were excluded if they had jobs that currently exposed them to both ceramic fibres and refractory brick dust—that is, mixed dust exposure.

HYGIENE SURVEYS

Methods used in the plant hygiene surveys are briefly summarised here. From preliminary visits to each plant, information about primary and secondary production methods, job descriptions, and location of work stations was used to categorise jobs and construct an occupational group structure that covered all plant activities for every plant. A total of 140 jobs were identified throughout the seven plants; these were classified into seven main groups. Full shift personal sampling was undertaken during normal working hours in the conditions prevailing in the plant at that time. Subjects were selected at random from each occupational group for personal sampling, and all groups were sampled. Inspirable dust and respirable fibre concentrations were measured. We report the outcome measures related to exposure to respirable fibres.

Inspirable dust was defined as the fraction of airborne particles that would be inspired through the nose or mouth of a worker and was measured gravimetrically. Samples were collected according to the American Conference for Governmental Industrial Hygienists' criteria for inspirable dust.¹⁷ Samples of respirable ceramic fibres were collected and analysed according to the World Health Organisation/EURO

reference method with phase contrast optical microscopy.¹⁸ Respirable fibres were defined as particles of length $>5\text{ }\mu\text{m}$ with an aspect ratio $>3:1$ and with a diameter $\leq 3\text{ }\mu\text{m}$.

HEALTH SURVEYS

Subjects were assessed with a self administered respiratory symptom questionnaire, lung function tests and full sized ($40 \times 40\text{ cm}$) chest films. The x ray films were read by three independent readers who used the ILO 1980 classification. Median readings were used in the analysis. The questionnaire was based upon the Medical Research Council's respiratory questionnaire¹⁹ with additional questions on nasal, eye, and skin symptoms, smoking habits, and occupational history during and before employment in the plant. The same questionnaire was used in the French and German plants after translation into the respective languages. Before use, the translated versions were carefully checked by bilingual French and German doctors to ensure that questions had similar meanings in these languages. Each subject's occupational history within the plant was recorded as a chronological sequence of durations of jobs selected by the subject from a complete list of jobs identified in each plant by the hygiene survey. A history of employment in occupations with respiratory risk before joining the plant was also recorded. Spirometric lung function tests of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and forced mid-expiratory flow (FEF_{25-75}) were determined with a Vitalograph dry wedge spirometer. The procedure for obtaining lung function tests and criteria for acceptability of recordings taken were strictly in accordance with the published recommendations of the American Thoracic Society.²⁰ The radiographic survey was undertaken with a single mobile x ray unit that visited all the plants in turn. The same technique was used for all films.

DATA ANALYSIS

The measurements of exposure to ceramic fibres obtained in the plant hygiene surveys were used to derive estimates of exposure to respirable fibres (f.ml^{-1}) within the seven main occupational groups in each plant. Each subject's current exposure was derived from the estimate for the main occupational group for that plant. Cumulative exposure was calculated by summing the exposure $\times$ time products for the entire sequence of jobs done by the employee in the plant. For this calculation an employee's exposure to ceramic fibres in any occupational group in which he had worked in the past was assumed to be the same as the estimated current exposure in that occupational group in the same plant. Subjects were then grouped by both current and cumulative exposure to respirable fibres, before any analysis of symptoms or lung function was undertaken. The prevalence of the various respiratory, nasal, eye, and skin symptoms was then compared between the current

exposure groups. The indices of lung function and symptoms were compared between the cumulative exposure groups. Symptoms were further investigated with a logistic regression and lung function by linear regression. This enabled the relation between exposure and the various health effects to be examined while the potential confounding effects of age, sex, and smoking habits, and (in the case of the lung function analysis) past occupational exposure to respiratory hazards were controlled. The regression analyses were undertaken with GLIM²¹ and SPSS²² statistical packages.

Results

STUDY PARTICIPANTS

After removal of 23 ineligible participants with mixed dust exposure who worked in the three plants with accompanying refractory brick manufacture, there were 628 participants, an overall participation rate of 89% (table 1). Participation at individual plants mostly exceeded 90%. Non-participation was mainly due to non-availability from holidays or rest periods. The mean age of participants was 37.7 years with little difference between the plants. Nine per cent of subjects were women who were most frequent in French plants. Forty four per cent of the study population were current smokers. There were quite

large differences in smoking habits between plants even within the same country. The mean duration of employment was 10.2 years (range from plant to plant 7.2–13.8 years).

The subjects' occupational histories before being employed in the plant showed that 4.5% had some asbestos exposure, 3% had worked in mining coal or ores, 5% had worked in iron and steel foundries, 7% in the insulation wool industry, and nearly 10% had worked in refractory brick manufacture. Overall, just over 19% had worked in dusty occupations outside the production of ceramic fibres.

Current exposure

Four groups were chosen that covered a range of exposures to respirable fibre and represented possible exposure limits. The numbers in each group vary, with particularly low numbers in the highest exposure group, which has been combined with group 3 for the statistical analyses (table 2). After dividing subjects into these groups, the prevalence of respiratory, nasal, eye, and skin symptoms in each group was compared.

Respiratory, nasal, eye, and skin symptoms

Symptoms of nasal stuffiness, eye, and skin irritation were common in all plants, the most frequent being nasal stuffiness in 55% of subjects; 41% complained of eye irritation, 36% complained of skin irritation, 18% of wheeze, 13% of dry cough, and 12% fulfilled the criteria for chronic bronchitis. Chronic bronchitis was similar to that found in one other respiratory morbidity study in the MMMF industry.⁷

All symptoms of the lower respiratory tract were more frequent in current smokers compared with ex or never smokers (table 3). The heaviest smokers had at least three times more frequent symptoms than did those who smoked least. For chronic bronchitis and wheeze, there was a clear increasing trend with the amount smoked but for dry cough and dyspnoea of grade 2 or above the pattern was not so consistent.

As the exposure groups differed for prevalence of smoking, mean ages, and proportions of each sex, the relation between symptoms and current exposure was investigated with multiple logistic regression models for each symptom. In these regression models the adjusted odds ratios for symptom prevalence in the middle (0.2–<0.6 f.ml⁻¹) and highest (≥0.6 f.ml⁻¹) exposure groups were compared with those of the baseline category for the model—that is men in plant 1 aged <25, who had never smoked and were in the lowest exposure group—(table 4). The P value gives the combined significance of any differences in the odds ratios between the exposure groups. The results show increasing odds ratios with increasing exposure for wheeze, dyspnoea, eye, and skin irritation. There were also increased odds ratios for dry cough and blocked or stuffy nose, but these did not increase with increasing current exposure.

Table 2 Current exposure to ceramic fibres

Exposure group	Range (f.ml ⁻¹)	Subjects (n(%))	Mean age (y)	Women (%)	Current smokers (%)
1	<0.2	294 (46.8)	38.0	11	38
2	0.2–<0.6	123 (19.6)	37.2	11	50
3	0.6–<1	200 (31.8)	37.2	2	54
4	≥1	11 (1.8)	45.9	64	18
ALL		628	37.7	8.9	44

Table 3 Prevalence of respiratory symptoms in each smoking category (%)

Symptoms	Never (%) (n = 209)	Ex (%) (n = 145)	Current cigarettes/day		
			1–14 (%) (n = 98)	15–24 (%) (n = 129)	≥25 (%) (n = 47)
Dry cough*	9	13	14	13	25
Chronic bronchitis*	10	8	9	17	28
Wheeze***	8	17	18	25	45
Dyspnoea ≥2***	9	15	12	9	36

*P < 0.05; ***P < 0.001 between categories who smoked by the χ^2 test with 4 degrees of freedom.

Table 4 Adjusted odds ratios (OR) and their 95% confidence intervals (95% CI) from multiple logistic regression analysis of symptom prevalence compared with the group with exposures <0.2 f.ml⁻¹

Symptom	Current respirable fibre concentration (f.ml ⁻¹)		P value
	0.2–<0.6	≥0.6	
Dry cough	2.53 (1.25 to 5.11)	2.01 (1.05 to 3.84)	<0.05
Chronic bronchitis	1 (0.48 to 2.09)	1.02 (0.54 to 1.93)	NS
Wheeze	1.14 (0.59 to 2.19)	1.42 (0.81 to 2.49)	<0.0001
Dyspnoea ≥2	1.26 (0.61 to 2.6)	2.66 (1.31 to 5.42)	<0.05
Stuffy nose	2.06 (1.25 to 3.39)	1.23 (0.8 to 1.89)	<0.05
Eye irritation	2.16 (1.32 to 3.54)	2.63 (1.7 to 4.08)	<0.0001
Skin irritation	1.25 (0.74 to 2.11)	3.18 (2.01 to 5.03)	<0.0001

Cumulative exposure

The resulting estimates of the mean of participants' cumulative exposure to respirable fibres for each plant ranged between 2.88 and 6.83 f.ml⁻¹.y and for the whole population was 3.84 f.ml⁻¹.y. The distribution of exposure throughout the study population was heavily skewed and with logarithmic ranges of exposure, comparable numbers were obtained in each of five exposure groups with the exception of the group with the highest exposure (table 5).

Lung function

Percentage predicted lung function indices were calculated with the European Community Coal and Steel (ECCS) set of reference values,²³ which have been obtained from comparable industrial populations over a wide area of Europe. Mean percentage predicted indices were then compared between the various categories of smokers (table 6). The indices were generally high, but were lower among ex and current smokers. Percentage predicted FEV₁ and FEF₂₅₋₇₅ showed a clear decreasing trend with increasing cigarette consumption. Overall FEV₁ fell by about 10% between the never and heaviest smoking categories. This is commonly found in lung function studies of this type.

When mean percentage predicted lung function indices for subjects in each of the five

cumulative exposure groups were compared, they showed an irregular decreasing trend with increasing exposure especially for FEV₁ and FEF₂₅₋₇₅ (table 7). The FEV₁ decreased by over 4% between the lowest and highest exposure groups. It was considered that this apparent trend might be due to differences in age, sex, smoking habits, and past exposures to respiratory hazards between the exposure groups. Therefore the results were further investigated with a multiple linear regression analysis. Observed lung function indices were investigated as continuous variables with adjustment for the effects of age, height, sex, and smoking (in cigarette-years) and with past exposure to ceramic fibres, asbestos, and refractory work included as dummy variables. Never, ex, and current smokers were investigated separately. The regression coefficients for each predictor and their significance levels are shown (table 8).

For men who were never smokers, the regression coefficients for exposure on all three indices were positive—that is, increasing exposure improving lung function) but not significantly at the 5% level. Exposure coefficients were negative and significant, however, for FEV₁ in both ex ($P < 0.05$) and current smokers ($P < 0.01$) and also for FEF₂₅₋₇₅ in current smokers only ($P < 0.05$). Thus only in never smokers was there an absence of significant effects of exposure. None of the regression coefficients for past exposures to respiratory hazards reached significance, which suggests that the results are not seriously confounded by past exposures.

The relative size of the effect of exposure and age on lung function can be predicted from the regression coefficients obtained for exposure and age in this analysis. To show the size of these effects, the predicted fall in FEV₁ for men who were current smokers was 32 ml/f.ml⁻¹.y compared with 28 ml/y of age. A similar but slightly larger effect was seen in exsmokers (37 ml/f.ml⁻¹.y compared with 35 ml/y of age). Thus the effects of exposure and age upon FEV₁ are of comparable magnitude.

Respiratory symptoms

There was no relation between chronic bronchitis or wheeze and cumulative exposure to respirable fibres (table 7). There was, however, a significant relation between increasing exposure to respirable fibres and the two degrees of breathlessness from the MRC respiratory questionnaire.

Chest x ray films

Chest x ray films of satisfactory standard for ILO classification were obtained from 592/628. Small opacities of $\geq 0/1$ were present in 13% (rounded 3.2%, irregular 5.1%, and mixed 4.7%). A profusion score of $\geq 1/1$ was found in 18/592, 11 of whom had confounding exposures to other dusts. The prevalence of small opacities increased with age, smoking, and previous exposure to asbestos, but not with any measure of

Table 5 Groups of cumulative exposure to respirable ceramic fibres

Exposure group	Range (f.ml ⁻¹ .y)	Subjects (n (%))	Mean age	Women (%)	Current smokers (%)
1	< 1	119 (18.9)	30.2	13	42
2	1–< 2	106 (16.9)	35.7	10	44
3	2–< 4	168 (26.8)	39.5	5	38
4	4–< 8	166 (26.4)	40.6	4	50
5	≥ 8	69 (11.0)	42.7	19	45
All	0–22.94	628	37.7	9	44

Table 6 Mean percentage predicted lung function for never, ex, and current smokers (ECCS predicted values)

Function	(n)	Current (cigarettes/day)				
		Never	Ex	1–14	15–24	≥ 25
FVC	604	111.2	110.5	109.8	109.3	109.1
FEV ₁	606	107.5	103.7	104.6	101.3	98.7
FEF ₂₅₋₇₅	597	89.9	84.7	84.5	78.3	72.8

Table 7 Relation between cumulative exposure to respirable fibres and chronic respiratory symptoms and lung function

Function	(n)	Exposure groups (f.ml ⁻¹ .y)					All
		< 1	1–< 2	2–< 4	4–< 8	≥ 8	
FVC	604	112.0	110.2	111.5	109.2	110.3	110.6
FEV ₁ **	606	106.5	105.5	106.0	102.3	102.1	104.6
FEF ₂₅₋₇₅ ***	585	89.0	90.1	85.3	79.7	74.4	84.1
Chronic bronchitis (%)	628	13	9	12	14	10	12
Breathless ≥ 2 (%)*	628	6	9	13	17	20	13
Breathless ≥ 3 (%)*	628	1	3	5	4	10	4
Wheeze (%)	628	15	11	20	20	25	18

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$.

Table 8 Regression coefficients for FVC, FEV₁ and FEF₂₅₋₇₅ by smoking, related to cumulative exposure to respirable fibres

	Smoking	(n)	Constant	Age (Δ/y)	Height (Δ/cm)	Smoking (Δ/ cigarette .y)	Cumulative exposure (Δ.f.ml ⁻¹ .y)	Past exposure to		
								Ceramic fibres yes or no	Asbestos yes or no	Other refractory fibres yes or no
FVC (l)	Never	154	-5.284	-0.023***	0.065***		0.007	-0.004	0.387	-0.062
	Ex	131	-8.833	-0.024***	0.087***	-0.0005*	-0.034	0.298	-0.29	0.19
	Current	247	-7.527	-0.015**	0.077***	-0.0002	-0.025	0.052	-0.221	0.055
FEV ₁ (l)	Never	154	-2.44	-0.031***	0.044***		0.014	-0.046	0.136	0.084
	Ex	131	-3.26	-0.035***	0.051***	-0.0005*	-0.037*	0.269	-0.223	0.12
	Current	247	-2.814	-0.028***	0.046***	-0.0004*	-0.032**	0.014	-0.185	-0.004
FEF ₂₅₋₇₅ (l/s)	Never	152	1.36	-0.057***	0.027*		0.028	0.053	-0.554	0.316
	Ex	130	7.67	-0.068***	-0.005	-0.0008*	-0.051	0.025	0.232	-0.077
	Current	247	2.807	-0.061***	0.02	-0.0007*	-0.063	-0.07	-0.183	-0.142

*P < 0.05; **P < 0.01; ***P < 0.001.

cumulative exposure to ceramic fibres. There were no large opacities. Sixteen films showed pleural abnormalities, only two of which were known to have previous exposure to asbestos. Pleural changes were related to age but not independently to exposure to ceramic fibres.

Discussion

In this study we have examined exposure to airborne dust and respirable fibres in seven European ceramic fibre production plants and the respiratory health of almost 90% of those working in them. Gravimetric measurements of current exposure in these plants showed occupational group means that varied between 1.7 and 3.4 mg/m³ for primary production workers and 1.8 and 11.2 mg/m³ for secondary production workers. Mean respirable fibre concentrations varied from 0.2 to 0.88 f.ml⁻¹ for primary production workers and 0.49 to 1.36 f.ml⁻¹ secondary production workers. Exposures for other occupational groups were lower and typically < 0.5 f.ml⁻¹.¹⁶ Exposures to dust and fibres were clearly highest in secondary production where a greater amount of manual handling of the ceramic fibres was required. The results of exposure measurements in our study were similar to those found in three ceramic fibre manufacturing plants in the United States² and respirable fibre concentrations were generally higher than in other MMMF production except for the manufacture of special purpose glass fibres.

The estimates of participants' cumulative exposure to respirable fibres were generally low by comparison with those associated with pneumoconioses due to asbestos. Although crystalline silica was detected in some samples the concentrations were low, ranged from 0.01 to 0.25 mg/m³, and were unlikely to have influenced respiratory symptoms or lung function.

Various authors have reported respiratory, skin, and eye symptoms in workers exposed to MMMFs. Hill *et al* found that 45% of 70 workers exposed to glass fibre had had for a short period what was referred to as "new starters" glass fibre rash.²⁴ Milby and Wolf reported 691 cases of occupational disease attributed to exposure to glass fibre over a two and a half year period in California of which 38 were attributed to irritation of the upper and lower respiratory tract and the rest to effects upon skin and eyes.²⁵ Although

these studies suggest an excess of irritant symptoms in populations exposed to MMMFs, other studies that correlated respiratory symptoms with measures of current or cumulative exposure to MMMFs, or to surrogate measures of exposure such as occupational group or duration of employment, have tended not to show any effects related to exposure after adjustment for any effects of age, sex, and smoking.^{7 26 27} In two of these studies, however, exposure to respiratory hazards in previous employment was found to be significantly associated with some symptoms of the lower respiratory tract.^{7 26}

In our study we examined symptoms in relation to current exposure to ceramic fibres. As many of the symptoms, particularly the irritant skin, eye, and nasal ones, are considered to be predominantly short term and reversible, it is more appropriate to relate these to current exposure. Also, in cross sectional studies there is often speculation about possible bias of results due to self selection of more sensitive individuals into situations of lower exposure. If this occurred in our study, then a real effect of exposure upon symptoms could be masked by comparison of symptoms between cumulative exposure groups, which may include subjects with both high and low current exposure within the same exposure group. Nevertheless it is still possible that the results of these investigations could be biased by self selection, which would tend to lessen the magnitude of effect of exposure upon symptoms.

We found a high prevalence of nasal, eye, and skin symptoms uniformly across all the plants. Respiratory symptoms were less frequent and more variable between plants but were more frequent in smokers and increased with the amount smoked. Although there are no established prevalence rates for all these symptoms in comparable populations, the similarity of prevalence rates between the plants and the relation of the respiratory symptoms with smoking suggests that our translated questionnaire had semantic equivalence across the study population.

After adjustments for potential confounding effects including age, sex, smoking, and plant, we found that the frequency of eye and skin symptoms, dyspnoea grade 2 or more, and wheeze increased significantly with exposure particularly in the highest exposure group. After similar adjustment, nasal stuffi-

ness and dry cough were most prevalent in exposure group 0.2–<0.6 f.ml⁻¹; the dose response relations were absent. These results contrast with those found in workers exposed to other MMMFs—for example, glass fibre—but may be due to the higher levels of current exposure to dust found in ceramic fibre plants compared with other areas of MMMF exposure in which those findings were made. We conclude that symptoms related to exposure are present in this study population and are likely to be causally related to exposure.

The chest x ray films showed few abnormalities, none of which were related to exposure to respirable fibres. Those with small opacities had a high prevalence of potentially confounding exposures. A small number of workers with pleural disease were seen where asbestos exposure seemed an unlikely confounding factor; however, the numbers were too small to investigate dose response relations.

Our examination of lung function has shown a significant relation between increasing cumulative exposure to respirable fibres and decrements in FEV₁ and FEF₂₅₋₇₅ in current smokers and FEV₁ in ex-smokers. The results are unlike those seen in other studies of working populations exposed to MMMF—such as glass and mineral fibre—where adverse effects of exposure have not been found.^{2 24 26}

As our study is cross sectional in design it may have included a survivor population, which is a potential problem in studies of this type. In studies of respiratory effects of dust exposure, it has been suggested that self selection of people with airway hyper-responsiveness will tend to weaken the relation between lung function abnormality and occupational exposure.²⁸ If present in some of the previous studies of effects from exposure to MMMFs on respiratory health, self selection would reduce the chances of detecting an effect from exposure and may explain why such effects have not been seen in these studies. This is not sufficient to explain our findings as the same effect would be expected to apply equally in our study.

Although the total number of subjects with past exposure to respiratory hazards was small there was a positive trend of an increasing proportion of subjects with past exposure to ceramic fibres, asbestos, and dust from refractory brick manufacture with cumulative exposure to respirable fibres. Therefore we did adjust for the potential confounding effect of these past exposures upon lung function in the multiple linear regression analysis. None of the regression coefficients for these factors reached significance.

After adjustment for age, height, sex, and cigarette-years, effects upon lung function related to exposure are present and are likely to represent a real effect of exposure on airway function. When the groups who smoked were separated the effect was only seen in current and ex-smokers. There is no evidence of an effect of cumulative exposure to ceramic fibres on the lung function of lifelong non-

smokers. It therefore seems that smoking is an essential prerequisite for an effect of cumulative exposure to ceramic fibres on lung function. Although the effects of cigarette smoking on lung function are well established,²⁹ the interaction of these effects with inhaled fibres and dust particles has not been found previously in studies of this type. It is more likely that exposure to ceramic fibres is acting as a promoter of the effects of exposure to cigarettes than the opposite. With other occupational exposures it is usually easier to see the effects of agents that affect lung function in non-smokers than smokers. The lack of an effect of cumulative exposure to ceramic fibres on chronic cough and sputum in non-smokers also suggests that ceramic fibres are acting in a different way from agents such as coal and silica.

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- 2 Soter NA, Wasserman SI, Austen KF. Cold urticaria: release into the circulation of histamine and eosinophil chemotactic factor of anaphylaxis during cold challenge. *N Engl J Med* 1976;294:687-90.
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