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Research Report TM/89/07
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A REPORT ON THE ENVIRONMENTAL CONDITIONS AT SEVEN EUROPEAN CERAMIC FIBRE PLANTS

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by

JW Cherrie, PL Bodsworth, Hillary A Cowie, Sheila K. Groat, S Pettie, J Dodgson

Research work carried out under the sponsorship of the European Ceramic Fibres Industry Association.

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SUMMARY

As part of an epidemiological study which was co-ordinated by the University of Birmingham in the European Ceramic Fibre Industry, the Institute of Occupational Medicine has carried out a series of occupational hygiene investigations in seven production plants. This report presents the results from surveys and the rationale and methods used to calculate each worker's cumulative exposure to airborne dust and fibres. The results from the epidemiological study are described in a companion report.

In each of the factories included in the study, a comprehensive occupational hygiene survey was undertaken. Workers were selected at random from within occupational groups and full shift personal dust samples obtained. Respirable and non-respirable fibre concentrations and total mass concentrations were obtained using the WHO/EURO MMMF Reference Method. Measurements of inspirable mass, respirable mass and silica and fibre size were also made.

Individual respirable fibre concentrations ranged up to 2.4 fibres/ml in the case of production workers and 3.4 fibres/ml for secondary production workers. The plant average concentrations for production workers ranged from 0.2 fibres/ml at one plant to 0.88 at another. Corresponding mean respirable fibre concentrations for secondary production ranged from 0.49 fibres/ml to 1.36 fibres/ml. The respirable fibre levels in other groups were substantially lower, typically less than 0.5 fibres/ml.

The mean mass concentrations of inspirable dust for production workers ranged from 1.4 mg/m^3 to 3.8 mg/m^3. The highest individual concentration for this group was 11.4 mg/m^3. The corresponding range for secondary production workers was 0.8 mg/m^3 to 7.4 mg/m^3.

Inspirable and total mass concentrations were reasonably well correlated ($r = 0.7$), with the inspirable mass in general being slightly higher. The relationship between these two measures was used to predict inspirable mass concentration for the purposes of estimating exposure.

Respirable mass and silica concentrations were generally low less than 1 mg/m^3 and 0.1 mg/m^3 respectively, the highest individual concentrations measured were 2.8 mg/m^3 and 0.25 mg/m^3 respectively. Crystalline silica was detected on approximately 50% of the samples.

The nominal fibre diameter of bulk ceramic fibres was found to range from 0.8 μm to 2.8 μm. The airborne fibres were thinner; geometric mean diameter ranged from 0.5 to 1.3 μm and mean lengths from 3.9 μm to 25.2 μm.

Cumulative exposures to respirable and non-respirable fibres and inspirable mass were calculated using individuals' occupational histories supplied by the University of Birmingham. The occupational hygiene data used in these calculations were combined across groups and plants where no differences were identified in the statistical analysis.

1. INTRODUCTION

Ceramic fibres are part of the group of synthetic inorganic fibres known as man-made mineral fibres (MMMF). They are produced by melting various mixtures of alumina and silica, sometimes with other additives, at temperatures of about 2000 °C and either blowing through or spinning the melt to produce vitreous fibres. Other members of the MMMF group include fibres manufactured from rock, glass and metallic slags. Ceramic fibres were first commercially manufactured in the United States in the early 1960s, but they were not produced in Europe until the mid 1960s.

Man-made mineral fibres have a shape similar to the natural mineral asbestos but MMMFs are thicker and longer, the fibres are non-crystalline and they do not split longitudinally as do asbestos fibres. However, the similarity in shape has led to the suggestion that synthetic fibres may also have the potential to cause ill health in exposed workers.

A number of epidemiological studies have been carried out in the rock, slag and glasswool fibre industries (SIMONATO *et al*, 1987; ENTERLINE *et al*, 1987). The results of these studies, and other experimental evidence, have recently been reviewed by the International Agency for Research on Cancer who concluded that MMMF should be categorised as being possibly carcinogenic in humans (IARC, 1987). No corresponding studies have been reported for workers in ceramic fibre manufacturing.

The European ceramic fibre industry, through their European Ceramic Fibre Industries Association (ECFIA) commissioned an epidemiological study in seven factories. The objective of this research programme was to investigate the respiratory morbidity of workers in the industry in relation to dust exposure. The work has been co-ordinated by the University of Birmingham with contributions from the University of London and the Institute of Occupational Medicine. Within the project, the Institute of Occupational Medicine has been responsible for conducting a series of occupational hygiene surveys at the plants and for use of the data obtained to estimate each worker's cumulative exposure to ceramic fibres and other dusts.

This report briefly summarises information about the production processes at the factories included in the study, describes the methods used in, and the results obtained from, the occupational hygiene surveys, and outlines the rationale and methods used to calculate cumulative exposures.

The actual cumulative exposures and the overall results from the epidemiological study are described elsewhere (TRETHOWAN *et al*, 1989).

2. THE FACTORIES INCLUDED IN THE STUDY

Seven factories were included in the study: two in the UK, four in France, and one in West Germany. Six of the plants produced aluminium silicate ceramic fibres and subsequently used these in the manufacture of products such as board or paper. One plant (Plant No. 4) was only engaged in secondary manufacture using fibre from one of the other factories.

The plants started production between 1965 and 1977. At the time of the survey each factory employed between 50 and 150 workers in ceramic fibre production and associated work. The method of manufacture is essentially the same in all of the factories. Pure aluminium oxide (Al_2O_3) and crystalline silica (SiO_2) are mixed and then melted in an electric resistance furnace. Fibres are produced from this by either blowing compressed air through a stream of the molten material or allowing the melt to fall onto a series of high speed spinning wheels.

For a small number of specific products, the plant may include a proportion of additives in addition to alumina and silica. The principle additives are chromic oxide (Cr_2O_3), zirconia and calcium and magnesium oxides.

In the past some of the plants have used natural aluminium silicate minerals (i.e. calcined kaolin) as a feedstock.

As the fibres are produced a small proportion of mineral oil is added to partly cover the surface. The fibre is then collected onto a moving belt to form a mat. This mat passes through a cooling section and is then 'needled' to improve the strength of the product, the oil acting as a lubricant at this point. The next stage is to remove the oil by heating and finally to cut and pack the product at the end of the line. The factories operated between one and four production lines of this type.

There is usually a facility to remove the ceramic fibre at various points along the production line for secondary processing; for example, granulating the mat into a loose form.

All of the factories operate a diverse range of secondary production processes. These included at the time of the surveys: manufacture of paper felts and board, vacuum forming of complex shapes from a slurry of ceramic fibre and other binders; die cutting blanket and board; manufacture of rope; and construction of thick blocks of furnace insulation. In some of these secondary process operations other man-made mineral fibres are used; for example, glass fibre textiles are used in rope manufacture.

The plants all have some exhaust ventilation installed. This is primarily in the production area where substantial quantities of air are required to cool the fibre and remove of the oil. In many instances local exhaust ventilation is installed at critical points in the production line or at dust emission sources in secondary process areas.

Three of the factories previously used asbestos in manufacturing. All plants have used asbestos for engineering uses such as gaskets, packings etc. One plant used asbestos in the manufacture of boards until 1977. Approximately 20–30 tonnes of asbestos were used each year. Between 1970 and 1977 another plant used asbestos in the manufacture of rope and in an associated brickworks, while a third plant used asbestos prior to the production of ceramic fibres, between 1956 and 1970, for the manufacture of a product called fibrosilex.

Two of the factories also manufacture products which do not contain ceramic fibre. These were globars (heating elements), refractory bricks (manufactured from silicon carbide), and bricks (using kaolin and sawdust as raw materials). Brickworks were attached to three other plants but these all ceased operating in 1974.

3. SURVEY AND SAMPLING PROCEDURES

3.1 Preliminary Visits to each Plant

A preliminary visit was made to each factory. At this stage information was gathered on the method of production, raw materials used, the nature of any secondary production, the number of workers, jobs carried out and the location of work stations. On the basis of this information jobs were categorised and an occupational group structure was drawn up to cover all plant activities. The outline occupational group classification is shown in Table 3.1. This table shows all of the combined occupational groups along with examples of occupational groups and jobs within these. A total of 140 jobs were identified. The largest number of occupational groups occurred in secondary production where nine were identified: wet production of paper; board production; vacuum forming; forming complex moulded shapes; cement manufacture; modules; conversion; and felt production.

During the preliminary visit a meeting was arranged with the workforce to ensure that they were aware of the nature and scope of the survey to be carried out.

3.2 Personal Airborne Dust Sampling

3.2.1 Sampling Protocol

Representatives of each occupational group were asked to wear personal samplers to measure full shift exposure to airborne dust during normal work activities. The survey was carried out during production activities which happened to be in progress at the time. They therefore represent typical conditions rather than being fully descriptive of the conditions at all times. As far as possible, workers in each job were included. All occupational groups were covered but the maximum sampling effort was concentrated amongst those groups identified as probably having higher exposure to airborne ceramic fibre.

A number of different sampling heads were used to obtain estimates of personal airborne dust concentrations: fibre number concentration and inspirable and respirable mass concentration. In each case the sampling heads were mounted on the worker's lapel or collar. Flowrates through the sampling head were recorded at the start and end of sampling and, where possible, were checked and recorded at least once during the period. All flowrate measurements were made with an electronic bubble meter (MINI Buck) calibrated traceable to UK national standards.

3.2.2 Airborne 'Total' Dust and Fibre Concentrations

Samples intended for microscopic analysis of airborne fibre concentration were collected using the method recommended by the WHO/EURO Technical Committee on MMMF (WHO/EURO Technical Committee, 1985A). In addition, the weight of dust collected on the filters was also determined.

To obtain an optimum loading for microscopic analysis it was necessary periodically to change the filters in certain occupational groups where airborne dust levels were high. In these circumstances the measured concentrations for individual samples have been combined to give a time weighted average concentration for the whole shift.

Two types of filters were used in this type of sampling head: 25 mm diameter gridded cellulose ester membranes with a pore size of 0.8 μm and 25 mm diameter polycarbonate filters with 0.4 μm pores. The former type of filter was used for samples to be evaluated by phase contrast optical microscopy and the latter for those to be evaluated by scanning electron microscopy.

All of the filters were pre-weighed according to the procedure outlined in Section 3.3.1. The filters were mounted in open-faced (Gelman) holders, each of which was fitted with an electrically conducting cowl. Air was drawn through each filter by means of a Casella AFC 123 sampling pump at a flowrate of approximately 1 l/min.

3.2.3 Inspirable and Respirable Dust Concentrations

Samples were also collected to assess the gravimetric concentration of dust according to the American Conference for Governmental Industrial Hygienists criteria for inspirable dust (ACGIH, 1985) and the British Medical Research Council respirable dust criteria (ORENSTEIN, 1960). Inspirable dust is defined as the fraction of airborne particles which would be inspired through the nose or mouth of a worker, while respirable dust is considered to be the sub-fraction which penetrates to the alveolar region of the lung.

For measurement of inspirable dust pre-weighed 25 mm diameter 0.8 μm pore cellulose ester membrane filters were mounted into personal inspirable dust sampling heads designed at the Institute of Occupational Medicine (MARK and VINCENT, 1986). Air was drawn through the filters using Casella AFC 123 sampling pumps at a flowrate of 2 l/min.

The respirable dust samples were taken using Casella cyclone dust sampling heads, with single hole entry and integral pulsation damper. Respirable dust was collected onto 37 mm diameter, 5 μm pore mineral filled PVC filters (Gelman VM1) held in aluminium cassettes. Air was drawn through the cyclone at 1.9 l/min.

3.2.4 Assessment of Ventilation Systems

Observations were made of the local exhaust and general ventilation systems present in the workplace. Wherever possible an assessment of the level of air exchange provided by these systems was made by introducing low levels of nitrous oxide were introduced into the environment during normal work activities. The peak concentration and the decay curve of the gas were charted using a portable infrared spectrophotometer (type MIRAN 1A). The decay curve was then used to calculate the air exchange rate expressed as workroom air changes per hour.

3.3 Analysis of Samples

3.3.1 Airborne Mass Concentrations

All filters were weighed before and after the survey to determine the total mass of particulate material collected. A double weighing procedure was used. Prior to the survey, filters were allowed to stabilise for 24 hours in the local humidity conditions of the laboratory and then weighed. After a further 24 hours of conditioning in the laboratory they were re-weighed. The same procedure was adopted after sampling. To enable filter weights to be corrected for variations in humidity one in ten of the filters was retained in the laboratory as a control.

3.3.2 Airborne Fibre Concentration assessed by Optical Microscopy

The membrane filters collected in cowl sampling heads were evaluated using the WHO/EURO Reference Method (WHO/EURO MMMF Technical Committee, 1985A). Each filter was placed on a glass microscope slide and cleared by exposing it to acetone vapour using an Aztec VAP 100 filter clearing unit. A drop of triacetin was then placed onto the filter and this was sealed with a glass coverslip. The samples were evaluated using a phase contrast optical microscope, with X40 objectives, X10 eyepieces and an overall magnification of X500. Particles longer than 5 μm and aspect ratio (ratio of length to diameter) greater than 3:1 were counted as fibres. These were further subdivided into those with diameter greater than 3 μm and those with a diameter less than or equal to 3 μm. The former being classified as 'non-respirable' fibres and the latter as 'respirable'.

Each sample was evaluated by two microscopists and the mean count derived. One in ten of the samples was checked by a third microscopist who also examined samples where the two principal microscopists differed by more than 50%.

All of the microscopists routinely count fibres and all participated in both internal and external quality assurance programmes (OGDEN *et al.*, 1986; WHO/EURO MMMF Technical Committee, 1985B). Their performance in these schemes was satisfactory.

The Institute is accredited for fibre counting using the MMMF Reference Method under the UK National Measurement Accreditation Scheme.

3.3.3 Airborne Fibre Concentrations and Fibre Size by Scanning Electron Microscopy

Airborne dust samples collected on polycarbonate filters in cowl heads were evaluated by scanning electron microscopy (SEM) (WHO/EURO MMMF Technical Committee, 1985A). The samples were prepared for analysis by mounting the filter onto aluminium stubs and applying a thin layer of gold. Each sample was examined at a magnification of X500, and length and diameter measurements of individual fibres made directly from the monitor screen. For this evaluation, fibres were defined as those particles with aspect ratio greater than 3:1; no maximum or minimum length or diameter was specified.

The resolution and contrast of fibres obtained with the SEM operating conditions used in these assessments were such that fibres with diameters greater than approximately 0.05 μm were visible.

From the SEM fibre evaluations the number of fibres corresponding to the respirable and non-respirable fibre definitions (see Section 3.3.2) were extracted and the concentrations calculated. In addition, the complete data set was used to calculate statistics summarising the size distribution. These summary statistics were the geometric means of length and diameter, the corresponding geometric standard deviation and the correlation coefficient between the natural logarithms of the length and diameter measurements. On the assumption that these data are well described by a bivariate log-normal distribution these parameters should completely describe the size distribution (SCHNEIDER *et al*, 1983).

3.3.4 Airborne Respirable Dust and Crystalline Silica Concentrations

Following weighing, the filters which were used to sample respirable dust were analysed directly by infrared spectrophotometry (HSE, 1987) and/or X-ray diffractometry (HSE, 1986) to determine the concentration of crystalline silica (quartz or cristobalite).

All of the samples were initially analysed using the infrared technique. Resultant spectra were compared with calibration graphs to give the weight of crystalline silica (where detected) and hence concentration. In circumstances where there was interference in the infrared spectra from, for example, amorphous silica, the analysis was repeated by X-ray diffraction.

3.3.5 Nominal Fibre Size of Bulk Ceramic Fibre

Representative bulk samples of ceramic fibre were obtained during the survey. These were prepared for evaluation by rubbing through a 125 μm mesh stainless steel sieve into filtered distilled water. The suspension was then filtered onto a 0.1 μm pore polycarbonate filter. The filters were prepared for SEM examination using the same procedure as that adopted for the airborne dust samples (Section 3.3.3). The filters were scanned at a magnification of X1000 in a straight line traverse. All of the fibres (i.e. particles with aspect ratio greater than 3:1) which crossed the centre of the monitor screen had their diameter measured. The nominal fibre size was calculated as the geometric mean of these measurements. This corresponds to a length weighted mean diameter which should be invariant with sample preparation or handling (SCHNEIDER *et al*, 1983).

4. RESULTS AND DISCUSSION OF THE OCCUPATIONAL HYGIENE SURVEY DATA

4.1 **Airborne Dust Concentration by Occupational Group**

4.1.1 Total and Inspirable Mass Concentrations

The airborne mass concentration data are shown in Figures 4.1 to 4.3.
There were 371 full shift measurements of 'total' dust concentration and 79 measurements of inspirable dust.

In the production group (Figure 4.1) the individual 'total' dust concentrations ranged from <0.1 mg/m^3 in Plant 06 to 11.4 mg/m^3 in Plant 07. The combined occupational group average concentrations ranged from 1.4 mg/m^3 in Plants 01 and 02 to 3.8 mg/m^3 in Plant 07.

The corresponding individual concentrations for inspirable dust ranged from 0.5 mg/m^3 to 5.7 mg/m^3 with the range of average concentrations being 1.7 mg/m^3 to 3.4 mg/m^3. In both cases the highest concentrations were found in Plant 07.

In secondary production (Figure 4.2), the measured mass concentrations were higher than production. The highest individual 'total' dust concentration, 33.1 mg/m^3, was found on a fibre milling operator at Plant 07 and for inspirable mass, 27.7 mg/m^3, for a vacuum forming operator in Plant 02. The mean concentrations for ranged from 0.8 mg/m^3 at Plant 01 to 7.4 mg/m^3 at Plant 07 for 'total' dust and 1.8 mg/m^3 at Plant 06 to 11.2 mg/m^3 at Plant 07 for inspirable dust.

Figure 4.2 also shows data for non-ceramic fibre work. In Plant 03, where insulating bricks were being manufactured, the mean 'total' dust concentrations in this operation ranged from 1.5 mg/m^3 to 22.2 mg/m^3, with a mean of 6.8 mg/m^3. The inspirable mass concentrations were lower: 26 mg/m^3 to 3.8 mg/m^3 with an average of 3.4 mg/m^3. In general the remaining mass concentration measurements were low, with the vast majority of individual results less than 5 mg/m^3.

Only total dust measurements were available for all other combined occupational groups (Figure 4.3). In these situations the mass concentrations were generally low.

4.1.2 Respirable Mass and Silica Concentrations

The respirable mass concentrations are also shown in Figures 4.1 and 4.2 and in Table 4.1. These data cover production, selected secondary production jobs and non-ceramic fibre operations. 41 measurements were made.

The respirable mass concentrations range from <0.1 mg/m^3 to 2.8 mg/m^3, the highest value being found in the manufacture of ceramic fibre cement at Plant 05.

Crystalline silica was detected in eight of the seventeen groups where samples were collected. In general the levels were low: individual measurements ranged from 0.01 mg/m^3 to 0.25 mg/m^3. The highest occupational group mean concentrations were noted for workers in non-ceramic fibre manufacturing at Plant 01. On the two samples in this group the average quartz concentration was 0.19 mg/m^3.

Cristobalite was found on a single sample collected on the bricklayer at Plant 01. This worker was dismantling an oven lining in the refractory brick area of the plant where ceramic fibre insulations had become de-vitrified to produce this form of crystalline silica. The presence and release of cristobalite in this type of work has been noted by others (GARTNER, 1986).

4.1.3 Respirable and Non-respirable Fibre Concentrations

Three hundred and seventy-one measurements of respirable and non-respirable fibre concentrations were made. These data are shown in Figures 4.4 to 4.6.

The fibre concentrations in the production group (Figure 4.4) ranged from <0.1 fibres/ml to 2.4 fibres/ml for respirable fibres and from <0.1 fibres/ml to 0.55 fibres/ml for non-respirable fibres. The mean respirable fibre concentrations for production workers at each plant varied from 0.20 fibres/ml at Plant 06 to 0.88 fibres/ml at Plant 01. The corresponding mean levels for non-respirable fibres were 0.03 fibres/ml to 0.15 fibres/ml. In this case the highest group mean concentration was found in Plant 05.

The concentrations in secondary production (Figure 4.4) were in general higher than those found in production. The occupational group mean concentrations ranged from 0.49 fibres/ml (Plant 06) to 1.36 fibres/ml (Plant 05) for respirable fibres and from 0.05 fibres/ml (Plant 06) to 0.29 fibres/ml (Plant 03) for non-respirable fibres. The highest individual concentrations were 3.4 fibres/ml (respirable) and 0.9 fibres/ml (non-respirable) recorded for a scondary production worker at Factory 02. A further discussion of the secondary production results by occupational groups is given in Section 4.1.4.

The fibre levels in the remaining groups were lower. Measurable levels of fibres were found in all cases including staff and workers in production not directly related to ceramic fibre work.

For warehousemen (Figure 4.5) the average respirable fibre concentrations ranged from 0.15 fibres/ml to 0.61 fibres/ml, the highest levels from Plant 07.

Exposures in other occupational groups, ranged from <0.1 fibres/ml to 01.3 fibres/ml for respirable fibres. The highest concentration was found for an insulation brick worker in Plant 03. It is notable that the fibre concentrations measured on staff members (Figure 4.6) are comparable with the other groups which were not directly involved in handling ceramic fibre. The mean respirable fibre concentrations for staff ranged from 0.01 fibres/ml to 0.42 fibres/ml.

4.1.4 Dust and Fibre Concentrations within Secondary Production

The secondary manufacture of products containing ceramic fibre was apparently the least homogeneous of all the combined occupational groups. It was therefore important to investigate the validity of treating these operations as a single group.

The respirable fibre concentration and 'total' mass concentration results from secondary production are shown by occupational group in Figures 4.7 and 4.8.

The mean levels for these groups range from 0.12 fibres/ml for a single measurement on ceramic fibre cement manufacture to 2.06 fibres/ml on a single sample in the production of blocks containing ceramic fibre and modules. The corresponding range for the 'total' mass concentrations 0.1 mg/m^3 for the manufacture of paper and board to 33 mg/m^3 found in the die cutting of blanket.

In the main the range of concentrations within the occupational groups was large in comparison with the differences between groups. Similar patterns were found for non-respirable fibres and inspirable mass.

We have not tested the significance of the differences statistically. However, there seems little justification for treating the individual occupational groups within plants separately.

4.2 Comparison between the various measures of Airborne Dust Concentration

4.2.1 Inspirable and Respirable Dust versus 'Total' Dust

Inspirable and respirable dust are two measures of airborne mass concentration which are biologically relevant to potential health effects in the ceramic fibre industry. In contrast 'total' dust measurements are arbitrary measures of airborne dust concentration and may be made with a variety of different sampling instruments. They are not standardised in the same way as the measures of inspirable and respirable dusts. The term 'total' dust is in some ways a misnomer since it is not an assessment of all of the dust in the air. Each of the instruments which could be used would have different particle size selection characteristics which depend on the orifice shape and size, sampling flowrate together with wind speed and direction.

In this study we have designated the mass measurements made with the cowl sampling head as 'total' dust samples. To maximise the available information we have looked for correlations between the various airborne mass data with the aim of predicting the biologically relevant concentrations from the total dust data.

Figure 4.9 is a scatter plot of inspirable mass concentration against 'total' mass for the 71 samples where both variables were measured. There is an apparent linear relationship between them with a correlation coefficient of 0.7 ($p < 0.001$). This association may have been unduly influenced by the outlying points with large values for one or both of the variables. The relationship was, therefore, further examined for those points with both total and inspirable masses of less than 8 mg/m^3. A similar linear relationship was evident with a correlation coefficient of 0.63 ($p < 0.001$).

Based on the relationship for all points the value of inspirable mass concentration can be predicted from the 'total' dust data using the best fit linear equation

$$I = 1.74 + 0.72\ T$$

where I is inspirable mass concentration in mg/m^3 and T is 'total' mass concentration in the same units.

There are only eleven instances where there are data for both 'total' and respirable dust. Figure 4.10 shows the relationship between these variables for the men with simultaneous measurements. There is no evidence of any association between them. The data were then transformed to the log-scale and the evidence for any relationship re-examined. However, there was still no apparent association. These results are similar to a recently completed study, where in a variety of industries simultaneous measures of inspirable, thoracic and respirable dust concentrations were made (MARK *et al.*, 1988). In MARK *et al*'s study there was a good correlation between the coarser fractions of dust but little association between them and respirable dust. In our study it has therefore not been possible to predict respirable mass from the 'total' dust data.

4.2.2 Respirable Fibres versus 'Total' Mass

In earlier work carried out in the ceramic fibre industry (HEAD and WAGG, 1980) a broad correlation between respirable fibre concentration and total airborne mass concentration was observed. Many countries have, or are in the process of adopting dual fibre number and mass occupational exposure limits for ceramic fibres. Any relationship between these measures is therefore important. If there is a correlation between the two variables then placing a limit on one would also effectively limit the other. Since it is easier to measure airborne mass concentration this could have considerable benefits.

Figure 4.11 shows the 342 simultaneous measurements of 'total' mass concentration and respirable fibres. There is no apparent relationship between these.

Twenty-four per cent of the measurements exceeded either 5 mg m^3 and/or 1 fibre ml. Almost all of the measurements (98%) which exceeded 1 fibre ml were drawn from the production or secondary production groups. The measurements which exceeded 5 mg/m^3 were drawn from these groups plus maintenance and production not involving ceramic fibres. Less than 1% of the measurements exceeded both 5 mg/m^3 and 1 fibre/ml.

Other authors (ESMEN *et al.* 1979), have reported an improved correlation when occupational group average mass and fibre number were compared. This was not the case in our study.

The reason for the poor correlation may be due to the narrow range of the concentrations coupled with the diversity of jobs sampled.

It is probable that where there are dual exposure limits for ceramic fibre it will be necessary to make measurements of both airborne mass and fibre number concentration.

4.3 Comparison with other studies in Man-made Mineral Fibre Production Plants

4.3.1 Other studies in Ceramic Fibre Manufacturing

There have been two previously reported studies in the manufacture and use of ceramic fibres (ESMEN *et al*, 1979; HEAD and WAGG, 1980). Mean occupational group data from these and the present study are shown in Figure 4.12.

The larger set of data was obtained from three factories located in the USA (ESMEN *et al.*, 1979). They found a slightly wider range of concentrations than in our study. Group mean concentrations in the American data ranged from 0.02 fibres/ml to 6.9 fibres/ml and from 0.3 mg/m^3 to 12 mg/m^3. The two highest fibre concentrations in ESMEN *et al*'s study were associated with vacuum forming and cutting and drilling vacuum formed products.

On average their mass concentrations were lower, typically around 1 mg/m^3 compared with 2 to 3 mg/m^3 in the present data. This may be due in part to the different sampling methodologies adopted : ESMEN *et al* used 37 mm diameter plastic sampling heads compared with our 25 mm diameter metallic cowls. The mean fibre concentrations found by ESMEN *et al* using these plastic cassettes were generally comparable with our data.

The smaller data set was obtained from a survey of ceramic fibre manufacturing and fabrication plants in the UK, carried out by the UK Government's Health and Safety Executive (HEAD and WAGG, 1980). Their results are generally in the upper range of the other two data sets. Mean concentrations ranged from 1.0 mg/m^3 to 15.5 mg/m^3 and 0.44 fibres/ml to 2.58 fibres/ml. In the HSE's study the sampling duration was chosen to be representative of the work activity and therefore may not necessarily be representative of 8 hour time weighted average exposure. This probably explains the higher mean concentrations reported in their work.

4.3.2 Other Studies in Man-made Mineral Fibre Manufacturing

There have been a number of studies carried out to assess the exposure of workers employed in the manufacture and use of other man-made mineral fibres. CHERRIE *et al* (1986) have summarised the results from a major study in ten European factories producing rockwool and glasswool. The occupational group average concentrations of respirable fibres in these studies ranged from 0.01 fibres/ml to 0.67 fibres/ml in rockwool and 0.01 fibres/ml to 1.00 fibres/ml in glasswool. The highest concentrations in rockwool were found in a specialist secondary production group and in glasswool in the manufacture of microfibres for earplugs. In the majority of production and secondary production groups the respirable fibre concentrations were less than 0.2 fibres/ml.

These data are comparable with measurements made in similar types of work in the USA (ESMEN *et al.*, 1979).

Concentrations in excess of 1 fibre/ml have been found in the manufacture of specialist glass microfibres, in blowing of mineral wools into confined spaces and in the production and use of mineral wool without oil or any other dust suppressants.

Clearly the concentrations in the ceramic fibre manufacturing industry are generally higher than in other man-made mineral fibre operations. Only in the small number of specialist situations noted above are there comparable levels.

The reason for concentrations being higher in ceramic fibre plants is probably that these fibres are generally finer than mineral wool and the products are produced without any dust suppressant (DODGSON *et al*, 1987). Oil added during fiberisation of mineral wool is subsequently retained in the product whereas it is removed in the case of ceramic fibre.

4.4 Factors which may have affected Dust Concentrations or Workers' Exposure

4.4.1 Bulk Nominal Fibre Size

The results from the nominal fibre size measurements are shown in Figure 4.13. Nominal fibre size ranged from 0.8 μm to 2.8 μm with the three lowest values coming from production line samples at Plant 01. Typically the nominal diameters were approximately 2 μm.

The minimum individual diameter measurements were typically 0.1 μm with the maximum diameters between 10 and 20 μm.

The geometric standard deviations ranged from 1.9 to 2.6.

Smaller nominal diameters would be expected to be associated with higher airborne fibre concentrations. Nominal diameter over the extremes of the range found would be expected to produce fibre concentrations differing by up to five or six times (DODGSON *et al*, 1987).

4.4.2 Local Exhaust Ventilation Systems and Housekeeping

All of the factories had some form of local exhaust ventilation installed in the main production area. These were generally located in the fibre forming section and at the needling and thereafter, variously at other sources of dust emission. In addition, all plants operate by adding a small quantity of oil to the product as it is formed. This oil was removed after needling by heating the blanket. There was always flue ducting from the oven and extraction from the cooling system.

The area least likely to have local exhaust ventilation was the end of the production line where the final product was manually removed and packed.

The results from the objective measurements of the general rate of air exchange in the plant production and selected secondary production areas are shown in Table 4.2. Measurements were made in five of the six plants which had production lines. These data range from 10 to 22 air changes per hour.

The highest air exchange rates were found in Plants 02 and 03 while the lowest was found in the vacuum forming section of Plant 01.

These rates of air exchange are higher than would normally be expected in industrial plants. This was mainly as a result of the large volumes of air being removed by the production process.

General air exchange rate is only a crude indication of the effectiveness of the system, however. It is more important that the entry or hoods of the ventilation system are correctly designed and located. During the course of the surveys there were many instances where the entry to the systems was observed to be of poor design.

The standard of housekeeping, i.e. the general cleanliness of the factories, varied considerably from plant to plant, and also from area to area within the plants. Subjectively, the housekeeping in the secondary processing appeared to be poorer than in production areas.

Most of the information regarding ventilation and housekeeping is necessarily anecdotal. On average the differences between plants for respirable fibre and inspirable mass concentrations were small. It is difficult to attribute these differences to variations in the standard of either local exhaust ventilation systems or housekeeping. The principal exception to this was the production area in Plant 06 where the lowest respirable fibre levels were measured. In this area both the design of the ventilation system and the standard of housekeeping were rated by the hygienist as very good. This clearly indicates the level of control which can be achieved with careful design.

4.4.3 Other factors

In other studies (DODGSON *et al*, 1987) we have found that the addition of oil to man-made mineral fibres can produce substantial reductions in the quantity of dust emitted during handling. The vast majority of products produced in the seven plants in this study did not contain any oil. This is perhaps the major explanation for the higher airborne fibre levels found in ceramic fibre plants when compared with mineral wool production. It would not, however, account for inter-plant variations in our study.

Another factor which would affect the fibre concentrations was the amount of manual handling of the ceramic fibre. In the plants which are included in the present study there was little difference in the type of technology in use. The principal handling of fibre in the production area occurred at the end of the line. There was almost always a greater degree of manual handling required in secondary production. This may have been a contribution, along with differences in ventilation and housekeeping, to the higher dust levels typically found in these areas.

4.4.4 Respirators

The use of respiratory protection would reduce the exposure of workers to fibres and other dust. Respirators were available at all of the factories (mostly disposable filtering facepiece respirators) but they were worn infrequently. Where they were worn their effectiveness was compromised in some situations by incorrect fitting and unauthorised modifications to straps or filter media.

4.5 Fibre Size and Concentration assessed by SEM

4.5.1 Fibre size and Concentration Data

The geometric mean length and diameter from the 38 samples collected in this study are shown in Figure 4.14. (The complete summary statistics : geometric mean length and diameter, geometric standard deviations and the correlation between the natural logarithms of the length and diameters are given in an Appendix).

The individual sample means range from 0.5 μm to 1.3 μm for the diameters and from 3.9 μm to 25.2 μm for the lengths. There is some indication that the samples with longer fibres were, on average, also thicker, although there is a considerable spread in the data.

The short thin fibre samples predominantly come from Plants 01 and 03, otherwise the data show no patterns in terms of occupational groups or plants. It is notable that Plant 01 produced the smallest nominal diameters in bulk samples taken from the production line (see Section 4.4.1).

Individual fibre measurements covered a much wider range of sizes : diameters ranged from 0.1 μm up to 10.5 μm and lengths from 0.9 μm to 20.0 μm.

The concentration of fibres longer than 5 μm, measured by SEM are shown in Figures 4.15 and 4.16, along with comparable data from the optical microscope assessments. These data are divided into samples from production and secondary production. The individual SEM fibre concentrations were between <0.01 fibres/ml and 5.44 fibres/ml. This is almost exactly the same range as that obtained from the samples analysed by optical microscopy.

Average concentrations for production or secondary production were also generally comparable with the corresponding optical microscope data. The range of optical microscope concentrations within individual plants is, however, almost always greater, because there was a larger number of this type of sample in each category.

4.5.2 Comparison with other studies in Man-made Mineral Fibre Production Plants

Data on the airborne fibre size in the ceramic fibre industry has been published by HEAD and WAGG (1980) for the UK industry and by ESMEN *et al.* (1979) for USA plants.

These data are shown as cumulative log probability plots in Figure 4.17 along with comparable plant average data from the present study. The graphs show the percentage number of fibres less than the stated size. Both length and diameter data are shown.

HEAD and WAGG (1980) used interference optical microscopy to measure length and diameter of fibres longer than 5 μm. Their data showed longer and thicker fibres which is probably because of the poorer fibre visibility with the microscope system used.

The results from the American study where electron microscope analysis was used are in much better agreement with our data. Their length distributions fall completely within the range found in the present work. Their plant median length was c. 14 μm while our corresponding data range was 7.2 μm to 17 μm. The diameter distribution showed that slightly finer fibres were found in the USA with a median c. 0.7 μm compared with 0.8 to 1.1 μm in our study.

We have also compared our data with those obtained in ten European Mineral Wool Production Plants by OTTERY *et al.* (1984). In that work the plant median lengths ranged from 10 to 20 μm for rockwool plants and from 8 to 15 μm in the glasswool plants. The corresponding median for diameter ranged from 1.2 to 2.0 μm and 0.7 to 1.0 μm for the rockwool and glasswool respectively. The ceramic fibre data are therefore comparable with those found in glasswool plants but the ceramic fibres are shorter and finer than the rockwool.

5. EXPOSURE ESTIMATION

5.1 Rationale for the Exposure Estimation

The calculation of cumulative exposure to airborne dust and fibre for each worker was a necessary part of the epidemiological investigation. By cumulative exposure we mean the products of years worked in an occupational group and the estimated concentration for that group, summed over the whole period a man worked in the factory.

An occupational group structure, on which the occupational hygiene sampling was based, had been drawn up in the course of the preliminary visits to the plants (Section 3.1). One approach would have been to accept this as the final occupational group structure, and to take the occupational group and plant specific mean values of the sampled concentrations as estimates of the corresponding true values.

Such an approach is simple: concentration estimates for each occupational group within each plant are based on measurements for this plant/occupational group combination only; and if there is no identifiable connection between groups at different plants, or different groups at the same plant than this simple approach is optimal. However, if there are structural similarities between groups and plants then it may be very inefficient. By exploiting such structural similarities important gains can potentially be made in the accuracy and precision of individual plant/group estimates. For example, by pooling information across selected plants or by modifying the estimated concentrations for individual plant/groups, (especially where samples are few) in the light of results from related occupational groups and plants.

A statistical analysis was carried out which focussed on identifying and using any structural similarities between measured concentrations in the various plant/combined occupational groups where samples were taken. Identification of structural similarities, by analysis of variance methods, is described in section 5.3. Use of these similarities to provide improved estimates of concentration are described in section 5.4.

5.2 Data Description

Three variables, respirable fibre concentration, non-respirable fibre concentration and inspirable mass concentration were investigated in detail in the statistical analysis. The inspirable mass concentrations used in this analysis comprised the actual measured values along with those predicted from the total mass data, using the relationship described in Section 4.2.1.

This procedure allowed us to present all of the available mass data on the same basis.

Tables 5.1 to 5.3 give the means and standard deviations for these variables by plant and occupational group. It can be seen from these tables that the standard deviations, and consequently the variances, vary considerably from cell to cell. It was therefore decided to investigate the data more closely to identify any outliers which may be inflating the variability.

The distribution of the three parameters was examined by plotting the data in the form of histograms. Using these diagrams the following definition of outliers was devised:

(a) for respirable fibres, concentrations >3 fibres/ml were designated as outliers. One measurement exceeded this limit

(b) for non-respirable fibres, concentrations >0.5 fibres/ml (5 points)

(c) for inspirable mass, concentrations >15 mg/m (6 points)

For non-respirable fibres and for inspirable mass four of the outlying points were from the secondary production group. Otherwise, no patterns for plants or occupational groups were seen in the excluded points. These outliers were omitted from all further analyses of the data.

5.3 Comparison and Grouping of Measurements

The variances in each plant/occupational group combinations were tested for equality using 'Levene's test' based on a one-way analysis of variance. Even after the omission of the outliers described above, the differences between variances were still generally statistically significant. It was therefore necessary to devise an *ad hoc* grouping of variances which were of 'similar size' to allow further analysis. Plant and occupational group combinations with similar variances were thus grouped together and an overall variability was calculated. This resulted in three 'variance groups' for each variable.

An analysis of variance (weighted to allow for the different variance groups) was then carried out for each variable, to look at the effect of plant, occupational group and the interaction of these two factors.

The results of the analysis showed that for all of the concentration measures there were significant differences between plants and between combined occupational groups. For respirable fibres there was also a significant interaction effect, showing that for this variable the differences between occupational groups vary between plants. However, the overall effects of plant and occupation were still significant compared to the interaction term.

Table 5.4 gives the overall observed and predicted means for plants and occupational groups for non-respirable fibres and inspirable mass. For non-respirable fibre concentrations, levels at Plant 05 are in general the highest and at Plant 06 the lowest. Values for occupational groups 2 and 1 are also high overall. For inspirable mass the pattern is slightly different, with the highest levels occurring at Plant 07 and the lowest at Plant 01. Among the occupational groups the highest predicted value is seen for group 7 but this is based on a sample from Plant 03 only. Apart from this value the highest levels were seen in occupational group 2.

Table 5.4 shows that the models are a good fit with the marginal predicted values generally close to the observed means. However it is also clear that, where there are differences, the observed values are almost always greater than the predicted values. Comparison of the observed and predicted values within the cells of the two-way tables showed that, as expected, approximately half the differences were negative and half positive. However there were a few large positive differences which have influenced the marginal results. This reflects a slight skewness in the distribution of the residuals.

The models were therefore re-fitted using the logs of the data, and the results examined in detail to determine whether this transformation would improve the fit. The results of this analysis did not appear to give a substantially better fit and the marginal observed values were still in general slightly greater than the marginal predicted. A comparison of the predicted values within cells for the two models showed that they were generally of similar magnitude and precision, and that the relative pattern of the means was preserved. Therefore, there did not seem to be any strong benefit from transformation to the log scale, and the detailed results are not reported here.

Table 5.5 shows the observed and predicted values by plant and occupational group for the respirable fibre concentration. These values were calculated from the model containing only main effects (PLANT and OG) and not the interaction. The cells which contribute most to the significant interaction in this model are those for which the predicted values from the main effects model are very different from the observed values (e.g. Plant 01 occupational group 1 and Plant 06 occupational group 3).

In the following sections, therefore, predicted values from the main effects model are used for non-respirable fibres and inspirable mass and predicted values from the model with interaction for respirable fibre concentration.

5.4 Combining Occupational Groups both within and between Plants

The statistical precision of cumulative exposures calculated retrospectively from concentration data with occupational groups - whether fibre concentration or inspirable mass - can be increased, if data from those groups having a common underlying mean are combined, and 'pooled' estimates used in exposure calculations. In the present study, data were available from up to seven combined occupational groups at each of seven plants, thus giving an estimated mean concentration (i.e. respirable fibre concentration, non-respirable fibre concentration, and inspirable mass concentration) and an associated standard error, for a maximum possible number of 49 occupational group/plant pairs or cells. Sampling was not carried out for certain of the occupational groups (see Tables 5.1, 5.2 and 5.3); the numbers of occupational group/plant pairs with an associated mean concentration were 39 for respirable and non-respirable fibre concentrations, and 38 for inspirable mass concentration.

Those occupational group/plant pairs where means were judged, with reasonable confidence, to be sufficiently close, were combined together to form a new set of pairs, and a 'pooled' mean concentration was calculated for the combined set. The term 'sufficiently close' was defined as follows:

(a) for respirable fibre concentrations, within 0.5 fibre/ml;
(b) for non-respirable fibre concentrations, within 0.1 fibre/ml;
(c) for inspirable mass concentrations, within 1.0 mg/m^3.

'Reasonable confidence' was ensured by requiring that the largest possible difference between two occupational group/plant pairs was less than the appropriate criterion (a), (b) or (c) before the pairs were combined. The largest possible difference was taken as the largest difference between any two points falling in each of the associated approximate 95% confidence intervals.

Thus, the combining procedure was carried out as follows. Cells were ordered by mean concentration. The first cell was grouped with those above it satisfying the criterion described above. When no further grouping was possible, the lowest cell so far ungrouped was then considered in relation to those cells above it, and the process continued in this way.

The pooling process yielded 24 new 'occupational groups' for use in the calculation of inspirable mass dust exposures; 17 groups for respirable fibre exposures; and five groups for non-respirable fibre exposures. These are shown in Tables 5.6, 5.7 and 5.8.

The final step in this part of the analysis was to estimate, using weighted regression methods, the mean concentrations and associated standard errors for each of the new 'occupational groups'. Results are shown in Table 5.9.

5.5 Calculation of Cumulative Exposures

The occupational history questionnaires were devised, administered and processed by the University of Birmingham. Details of this work are contained in their report on the study.

Information on each participant, i.e. plant code, personal identification number and time worked in specified jobs, was supplied to the IOM on computer tape. This information was then validated to identify possible errors and omissions. Corrections were made in consultation with Birmingham. Where the month of the start or finish date was missing from an entry a value of 06, i.e. June, was assumed. Similarly where the day in an individual's date of birth was missing a value of the 15th of the month was used.

Estimates of cumulative exposure and current concentration, plus standard errors, were made for a total of 671 persons. For each worker, exposure to respirable and non-respirable fibres and inspirable mass were estimated by mutliplying the number of years worked in each of the occupational groups with the concentration obtained from the procedure outlined in the previous section.

Where individuals had worked at other ceramic fibre plants, not included in the study, or where a job was not specified, then the mean of the predicted concentration data for the occupational group concerned was used in the calculation. There were some subjects with interrupted employment, i.e. periods of illness or army service. In these cases it was assumed that the workers were not exposed to ceramic fibres and the time was not included in the calculations.

In addition a small number of instances arose where a specific job had previously been carried out at a plant in the study for which no measurements existed. In these instances the concentrations were estimated using the regression model described in section 5.3. These data were judged to be less reliable because of the absence of measured results. Cumulative exposures calculated using these data were marked in the computer file to indicate the poorer reliability.

When a worker carried out more than one job concurrently, the time was divided on a percentage basis as specified by the individual, for the calculation of both cumulative exposure and current concentration. When no data existed on the division of work between concurrent jobs it was assumed that they contributed equally to the exposure.

The results from these calculations were sent to the University of Birmingham to be used in the analysis of the epidemiological data. Further discussion of these data are contained in their report.

5.6 The Validity of Exposure Estimates based on Current Concentration Measurements

All of the exposure estimates have been based on the occupational hygiene data collected over a short period of time by the IOM. The exposures were based on the assumption that the current concentrations reflected the conditions which prevailed throughout the history of the plants, and this implies that the airborne dust concentrations are assumed to have been relatively stable through time. In the absence of detailed information about past conditions this seems the only possible basis on which to estimate cumulative exposure.

In our earlier study of the man-made mineral fibre insulation wool industry (CHERRIE *et al*, 1986), there was evidence to suggest that conditions changed substantially with time. Since the start of that industry in Europe, during the 1930s, there had been numerous changes which may have affected airborne fibre levels in those plants. These factors were related to the product (i.e. the fibre nominal diameter and the use of oil), factors in the process or environment (i.e. method of handling the MMMF, ventilation and the rate of production) and other factors (such as method of cleaning or the use of respirators). The most important changes were those related to the product, both of which could have affected the airborne fibre levels by up to an order of magnitude. Other parameters were judged to have been of lesser importance.

The European ceramic fibre industry, however, has a much shorter production history. In the present study the first factory started production in 1965. Since this time the production process, and hence the product, have remained essentially unchanged. There is no reason to expect that nominal diameter of the products have changed substantially and the majority of production has always been without oil remaining in the final product.

Conditions in some areas at some plants will have improved, new ventilation systems will have been introduced, and the method of handling the ceramic fibre may have been improved. Other changes, such as increased rate of production may have resulted in increased airborne fibre levels.

It is difficult to judge the overall effect of these changes without relevant dust concentration data. It is unlikely, however, that airborne fibre levels in the past were substantially different from the current concentrations.

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REFERENCES

AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS (1985) Particle size-selective sampling in the workplace. Report of the ACGIH Technical Committee on Air Sampling Procedures. Cincinnati (OH): ACGIH.

CHERRIE J, DODGSON J, GROAT S, MACLAREN W. (1986) Environmental surveys in the European man-made mineral fiber production industry. In: Saracci R, ed. Contributions to the IARC study on mortality and cancer incidence among man-made mineral fiber production workers. Helsinki: Institute of Occupational Health, Finland: 18-25 (Scandinavian Journal of Work, Environment and Health; 12 (suppl. 1)).

CHERRIE JW, CRAWFORD NP, DODGSON J. (1988) Problems in assessing airborne man-made mineral fibre concentrations in relation to epidemiology. In: Dodgson J, McCallum RI, Bailey MR, Fisher DR, eds. Inhaled Particles VI. Proceedings of an International Symposium and Workshop on Lung Dosemetry organised by the British Occupational Hygiene Society in co-operation with the Commission of the European Communities, Cambridge 2-6 September 1985. Oxford; Pergamon Press, 1988: 715-723. (Annals of Occupational Hygiene; 32 (suppl.1)).

DODGSON J, CHERRIE JW, GROAT S. (1987) Estimates of past exposure to respirable man-made mineral fibres in the European insulation wool industry. In: Walton WH, ed. Man-made mineral fibres in the working environment. Proceedings of an International Symposium. Copenhagen, 28-29 October 1986. Oxford: Pergamon Press, 1987: 57-582. (Annals of Occupational Hygiene: 31(4B)).

ENTERLINE PE, MARSH GM, HENDERSON V, CALLAHAN C. (1986) Mortality update of a cohort of US man-made mineral fibre workers. In: Walton WH, ed. Man-made mineral fibre in the working environment. Proceedings of an International Symposium. Copenhagen, 28-29 October 1986. Oxford: Pergamon Press, 1987: 625-656. (Annals of Occupational Hygiene; 31(4B)).

ESMEN NA, CORN M, HAMMAD YY, WHITTIER D, KOTSKO N, HALLER M, KAHN RA. (1979) Exposure of employees to man-made mineral fibres: ceramic fibre production. Environmental Research 19, 265-278.

GARTNER BA. (1986) Respiratory hazard from removal of ceramic fibre insulation from high temperature industrial furnaces. American Industrial Hygiene Association Journal; 47: 530.

HEAD IWH, WAGG RM. (1980) A survey of occupational exposure to man-made mineral fibre dust. Annals of Occupational Hygiene; 23: 235-258.

HEALTH AND SAFETY EXECUTIVE (1987) Quartz in respirable airborne dusts - Laboratory Method using infrared spectroscopy (Direct Method). Methods for Determining hazardous Substances; 37 (revised 1987).

HEALTH AND SAFETY EXECUTIVE (1986) Quartz in respirable airborne dusts - Laboratory method using X-ray diffraction (Direct Method). (HSE Methods for Determining Hazardous Substances MDHS 51).

IARC Working Group on the evaluation of carcinogenic risks to humans (1987) Man-made mineral fibres and radon. Press Release, IARC/88, Lyon, 25 June 1987.

MARK D, VINCENT JH. (1986) A new personal sampler for airborne total dust in workplaces. Annals of Occupational Hygiene; 30: 89-102.

MARK D, COWIE H, VINCENT JH, GIBSON H, LYNCH G, GARLAND R, WESTON P, BODSWORTH PW, WITHERSPOON WA, CAMPBELL S, DODGSON J. (1988) The variability of exposure of coalminers to inspirable dust. Edinburgh: Institute of Occupational Medicine. (IOM Report TM/88/02).

OGDEN TL, SHENTON-TAYLOR T, CHERRIE JW, CRAWFORD NP, MOORCROFT S, DUGGAN MJ, JACKSON PA, TREBLE RD. (1986) Within-laboratory quality control of asbestos counting. Annals of Occupational Hygiene; 30: 411-425.

ORENSTEIN AJ, ed. (1960) Proceedings of the Pneumoconiosis Conference held at the University of Witwatersrand, Johannesburg, February 1959. London: J & A Churchill.

OTTERY J, CHERRIE JW, DODGSON J, HARRISON GE. (1984) A summary report on environmental conditions at 13 European MMMF plants. In: World Health Organisation: Regional Office for Europe. Biological effects of man-made mineral fibres. Proceedings of a WHO/IARC Conference in association with JEMRB and TIMA, Copenhagen, 20-22 April 1982. Vol. 1. Copenhagen: WHO: 83-117,

SIMONATO L, FLETCHER AC, CHERRIE JW, ANDERSON A, BERTAZZI P, CHARNAY N, CLAUDE J, DODGSON J, ESTEVE J, FRENTZEL-BEYME R, GARDNER MJ, JENSEN O, OLSEN J, TEPPO , WINKELMANN R, WINTER PD, WINTER D, ZOCCETTI C, SARACCI R. (1987) The International Agency for Research on Cancer historical cohort study of MMMF production workers in seven European countries: extension of the follow-up. In: Walton WH, ed. Man-made mineral fibres in the working environment. Proceedings of an International Symposium. Copenhagen, 28-29 October 1986. Oxford: Pergamon Press, 1987: 603-613. (Annals of Occupational Hygiene; 31(4B)).

SCHNEIDER T, HOLST E, SKOTTE J. (1983) Size distributions of airborne fibres generated from man-made mineral fibres products. Annals of Occupational Hygiene; 27, 2: 157-171.

TRETHOWAN WN, CALBERT I, HARRINGTON JM. (1989) A report on the respiratory health of employees in seven European ceramic fibre plants. Birmingham; University of Birmingham.

WHO/EURO TECHNICAL COMMITTEE FOR MONITORING AND EVALUATING AIRBORNE MMMF (1985a) Reference methods for measuring airborne man-made mineral fibres (MMMF). Monitoring concentration using a phase contrast optical microscope. Determining size using a scanning electron microscope. Copenhagen: WHO Regional Office for Europe. (WHO Environmental Health EH4).

WHO/EURO TECHNICAL COMMITTEE FOR MONITORING AND EVALUATING MMMF (1985b) The WHO/EURO man-made mineral fibre reference scheme. Scandinavian Journal of Work, Environment and Health; 11: 123-129.

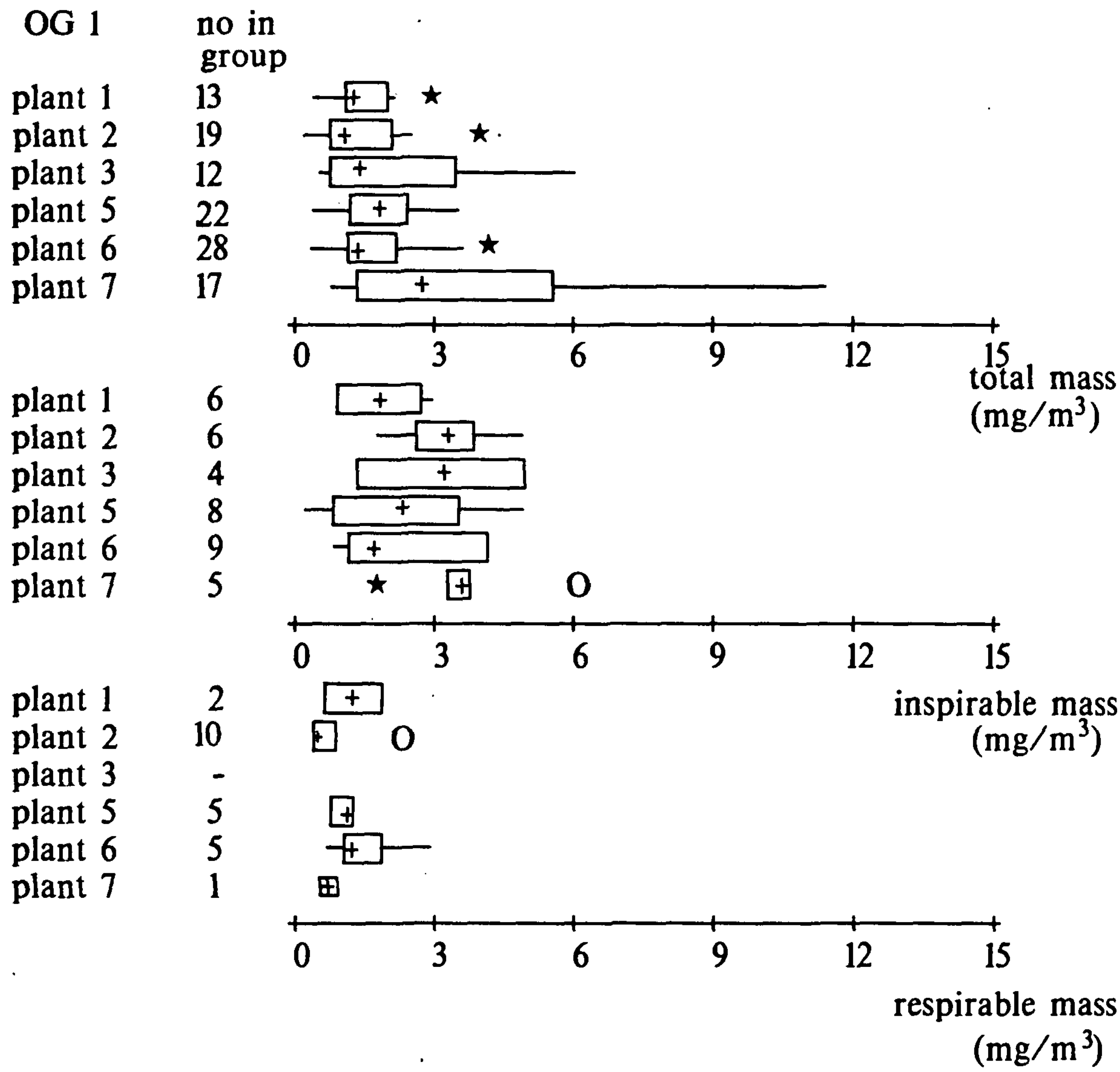

Figure 4.1 "Total", inspirable and respirable mass concentrations for production workers (OG 1).

The data are given for each plant within broad occupational group and the results for 'total', inspirable and respirable mass are shown together for ease of comparison. Where there are less than seven points the individual values have been plotted as '*'s (codes 2–9 indicate a number of coincident points). Where there are larger numbers of measurements in a group the data have been summarised using 'boxplots'. In these plots a '+' indicates the median or middle of the distribution. The box has been drawn to include the middle 50% of the points, i.e. it excludes the highest 25% and the lowest 25%, and the lines extending from the box extend to the highest and lowest measurements which lie within the body of the distribution.

The more extreme points which occur outside these limits are represented by '*' with the most extreme represented by 'o'. In a small number of cases the extreme points are omitted from the figures since they fell outside the range of the graph. These points are given in brackets at the end of the axis.

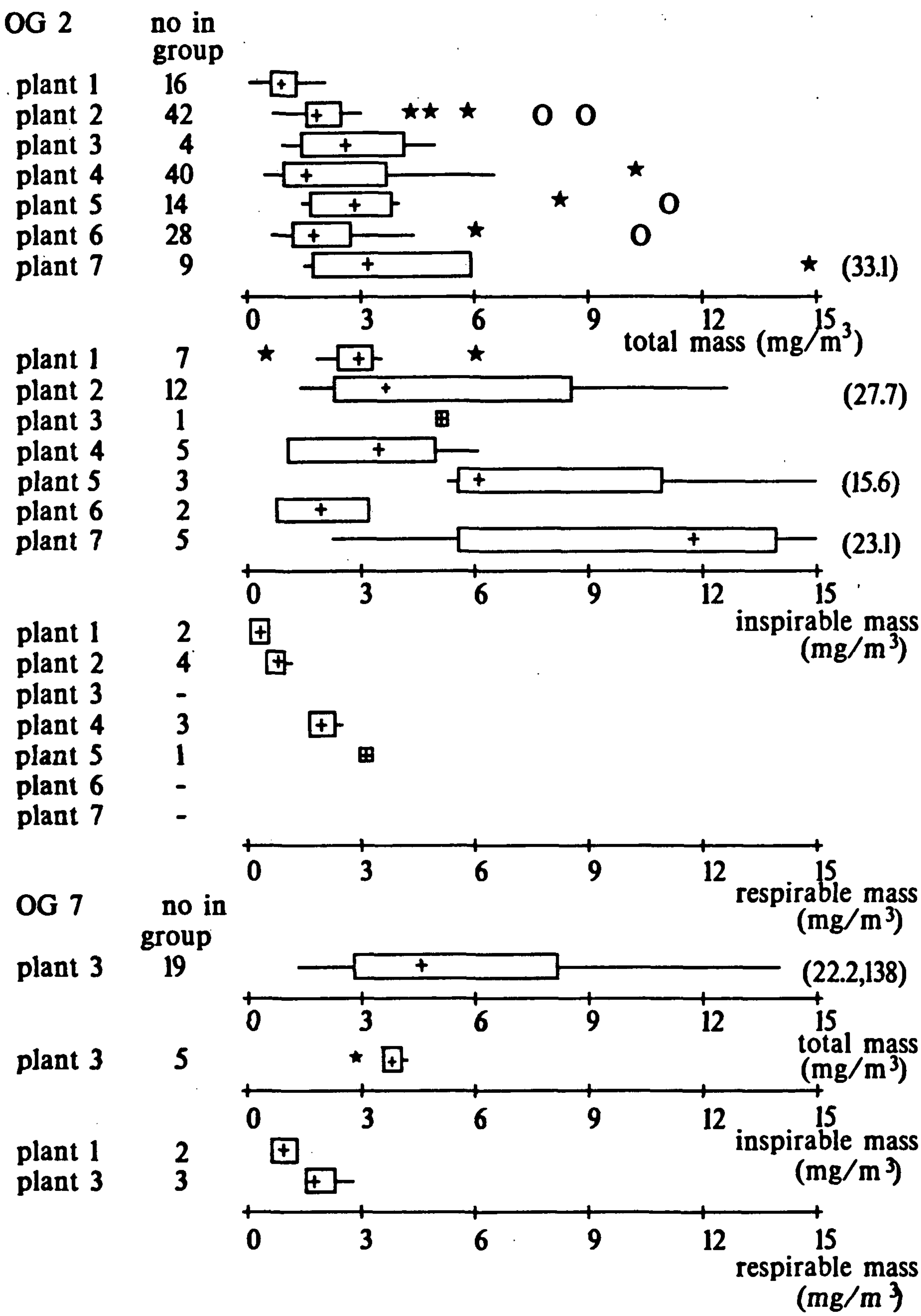

Figure 4.2 "Total", inspirable and respirable mass concentrations for secondary production (OG2) and non-ceramic fibre production workers (OG7).

See Caption on Figure 4.1 for explanation of symbols.

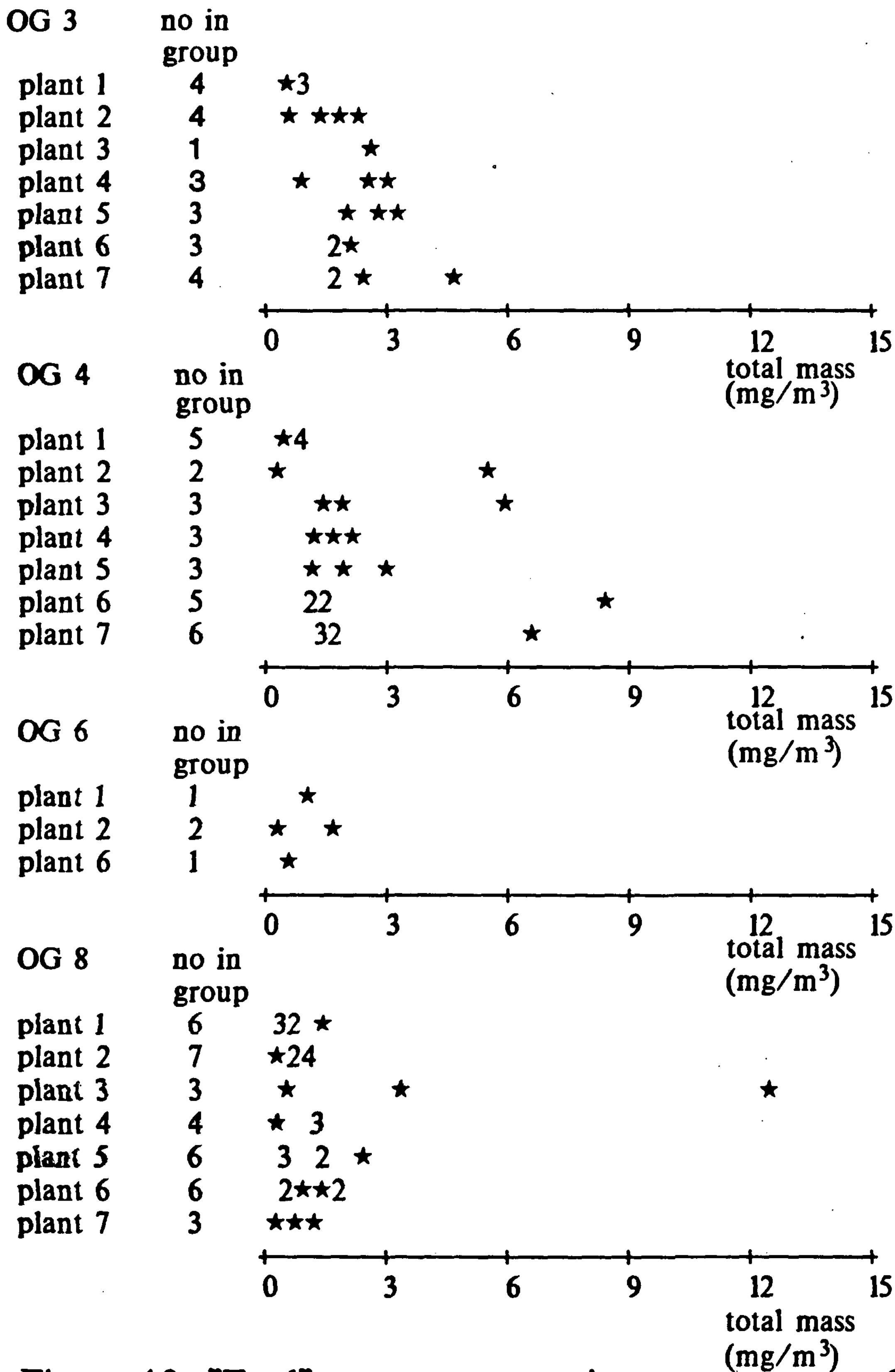

Figure 4.3 "Total", mass concentration measurements for warehouse workers (OG3), maintenance (OG4), cleaning (OG6) and staff (OG8).

See Caption on Figure 4.1 for explanation of symbols.

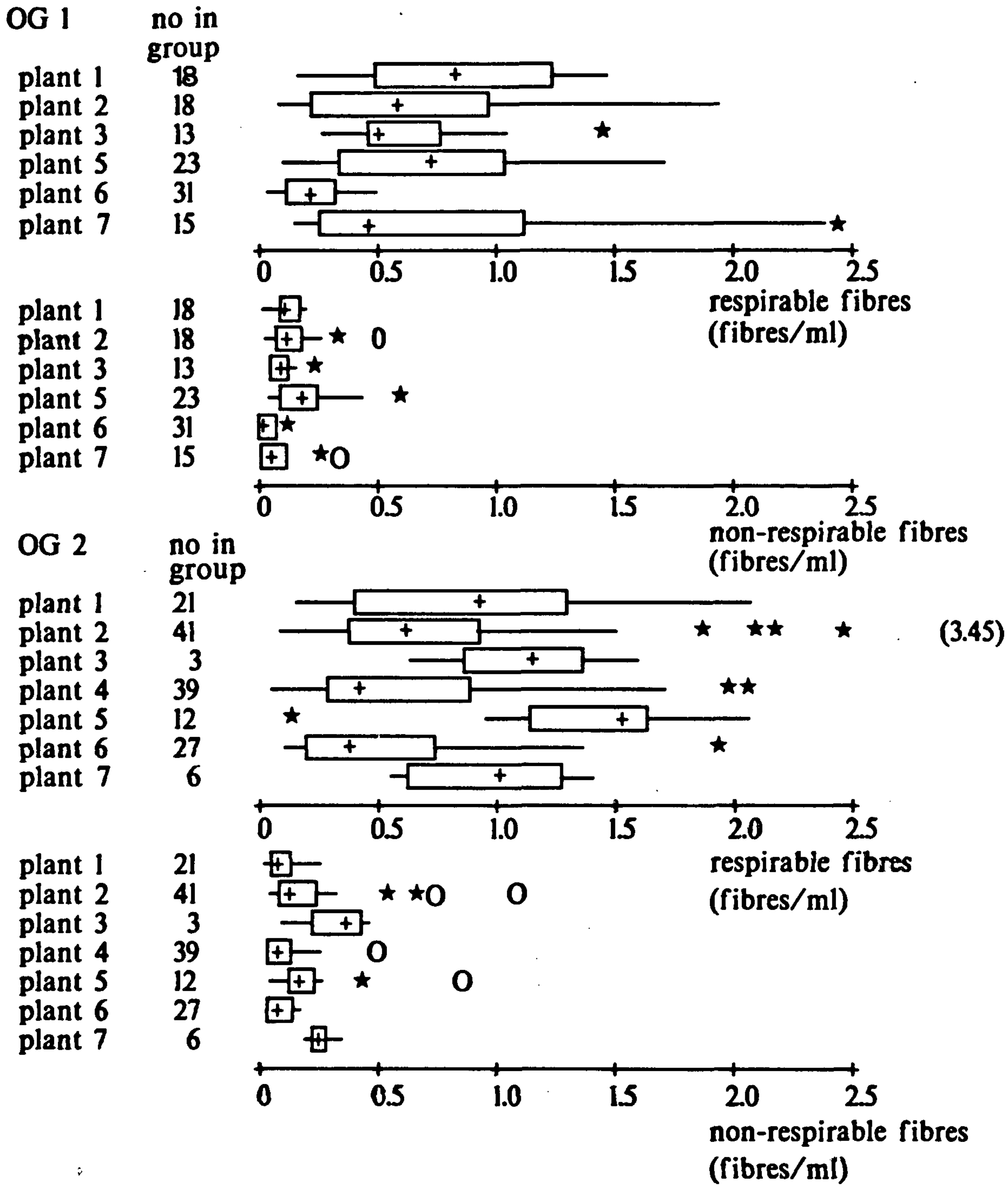

Figure 4.4 Respirable and non-respirable fibre concentrations for production (OG1) and secondary production workers (OG2).

See Caption on Figure 4.1 for explanation of symbols.

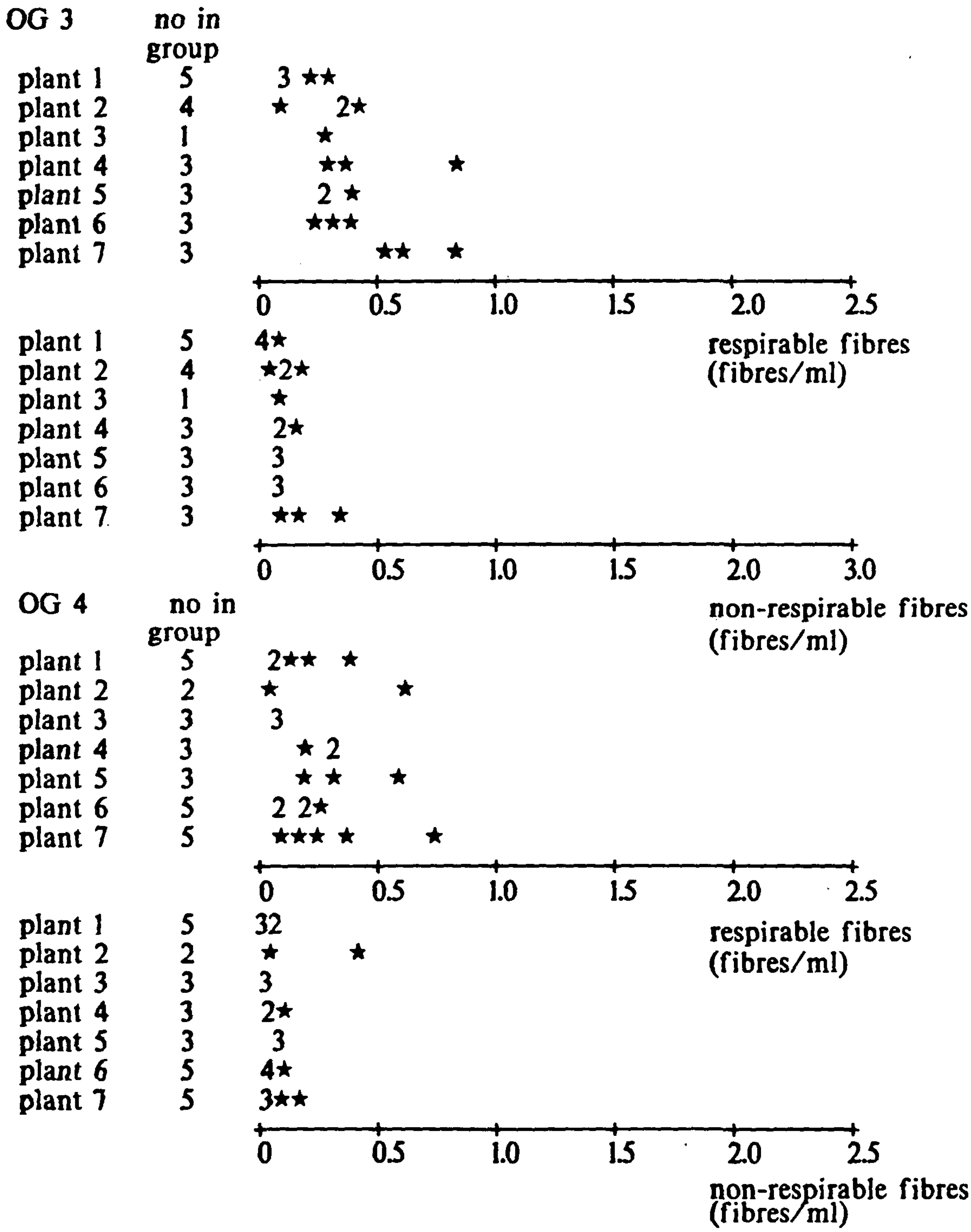

Figure 4.5 Respirable and non-respirable fibre concentrations for warehouse (OG3) and maintenance (OG4).

See Caption on Figure 4.1 for explanation of symbols.

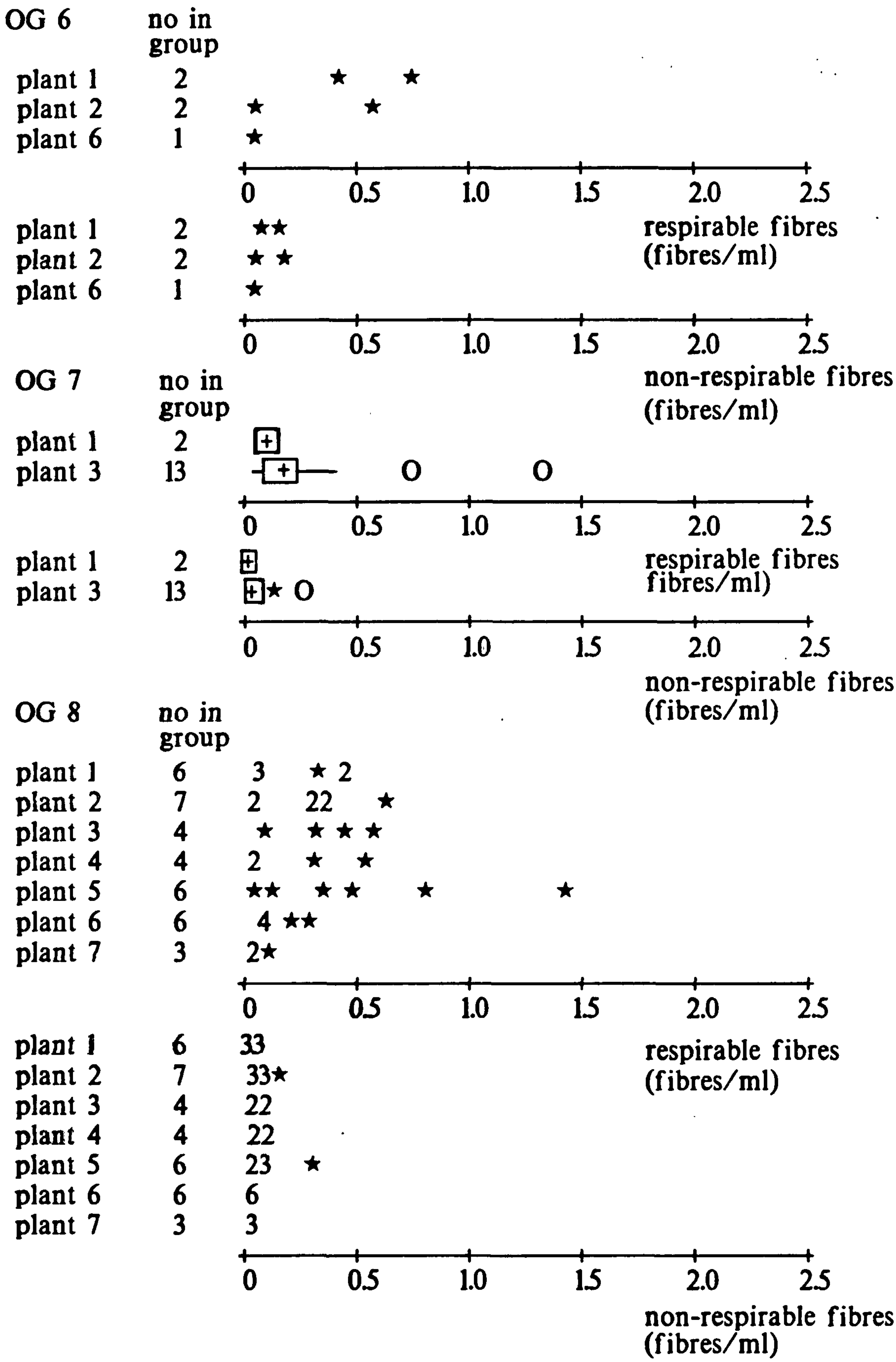

Figure 4.6 Respirable and non-respirable fibre concentrations for cleaners(OG6), non-ceramic fibre production(OG7), and staff (OG8).

See Caption on Figure 4.1 for explanation of symbols.

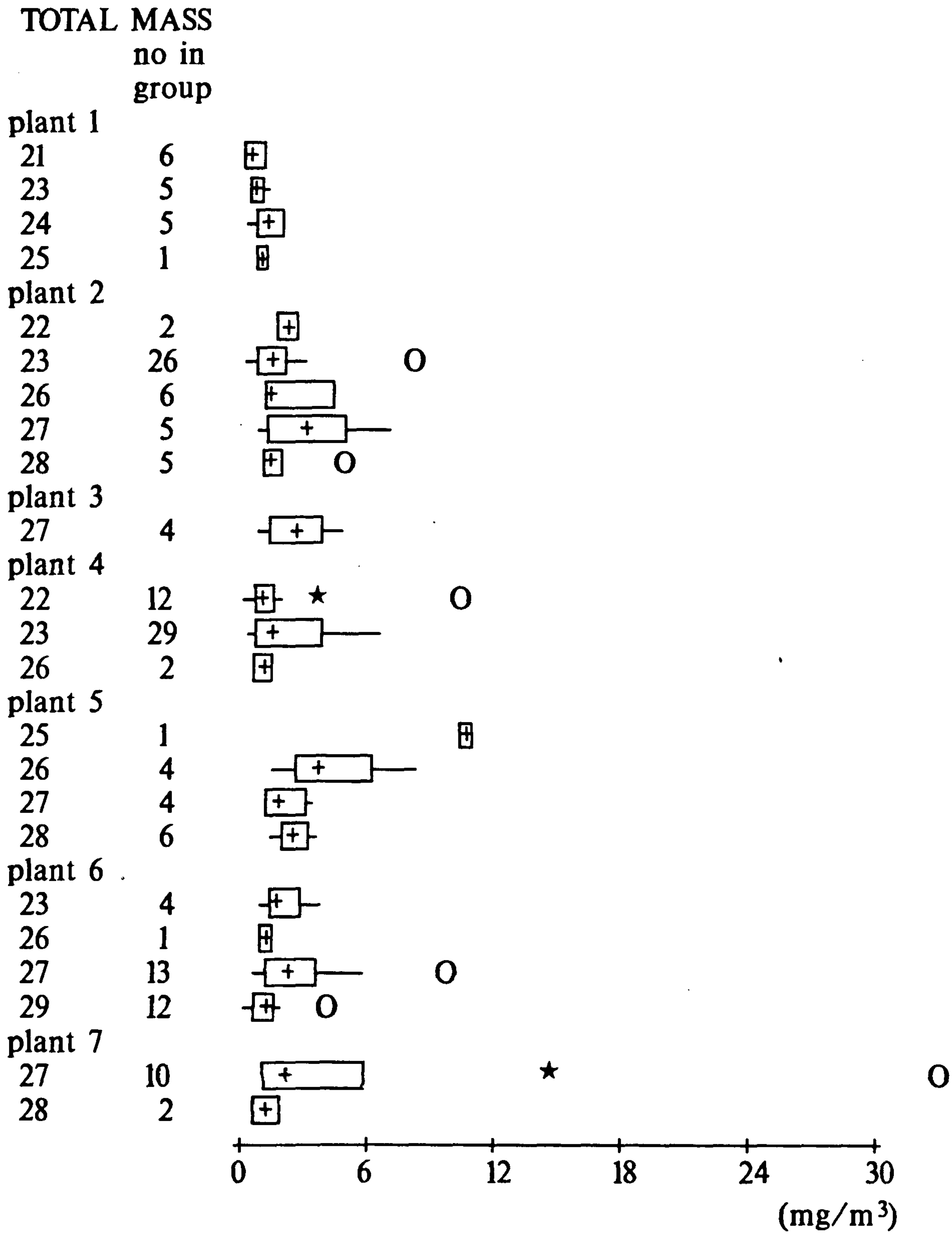

Figure 4.7 "Total" mass concentration for secondary production workers, by occupational group.

See Caption on Figure 4.1 for explanation of symbols.

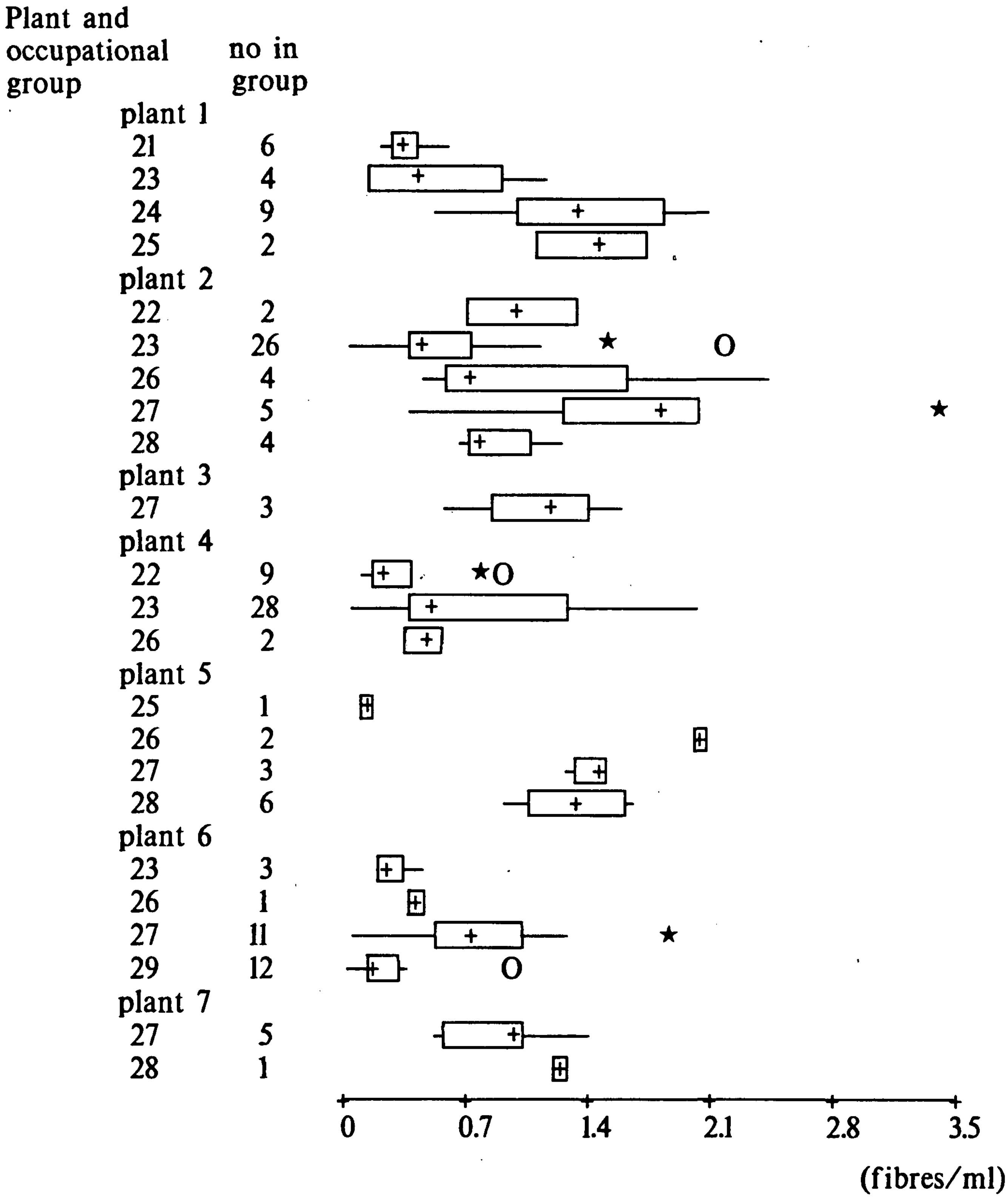

Figure 4.8 Respirable fibre concentrations for secondary production workers, by occupational group.

See Caption on Figure 4.1 for explanation of symbols.

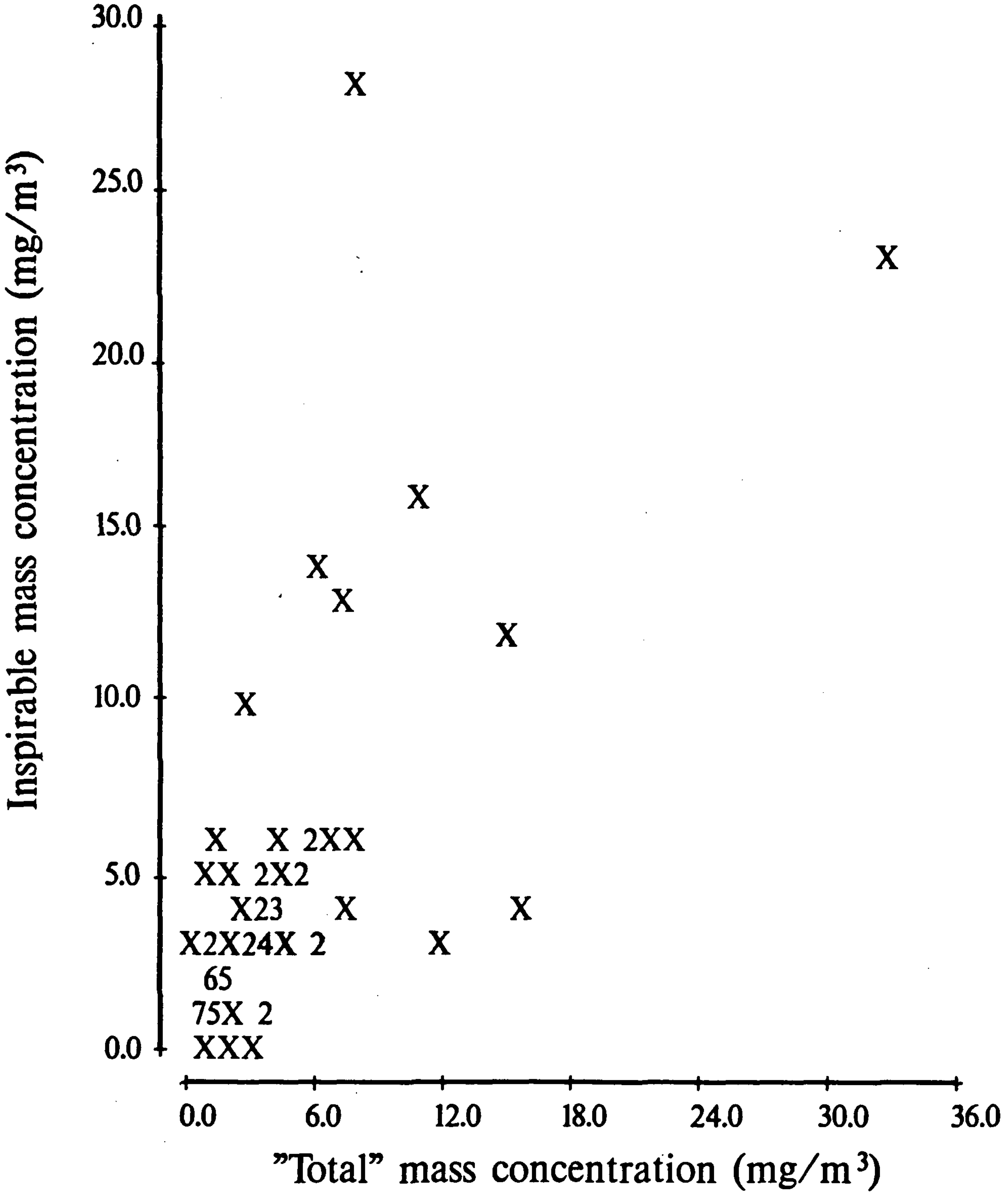

Figure 4.9 Simultaneous measurements of inspirable and "total" dust mass concentrations.

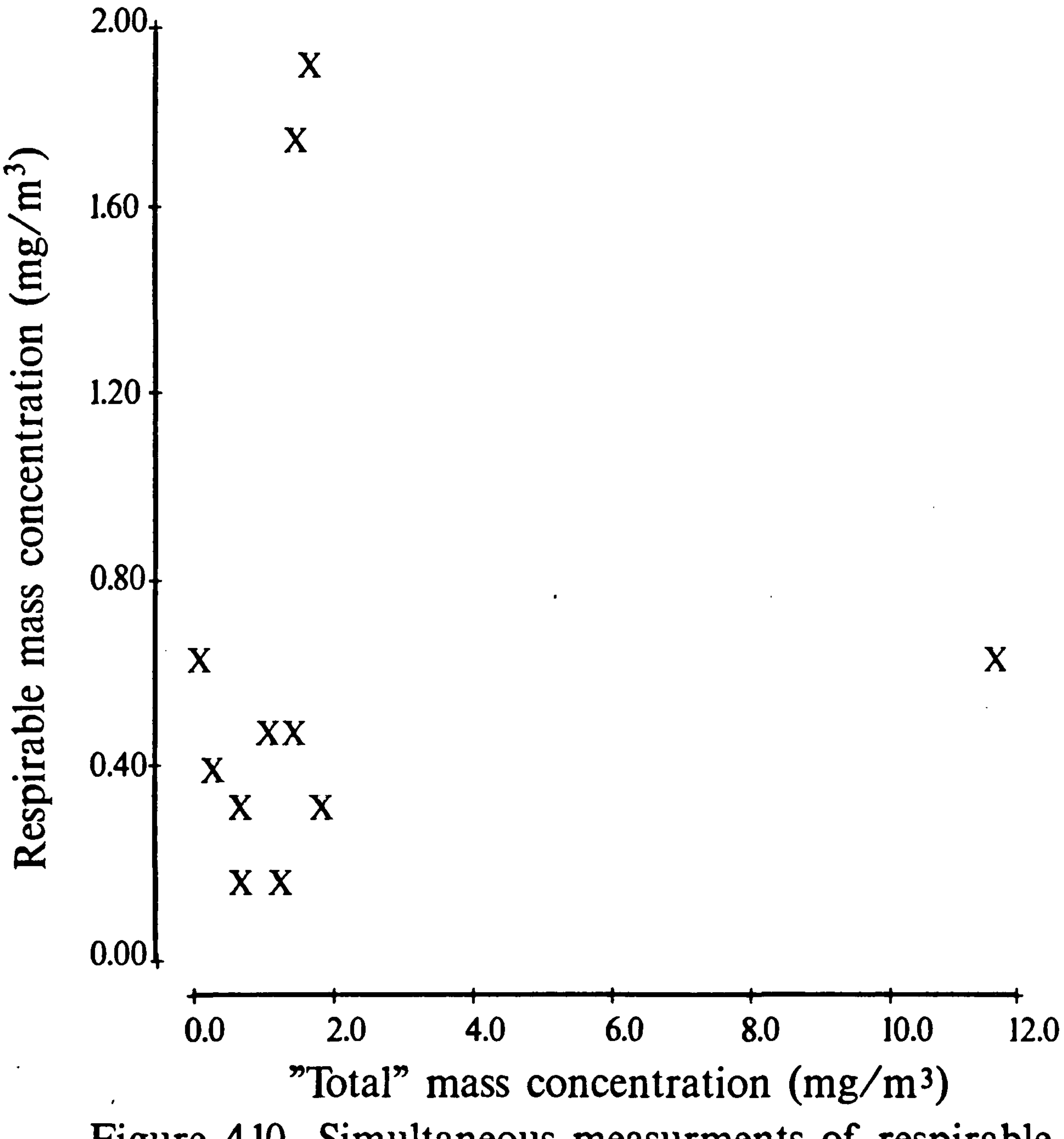

Figure 4.10 Simultaneous measurments of respirable and "total" dust mass concentration.

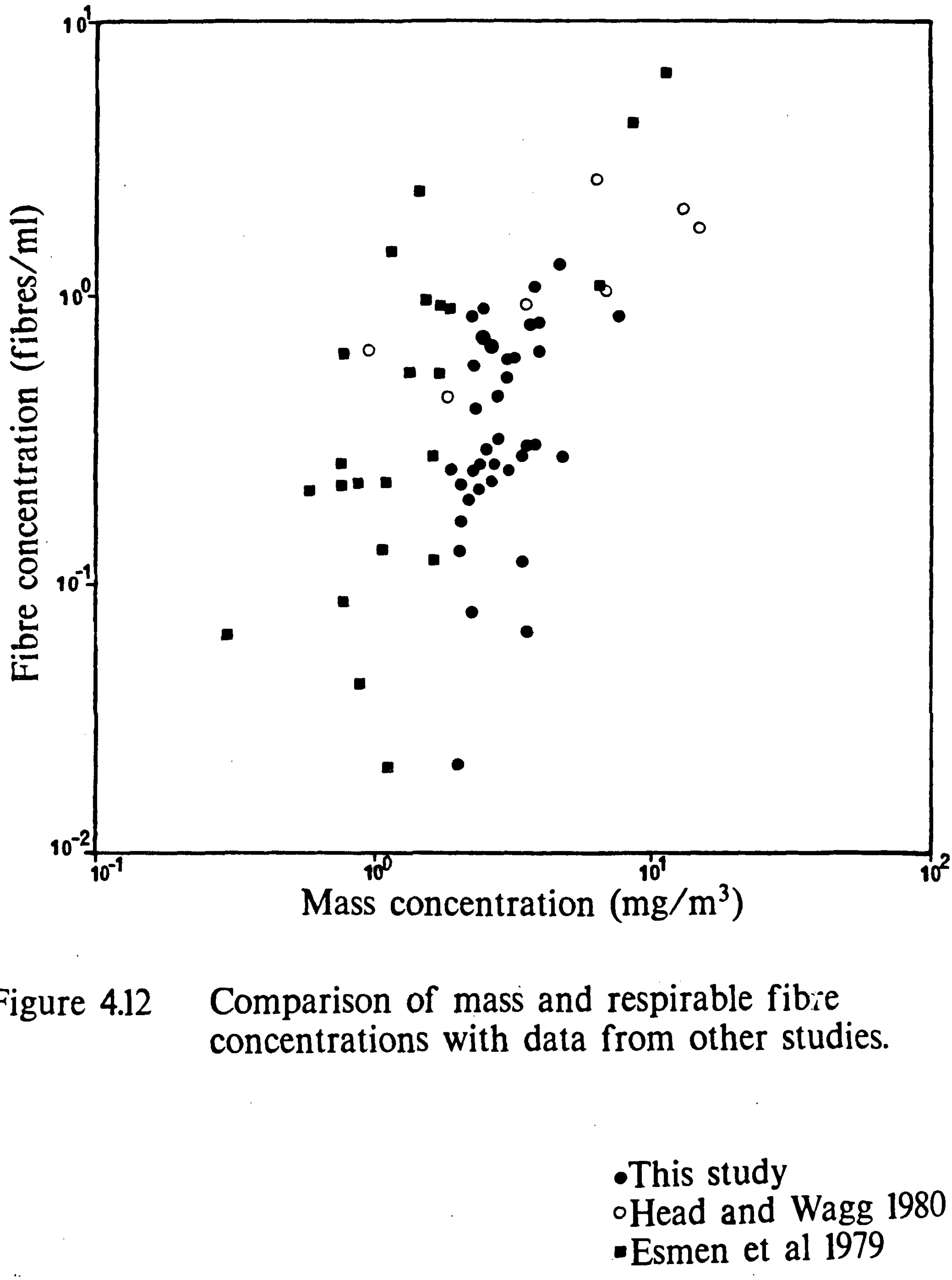

Figure 4.12 Comparison of mass and respirable fibre concentrations with data from other studies.

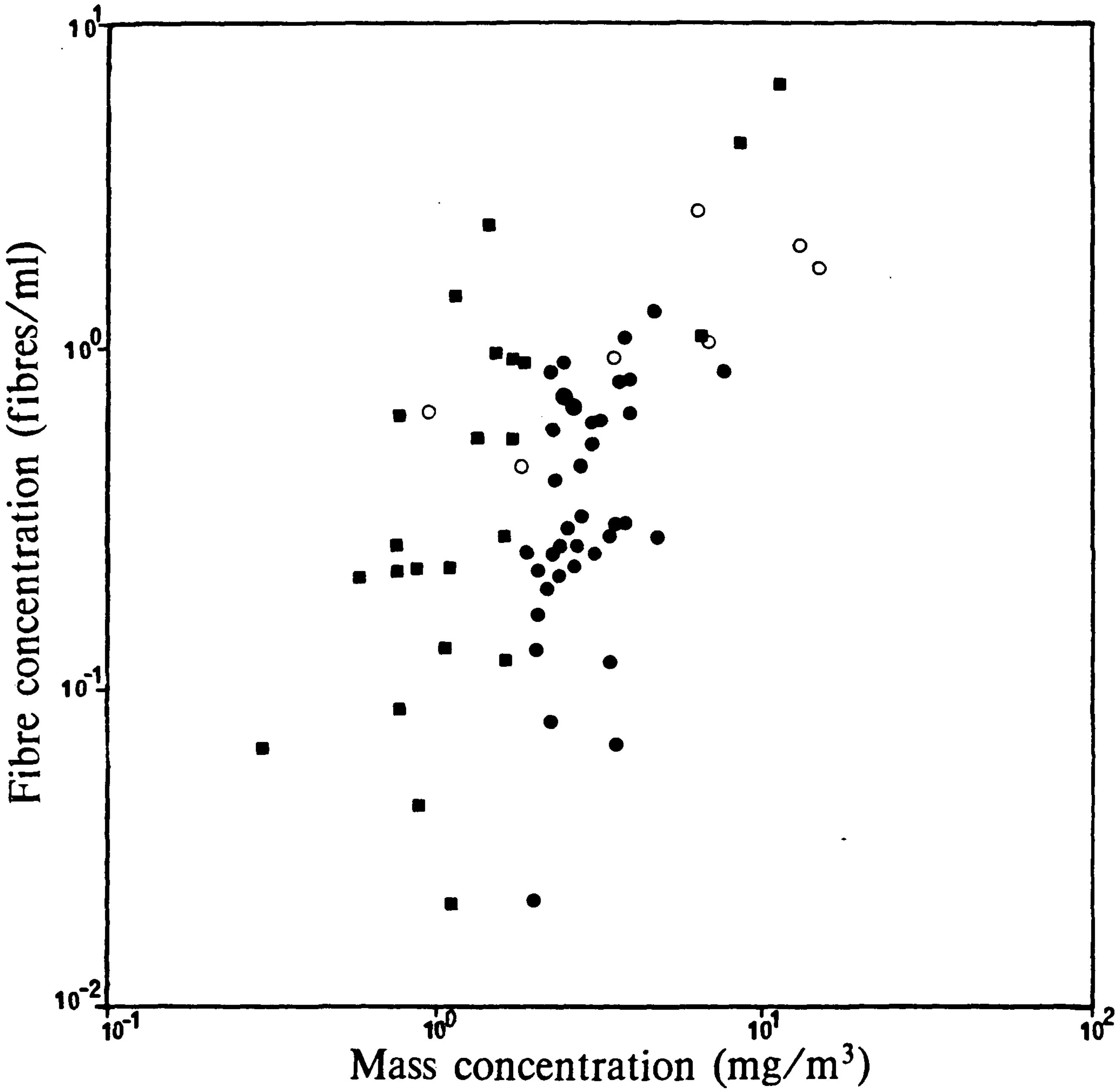

Figure 4.12 Comparison of mass and respirable fibre concentrations with data from other studies.

•This study
○Head and Wagg 1980
▪Esmen et al 1979

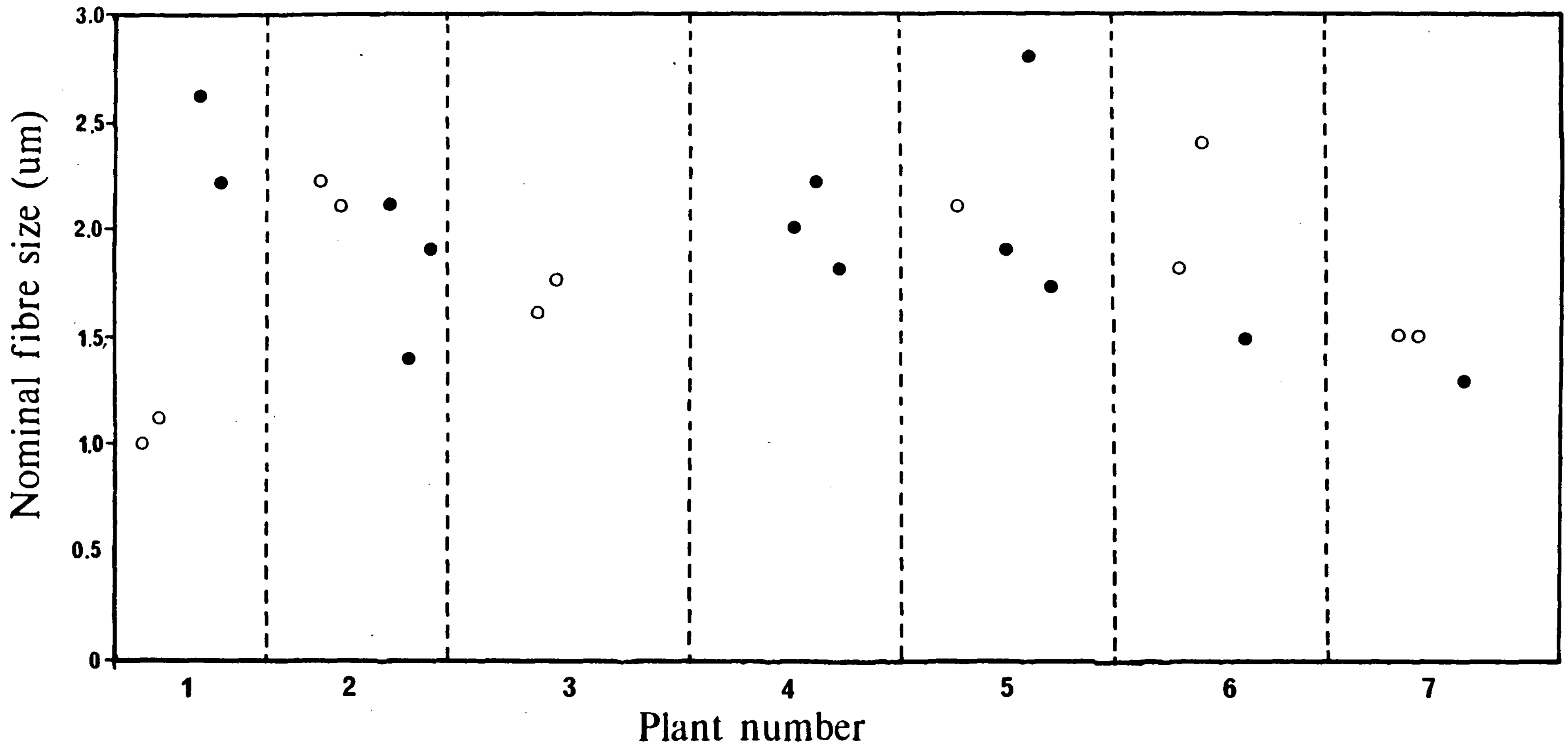

Figure 4.13 Nominal fibre sizing for samples of bulk ceramic fibre, by plant.

○Production
•Secondary production

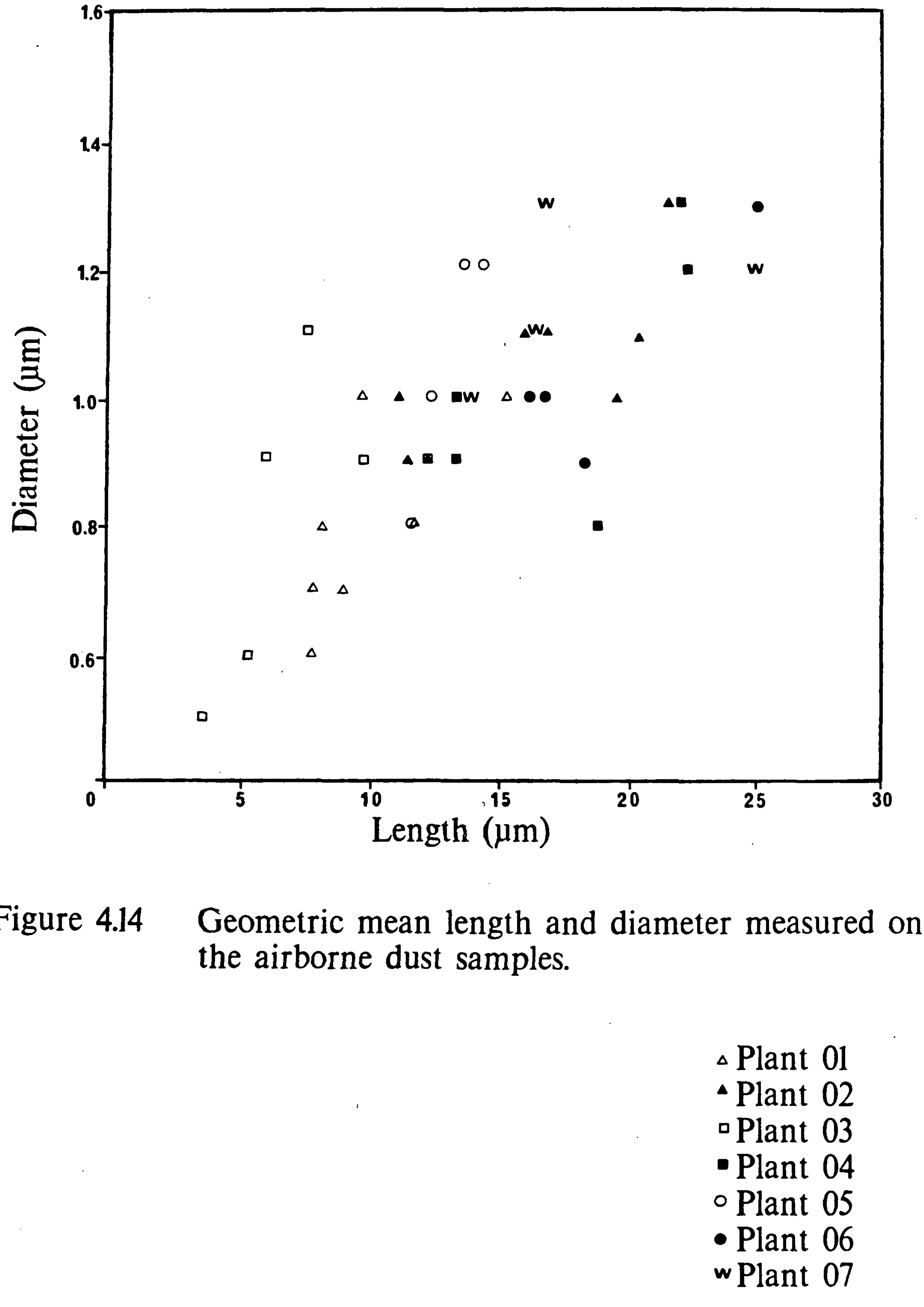

Figure 4.14 Geometric mean length and diameter measured on the airborne dust samples.

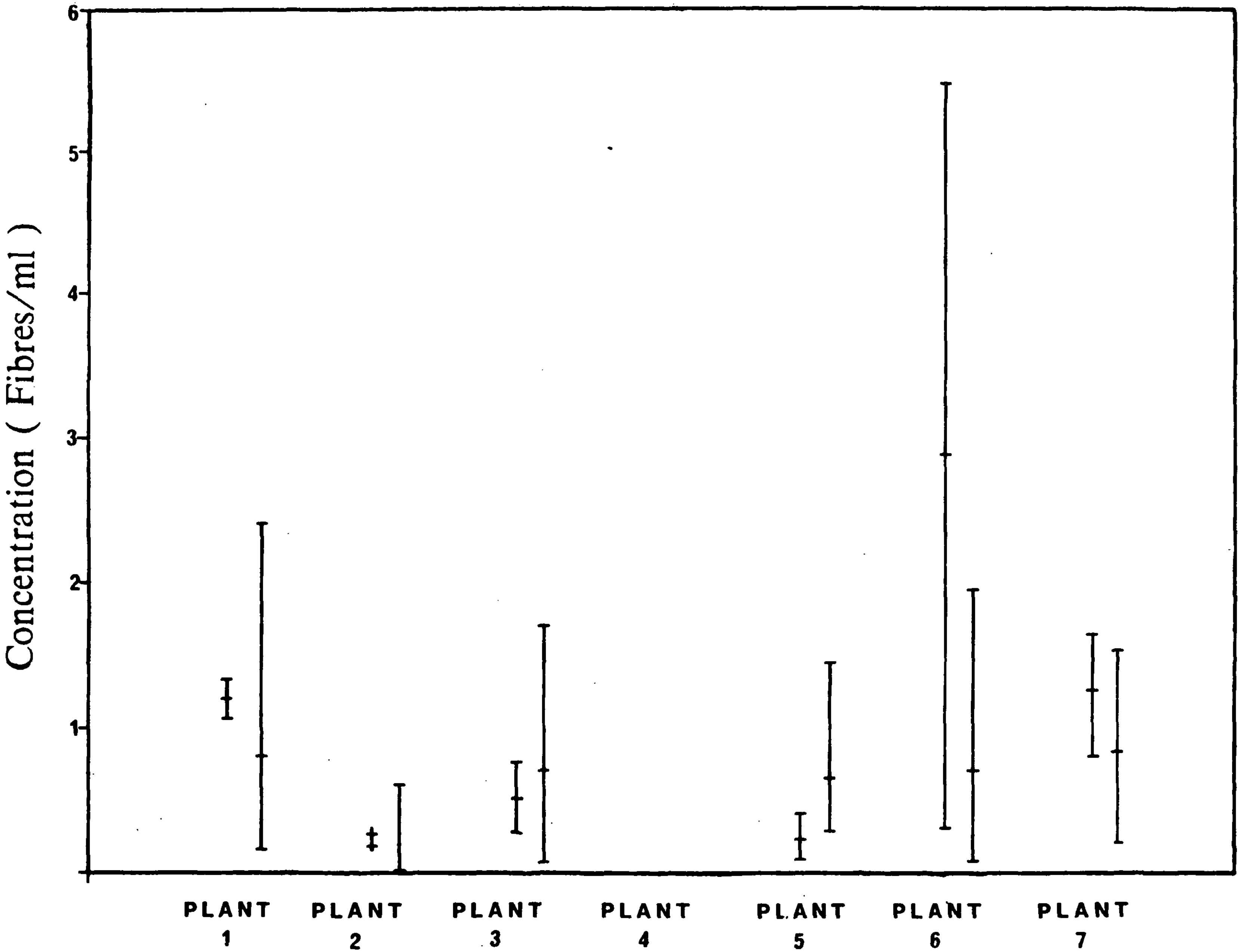

Figure 4.15 Comparison of the mean and range of airborne fibre concentrations obtained by optical microscopy and SEM for production workers.

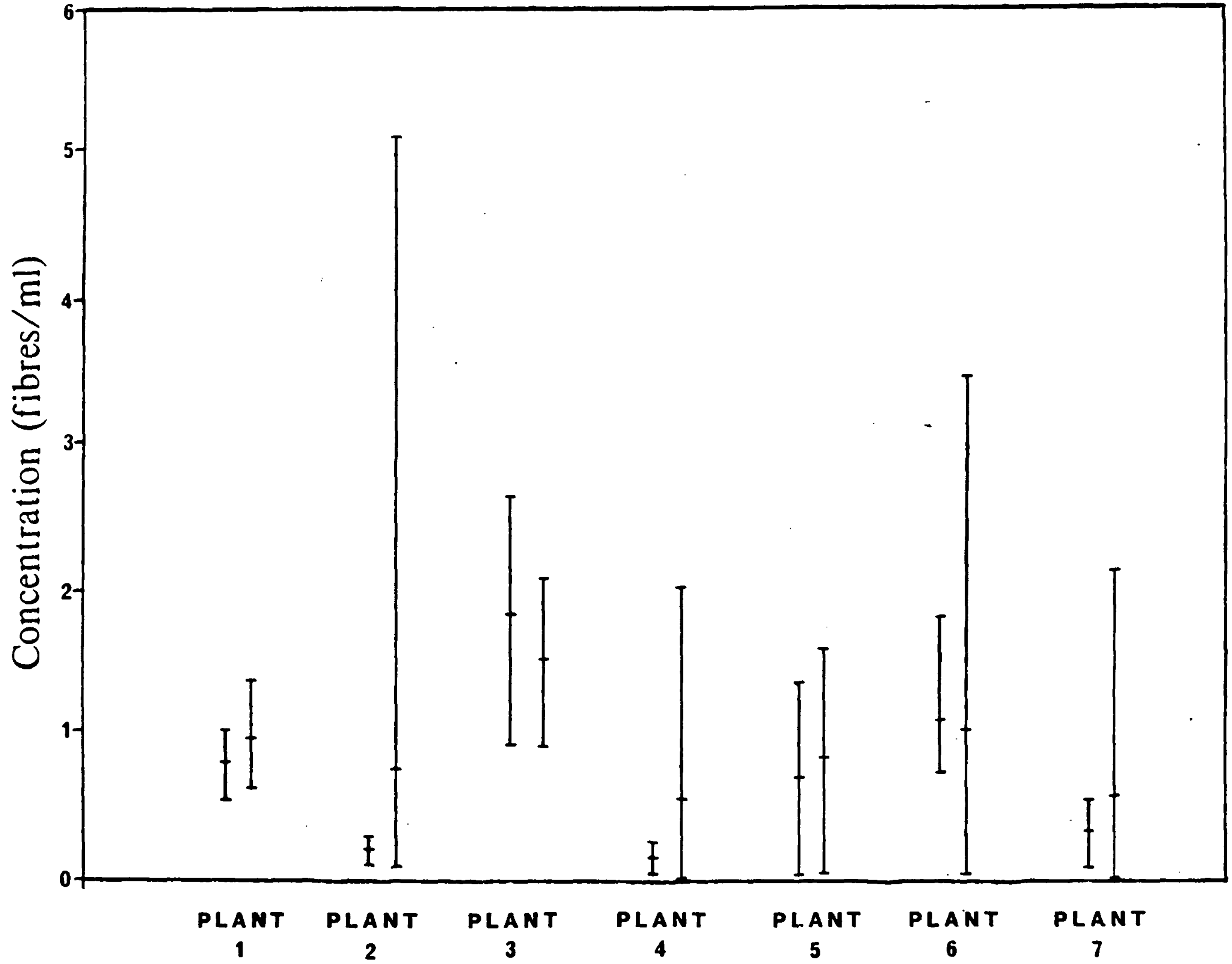

Figure 4.16 Comparison of the measured range of airborne fibre concentrations obtained by optical microscopy and SEM for secondary production workers.

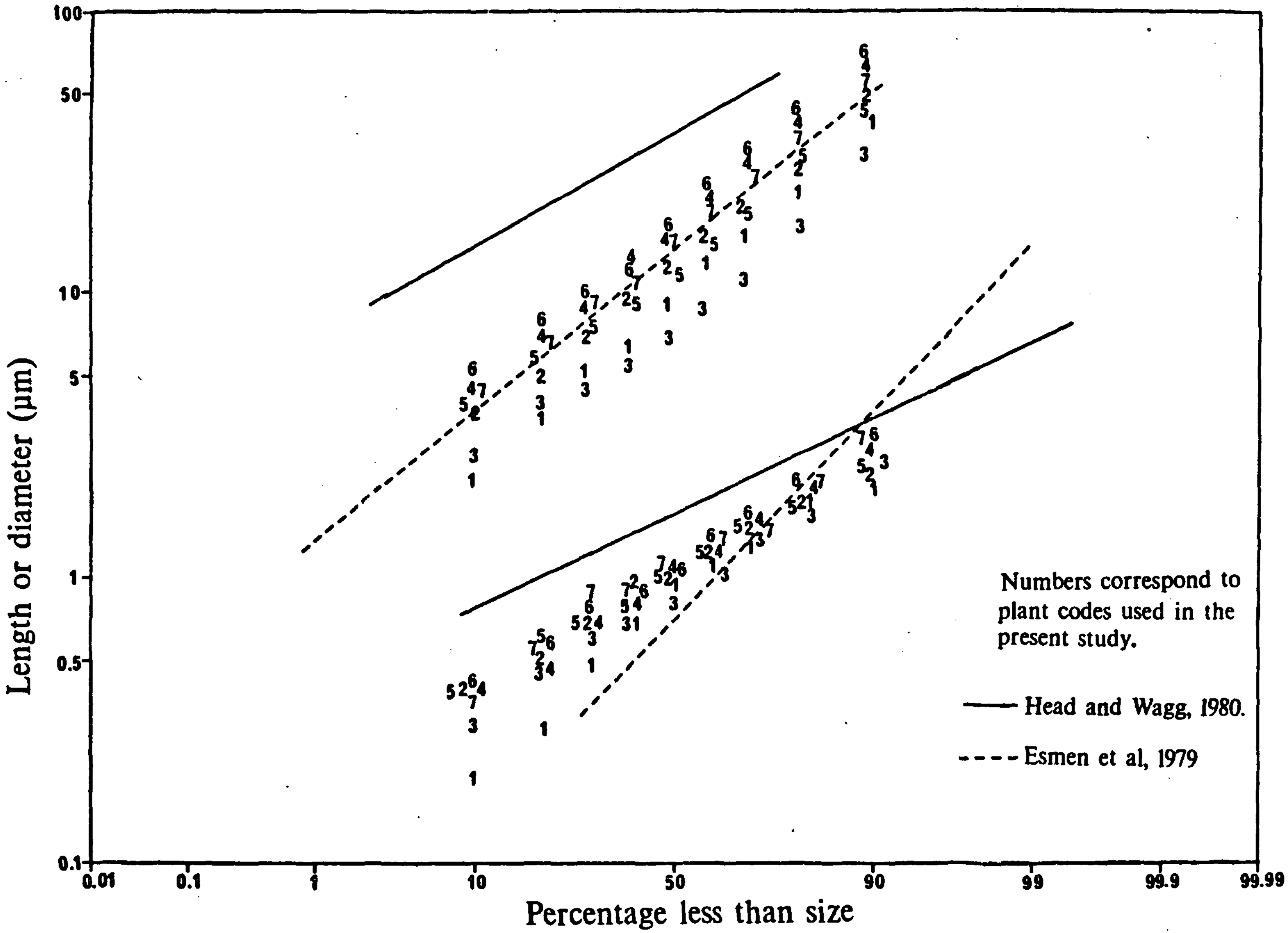

Figure 4.17 Cumulative length and diameter distributions for airborne dust samples, by plant plus corresponding data from other studies in ceramic fibre manufacturing.

TABLE 3.1

Occupational Group Structure

Combined Occupational Group		Occupational Group		Job	
Title	Code	Title	Code	Title	Code
Production of Ceramic Fibre	1	Production plant operator	11 & 12	Furnace man Needler Packer	111 112 113
Secondary production with ceramic fibre	2	Production of paper or board	21	Mixer Vacuum drum Packer	211 212 213
	2	Vacuum forming shapes	23	Mixer Line operator Line end operator	231 232 233
Warehouse	3	Warehouse man	31	Operator handling ceramic fibres	311
Maintenance	4	Maintenance Worker	41	Fitter in ceramic fibre plant Fitter elsewhere Electrician	411 412 413
Cleaning	6	Cleaner	61	Cleaner in ceramic fibre plant	611
Production not involving ceramic fibre	7	Globar manufacture	71	Plant operator	711
Staff	8	Staff	81	Staff in daily contact with ceramic fibre	811

TABLE 4.1

Personal respirable dust and respirable silica dust concentrations

Occupational group	No. of samples	Respirable dust: mean conc. (mg/m³)	Respirable dust: min conc. (mg/m³)	Respirable dust: max. conc. (mg/m³)	Respirable dust: std. dev. (mg/m³)	Respirable Silica*: mean conc. (mg/m³)	Respirable Silica*: min conc. (mg/m³)	Respirable Silica*: max. conc. (mg/m³)	Respirable Silica*: std. dev. (mg/m³)
Plant 01									
Primary production operator	2	1.2	0.6	1.8	0.8	0.06	0.04	0.08	0.03
Secondary production - paper and board	1	0.2	-	-	-	n.d.	-	-	-
- vacuum forming	1	0.1	-	-	-	-	-	-	-
Shipping (Fibre and Refractory warehouse operators)	2	0.2	0.1	0.2	0.1	n.d.	-	-	-
Maintenance worker - bricklayer	1	0.6	-	-	-	0.06**	-	-	-
Non-ceramic fibre manufacture	2	0.9	0.6	1.2	0.4	0.19	0.12	0.25	0.09

n.d. - none detected * quartz except for the sample marked ** which was cristobalite

TABLE 4.1 (contd)

Personal respirable dust and respirable silica dust concentrations

Occupational group	No. of samples	Respirable dust: mean conc. (mg/m³)	Respirable dust: min conc. (mg/m³)	Respirable dust: max. conc. (mg/m³)	Respirable dust: std. dev. (mg/m³)	Respirable Silica: mean conc. (mg/m³)	Respirable Silica: min conc. (mg/m³)	Respirable Silica: max. conc. (mg/m³)	Respirable Silica: std. dev. (mg/m³)
Plant 02									
Primary production operators	10	0.6	0.2	2.0	0.5	0.01	n.d.	0.13	0.04
Secondary production - vacuum forming	1	0.6	0.5	0.8	0.2	0.01	n.d.	0.02	0.01
- conversion	1	0.4	-	-	-	n.d.	-	-	-
Plant 03									
Insulation brickworks operators	3	1.9	1.5	2.7	0.7	0.02	n.d.	0.06	0.03

n.d. - none detected

TABLE 4.1 (contd)

Personal respirable dust and respirable silica dust concentrations

Occupational group	No. of samples	Respirable dust mean conc. (mg/m³)	Respirable dust min conc. (mg/m³)	Respirable dust max. conc. (mg/m³)	Respirable dust std. dev. (mg/m³)	Respirable Silica mean conc. (mg/m³)	Respirable Silica min conc. (mg/m³)	Respirable Silica max. conc. (mg/m³)	Respirable Silica std. dev. (mg/m³)
Plant 04									
Secondary production - board	1	2.5	-	-	-	0.04	-	-	-
- vacuum forming	2	1.6	1.6	1.7	0.1	n.d.	-	-	-
Plant 05									
Primary production operators	4	0.8	0.6	0.9	0.1	n.d.	-	-	-
Secondary production - cement	1	2.8	-	-	-	0.10	-	-	-

n.d. - none detected

TABLE 4.1 (contd)

Personal respirable dust and respirable silica dust concentrations

Occupational group	No. of samples	Respirable dust mean conc. (mg/m^3)	Respirable dust min conc. (mg/m^3)	Respirable dust max. conc. (mg/m^3)	Respirable dust std. dev. (mg/m^3)	Respirable Silica mean conc. (mg/m^3)	Respirable Silica min conc. (mg/m^3)	Respirable Silica max. conc. (mg/m^3)	Respirable Silica std. dev. (mg/m^3)
Plant 06									
Primary production operators	5	1.3	0.6	2.5	0.8	n.d.	-	-	-
Plant 07									
Primary production operators	2	0.3	<0.1	0.6	0.4	n.d.	-	-	-

n.d. - none detected

TABLE 4.2

Rate of air exchange measured in the production and secondary production areas

Plant	Area	Air exchange rate (hr^{-1})
01	Production	10 to 16
	Secondary production - vacuum forming	6
02	Production	22
	Secondary production	
	- board	19
	- conversion	9
03	Production	22
04	-	- †
05	Production	11
06	-	- †
07	Production	10

† no measurements made

TABLE 5.1

Distribution of Respirable Fibre Concentration
by Plant and Occupational Group

Plant	OCCUPATIONAL GROUP 1	2	3	4	6	7	8	All
1	0.878	0.928	0.152	0.124	0.565	0.120	0.215	0.667*
	0.411	0.623	0.059	0.116	0.219	0.071	0.168	0.553
	18	21	5	5	2	2	6	59
2	0.647	0.817	0.240	0.285	0.250	-	0.240	0.660
	0.511	0.702	0.122	0.389	0.325	-	0.185	0.622
	18	41	4	2	2	0	7	74
3	0.645	1.110	0.270	0.063	-	0.258	0.270	0.449
	0.326	0.503	-	0.006	-	0.362	0.182	0.420
	13	3	1	3	0	13	4	37
4	-	0.633	0.437	0.207	-	-	0.175	0.557
	-	0.533	0.280	0.058	-	-	0.197	0.506
	0	39	3	3	0	0	4	49
5	0.716	1.364	0.287	0.313	-	-	0.420	0.791
	0.482	0.530	0.064	0.183	-	-	0.468	0.585
	23	12	3	3	0	0	6	47
6	0.204	0.492	0.257	0.110	0.010	-	0.077	0.293
	0.133	0.445	0.035	0.071	-	-	0.609	0.324
	31	27	3	5	1	0	6	73
7	0.821	0.943	0.610	0.230	-	-	0.023	0.657
	0.742	0.351	0.132	0.217	-	-	0.006	0.611
	15	6	3	5	0	0	3	32
ALL	0.601	0.781	0.307	0.178	0.328	0.240	0.217	0.571
	0.500	0.614	0.187	0.162	0.308	0.339	0.250	0.544
	118	149	22	26	5	15	36	371

* mean
standard deviation
number of measurements

TABLE 5.2

Distribution of Non-respirable Fibre Concentration
by Plant and Occupational Group

	OCCUPATIONAL GROUP							
Plant	1	2	3	4	6	7	8	All
1	0.132	0.092	0.018	0.020	0.080	0.010	0.033	0.083*
	0.089	0.065	0.008	0.016	0.028	0.000	0.030	0.076
	18	21	5	5	2	2	6	59
2	0.111	0.164	0.065	0.185	0.060	-	0.039	0.131
	0.116	0.186	0.033	0.262	0.085	-	0.040	0.159
	18	41	4	2	2	0	7	74
3	0.097	0.290	0.050	0.013	-	0.043	0.032	0.079
	0.054	0.197	-	0.006	-	0.053	0.028	0.095
	13	3	1	3	0	13	4	37
4	-	0.082	0.057	0.020	-	-	0.018	0.072
	-	0.099	0.038	0.010	-	-	0.021	0.091
	0	39	3	3	0	0	4	49
5	0.149	0.201	0.050	0.043	-	-	0.067	0.139
	0.135	0.208	0.010	0.012	-	-	0.098	0.152
	23	12	3	3	0	0	6	47
6	0.031	0.053	0.037	0.016	0.000	-	0.007	0.036
	0.028	0.040	0.006	0.009	-	-	0.010	0.034
	31	27	3	5	1	0	6	73
7	0.075	0.207	0.140	0.034	-	-	0.000	0.092
	0.081	0.047	0.092	0.034	-	-	0.000	0.091
	15	6	3	5	0	0	3	32
ALL	0.094	0.119	0.057	0.037	0.056	0.039	0.031	0.089
	0.099	0.141	0.050	0.071	0.056	0.050	0.048	0.114
	118	149	22	26	5	15	36	371

* mean
standard deviation
number of measurements

TABLE 5.3

Distribution of Inspirable Mass
by Plant and Occupational Group

Plant	OCCUPATIONAL GROUP 1	2	3	4	6	7	8	All
1	2.453	2.472	2.142	2.160	2.410	-	2.142	2.382*
	0.755	0.883	0.124	0.088	-	-	0.226	0.715
	19	24	4	5	1	0	6	59
2	2.768	3.904	2.432	3.595	2.255	-	2.036	3.370
	0.849	3.829	0.346	2.567	0.644	-	0.170	3.034
	25	56	4	2	2	0	7	96
3	3.162	3.858	3.510	3.693	-	9.246	5.443	6.150
	1.459	1.258	-	1.669	-	19.528	4.421	13.397
	18	5	1	3	0	25	3	55
4	-	3.257	2.943	2.673	-	-	2.225	3.139
	-	1.596	0.629	0.208	-	-	0.293	1.484
	0	48	3	3	0	0	4	58
5	2.649	4.878	2.750	2.930	-	-	2.410	3.283
	1.001	3.260	1.310	0.531	-	-	0.555	2.139
	32	18	4	3	0	0	6	63
6	2.554	3.134	2.820	3.518	1.980	-	2.308	2.814
	0.989	1.429	0.147	2.229	-	-	0.251	1.245
	38	32	3	5	1	0	6	85
7	4.096	7.510	3.438	3.290	-	-	1.933	4.912
	2.242	7.402	0.983	1.460	-	-	0.160	4.734
	24	17	4	6	0	0	3	54
ALL	2.903	3.847	2.776	3.082	2.225	9.246	2.470	3.608
	1.375	3.470	0.790	1.401	0.412	19.528	1.450	5.252
	156	200	23	27	4	25	35	470

* mean
standard deviation
number of measurements

TABLE 5.4

Observed and Predicted Means for Plants and OGs

Non-Respirable Fibres

		Observed	Predicted	Diff	Ratio
Plant	1	0.07	0.07	0.00	1.00
	2	0.10	0.09	0.01	1.11
	3	0.12	0.08	0.04	1.50
	4	0.05	0.05	0.00	1.00
	5	0.11	0.11	0.00	1.00
	6	0.03	0.03	0.00	1.00
	7	0.11	0.09	0.02	1.22
OG	1	0.09	0.08	0.01	1.12
	2	0.12	0.10	0.02	1.20
	3	0.05	0.04	0.01	1.25
	4	0.05	0.02	0.03	2.50
	6	0.04	0.05	-0.01	0.80
	7	0.02	0.03	-0.01	0.67
	8	0.03	0.02	0.01	1.50

Inspirable Mass

		Observed	Predicted	Diff	Ratio
Plant	1	2.37	2.28	0.09	1.04
	2	2.85	2.81	0.04	1.02
	3	3.70	3.44	0.26	1.08
	4	2.88	2.87	0.01	1.00
	5	3.14	2.84	0.30	1.11
	6	2.72	2.67	0.05	1.02
	7	3.99	3.55	0.44	1.12
OG	1	2.72	2.68	0.04	1.01
	2	3.40	3.18	0.22	1.07
	3	2.66	2.65	0.01	1.00
	4	3.05	2.75	0.30	1.11
	6	2.22	2.15	0.07	1.03
	7	4.86	4.86	0.00	1.00
	8	2.39	2.18	0.21	1.10

TABLE 5.5

Observed and Predicted Means by Plant and Occupational Group

Respirable Fibre Concentration

Plant	Occupational Group 1	2	3	4	6	7	8
1	0.88, 0.45 195 18	0.93, 0.79 118 21	0.15, 0.27 56 5	0.12, 0.18 68 5	0.56, 0.26 220 2	0.12, 0.16 76 2	0.22, 0.20 105 6
2	0.65, 0.47 138 18	0.75, 0.81 93 40	0.24, 0.29 82 4	0.28, 0.20 142 2	0.25, 0.28 91 2		0.24, 0.22 107 7
3	0.64, 0.48 135 13	1.11, 0.82 136 3	0.27, 0.30 90 1	0.06, 0.21 30 3		0.26, 0.19 139 13	0.27, 0.23 116 4
4		0.63, 0.74 86 39	0.44, 0.22 194 3	0.21, 0.14 153 3			0.18, 0.16 111 4
5	0.72, 0.62 115 23	1.36, 0.96 142 12	0.29, 0.44 65 3	0.31, 0.35 89 3			0.42, 0.38 112 6
6	0.20, 0.25 82 31	0.49, 0.59 84 27	0.26, 0.07 362 3	0.11, 0.00 - 5	0.01, 0.06 18 1		0.08, 0.00 - 6
7	0.82, 0.56 148 15	0.94, 0.89 105 6	0.61, 0.38 161 3	0.23, 0.29 80 5			0.02, 0.31 7 3

Cell Contents:
respfib: observed mean, predicted mean (from main effects model)
ratio obs/pred*100
no in group

TABLE 5.6

Grouping structure used for the calculation of cumulative exposures to respirable fibres (i.e. fibre/ml x hour)

	OCCUPATIONAL GROUP						
Plant	1	2	3	4	6	7	8
1	14	14	1	1	10	1	1
2	12	12	1	6	3		1
3	11	16	5	1		4	1
4		9	8	1			1
5	13	17	1	1			7
6	1	9	1	1	1		1
7	13	15	9	2			1

TABLE 5.7

Grouping structure used for the calculation of cumulative exposure to non-respirable fibres (i.e. fibre/ml x hour)

	OCCUPATIONAL GROUP						
Plant	1	2	3	4	6	7	8
1	3	4	1	1	2	1	1
2	4	4	1	1	3		1
3	4	4	1	1		1	1
4		3	1	1			1
5	4	5	3	1			1
6	1	1	1	1	1		1
7	4	4	1	1			1

TABLE 5.8

Grouping structure used for the calculation of cumulative exposures to inspirable dust (mg/m^3 x hour)

Plant	OCCUPATIONAL GROUP						
	1	2	3	4	6	7	8
1	3	7	3	5	2		1
2	7	16	8	11	6		3
3	16	22	17	18		24	13
4		16	9	12			3
5	7	16	10	14			3
6	7	15	7	8	4		3
7	20	23	19	21			15

TABLE 5.9

Predicted means and associated Standard Errors for new occupational groups for Respirable Fibres, Non-respirable Fibres and Inspirable Mass

New	Resp. Fibres		Non-resp. Fibres		Inspirable Mass	
OG No.	mean	s.e.	mean	s.d.	mean	s.d.
1	0.185	0.014	0.033	0.004	2.142	0.338
2	0.230	0.219	0.080	0.036	2.410	0.827
3	0.250	0.347	0.091	0.010	2.318	0.122
4	0.258	0.136	0.113	0.007	1.980	0.827
5	0.270	0.139	0.148	0.015	2.160	0.370
6	0.285	0.347			2.255	0.585
7	0.420	0.200			2.613	0.075
8	0.437	0.283			2.645	0.371
9	0.588	0.048			2.943	0.478
10	0.565	0.347			2.750	0.938
11	0.645	0.136			3.595	1.327
12	0.719	0.064			2.673	0.478
13	0.742	0.088			5.443	2.298
14	0.905	0.078			2.930	0.478
15	0.943	0.200			2.743	0.272
16	1.110	0.283			3.452	0.160
17	1.364	0.142			3.510	0.827
18					3.693	1.083
19					3.438	0.414
20					4.096	0.383
21					3.290	0.766
22					3.858	0.370
23					5.254	1.028
24					4.860	0.391

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 1

Occupational group	Sample No.	No. of fibres sized	Length (µm) geom. mean	Length (µm) min.	Length (µm) max.	Geom Std. dev.	Diameter (µm) geom. mean	Diameter (µm) min.	Diameter (µm) max.	Geom Std. dev.	Correlation coefficient*
Primary Production Plant	N 01	82	12.0	1.2	183	2.8	0.8	0.2	5.0	2.3	0.47
Primary Production Plant	N 03	84	8.4	1.7	52	2.3	0.8	0.2	8.0	2.2	0.59
Primary Production Plant	N 11	103	13.7	0.9	95	2.7	0.9	0.1	4.3	2.1	0.53
Secondary Production	N 04	83	9.4	1.6	273	3.0	0.7	0.1	6.4	2.5	0.59
Secondary Production	N 09	18	15.6	2.8	237	3.6	1.0	0.4	2.8	1.8	0.74
Secondary Production	N 06	65	10.0	0.9	132	2.9	1.0	0.2	3.8	2.4	0.59
Secondary Production	N 08	83	7.8	1.0	110	2.7	0.6	0.1	3.2	2.4	0.53
Maintenance	N 07	33	8.2	1.2	124	2.9	0.7	0.1	4.1	2.2	0.53

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 2

Occupational group	Sample No.	No. of fibres sized	Length (μm) geom. mean	Length (μm) min.	Length (μm) max.	Geom Std. dev.	Diameter (μm) geom. mean	Diameter (μm) min.	Diameter (μm) max.	Geom Std. dev.	Correlation coefficient*
Primary Production	N022	101	21.8	1.6	250	2.6	1.3	0.2	7.5	2.2	0.52
Plant	N026	100	19.8	2.7	284	3.0	1.0	0.2	8.0	2.1	0.43
Board Production	N023	102	16.3	2.0	140	2.4	1.1	0.3	10.5	2.1	0.52
Vacuum Forming	N025	100	20.6	2.8	290	3.0	1.1	0.2	6.7	2.0	0.51
	N028	100	11.6	1.6	97	2.5	0.9	0.1	2.9	2.3	0.36
Pyro Blocks	N021	100	17.0	1.7	190	2.9	1.1	0.2	7.5	21.2	0.56
Conversion	N024	102	11.2	2.2	85	2.2	1.0	0.2	3.6	1.9	0.56

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 3

Occupational group	Sample No.	No. of fibres sized	Length (μm) geom. mean	Length (μm) min.	Length (μm) max.	Geom Std. dev.	Diameter (μm) geom. mean	Diameter (μm) min.	Diameter (μm) max.	Geom Std. dev.	Correlation coefficient*
Primary Production Plant	NO35	74	9.7	2.5	167	2.3	0.9	0.1	5.1	2.1	0.62
	NO39	76	11.6	2.3	160	2.5	1.0	0.2	5.8	2.1	0.67
Conversion	NO41	100	6.3	1.6	62	1.8	0.9	0.2	5.8	1.0	0.42
Insulation brickworks	NO36	17	8.0	2.2	88	2.6	1.1	0.4	4.2	1.9	0.62
	NO37	13	3.9	1.6	88	1.6	0.5	0.2	0.9	1.6	0.22
	NO38	111	6.3	1.6	62	1.8	0.9	0.2	5.8	2.0	0.42
	NO42	61	5.7	1.7	172	2.4	0.6	0.2	4.3	0.2	0.63

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 4

Occupational group	Sample No.	No. of fibres sized	Length (µm) geom. mean	min.	max.	Geom Std. dev.	Diameter (µm) geom. mean	min.	max.	Geom Std. dev.	Correlation coefficient*
Board production	N044	135	19.1	2.8	310	2.7	0.8	0.1	5.2	2.3	0.84
	N045	119	22.4	2.3	300	2.7	1.2	0.3	5.5	2.0	0.70
	N047	95	13.6	2.2	130	2.5	1.0	0.2	4.3	2.1	0.71
Vacuum forming	N043	147	12.3	2.8	350	2.8	0.9	0.2	3.9	2.1	0.77
	N046	131	22.2	5.5	190	2.4	1.3	0.2	5.3	2.1	0.63

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 5

Occupational group	Sample No.	No. of fibres sized	Length (μm) geom. mean	Length (μm) min.	Length (μm) max.	Geom Std. dev.	Diameter (μm) geom. mean	Diameter (μm) min.	Diameter (μm) max.	Geom Std. dev.	Correlation coefficient*
Primary Production Plant	NO49	100	14.7	2.9	250	2.6	1.2	0.1	7.5	2.1	0.41
	NO51	100	11.8	1.8	106	2.4	0.8	0.1	8.4	1.9	0.29
Conversion	NO48	87	12.7	2.8	92	2.3	1.0	0.1	4.8	2.1	0.21
	NO53	101	14.0	1.8	130	2.4	1.2	0.2	6.4	2.1	0.37

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 6

Occupational group	Sample No.	No. of fibres sized	Length (μm) geom. mean	min.	max.	Geom Std. dev.	Diameter (μm) geom. mean	min.	max.	Geom Std. dev.	Correlation coefficient*
Fibre Production	N054	100	18.5	2.8	130	2.5	0.9	0.1	5.6	2.0	0.33
	N058	100	16.4	2.2	150	2.8	1.0	0.1	7.5	2.6	0.44
Vacuum Forming	N055	100	25.2	3.0	1200	3.4	1.3	0.1	6.4	2.0	0.54
Finishing	N056	100	16.8	3.2	460	2.3	1.0	0.2	5.8	2.1	0.34

* log L vs log D

APPENDIX

Geometric mean lengths and diameters for airborne dust samples

Plant 7

Occupational group	Sample No.	No. of fibres sized	Length (μm) geom. mean	Length (μm) min.	Length (μm) max.	Geom Std. dev.	Diameter (μm) geom. mean	Diameter (μm) min.	Diameter (μm) max.	Geom Std. dev.	Correlation coefficient*
Fibre Production	N061	100	16.5	2.7	340	2.7	1.1	0.1	4.9	2.0	0.45
	N062	100	11.9	2.2	169	2.4	0.8	0.1	4.5	2.1	0.39
Secondary Production - Conversion	N064	100	24.9	1.6	478	2.7	1.2	0.1	6.8	2.7	0.37
	N065	100	13.9	2.6	190	2.5	1.0	0.2	3.2	1.9	0.33
	N066	100	16.8	3.3	140	2.5	1.3	0.2	7.0	2.3	0.33

* log L vs log D

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