

Environmental surveys in the European man-made mineral fiber production industry

by John Cherrie, BSc, Jim Dodgson, BSc, FIOH, Shiela Groat, BSc, William Maclaren, MSc¹

CHERRIE J, DODGSON J, GROAT S, MACLAREN W. Environmental surveys in the European man-made mineral fiber production industry. *Scand J Work Environ Health* 12 (1986): suppl 1, 18–25. This paper presents estimates of airborne fiber concentrations and fiber size for European man-made mineral fiber (MMMF) factories on the basis of measurements made in 1977–1980. The airborne fiber concentrations previously reported at a conference of the World Health Organization (WHO) and the International Agency for Research on Cancer in 1982 have been revised to harmonize the results with the WHO-European MMMF reference counting level. The result was an approximate doubling of the reported airborne fiber levels. After the revisions the average combined occupational group concentrations in the rock- and glass-wool plants were still generally low (<0.1 fibers/ml). In the glass continuous-filament factories the airborne fiber concentrations were very low (<0.01 fibers/ml). The average plant median for fiber length ranged from 10 to 20 μm , and the corresponding median diameters ranged from 0.7 to 2 μm . In general the glass-wool fibers were thinner than the rock-wool fibers. The fiber concentrations measured in other studies in the MMMF production and user industries are reviewed. Higher levels (between 0.1 and 1.0 fibers/ml) have been measured in some insulation wool production, secondary production, and user industries. The highest levels (>1.0 fibers/ml) occurred in very fine glass-fiber production and in other specialist insulation wool usage.

Key terms: exposure levels, glass wool, mineral wool, rock wool.

Between 1977 and 1980 the European man-made mineral fiber (MMMF) production industry, via their Joint European Medical Research Board, supported environmental research in the industry. This research comprised a series of environmental surveys by the Institute of Occupational Medicine in Edinburgh in those factories selected for the epidemiologic study coordinated by the International Agency for Research on Cancer (IARC). The principal aim of these investigations was to assess the fiber number concentration and fiber size distribution to which workers were exposed. These data have been reported earlier (9).

In general the respirable levels of airborne fibers were low, the average concentrations in the insulation wool plants being less than 0.1 fibers/ml and less than 0.01 fibers/ml in the glass continuous-filament factories.

During the course of this research it became apparent that the phase contrast optical microscope methods used to monitor fiber levels did not always produce the same results when applied by different laboratories. A similar problem had already arisen in asbestos fiber assessment (1, 7) and therefore these findings were not wholly unexpected.

A consultation was arranged by the World Health Organization (WHO) during 1980 to consider these problems. Following this meeting a scheme was instigated to produce reference sampling and evaluation methods and to harmonize the performance of laboratories during the use of these methods. The work of the group of laboratories which participated in this scheme has produced substantial changes in their fiber counting levels, and, in particular, the level of the Edinburgh Institute has increased (13).

As a consequence the fiber concentrations previously reported would have been lower than currently assessed levels. Cherrie et al (2) have estimated that the respirable fiber concentrations from the original surveys, assessed on the WHO/EURO reference level (13), could have been up to three times higher than the original assessment.

The present paper provides revised estimates of the fiber number concentrations and summarizes the fiber size measurements from the factories included in the IARC epidemiologic study.

Outline of the original investigations

Thirteen factories were selected for inclusion in the IARC epidemiologic study, seven factories² producing rock wool, four producing glass wool, and two manufacturing glass continuous filaments.

¹ Institute of Occupational Medicine, Edinburgh, United Kingdom.

Reprint requests to: Mr J Cherrie, Institute of Occupational Medicine, 8 Roxburgh Place, Edinburgh EH8 9SU, United Kingdom.

² One rockwool factory closed prior to the survey period. This plant was replaced with an additional glass continuous-filament plant, not included in the epidemiologic study.

A detailed description of the sampling and analysis procedures is contained in the report of Ottery et al (9). At each factory the workforce was classified into occupational groups on the basis of job and workzone. A proportion of the workforce in each occupational group was selected at random, and personal airborne dust samples were obtained from these workers. The samples were collected with Casella pumps and a shielded Gelman filter holder 25 mm in diameter. The samples were collected on two types of filter, cellulose ester membranes for evaluating fiber number concentrations by phase contrast optical microscopy (PCOM) and Nuclepore polycarbonate membranes for assessing fiber size by scanning electron microscopy (SEM).

For interplant comparison the occupational group data were collated into seven combined occupational groups (preproduction, production, maintenance, general, secondary production 1, secondary production 2, and cleaning) according to uniformly defined criteria for each factory.

The sampling and analytical techniques which were used in this work were broadly in agreement with the methods and equipment selected for the WHO/EURO reference methods (14).

Airborne fiber concentrations and fiber size

For estimates of the airborne respirable fiber levels in relation to the WHO/EURO reference level, a randomly selected proportion of the original survey samples (about 10 %) from the rock-wool and glass-wool plants were reevaluated. Ten samples were selected at random from each of the 10 factories together with an additional 20 "high" and "low" density samples to insure adequate coverage of the complete range of fiber densities. This was a more representative selection of samples from the original surveys than reported previously (2). The microscopist selected for this task

has been shown to produce a counting level similar to the average of the five laboratories which participated in the scheme. All of these assessments were carried out in accordance with the WHO/EURO phase contrast optical microscope reference method (14). The results from this exercise are shown in figure 1.

As expected, the new fiber concentrations were higher than the original estimates. To investigate the relationship, a multiple linear regression model was fitted to the data. The results from this analysis showed that the increase in level differed significantly ($p < 0.05$) between fiber types. For rock-wool plants the average increase was 1.8 times, while for glass wool the levels were increased 2.2 times. This difference between fiber types is similar to the earlier findings (2) and may possibly be attributable to the poorer visibility of glass fibers than rock-wool fibers when observed with a phase contrast microscope.

The fitted relationship shown in figure 1 explains over 80 % of the variation between the original and recounted data. The derived factors have been applied to the original data, and the revised respirable fiber concentrations are summarized in tables 1 to 4 in terms of arithmetic and geometric mean values.

In the rock-wool plants the combined occupational group means ranged from 0.01 to 0.67 fibers/ml, the highest concentrations being observed in certain specialist secondary production groups. The mean respirable fiber concentrations in the main production and secondary production groups ranged from 0.05 to 0.12 fibers/ml.

The range of the group means of the respirable fiber concentrations measured in the four glass-wool factories was 0.01 to 1.00 fibers/ml, the highest concentrations being associated with the manufacture of special fine fiber earplugs. In the main production and secondary production groups the concentrations ranged from 0.01 to 0.16 fibers/ml.

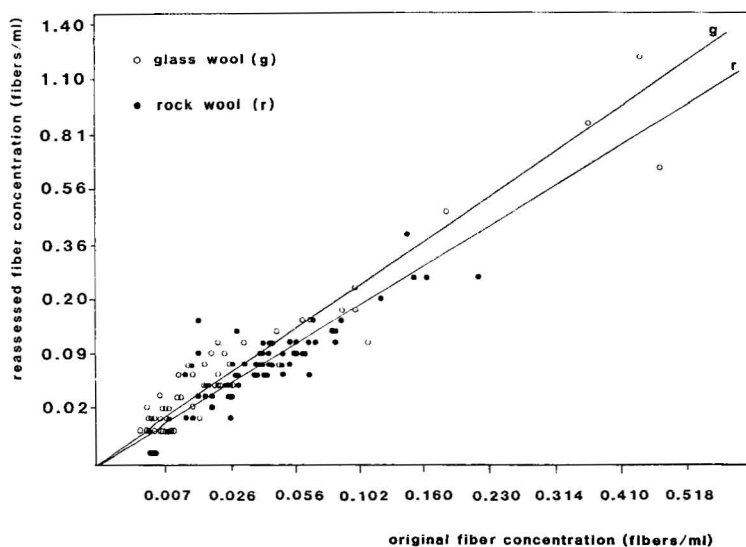


Figure 1. Comparison of the original and reassessed respirable fiber concentrations.

Table 1. Respirable fiber concentrations (fibers/ml) in combined occupational groups of six European rock-wool plants (arithmetic mean values, revised 1986).

Combined occupational groups	Plant 01				Plant 05				Plant 04				Plant 03			
	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD
Preproduction	8	0.08	0.01—0.22	0.08	2	0.01	0.01—0.01	.	7	0.03	0.01—0.07	0.02	3	0.06	0.03—0.11	0.04
Production	36	0.10	0.02—0.37	0.06	22	0.06	0.02—0.14	0.03	27	0.06	0.02—0.19	0.03	28	0.12	0.03—0.32	0.07
Maintenance	9	0.08	0.05—0.18	0.04	12	0.05	0.01—0.14	0.03	20	0.05	0.02—0.12	0.02	8	0.05	0.03—0.10	0.03
General	16	0.08	0.02—0.37	0.08	7	0.04	0.03—0.07	0.01	13	0.06	0.02—0.09	0.02	8	0.07	0.04—0.14	0.04
Secondary production 1	32	0.10	0.03—0.21	0.05	16	0.07	0.01—0.15	0.03	28	0.08	0.03—0.33	0.06	11	0.12	0.06—0.23	0.04
Secondary production 2	11	0.40	0.09—1.40	0.44	—	.	.	.	—	.	.	.	3	0.34	0.25—0.41	0.08
Cleaning	—	.	.	.	5	0.09	0.04—0.11	0.03	8	0.06	0.02—0.14	0.04	4	0.13	0.05—0.29	0.17

^a Number of measurements.

Table 2. Respirable fiber concentrations (fibers/ml) in combined occupational groups of six European rock-wool plants (geometric mean values, revised 1986).

Combined occupational groups	Plant 01		Plant 05		Plant 04		Plant 03		Plant 08		Plant 09	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Preproduction	0.05	2.87	0.01	1.22	0.03	1.66	0.05	2.07	0.04	1.00	0.01	1.44
Production	0.09	1.72	0.05	1.66	0.05	1.76	0.11	1.66	0.04	1.84	0.04	2.03
Maintenance	0.08	1.56	0.04	1.93	0.05	1.52	0.05	1.48	0.03	1.70	0.03	1.95
General	0.05	2.32	0.04	1.31	0.05	1.57	0.07	1.58	0.04	1.03	0.05	2.03
Secondary production 1	0.09	1.67	0.06	1.80	0.07	1.59	0.11	1.45	0.07	1.99	0.0	1.68
Secondary production 2	0.26	2.60	.	.	.	.	0.34	1.30	0.24	1.42	0.51	2.52
Cleaning	.	.	0.08	1.5	0.05	1.97	0.11	2.09	0.07	2.24	0.11	2.07

Table 3. Respirable fiber concentrations (fibers/ml) in combined occupational groups of four European glass-wool plants (arithmetic mean values, revised 1986).

Combined occupational groups	Plant 07				Plant 02				Plant 06				Plant 10			
	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD	N ^a	Mean	Range	SD
Preproduction	5	0.01	0.02—0.01	0.05	8	0.01	<0.01—0.01	<0.01	5	0.01	0.01—0.01	<0.01	5	0.01	<0.01—0.03	0.01
Production	39	0.05	0.01—0.62	0.10	26	0.01	<0.01—0.027	0.01	27	0.03	0.01—0.11	0.02	61	0.05	<0.01—0.22	0.05
Maintenance	20	0.07	0.01—0.60	0.13	4	0.03	0.01—0.06	0.02	12	0.04	<0.01—0.17	0.05	27	0.02	<0.01—0.06	0.01
General	15	0.03	0.01—0.06	0.02	10	0.02	0.01—0.043	0.01	10	0.023	0.01—0.04	0.01	12	0.03	<0.01—0.06	0.03
Secondary production 1	37	0.04	0.01—0.11	0.02	32	0.05	0.01—0.21	0.05	26	0.03	<0.01—0.07	0.02	36	0.02	<0.01—0.06	0.01
Secondary production 2	23	1.00	0.17—4.02	0.87	—	.	.	.	2	0.07	0.05—0.09	0.03	45	0.16	0.02—1.39	0.22
Cleaning	—	.	.	.	—	.	.	.	4	0.01	0.01—0.02	0.01	—	.	.	.

^a Number of measurements.

The fiber size distributions from the SEM assessments are summarized in the appendix in the form of length and diameter matrices. Figure 2 shows the median length and diameters from 185 samples collected in the rock- and glass-wool factories. The median lengths ranged from 5 to 44 μm , and the median diameters

from 0.3 to 3.3 μm in the rock-wool and 0.3 to 2.5 μm in the glass-wool plants.

The observed correlation between median fiber length and diameter (correlation coefficient 0.63) was similar to that previously reported for a subset of these data (3).

values, revised 1986).

Plant 08				Plant 09			
N ^a	Mean	Range	SD	N ^a	Mean	Range	SD
1	0.04	0.04—0.04	.	4	0.01	<0.01—0.01	<0.01
19	0.05	0.01—0.13	0.03	51	0.05	0.01—0.16	0.03
9	0.03	0.01—0.07	0.02	10	0.04	0.01—0.11	0.03
2	0.04	0.04—0.04	<0.01	23	0.06	0.01—0.36	0.08
24	0.08	0.01—0.20	0.05	55	0.06	0.02—0.39	0.06
3	0.25	0.19—0.36	0.09	22	0.67	0.06—1.37	0.38
8	0.09	0.01—0.18	0.06	12	0.14	0.02—0.44	0.11

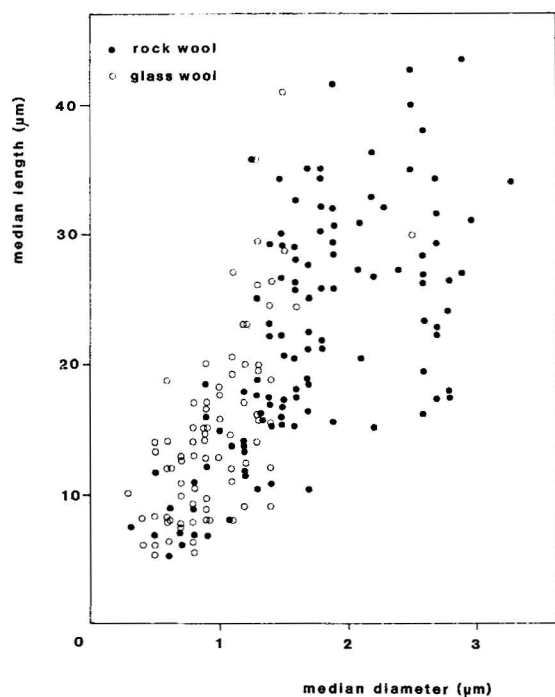


Figure 2. Relationship between the median fiber length and diameter.

There is a clear distinction in size between the two types of factory, samples from rock-wool factories tending to contain longer and thicker fibers. This difference is clearly reflected in the median diameters obtained when all of the samples within a factory are pooled.

The plant median fiber lengths were within the range 10–20 μm for the rock-wool plants and 8–15 μm for the glass-wool plants. The corresponding medians for the diameter distributions ranged from 1.2 to 2 μm and from 0.7 to 1 μm for the rock-wool and glass-wool factories, respectively.

Table 5 shows the percentage of all of the fibers measured which were greater than 8 μm in length and less than 1.5 μm in diameter. This size category corresponds to that suggested by Stanton et al (12) to be biologically significant. These fibers have been termed Stanton-type fibers or S fibers.

In general there was a higher proportion of S fibers in the glass-wool plants than in the rock-wool plants. No clear pattern existed for the fiber types or the occupational groups.

In the bulk of the SEM assessments no estimate of fiber number concentration was obtained. To obtain a comparison of fiber concentration assessed by PCOM and SEM, paired samples from the MMMF factories were evaluated with the two techniques. Figure 3 shows the average relationship between the PCOM and SEM counts of all fibers longer than 5 μm and the SEM S-fiber concentration. For purposes of comparison data from nine pairs of chrysotile textile samples are also shown. The concentration of SEM fibers longer than 5 μm is about eight times the PCOM concentration for these chrysotile asbestos samples, while for MMMF the corresponding increase is only 1.3 times.

The measurements reflect the ability of asbestos fibers to split longitudinally into long thin fibers. The S-fiber concentrations determined by SEM were on the average of four times higher than the PCOM fiber concentration for the asbestos and 40 % lower than the

Table 4. Respirable fiber concentrations (fibers/ml) in combined occupational groups at four European glass-wool plants (geometric mean values, revised 1986).

Combined occupational groups	Plant 07		Plant 02		Plant 06		Plant 10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Preproduction	0.01	2.03	0.01	1.95	0.01	1.25	0.01	1.98
Production	0.04	1.99	0.01	1.53	0.03	1.81	0.03	2.95
Maintenance	0.03	3.00	0.02	1.97	0.01	3.73	0.01	1.90
General	0.03	1.80	0.02	1.47	0.02	1.51	0.02	2.43
Secondary production 1	0.03	1.76	0.04	2.29	0.02	1.96	0.01	2.54
Secondary production 2	0.77	2.15	.	.	0.07	1.69	0.11	2.47
Cleaning	.	.	.	.	0.01	1.79	.	.

Table 5. Percentage of all fibers with length $>8\ \mu\text{m}$ and diameter $<1.5\ \mu\text{m}$.

Plant	Combined occupational group						
	Preproduction	Production	Maintenance	General	Secondary production 1	Secondary production 2	Cleaning
01	16	31	40	22	31	32	0
05	29	32	25	16	26	0	0
04	24	26	24	17	27	33	0
03	54	34	20	20	20	37	0
08	42	22	23	24	28	0	23
09	40	30	32	21	30	38	39
10	39	44	34	48	49	33	0
07	24	42	27	24	28	32	0
02	21	27 ^a	23	31	51	0	0
06	31	40	26	37	44	42	30

^a Production of fibers with nominal diameter about $12\ \mu\text{m}$.

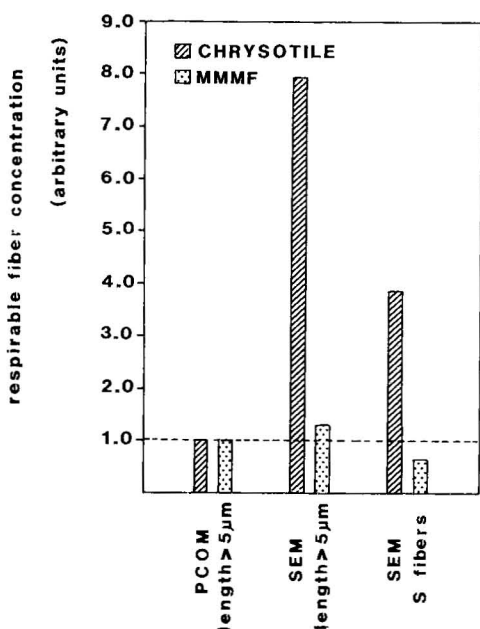


Figure 3. Relationship between the different measures of fiber concentrations. (MMMF = man-made mineral fiber, PCOM = phase contrast optical microscopy, SEM = scanning electron microscopy, S fiber = Stanton-type fiber)

Table 6. Comparison of airborne fiber concentrations in the man-made mineral fiber production industries of Europe and the United States.

Country	Range of occupational group mean (fibers/ml)	
	Production	Secondary production
United States ^a		
Glass wool	0.01—0.07	0.01—0.05
Mineral wool	0.03—0.24	0.03—0.43
Europe		
Glass wool	0.01—0.06	0.02—0.05
Rock wool	0.05—0.12	0.06—0.11

^a From Esmen et al (6).

PCOM concentration in the case of the MMMF. For equivalent PCOM concentrations therefore we estimate that there would have been approximately six times more S fibers in the chrysotile asbestos samples than in the MMMF samples.

Discussion

In the past five years there has been considerable effort within Europe to standardize the sampling and evaluation of MMMF and to harmonize the performance of various national laboratories using these methods (13). To achieve this better interlaboratory agreement, the counting level of several laboratories changed; in particular that of the Institute of Occupational Medicine in Edinburgh has doubled. The original measurements made in the European MMMF production industry (9) therefore underestimate the fiber concentrations in relation to the WHO/EURO reference level. This paper has presented revised estimates of airborne fiber concentrations based on a recounting of a proportion of the original samples. These data confirm the systematic increase in counting performance: 1.8 times in the rock-wool plants and 2.2 times in the glass-wool plants. Despite these changes the airborne fiber concentrations in the factories remained low; in the principal production and secondary production groups the average fiber concentrations were generally less than 0.1 fibers/ml.

These revised estimates of fiber concentration are consistent with measurements made in other European factories (10), and they compare favorably with data from manufacturing plants in the United States (5). Table 6 shows the range of average fiber concentrations from production and secondary production groups in the American study in comparison with our revised data. The results from the glass-wool plants are directly comparable, while the range of average concentrations in the American mineral-wool³ plants

³ Mineral wool refers to factories producing either rock or slag wool or mixtures of these materials.

Table 7. Summary of airborne fiber concentration and fiber size measurements.

Fiber concentration	Location/use	Nominal fiber size (μm)	Percentage S fibers in airborne dust
Very low (<0.01 fibers/ml)			
Glass continuous filament	Production and use	9—25	5—25
Coarse glass fiber	Production and use	>10	<5
Low (0.01 — 0.1 fibers/ml)			
Glass wool	Production and most secondary production	5—7	20—50
Rock wool	Production and most secondary production	3—6	20—30
Mineral wool	Production and most secondary production	6—8	
Medium (0.1 — 1.0 fibers/ml)			
Fine glass fiber	Production	about 3	30—40
Rock wool	Some secondary production and user industry	3—6	30—40
Mineral wool (United States)	Some production and user industry	6—8	about 30
Glass wool	User industry	3—7	
High (>1.0 fibers/ml)			
Very fine glass fiber	Production and use	<2	about 60
Glass wool/rock wool — loose	User industry — blowing into attic	3—6	..
Glass wool/rock wool — without dust suppressants	Production and use	3—6	..

is slightly larger. This difference is primarily due to one factory where high fiber levels were associated with some operations involving an unusually large number of cutting, sawing, and sanding products.

Esmen (4) has reported the proportion of S fibers from the 16 factories included in the aforementioned studies. In mineral-wool plants approximately 30 % of all fibers fell into this category, while in glass-wool plants only 20 % of all fibers were the S-fiber type. These data are similar to the European data, although a slightly higher proportion of S fibers was found in European glass-wool plants.

The available data concerning airborne fiber concentrations and the percentage of S fibers in a range of production, secondary production, and end-user industries are summarized in table 7. The following four broad categories of fiber concentration have been identified: (i) very low (<0.01 fibers/ml), (ii) low (0.01 — 0.1 fibers/ml), (iii) medium (0.2 — 1.0 fibers/ml), and (iv) high (>1.0 fibers/ml).

There is a general pattern of increasing concentrations and percentages of S fibers as the nominal diameter⁴ of a product increases, as found by Esmen et al (5). In the user industry, as the ventilation conditions (ie, room volume and air changes per hour) become poorer and the method of handling becomes more aggressive (ie, cutting, sawing, blowing, etc), the airborne fiber concentration also increases.

⁴ Nominal diameter is a length-weighted average diameter assessment of the bulk product.

Where insulation wools are produced or used without the addition of oil as a dust suppressant, high fiber concentrations may be expected (8).

Table 7 shows the *concentration* which might be expected during the production or use of various products. In some situations, particularly in the user industry, the duration of exposure may be short, and hence the overall exposure may be considerably lower than the measured fiber concentrations. Schneider (11) indicates that in a survey only 12 % of various groups of construction workers spent more than 3 d per month working with MMMF. In addition it is likely that many workers involved in these dusty jobs would use respiratory protection.

Conclusions

1. The previously reported airborne levels of respirable fiber from the European MMMF production industry were made prior to agreement on a European reference counting level. When these samples were re-evaluated, the revised fiber concentrations were approximately twice the original level.

2. After these changes were applied, the airborne fiber concentrations within the insulation wool factories were still generally low (ie, average concentrations less than 0.1 fibers/ml). Concentrations in the glass continuous-filament plants were very low (ie, less than 0.01 fibers/ml).

3. On the average between 20 and 50 % of all airborne fibers in the insulation wool plants were within the S-fiber size category. The S-fiber category comprises fibers greater than 8 μm in length and less than 1.5 μm in diameter, and it has previously been indicated by Stanton and his co-workers to be a biologically significant fiber-size fraction.

4. Higher airborne fiber levels (between 0.1 and 1.0 fibers/ml) have been measured in some insulation wool production, in secondary production, and in the user industries. The highest levels (greater than 1.0 fibers/ml) have been found in very fine glass-fiber production and in other specialist insulation wool usage.

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Appendix

Percentage of fibers in given size categories^a

Diameter (μm)	Length (μm)					
	≤ 1	1.1–5	5.1–10	10.1–20	20.1–100	> 100
<i>Plant 01</i>						
≤ 0.2	0.1	5.1	2.5	1.1	0.3	0
0.21–0.6	0	7.4	6.2	3.5	1.8	< 0.1
0.61–1.0	0	4.2	7.3	5.6	3.1	< 0.1
1.1–3	0	1.2	9.7	14.9	15.7	1.3
3.1–5	0	0	0.1	2.0	5.2	0.3
> 5	0	0	0	0.1	1.0	0.2

(continued)

Diameter (μm)	Length (μm)					
	≤ 1	1.1–5	5.1–10	10.1–20	20.1–100	> 100
<i>Plant 02</i>						
≤ 0.2	0	5.3	3.0	1.5	0.2	0
0.21–0.6	0	11.1	6.2	4.7	3.0	0.2
0.61–1.0	0	3.9	7.7	5.5	5.5	0.4
1.1–3	0	1.5	7.7	8.8	14.3	1.9
3.1–5	0	0	0	2.1	2.6	0.8
> 5	0	0	0	0	1.5	0.8

(continued)

Diameter (μm)	Length (μm)					
	≤ 1	1.1—5	5.1—10	10.1—20	20.1—100	> 100

<i>Plant 03</i>						
≤ 0.2	0	0.4	0.4	0.2	0.2	0
0.21—0.6	0	3.8	3.3	2.9	2.5	0
0.61—1.0	0	2.7	3.6	3.4	3.9	0.7
1.1—3	0	0.9	10.8	20.6	21.8	2.6
3.1—5	0	0	0	3.4	8.0	1.2
> 5	0	0	0	0	1.9	0.6

<i>Plant 04</i>						
≤ 0.2	0	4.2	1.3	0.3	0.1	0
0.21—0.6	0	7.5	4.8	2.8	1.9	0
0.61—1.0	0	2.3	4.6	4.4	4.0	0.4
1.1—3	0	0.8	7.0	12.2	21.7	4.8
3.1—5	0	0	0	1.8	9.0	2.3
> 5	0	0	0	0.1	1.5	0.3

<i>Plant 05</i>						
≤ 0.2	0.1	3.6	1.3	0.4	0.2	0
0.21—0.6	0	6.1	4.1	2.7	2.9	0.3
0.61—1.0	0	2.8	2.8	3.8	4.5	0.6
1.1—3	0	0.9	8.2	13.4	20.2	4.5
3.1—5	0	0	0	2.4	6.9	3.0
> 5	0	0	0	0.2	2.8	1.1

<i>Plant 06</i>						
≤ 0.2	0.1	2.2	1.3	0.7	0.4	0
0.21—0.6	0	10.5	8.6	5.6	4.6	0
0.61—1.0	0	3.9	6.7	5.8	6.8	0.8
1.1—3	0	0.7	8.2	7.7	13.6	4.3
3.1—5	0	0	0	0.9	2.9	1.3
> 5	0	0	0	0	1.8	0.7

<i>Plant 07</i>						
≤ 0.2	0.2	8.6	5.0	1.8	0.1	0
0.21—0.6	0	12.3	10.0	7.3	3.5	0
0.61—1.0	0	5.6	7.3	4.7	2.6	0.1
1.1—3	0	1.0	8.4	10.2	6.8	0.5
3.1—5	0	0	0	1.0	2.4	0.1
> 5	0	0	0	0	0.5	0

<i>Plant 08</i>						
≤ 0.2	0	1.0	0.3	0.1	0.2	0
0.21—0.6	0	3.3	2.6	1.9	1.9	0
0.61—1.0	0	2.5	4.1	3.3	3.6	0.4
1.1—3	0	0.8	10.0	17.5	25.3	4.2
3.1—5	0	0	0.1	3.8	9.8	1.3
> 5	0	0	0	0	1.5	0.5

<i>Plant 09</i>						
≤ 0.2	0	1.8	0.5	0.4	0.2	0
0.21—0.6	0	5.3	3.5	3.2	3.0	0.2
0.61—1.0	0	2.2	4.6	3.9	5.6	0.7
1.1—3	0	0.4	6.0	11.9	22.3	6.1
3.1—5	0	0	< 0.1	3.4	9.8	2.5
> 5	0	0	0	< 0.1	1.7	0.7

<i>Plant 10</i>						
≤ 0.2	0	2.7	4.7	2.7	0.6	0
0.21—0.6	0	7.4	8.9	6.9	5.1	0.1
0.61—1.0	0	3.4	6.6	6.4	5.8	0.5
1.1—3	0	0.7	5.9	10.1	13.2	1.6
3.1—5	0	0	0	0.7	3.0	1.1
> 5	0	0	0	0.1	1.3	0.8

<i>Plant 11</i>						
≤ 0.2	0	0	0	0	0	0
0.21—0.6	0	17.6	5.4	1.4	0.7	0
0.61—1.0	0	6.8	4.7	4.1	2.7	0
1.1—3	0	1.4	13.5	12.8	4.7	2.0
3.1—5	0	0	0	3.4	10.1	4.1
> 5	0	0	0	0	3.4	1.4

<i>Plant 13</i>						
≤ 0.2	1.0	7.6	5.7	1.0	1.0	0
0.21—0.6	0	20.0	9.5	5.7	2.9	0
0.61—1.0	0	8.6	10.5	2.9	3.8	1.0
1.1—3	0	1.0	5.7	5.7	2.0	0
3.1—5	0	0	0	1.0	2.0	0
> 5	0	0	0	0	1.0	1.0

<i>Plant 14</i>						
≤ 0.2	0	12.6	1.6	0.2	0	0
0.21—0.6	0	48.0	13.2	1.6	0.2	0
0.61—1.0	0	8.9	5.8	0.9	0	0
1.1—3	0	0.4	2.1	1.4	0.7	0.2
3.1—5	0	0	0.1	0.5	0.4	0.2
> 5	0	0	0	0	0.7	0.3

^a Number of fiber measurements: plant 01: 2 373; plant 02: 532; plant 03: 967; plant 04: 1 200; plant 05: 985; plant 06: 1 064; plant 07: 1 456; plant 08: 1 436; plant 09: 2 466; plant 10: 3 013; plant 11: 148; plant 13: 105; plant 14: 1 353.