German Social Accident Insurance
Deutsche Gesetzliche Unfallversicherung
Analytical Subcommittee of the Chemistry Board of Experts

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Method for the determination of alveolar fibres – Phase-contrast optical microscopy method –

Method tested and recommended by the German Social Accident Insurance for the determination of airborne respirable fibres having a length of L >5 µm, a width of D <3 µm and a length-to-width-ratio of L/D >3 : 1 [1] in work areas after discontinuous sampling.

Both personal and stationary sampling can be conducted for the assessment of work areas.

Sampling is carried out by separation of particles in air drawn by means of a pump and collected onto a membrane filter.

Analysis is performed by phase-contrast optical microscopy (PCM) after filter preparation.

The method described here is in accordance with the method recommended by the World Health Organisation (WHO) in 1997 [1] – through changed EU guidelines regarding the safety of workers against hazards of asbestos in work areas [2] mentioned as European reference method. The method can be applied if the total number of respirable fibres is of interest.

As this method delivers fibre-specific (morphology) but not fibre type specific (material) information, the use of the scanning electron microscopic method BGI 505-46 [3] is helpful in those cases where determination of concentrations of fibre numbers for different types of fibres is necessary.

Infrared spectroscopic method (BGI 505-30 [4]) permits a directly quantitative determination of asbestos weight fractions in respirable dust or after respective preparation in material samples and can deliver useful information in addition to the methods BGI 505-31 and BGI 505-46.

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Summary

This method permits the determination of concentrations of fibrous particles having a length of L >5 µm, a width of D <3 µm and a length-to-width-ratio (aspect ratio) of L/D >3 : 1 [1] in work areas averaged over the sampling time after personal or stationary sampling.

Principle: A pump is used to draw a measured volume of air through a membrane filter. Collected fibres are counted by means of phase-contrast optical microscopy after filter preparation.

Technical data:

Limit of detection: Limit of detection depends on the sample. Under favourable conditions (low dust concentration, no coarse dust particles) the limit of detection is for a sample volume of approx. 34 litres per cm^2 filter area 30 000 fibres/m^3, and of approx. 68 litres per cm^2 15 000 fibres/m^3.

Selectivity: The analysis is fibre specific (morphology) but does not deliver any fibre type specific (material) results.

Advantages: Relatively little instrumentation and less time-consuming.

Disadvantages: Not fibre type specific. Very thin fibres (fibre width below 0.2 to 0.25 µm) are not visible.

Apparatus: Sampling apparatus,
Preparation equipment,
Phase-contrast optical microscope with Walton Beckett eyepiece graticule,
Test slide HSE/NPL, Mark II.

Detailed description of the method

Contents

1 Equipment, consumables and accessories

For the procedure of a measurement according to the method here described the equipment, consumables, and accessories as given in 1.1 to 1.5 are required. It must be safeguarded that they are clean and free of fibres before being used. Monitoring occurs in random tests by means of laboratory blank samples. For this the entire analytical procedure is applied to an unloaded sample collection filter.

1.1 Apparatus for sampling

Sampling head:
It mainly consists of a cylindrical cowl, filter holder with sample collection filter with or without backing filter (no fibrous material such as glass fibre filter or cardboard) and an intake tube. Practical experience shows that the use of a backing filter usually is not necessary. Cowl and filter holder must be manufactured from non-corrosive mate-

rial. Airtight fit of the inserted sample collection filter must be guaranteed. The length of the cowl before the filter must be 1.5 to 3.0 times the exposed (effective) filter diameter deff (diameter of the circular filter area being exposed) [1]. Figure 1 shows the schematic diagram of a suitable sampling head with a cassette serving as filter holder for the sample collection filter located on a backing filter. After sampling the cassette is sealed with covers and used as a transport vessel (filter case). Figure 2 shows an example of the sampling apparatus used (sampling system FAP-BIA).

Sampling pump:
For sampling a pump is used which is able to draw volumes of air at least between 0.24 L/min and 0.3 L/min per cm^2 through the filter. Higher flow rates may be used for work areas with low dust concentrations.
The volumetric flow must be free of pulsation so that a reliable flow rate measurement is possible. In case of a battery-driven pump is used, capacity of the battery must be sufficient for a continuous use throughout the entire sampling time chosen.

Flow meter:
Suitable measuring apparatus, permitting the measurement of the flow rate with a precision of better than 5%. Monitoring is carried out using a calibrated volumetric flow meter (e.g. soap bubble flow meter, variable area flow meter).

Chronometer: stop watch

1.2 Apparatus for filter preparation

Acetone evaporation device for smallest amounts, e.g. JS Holdings, Unit 6, Leyden Road, Stevenage, Hertfordshire, SG1 2BW, UK.
If need be, hot plate or cabinet desciccator.

1.3 Apparatus for analysis

Optical microscope (transmitted light) with phase-contrast condenser with a centering focusing and achromatic phase-contrast objectives, e.g. from Carl Zeiss Jena GmbH, 07745 Jena. Nominal magnification: 10× (or 12.5×) for the eyepiece and 40× for the objective. The objective should have a numerical aperture between 0.65 and 0.75 and the phase ring absorption should not be less than 65% and not more than 85%. The microscope must be equipped with a built-in luminous source with radiant field stop so that the Köhler illumination can be adjusted. One of the eyepieces should be equipped for diopter adjustment. A focusing type eyepiece with a Walton Beckett graticule for a counting field diameter of (100 ± 2) µm for objective 40×. The specification for ordering the Walton Beckett graticule (reference number G-22)[1] must dependent on the actual applied microscope under exact the conditions (objective, eyepiece, intermediate magnification, eye distance (for older microscopes)), under which analysis is carried out.

1 Available from: Graticules Ltd., Sovereign way, Botany Trading Estate, Tonbridge, Kent, TN9 1RN, UK.

Information regarding the order: The required diameter of the circular counting field is determined as follows: A micrometer is inserted into the eyepiece micrometer and it is determined which distance on this scale corresponds to 100 µm of the object micrometer. This distance in mm (it can e.g. be measured under the microscope using a mechanical stage equipped with a nonius) is equivalent to the counting field diameter which is to be specified in the order. (Example: 4.50 mm correspond to 108 µm; then 100 µm correspond to 4.50/1.08 = 4.17 mm). When ordering it is necessary to give the total diameter of the eyepiece graticule (e.g. 17 mm).

Mechanical stage with object guide (x-y-shift). Centering telescope or Bertrand lens to help adjust phase-contrast rings in condenser and objective.

1.4 Consumables

Sample collection filter: White membrane filter made of cellulose ester with or without grid print, pore diameter 0.8 µm to max. 1.2 µm, e.g. alto tec GmbH, D-22763 Hamburg. The filter must be suitable for the mode of operation, i.e. it must become transparent by treating with acetone vapour and be particle-free (blank mean value not more than 2 fibres in 100 counting fields).
Possibly backing filter (fibre-free, e.g. membrane filter with an average pore diameter of >5 µm)
Acetone, glycerol triacetate (triacetin)

1.5 Accessories

Object micrometer (subdivided in 2 µm or 10 µm).
Test slide HSE/NPL Mark II, e.g. PTR Optics, Unit C6, Cross Green Garth, Leeds LS9 0SF, UK
Pipette, tweezers, scalpel, microscope slides, cover slips

2 Sampling

2.1 Preparation of sample collection filters

Prior to further usage membrane filters from a new batch are checked for impurities resulting from fibrous particles. From a new batch at least two filters are taken, prepared as described in Section 3 and analysed according to the conditions described in Section 4. In this process, a maximum of two fibrous particles should be found for every analysed filter. If on one of the filters three fibrous particles are detected, the process is to be repeated for another unloaded filter. If four fibrous particles are found on the filter or three after repetition, the batch must not be used.

In addition to determination of filter blank values it should be safeguarded that the apparatus and consumables used are clean and cause no contamination with fibrous particles. If they have high ground contamination they must not be used for sampling.
The sample collection filter prepared for sampling is placed into the filter holder such that it is not damaged when inserted and an air tight fit is guaranteed. If a backing filter is used, the sample collection filter must lie plan. Contact with filter surfaces with naked fingers is to be avoided. The filter cassettes are already equipped with sample collection filters and sealed in the laboratory.

2.2 Procedure of sampling

Touching the filters with naked fingers during manipulation is to be avoided. The sampling head with inserted sample collection filter (e. g. 25 mm diameter) is opened right before starting sampling. When using filter cassettes (e. g. 37 mm diameter) these are opened right before starting sampling and placed into the sampling head; contact with filter surface is to be avoided. Sampling takes place with open filter holder and a downwards oriented cowl. An example of a sampling head with filter cassette is shown in Figure 2 (Section 1.1).
Before starting sampling the flow rate is to be adjusted such that for each cm^2 exposed (effective) filter area an air volume of 0.24 to 0.3 L/min (respectively 4 cm/s to 5 cm/s filter flow velocity) is delivered. For instance, if a filter holder with an exposed diameter of 30 mm is used, a flow rate of 1.7 L/min to 2.1 L/min is required. The specific flow rate shall not fall short of 0.24 $L/(cm^2 \cdot min)$. For individual cases (e. g. for high dust concentrations) the flow velocity may be decreased to 2 cm/s. Only if no coarse airborne dust particles can be expected in the work area, it can be recommended to increase the specific flow rate. At this, it is to be safeguarded that the filter is not deformed or damaged due to the increased resistance of flow. Measurement of the flow rate is carried out for the complete sampling system (sampling head equipped with sample collection filter and, if need be, backing filter, hose with intake tube and pump) by means of a suitable and calibrated flow meter (e. g. variable area flow meter).
For the flow rate given, the duration of sampling is dependent on the dust concentration. High dust loading must be avoided in any case. The grid pattern printed onto the filter (if existing) or the white filter surface must still be markedly visible at the end of sampling. Too high dust loadings can not be quantitatively analysed. As a rule, a sampling time from 2 to 3 hours for a filter flow velocity of 5 cm/s delivers evaluable filter loadings. In case of reduced dust concentrations without coarse dust particles a sampling time of 8 hours or even longer or a higher flow velocity is possible as well. In case of doubt, a set of filters with graded sampling time (e. g. 1 hour, 2 hours, 4 hours, etc.) may be loaded, so that at least one evaluable sample may be expected among them. In exceptional cases it may be inevitable to select a sampling time of less than 1 hour, e. g. for high dust concentrations or a large amount of coarse dust particles. The multiple application of the same sample collection filter for short-term exposures during various short-term phases has proved reliable in order to achieve sufficient limits of detection (see Section 5.2). With this a mean value for the short-term exposure is ob-

tained. Even if only one single short-term exposure appears, a sampling time of at least one hour is recommended.
Immediately after completion of sampling, the sampling apparatus is switched off, the sampling time is recorded and the filter cassette is removed together with the loaded sample collection filter and sealed dust-tight. Place, time and duration of sampling are to be chosen such that the exposure is covered representatively.

3 Sample preparation

If it is necessary to cut the membrane filter into halves, it should be carried out in a rolling manner by means of a sharpe scalpel with a crooked blade (scissors should not be used). Subsequently, using tweezers the filter which is taken up at the unloaded filter edge is placed onto a clean glass microscope slide with its dust side up such that the grid lines (if existing) are in parallel with the edges of the microscope slide. According to the manual describing the acetone evaporation device the filter is placed under the acetone vapour outlet tube. The acetone vapour must react uniformly on the membrane filter. This is achieved by slowly moving the filter back and forth under the outlet tube. In this it is to be safeguarded that the amount of vapour is kept at the lowest level possible[2]. After a few seconds the filter becomes transparent. In order to obtain an optimal contrast one drop of glycerol triacetate (triacetin) is then placed on the filter by means of a pipette. Directly afterwards a clean cover slip is placed on top at a slant angle to the edge. The cover slip must not be pressed onto the filter. After a couple of hours the prepared filter is transparent and may be analysed under the phase-contrast microscope. The disintegration of the filter structure can be reduced to approximately 15 minutes, if the filter is heated to approx. 50 °C (hot plate or cabinet desiccator). In case the filter is to be stored or shipped it is recommended to seal the edges of the cover glass by e. g. nail varnish. Membrane filters exposed to high humidity should be carefully dried before being treated with acetone vapour.

4 Analysis

4.1 General directions

The microscope is adjusted according to the manufacturer's instructions. The Köhler illumination is adjusted and the diaphragm ring of the phase-contrast condenser centered on the phase ring of the objective 40×. The diameter of the Walton Beckett graticule must be calibrated for (100 ± 2) µm referring to the object and is monitored by

2 The procedure of treating with acetone vapour should be practised with blank filters.

means of an object micrometer. When using older binocular microscopes it is to be considered that the magnification can change with the eye distance.
Then the test slide HSE/NPL Mark II is placed under the microscope and evaluated according to the directions of the manual. Based on the set of the thickest ridges at least the ridges in set 5 must still be visible (the slide consists of 7 sets of ridges of resin). Usually slight re-focussing is necessary. Counting the individual ridges is not necessary. This test determines whether the microscope and the counting person are qualified for the analysis.
The transparent filter is placed under the microscope, and the focus onto the dust-loaded filter surface as well as the Köhler illumination is readjusted. This is necessary since filter preparation and test slide do not have the same thickness.
It is recommended to scan the filter first at reduced magnification (100× to 150×). In case individual fields are found to show markedly different loadings (accumulation of particles, "holes" in loading, island effects), the filter is not suitable for quantitative analysis.
Actual fibre counting is carried out for a total magnification of 400× to 500× (objective 40×, eyepiece 10× to 12.5×).The grid printed onto the filter (if existing) facilitates finding the filter surface (coarse-focussing). For fibre counting the button for fine-focussing is to be moved back and forth in order to be able also to detect those fibres which are collected in the inner of the filter. If too much solvent was used for filter preparation, which can be recognized by distortion of the printed grid or the filter edge, an adequately secure and reliable analysis of the amount of fibres on the sample collection filter and thus of the numerical fibre concentration is not guaranteed.
The image fields to be analysed are randomly selected in a way that the complete area of the filter section is taken into account uniformly without preference of the margins or the centre of the filter area. Distribution in zigzag fashion over the entire exposed filter area has also proved reliable. Only those image fields should be taken into account which are at least 4 mm away from the filter margins. If a grid line crosses or more than 1/8 of the counting field is covered by fibre or particle agglomerates or air bubbles (due to improper preparation), this field is not taken into account.

4.2 Fibre counting rules

Basis for fibre counting is the criteria according to the WHO [1].

- According to these rules each object is considered to be a fibre, showing a length of $L > 5$ µm, a width of $D < 3$ µm and an aspect ratio of $L/D > 3:1$. The length applies to the rectified length, the width to the average width (see Figure 3).
- Convexities that can ensue from e.g. resins or binders in synthetic mineral fibres (SMF) are ignored. In case of doubt $D < 3$ µm is assumed [1].
- Fibres adjoining non-fibrous particles or seem to adjoin them, are treated as if the non-fibrous particles were not present. However, only the visible length of fibres is taken into account, unless the fibres penetrate the particles and do not appear to be interrupted.

- Fibres whose both ends are lying within the counting field are counted as 1 fibre. Fibres having one end within the counting field are counted as ½ fibre. Fibres whose both ends are lying outside of the field are not counted.
- Fibre agglomerates that appear to be compact and not separated in one or more sections but, however, seem to be separated in individual fibres in other sections are considered to be split fibres. All other agglomerates with fibres touching or crossing, are considered to be bundles.
- Split fibres are counted as 1 fibre, as long as the above mentioned criteria are fulfilled. Their width is measured in the section not split. Overlapping (crossing) fibres (fibre bundles) are counted individually, if possible.
- In case too many fibres are overlapping so that they cannot be counted individually (fibre bundle), the fibre bundle is only counted as one fibre as long as its total dimensions meet the above mentioned criteria for length, width and aspect ratio. Otherwise the fibre bundle is not taken into account.
- At least a total of 100 fibres are to be counted or 100 counting fields analysed. A minimum of 20 counting fields must be analysed, even if they contain more than 100 fibres.

Schematic examples for the application of the fibre counting rules are shown in Figure 4.

4.3 Calculation of the analytical result

As analytical result this method delivers the numerical fibre concentration C (fibres per m^3 air). The concentration of the number of fibres is calculated according equation (1):

$$C = \frac{n \cdot A}{N \cdot a \cdot V} \tag{1}$$

Where:
C is the numerical fibre concentration in fibres/m^3
n is the number of fibres determined according to the counting rules (Section 4.2)
A is the exposed (effective) filter area in mm^2
N is the number of counting fields analysed
a is the area of a counting field in mm^2
V is the air sample volume in m^3 with $V = Q \cdot t$
(Q: sample flow rate in m^3/h, t: sampling time in hours)

4.4 Analytical report

During analysis it is recommended to record a protocol (fibre counting form) following that in [1]. This is the basis for the compilation of the analytical report.
The analytical report contains at least:

- Name and address of the analysing laboratory,
- Name and address of the customer,

- Unequivocal sample identification,
- Data for sampling,
- Date of analysis,
- Information regarding the analytical method used (here: BGI 505-31),
- Name of analyst,
- Analytical result consisting of the numerical fibre concentration, the number of fibres found, area and number of analysed image fields, remarks (e.g. regarding fibre bundles and fibres having a width of D >3 μm).

5 Performance characteristics

5.1 Uncertainty of measurements

Deviations of the measuring value (numerical fibre concentration) from the true value may appear in addition to sampling:

- During sample preparation (when handling and cutting filters, by improper application of acetone vapour and glycerol triacetate (triacetin)).
- During analysis (instrument adjustment, selection of counting fields, fibre counting).
- During assessment of agglomerates consisting of fibres and isometric particles during fibre counting.
- Random variations of measurement results due to counting statistics.
- Blank values due to contamination of the sample collection filters used.

The optimal amount of fibres on the sample collection filter lies within a range of around 100 to 1000 fibres/mm^2. Also high fractions of non-fibrous particles affect evaluation, as they can interfere and cover fibres. Only irrelevant enhancement of precision is achieved by counting more than 100 fibres; however, if fewer fibres are counted a progressive decline in precision takes place as the following table shows [1].

Table 1. Characteristic variation coefficient (intralaboratory values) for counting n fibres [1].

Counting fibres n	Characteristic variation coefficient %
5	49
10	37
20	30
50	25
80	23
100	22
200	21

The values in the table given above are valid for experienced analysts in a laboratory, applying quality assurance techniques e. g. in form of periodic comparative counts and regular round robin tests.
It is to be observed that especially for a short sampling time the confidence range of measurement values can be very high.
The 95 % confidence interval for the numerical fibre concentration due to the counting statistics may be estimated by Poisson distribution [8] (compare Appendix 1). For calculation of the confidence range the limits of confidence λ_u and λ_o associated with the determined fibre number n are inserted into the equation given in Section 4.3.

5.2 Limit of detection

The less fibres are counted, the counting precision becomes a progressive decline (compare Table in Section 5.1). For a "true" average counting value of 7 fibres in 100 counting fields, in around 5 % of the cases counts are made in the near of the maximum permissible average ground contamination or below. Therefore it is reasonable to set about 10 fibres/mm^2 as a limit of detection. This corresponds to approx. 30 000 fibres/m^3 for an effective filter area of 707 mm^2 and an air sample volume of 240 L. This value may be reduced by increased analysis efforts and air sample volumes (the latter only to the extent to which the loading of particles on the sample collection filter can still be analysed microscopically).
Reducing the limit of detection to pronouncedly below 15 000 F/m^3 is not always efficient as in most cases a background of some thousand organic and inorganic fibres per m^3 must be expected, which cannot be distinguished from the type of fibre explicitly of interest [6, 7].
Fibres having a width of D <0.2 to 0.25 µm (corresponding to contrast conditions) are not detected using this method.

5.3 Selectivity

The method is fibre-specific according to the criteria given in Section 4. It is not possible to distinguish the type of fibres, therefore, preliminary information concerning the materials used in the work place or further analytical methods must be taken into account, e. g. [3].
Some organic fibres – particularly those of animal origin – can be dissolved or corroded to a greater or lesser extent by the treatment with acetone vapour. Thus, this method must be adequately validated.
Chain like smoke particles (welding fumes, tobacco fumes) may be misinterpreted to be fibres.

6 References

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Appendix 1: Limits of confidence range for the counting result

Table A1: Lower and upper limits λ_u and λ_o of 95% confidence interval of a counting result x using Poisson distribution.

x	λ_u	λ_o	x	λ_u	λ_o
0.5	0.000	4.674	21.5	13.393	32.705
1	0.025	5.572	22	13.787	33.308
1.5	0.108	6.416	22.5	14.183	33.910
2	0.242	7.225	23	14.580	34.511
2.5	0.416	8.006	23.5	14.978	35.111
3	0.619	8.767	24	15.377	35.710
3.5	0.845	9.511	24.5	15.777	36.308
4	1.090	10.242	25	16.179	36.905
4.5	1.350	10.960	25.5	16.581	37.501
5	1.623	11.668	26	16.984	38.096
5.5	1.908	12.368	26.5	17.388	38.690
6	2.202	13.059	27	17.793	39.284
6.5	2.504	13.744	27.5	18.199	39.876
7	2.814	14.423	28	18.606	40.468
7.5	3.131	15.095	28.5	19.013	41.059
8	3.454	15.763	29	19.422	41.649
8.5	3.782	16.426	29.5	19.831	42.238
9	4.115	17.085	30	20.241	42.827
9.5	4.453	17.739	30.5	20.652	43.415
10	4.795	18.390	31	21.063	44.002
10.5	5.141	19.038	31.5	21.475	44.589
11	5.491	19.682	32	21.888	45.174
11.5	5.844	20.323	32.5	22.301	45.760
12	6.201	20.962	33	22.716	46.344
12.5	6.560	21.597	33.5	23.130	46.928
13	6.922	22.230	34	23.546	47.512
13.5	7.287	22.861	34.5	23.962	48.094
14	7.654	23.490	35	24.379	48.676
14.5	8.024	24.116	35.5	24.796	49.258
15	8.395	24.740	36	25.214	49.839
15.5	8.769	25.363	36.5	25.632	50.420
16	9.145	25.983	37	26.051	51.000
16.5	9.523	26.602	37.5	26.471	51.579
17	9.903	27.219	38	26.891	52.158
17.5	10.285	27.834	38.5	27.312	52.736
18	10.668	28.448	39	27.733	53.314
18.5	11.053	29.060	39.5	28.154	53.892
19	11.439	29.671	40	28.577	54.469
19.5	11.827	30.280	40.5	28.999	55.045
20	12.217	30.888	41	29.422	55.621
20.5	12.607	31.495	41.5	29.846	56.197
21	12.999	32.101	42	30.270	56.772

Table A1: (continued)

x	λ_u	λ_o	x	λ_u	λ_o
42.5	30.694	57.346	65	50.17	82.85
43	31.119	57.921	65.5	50.60	83.41
43.5	31.545	58.495	66	51.04	83.97
44	31.970	59.068	66.5	51.48	84.53
44.5	32.397	59.641	67	51.92	85.09
45	32.823	60.214	67.5	52.36	85.65
45.5	33.250	60.786	68	52.80	86.21
46	33.678	61.358	68.5	53.25	86.77
46.5	34.106	61.929	69	53.69	87.32
47	34.534	62.500	69.5	54.13	87.88
47.5	34.962	63.071	70	54.57	88.44
48	35.391	63.641	70.5	55.01	89.00
48.5	35.821	64.211	71	55.45	89.56
49	36.250	64.781	71.5	55.89	90.11
49.5	36.681	65.350	72	56.34	90.67
50	37.111	65.919	72.5	56.78	91.23
50.5	37.54	66.49	73	57.22	91.79
51	37.97	67.06	73.5	57.66	92.34
51.5	38.40	67.62	74	58.11	92.90
52	38.84	68.19	74.5	58.55	93.46
52.5	39.27	68.76	75	58.99	94.01
53	39.70	69.33	75.5	59.44	94.57
53.5	40.13	69.89	76	59.88	95.13
54	40.57	70.46	76.5	60.32	95.68
54.5	41.00	71.02	77	60.77	96.24
55	41.43	71.59	77.5	61.21	96.79
55.5	41.87	72.16	78	61.66	97.35
56	42.30	72.72	78.5	62.10	97.90
56.5	42.74	73.29	79	62.55	98.46
57	43.17	73.85	79.5	62.99	99.01
57.5	43.61	74.41	80	63.44	99.57
58	44.04	74.98	80.5	63.88	100.12
58.5	44.48	75.54	81	64.33	100.68
59	44.91	76.11	81.5	64.77	101.23
59.5	45.35	76.67	82	65.22	101.78
60	45.79	77.23	82.5	65.66	102.34
60.5	46.22	77.79	83	66.11	102.89
61	46.66	78.36	83.5	66.56	103.44
61.5	47.10	78.92	84	67.00	104.00
62	47.54	79.48	84.5	67.45	104.55
62.5	47.97	80.04	85	67.89	105.10
63	48.41	80.60	85.5	68.34	105.66
63.5	48.85	81.17	86	68.79	106.21
64	49.29	81.73	86.5	69.24	106.76
64.5	49.73	82.29	87	69.68	107.31

Table A1: (continued)

x	λ_u	λ_o	x	λ_u	λ_o
87.5	70.13	107.87	94	75.96	115.03
88	70.58	108.42	94.5	76.41	115.58
88.5	71.03	108.97	95	76.86	116.13
89	71.47	109.52	95.5	77.31	116.68
89.5	71.92	110.07	96	77.76	117.23
90	72.37	110.63	96.5	78.21	117.78
90.5	72.82	111.18	97	78.66	118.33
91	73.27	111.73	97.5	79.11	118.88
91.5	73.72	112.28	98	79.56	119.43
92	74.16	112.83	98.5	80.01	119.98
92.5	74.61	113.38	99	80.46	120.53
93	75.06	113.93	99.5	80.91	121.08
93.5	75.51	114.48	100	81.36	121.63

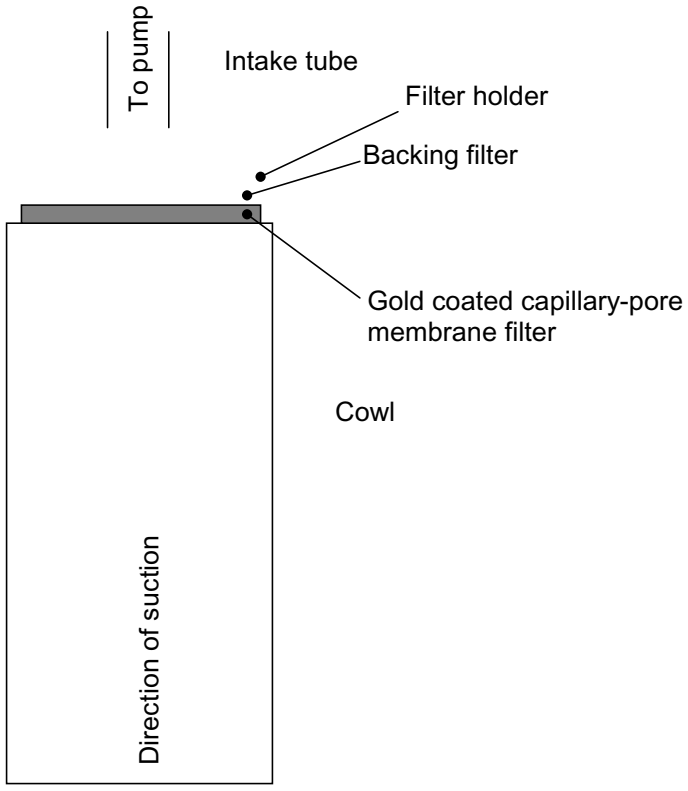


Fig. 1. Schematic diagram showing a suitable sampling head.

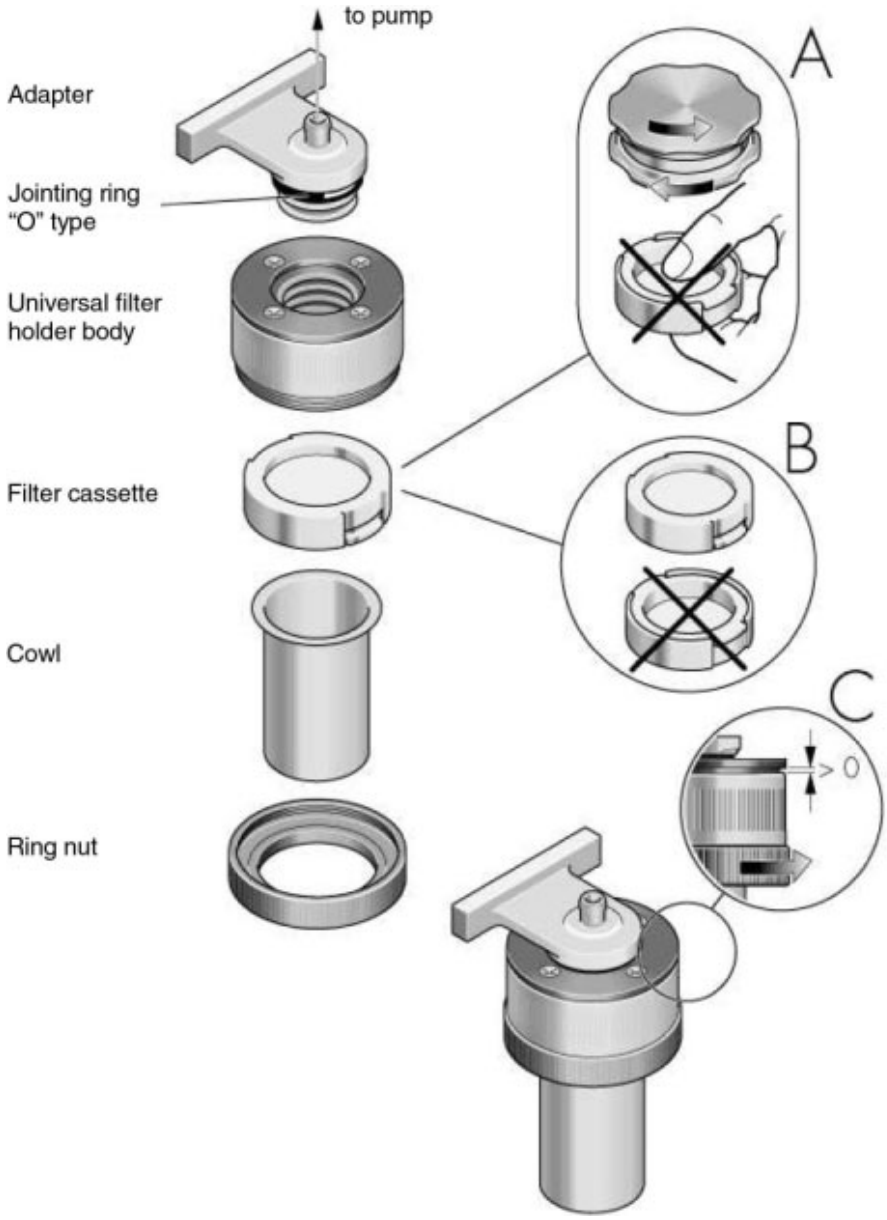


Fig. 2. Sampling head with filter cassette system BGIA [5].

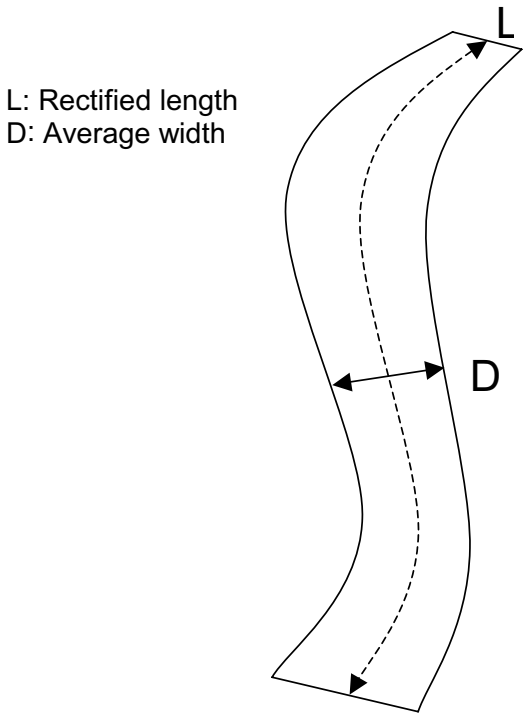
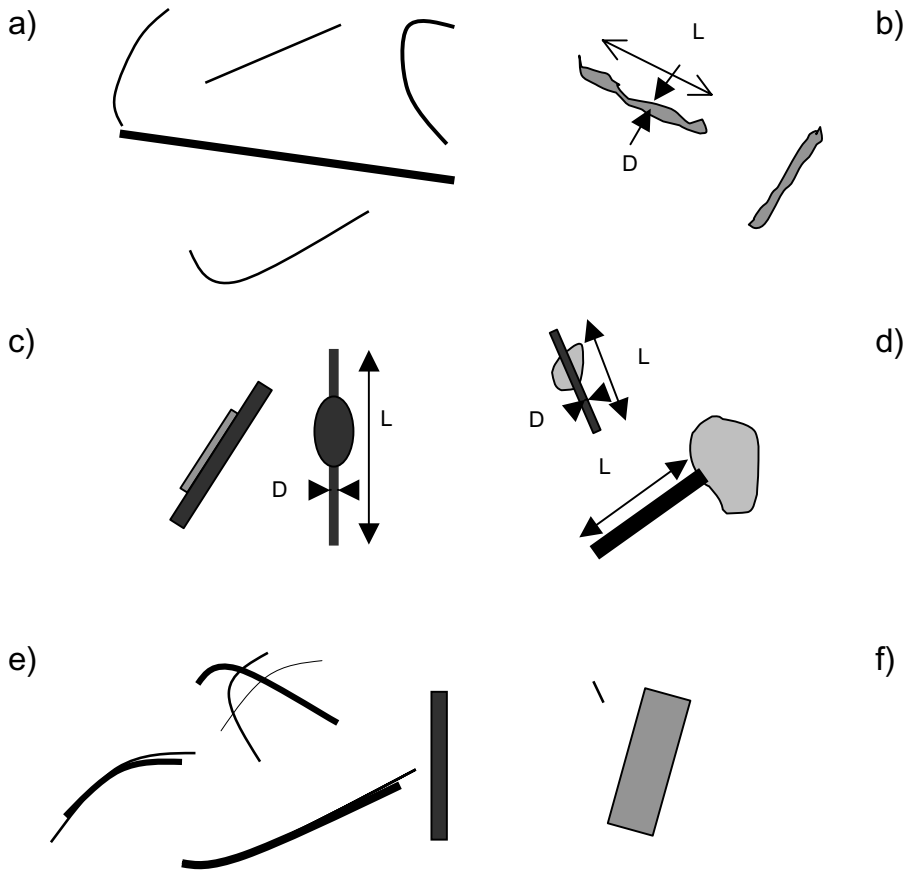


Fig. 3. Determination of fibre length and width.



a) 2 ½ Fibres: 5 Ends in the counting field
b) 1 ½ Fibres
c) 3 Fibres: The two adjoining fibres can be discriminated easily. Convexity is ignored for width determination
d) 2 Fibres: The visible section of the fibre is taken into account
e) 4 ½ Fibres: Agglomerate consisting of 3 fibres; splits are ignored. The ends of the fibre located at the right edge are considered to be out of field.
f) 0 Fibres: The fibrous particles are too short or too thick

Fig. 4. Examples for the application of the fibre counting rules (the length of the edge of the image is equivalent to 38 μm).