Australian Government

National Occupational
Health and Safety Commission

GUIDANCE NOTE ON THE MEMBRANE FILTER METHOD FOR ESTIMATING AIRBORNE ASBESTOS FIBRES

2ND Edition

[NOHSC:3003(2005)]

CANBERRA
APRIL 2005

NATIONAL OCCUPATIONAL HEALTH AND SAFETY COMMISSION

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FOREWORD

The National Occupational Health and Safety Commission (NOHSC) leads and coordinates national efforts to prevent workplace deaths, injury and disease in Australia.

Through the quality and relevance of the information it provides, the NOHSC seeks to influence the awareness and activities of every person and organisation with a role in improving Australia's occupational health and safety (OHS) performance.

More specifically, the NOHSC aims to:

- support and enhance the efforts of the Australian Government and State and Territory governments to improve the prevention of workplace deaths, injury and disease;
- work in alliances with others to facilitate the development and implementation of better preventative approaches; and
- ensure the needs of small business are integrated into these approaches.

The NOHSC's *National OHS Strategy 2002-2012*, which was endorsed by the Workplace Relations Ministers' Council on 24 May 2002, records a commitment by all Australian, State and Territory governments, the Australian Chamber of Commerce and Industry and the Australian Council of Trade Unions to share in the responsibility of ensuring Australia's performance in work-related health and safety is continuously improved.

This *National OHS Strategy* sets out five 'national priorities' to achieve short-term and long-term improvements.

These priorities are to:

- reduce high incidence and high severity risks;
- improve the capacity of business operators and workers to manage OHS effectively;
- prevent occupational disease more effectively;
- eliminate hazards at the design stage; and
- strengthen the capacity of government to influence OHS outcomes.

In line with these priorities, the NOHSC declares national guidance materials under section 38 of the National Occupational Health and Safety Commission Act 1985 (Cth).

In common with other NOHSC documents, national codes of practice and guidance notes are advisory instruments only, unless they are made mandatory by a law other than the National Occupational Health and Safety Commission Act or by an award or instrument made under such a law.

The application of a national code of practice or guidance note in any particular State or Territory is the prerogative of that State or Territory.

The Australian Government and the NOHSC expect, however, that national codes of practice and guidance notes will be adopted by all State and Territory governments.

CONTENTS

PREFACE

With the establishment of NOHSC, some functions, which were previously the responsibility of the National Health and Medical Research Council (NHMRC), were transferred to NOHSC. One such function was the continuing development of the Membrane Filter Method for Estimating Airborne Asbestos Fibres.

Whereas other NOHSC Working Parties are of a tripartite nature, the Working Party on the 1988 version of the Membrane Filter Method retained its existing NH&MRC membership of experienced occupational hygienists. Due to the need to update the Method, a new Technical Review Group was established and charged with reviewing and updating the existing NOHSC Membrane Filter Method (MFM) of sampling and analysing airborne asbestos fibres.

Although the Membrane Filter Method for Estimating Airborne Asbestos Fibres addresses only the scientific or technical considerations of this technique, this document should be read in conjunction with the National Commission's *Code of Practice for the Safe Removal of Asbestos* [NOHSC:2002(2005)], and the *Code of Practice for the Management and Control of Asbestos in Workplaces* [NOHSC:2018(2005)]. These publications outline appropriate strategies and methodology to safely manage, control and remove existing applications of asbestos and asbestos containing materials in various structures.

While airborne asbestos fibre concentrations from all types of asbestos[1] in the occupational environment are generally determined by the Membrane Filter Method (MFM), experience has shown that this method does not always produce comparable results when used by different laboratories and by different workers. Differences can arise due to variations in sampling, preparation of the slide, optical counting, the calculation of the results and other influencing factors. Inter-laboratory comparisons of dust measurements are feasible only if agreement can be reached concerning all details of the method. However, the MFM has proved reliable with extensive use over a long period of time and it is still the recommended method for measuring airborne asbestos fibres. The use of alternative, more sensitive methods such as scanning or transmission electron microscopy is not considered useful or necessary as the exposure standard has been developed from results of asbestos exposure measured by the MFM. The MFM remains the most appropriate and sensitive method for detecting airborne asbestos fibres as defined by the geometric criteria presented later in this document.

It is important to note that this updated version of the original 1976 NHMRC Membrane Filter Method[2] and the 1988 NOHSC Guidance Note, retains the basic analytical method of phase contrast light microscopy and geometrically defined countable fibres. No attempt has been made to change the definition of a countable fibre due to the fact that the analytical method is an empirical one, based on the original method, with the objective of trying to maintain a relevance between historical and current results as much as possible. For example, it is conservatively estimated that the sensitivity of the method has increased at least 10 and possibly 20 times over the first 10 or so year period following the method's development in the 1960's. The detection limit is estimated to be approximately 0.1 micrometre wide asbestos fibres.

Airborne fibres found in the mining industry pose a special problem[3] because many countable fibres found in mines are cleavage fragments that fit the geometric criteria set by

this method. These cleavage fragments, also described as acicular particles do not contain asbestos fibrils, and do not lead to asbestos related disease. Various attempts have been made to cater for this difficulty, including changing the length to width ratio from the present definition of 3 to 1, up to as high as 20 to 1, and/or reducing the maximum fibre width definition. With any of these approaches, the airborne asbestos fibre concentration can no longer be compared to the exposure standard. This document does not address this problem, because of the fundamental need to characterise the fibres on a mine by mine basis by more sophisticated methods such as electron microscopy techniques.

Any changes seen in this version should not markedly affect the estimates of airborne fibre concentration but should improve the reliability of the method and produce more reliable results when used by different laboratories. The original NHMRC method (amongst others) was used extensively in developing original versions of the Asbestos International Association (AIA) RTM-1[4], the International Standard Organisation[5] and the European Reference Method[6].

This updated version is based largely on the 1988 NOHSC Guidance Note. It continues to include control monitoring (previously known as paraoccupational sampling), which employs sampling positions outside the temporary enclosures erected during the removal of asbestos containing materials. Here, asbestos fibres often comprise only a small percentage of the total number of fibres, which might be found in monitoring of the ambient air. **It must therefore be strongly emphasised that the results obtained using control monitoring should not be related to exposure standards, which apply to occupational situations where the fibres are principally asbestos. The fibre counts should not be interpreted as representing *asbestos* fibre counts.** In contrast, in occupational situations, the observed result is closer to the real asbestos fibre count due to all fibres being predominantly asbestos.

Regulatory authorities, though recognising the limitations of control monitoring, have identified applications where the MFM is to be used to confirm the effectiveness of control measures in use during asbestos abatement or asbestos disturbance operations and where specific and significant actions are mandated on the basis of these results. Control monitoring in a regulatory environment now requires formalisation which will stand legal scrutiny.

This version of the MFM also retains exposure monitoring, previously known as ‘personal sampling’, so that valid comparisons can be made to exposure standards.

Persons new to asbestos dust sampling and analysis should not undertake work in this field without making personal contact with an experienced occupational hygienist or scientist to obtain the essential training in the techniques involved. It is highly preferable that laboratories performing this analysis are accredited by the National Association of Testing Authorities (NATA) or similar authority. Formal accreditation is a mandatory requirement in some jurisdictions.

PART 1. TITLE

This guidance note may be cited as the *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres* [NOHSC: 3003 (2005)].

PART 2. OBJECTIVE

This guidance note has been developed to provide laboratories and analysts with a consistent methodology for the sampling and analysis of airborne asbestos fibres in workplaces.

The MFM is used to assist in monitoring the effectiveness of control measures for preventing exposure to airborne asbestos fibres, and in determining worker exposure to airborne asbestos fibres.

PART 3. SCOPE AND APPLICATION

Part 6 of this document describes the procedures required to estimate personal exposure by means of exposure monitoring, and to assist in the control of occupational environments, where asbestos processes are in operation and the airborne fibres, which are present, are known to be predominantly asbestos.

Part 7 describes the monitoring techniques that can be used in other environments, by means of control monitoring where airborne fibre levels are usually low, or fibres may not necessarily be asbestos.

Part 8 details sampling procedures that are common to both the exposure and control monitoring components of this method.

Part 9 shows limitations of the method and appropriate ways to present results.

Part 10 details laboratory analytical procedures that are common to both the exposure and control monitoring components of this method.

It should be emphasised that in mixed dust situations the presence of other fibres and fibre-like particles may interfere with the interpretation of any results. The MFM does not distinguish between the different types of fibres, including organic fibres and synthetic mineral fibres (SMF).

It must also be recognised that the use of the MFM has limitations when applied to monitoring samples containing plate-like or acicular particles (e.g. vermiculite, talc, gypsum and certain other minerals and fibres), and consequently should not be implemented without a full qualitative understanding of the sampling environment. There are analytical methods, which can be used to develop a more complete understanding of complex samples. These techniques include polarising light microscopy (PLM), scanning or transmission electron microscopy (SEM or TEM), X-ray diffractometry (XRD) and gravimetric methods.

For exposure monitoring, in the absence of other technically convincing information, all particles complying with the defined geometric conditions (see section 10.4.4) are to be considered as respirable fibres and counted as such, thereby ensuring that under-estimates of asbestos exposure are minimised. This rule should also be applied to control monitoring but with the knowledge that it frequently over-estimates the asbestos concentration. It is also intended that the procedures described in this document for exposure monitoring can be used for epidemiology. However, for epidemiological purposes, more complex analysis may be required to achieve a complete understanding of occupational exposure.

To provide technically convincing information, simplified application of either form of electron microscopy can be a useful adjunct in determining the percentage of asbestos fibres to the total number of fibres estimated by the MFM, particularly when this method is used in environments containing a significant proportion of non-asbestos fibres.

Analysing settled dust for the presence of asbestos fibres, which is sometimes useful in assisting the clearance process associated with asbestos abatement, is outside the scope of this method.

Part 11 describes the main sources of errors that arise when using the method, and gives several quantitative estimates of the statistical uncertainty.

PART 4. DEFINITIONS

Accredited Laboratory	means a testing laboratory accredited by the National Association of Testing Authorities (NATA), Australia or similar accredited laboratory, or otherwise granted recognition by NATA solely or in conjunction with one or more other persons.
Airborne Asbestos Fibres	means any fibres of asbestos small enough to be made airborne. For the purposes of monitoring airborne asbestos fibres, only those fibres less than 3 μm in width, greater than 5 μm long and greater than 3 to 1 length to width ratio are counted. Note: *Airborne asbestos fibres are generated by the mechanical disintegration of asbestos-containing materials (ACM) and subsequent dispersion of fibres into the air from activities such as mining, use, removal and disposal of asbestos fibres and ACM. Airborne dust has the potential to contain respirable asbestos fibres.*
Air Monitoring	means airborne asbestos fibre sampling to assist in assessing exposure to a hazardous substance and the effectiveness of implemented control measures. Air monitoring includes exposure monitoring and control monitoring.
Analytical Blank	means a filter that has had no air passed through it, generally selected at random from an unused batch of filters. The blank is analysed along with other sample filters to ensure that no unacceptable fibres as defined in this method are present on unused filters (see also *Field Blank*).
Asbestos-Containing Material (ACM)	means any material, object, product or debris that contains asbestos as determined in a representative sample by a competent person.
Breathing Zone	means a hemisphere of 300 mm radius extending in front of a person's face and measured from the midpoint of an imaginary line joining the ears. Breathing zone samples are usually obtained by fastening a filter holder to a jacket lapel of the worker.
Control Monitoring	means monitoring using **static or positional samples** to measure the level of a hazardous substance in an area. Control monitoring is designed to assist in assessing the effectiveness of

	implemented control measures. Control monitoring is not representative of actual occupational exposures and should not be used for that purpose.
Countable Fibre	means any object having a maximum width less than 3 micrometres, a length greater than 5 micrometres and a length/width ratio greater than 3:1; and which does not appear to touch any particle with a maximum width (i.e. the smaller of the two dimensions) greater than 3 micrometres.
Exposure Monitoring	means monitoring in a persons **breathing zone** to measure their likely exposure to a hazardous substance. Exposure monitoring is designed to reliably estimate exposure so that it can be compared with the occupational **exposure standard** or provide an estimate of a persons exposure. Note: *In relation to asbestos exposure monitoring includes **airborne asbestos fibre** sampling, analysis, estimation of time-weighted average exposure and interpretation.*
Field Blank	means a filter is treated in a similar manner as that of an analytical blank, except that it is associated with each batch of filters used for sampling in the field (see also *Analytical Blank*).
Single Sample Duration	Single Sample Duration is the actual time during which a single sample is collected. This duration is dependent upon analytical requirements (see section 10.4.6), and on the objective of monitoring.
Static Samples (positional)	means samples taken at fixed locations, usually between one and two metres above floor level.
Total Sample Duration	Total Sample Duration is the sum of the Single Sample Durations for a sample taken over the monitoring period (see section 10.4.7.2).

PART 5. GENERAL METHOD DESCRIPTION

A sample is collected by drawing a measured quantity of air through a membrane filter by means of a sampling pump. The filter is later transformed from an opaque membrane into a transparent, optically homogeneous specimen. The respirable fibres are then sized and counted in accordance with defined geometric criteria, using a phase contrast microscope and calibrated eyepiece graticule. The result is expressed as fibres per millilitre of air, calculated from the number of fibres observed on a known area of the filter and the volume of air sampled.

PART 6. EXPOSURE MONITORING FOR OCCUPATIONAL SITUATIONS

Exposure monitoring involves the taking of regular samples within the breathing zone to determine a person's risk from, or level of exposure to, airborne asbestos fibres. This method is intended to be used for the sampling of airborne asbestos fibres in occupational environments where the airborne fibres are known to be predominantly asbestos. This method shall be used to determine compliance with the exposure standard[7] for asbestos processes. This includes maintenance, construction and demolition work directly concerned with *in situ* asbestos containing materials (ACM), or working with chrysotile as permitted under the exemptions from the chrysotile ban brought into force nationally in December 2003.

6.1 Strategy for Exposure Monitoring

Exposure monitoring is carried out to achieve one or both of two major objectives:

- To assess exposure relative to the exposure standard.
- To provide estimates of exposure for epidemiological investigations of morbidity and mortality, and for civil or worker's compensation legal reasons.

Sampling procedures should be arranged so as to cause minimal interference with the work activities. All sampling must be conducted in the breathing zone of a worker so that the results are indicative of the worker's exposure to asbestos fibres under representative working conditions.

6.2 Total Sample Duration and Number of Samples

Sample duration is influenced primarily by the reason for monitoring, the level of fibre concentration to be measured, the concentration of non-fibrous dust and the requirements of the analytical method. This may result in more than one single sample being required. **The total sample duration should aim at collecting a sample that is representative of the period in question, usually an entire shift**. Detailed knowledge of work being conducted is necessary at all times, especially when the actual asbestos work does not cover the entire shift.

Section 10.4.6 details acceptable minimum and maximum loadings of fibres on the filter, and it is this loading, which dictates the range of possible sampling durations for different airborne fibre concentrations.

PART 7. CONTROL MONITORING FOR OTHER SITUATIONS

Control monitoring uses static samples to measure the level of airborne asbestos fibres in an area and is designed to assist in assessing the effectiveness of implemented control measures. This method is intended to be used for the control monitoring of airborne asbestos fibres in situations that include sampling in the following situations:

- Outside asbestos removal and encapsulating areas.
- At the clean end of asbestos decontamination units.
- For clearance sampling after asbestos removal and encapsulating.
- Inside buildings, structures or ships which contain asbestos.

This type of sampling is often conducted in areas that contain high proportions of non-asbestos fibres or particles, which conform with the geometric requirements of a fibre as defined by this method. Many experienced occupational hygienists recommend against this form of control monitoring as these non-asbestos fibres cause problems in interpretation, especially where the results of the monitoring are intended for use in estimating risks to health from suspected environmental contamination by airborne asbestos fibres. **In such situations it is inappropriate to consider that the results from such monitoring have the same significance in terms of health consequences as does exposure monitoring outlined in Part 6.**

7.1 Strategy for Control Monitoring

All sampling must be conducted so that the results are representative of the particular and specific situation being monitored. Generally, only static sampling is used, and this should be taken over a single sample duration of not less than one hour (see Part 8).

In situations where asbestos is actively being removed or disturbed, dust concentrations may vary widely both within a single day and from day to day, or from place to place. Additionally, variations in work procedures produce concentrations, which can vary over one or more orders of magnitude. These factors may influence airborne levels obtained outside the asbestos removal area.

Air sampling outside asbestos removal enclosures is often carried out to ensure that negligible airborne asbestos fibres are present. However, some results can be misleading due to non-asbestos fibres, which monitoring will detect but not identify by the MFM. Air sampling can be used for testing the reliability of enclosures when they are initially installed. Once it has been established that such enclosures are controlling dust emissions, the emphasis should be placed on more efficient methods of measuring control, such as daily checking of the integrity of the barrier, negative pressure conditions, and the work practices that are carried out inside the enclosure. The choice of sampling conditions and interpretation of results should be determined by an experienced occupational hygienist. Various State authorities and occupational hygienists use action levels that require review

and/or revision of risk control measures. These levels have previously been estimated by paraoccupational sampling, which is now known as control monitoring.

Air sampling in an environment which is representative of normal work activities is desirable, however the artificial generation of an unrealistic environment is not acceptable. **The use of air sampling which is associated with the deliberate creation of artificial contamination by sweeping, beating, or the blowing of air on to asbestos containing materials or contaminated areas (that is, `aggressive' air sampling) must not be employed.** Data obtained under such conditions do not reflect current or future activities and therefore are of no value in the assessment of risk. Furthermore the practice may result in the transference of contamination from one part of a building to another without significantly affecting the measured airborne asbestos fibre concentration and/or can lead to misleading results due to the disturbance of non-asbestos fibres in the environment.

It is important to understand that air sampling should not be used as a substitute for frequent and thorough inspections by an occupational hygienist experienced in asbestos matters. Careful visual examination will reveal situations that are likely to create future contamination problems. Meticulous cleaning, resulting in the absence of any visible dust, will generally reduce contamination levels to below detectable levels.

7.2 Total Sample Duration

Sample duration is influenced primarily by the reason for monitoring, the level of fibre concentration to be measured, the concentration of non-fibrous dust and the requirements of the analytical method. This may result in more than one single sample being required.

In general, airborne asbestos fibre concentrations decay over time, especially when the sampling immediately follows dust generation activities in the location being sampled. Hence, a short-term sample taken immediately after these activities may return a concentration significantly more elevated than would a long-term sample. Therefore, the objective of the monitoring should be taken into account in relation to any dust generating activities preceding the sampling period.

If higher flowrates are to be used for this monitoring, it is necessary to ensure that the flowrate can be accurately measured and must comply with the total volume range specified in Part 8.

Section 10.4.6 details acceptable maximum and minimum loadings of fibres on the filter, which therefore dictate the range of possible sample times for different airborne fibre concentrations.

Single samples of short duration may be necessary in some situations if high background levels of particulate matter or fibres are present, which may prevent accurate microscopic analysis.

PART 8. FLOW RATE, SAMPLE VOLUME AND REPORTING

For control and exposure[*] [8]monitoring, the flowrate should be selected in the range 0.4 to 8 litres/min (L/min) for a 25 mm diameter filter. Less than 0.4 L/min may preclude countable fibres from being collected from the airborne dust cloud, and greater than 8 L/min may result in interference from excessively large particles and may also cause leakage problems for most available filter holders. For most control and exposure monitoring, a flowrate of 2 L/min is appropriate.

In some situations, ambient levels of airborne dust from other parts of the site may lead to very dense samples that cannot be counted due to excess non-fibrous particulate matter, which may obscure some asbestos fibres in the sample.

Where past experience has shown that this is likely to occur, a lower sample volume may be used. Sample volumes of less than 100 litres are not recommended because of the increased loss of precision in the results obtained. Low sample volumes may also lead to higher reporting limits than may be desired.

Under conditions of very low airborne fibre concentrations or when single sample durations much greater than four hours are desired, it is permissible to increase the sample volume appropriately. Sample volumes in excess of 1000 litres may lead to unreadable filters in some environments.

The flowrate through the filter holder should be checked at least immediately before and after monitoring. If the difference is greater than 10 per cent from the initial flowrate, the sample must be rejected, unless a valid method of estimating total volume can be applied.

An external flowmeter is used to determine the flowrate of the pump. Care must be taken to ensure that the flowmeter does not cause unknown changes to the flowrate. Measurement of the flowrate using a soap-film flowmeter, with and without the external flowmeter connected, is one satisfactory method of determining any change in flowrate.

The flowmeter used must be able to measure flowrate to an uncertainty of $\pm$5 per cent of the true flow at the 95 per cent confidence level. See Appendix A for flowrate calibration.

Internal flowmeters fitted in some pumps are not sufficiently accurate and can indicate different readings depending upon the pressure drop across the filter. They should not be used to measure flowrate unless both of these factors are taken into account.

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[*] When two samples are to be taken in parallel by two parties checking each other, it is important to make sure that the sample volume collected by each party is within ± 20% of each other. This will overcome an analytical anomaly (see endnote 8) where different volumes can give rise to different apparent airborne asbestos fibre concentrations. In general, low air volumes lead to overestimations in comparison to high air volumes that lead to underestimations due largely to subjective phenomena during the fibre counting process.

8.1 Single Sample Duration

To assist in the selection of flowrates, Table 1 gives Single Sample Durations for various flowrates at volumes of 100, 500 and 1,000 litres.

TABLE 1 – SINGLE SAMPLE DURATIONS FOR VARIOUS FLOWRATES

	Sample Volume (litres)		
Flowrate	100	500	1,000
(L/min)	(minutes)		
0.4	250	1,250	2,500
1.0	100	500	1,000
2.0	*	250	500
8.0	*	63	125

* denotes less than 60 minute sample duration

Table 1 shows that a flowrate of 2 L/min would be appropriate for sampling in a relatively clean environment for a sampling duration of 4 to 8 hours.

Table 2 is based on a 25 mm diameter filter, and shows the lowest calculated concentrations that would result from loadings detailed in section 10.4.6. See Part 9 for presentation of results.

TABLE 2 – LOWEST CALCULATED CONCENTRATIONS FOR VARIOUS FILTER LOADINGS

	Sample Volume (litres)		
	100	500	1,000
Minimum Filter Loading	Calculated Concentration (fibres/mL)		
40 fibres/100 graticule areas	0.200	0.040	0.032
15 fibres/100 graticule areas	0.075	0.015	0.012
10 fibres/100 graticule areas	0.050	0.010	0.008
Maximum Filter Loading	Calculated Concentration (fibres/mL)		
1 fibres/graticule areas	0.5	0.10	0.05
2 fibres/graticule areas	1.0	0.20	0.10
10 fibres/graticule areas	5.0	1.00	0.50

Table 2 shows that a 500 to 1,000-litre sample is sufficient to maintain a lowest calculated concentration less than 0.01 fibres/mL.

Table 2 also shows that a Sample Period of 100 minutes is necessary to measure a concentration around 5 fibres/mL to avoid overloading due to the presence of excessive fibres.

8.2 Blanks

For each batch of 100 filters received by the accredited laboratory, one unused filter can be selected and mounted as an analytical blank. Do not load this filter into a filter holder, nor draw any air through it, nor attach it to the worker. Analytical blank filters can assist in the quality control process by ensuring that the batch of filters is satisfactory in being able to be made suitably transparent, and do not have an unacceptable loading of background fibres. See section 10.4.5 for details of blank analysis.

Field blanks can be used if added confidence is required for low ambient concentrations of dust and/or fibres. If so, for each batch of filters used for actual field tests, or for every 50

filters in the batch used for actual field tests, select an unused filter and subject it to the same treatment as described above for analytical blanks.

8.3 Sampling Record

All sampling details and data necessary for the determination of the fibre concentration must be recorded. Furthermore, as much data as available should be recorded for control design and epidemiological studies. Appendix A gives an example of information used in a sampling record.

PART 9. LIMITATIONS OF THE METHOD AND PRESENTATION OF RESULTS

With the parameters specified in Part 8, the reporting limit is defined as 0.01 fibres/mL for control and exposure monitoring. This has changed from 0.01 and 0.05 fibres/mL respectively due to merging the exposure and control monitoring requirements, as well as the fact that exposure monitoring will be rarely used in practice.

Whilst it is generally accepted that blank, unused filters frequently give a reading of zero countable fibres per 100 graticule areas, more careful examination of these blank filters sometimes shows the presence of one or two fibre-like artefacts which can appear identical to very fine chrysotile asbestos fibres not often seen outside of the asbestos manufacturing industry. Further, artefacts from the clearing process may be present which have the appearance of fibres. Thus in some cases the above-mentioned reporting limit may be difficult to achieve.

It must be recognised that neither counting more fields nor increasing monitoring duration overcomes the problem of background dust that has been collected on the filter, especially when asbestos is a minor constituent in the overall dust cloud.

Insufficient information is available to determine at what level the reliability of the method becomes so poor that results have little meaning. It is clear that this level will not be a single value, but will be a range depending at least upon the relative and absolute fibre concentration. In view of this situation and the inherent variability of the method, all calculated values should be expressed in the manner detailed in Table 3. The reporting limit can only be lowered when comprehensive blank filter testing has been conducted and when the sample filters show no interference of fibrous or particulate matter. Any such reporting should be supported by this test data, and be conducted only by experienced analysts.

Because of the inherent variability of the method, especially at the very low concentration levels associated with control monitoring, all calculated values should be normally expressed in the manner detailed in Table 3. For each sample it is essential to describe conditions existing prior to, and during monitoring, as well as the exact position of the static sample, the area of the location being monitored and any other relevant details.

TABLE 3 – REPORTING OF RESULTS

Calculated Concentration * (fibres/mL)	Reported Concentration (fibres/mL)
less than 0.005	< 0.01
0.005 to less than 0.100	to 2 decimal places and 1 significant figure
0.10 to 1.00	to 1 decimal place and 1 significant figure
greater than 1.00	to 2 significant figures and 0 decimal places

* If the actual count is less than 10 fibres/100 graticule areas, then the count is not significantly above that of background. The results should be calculated using the minimum practical lower limit of detection of 10 fibres/100 graticule areas and reported as less than the calculated value expressed to one significant figure and no more than the second decimal place, unless supported by valid technical considerations.

Examples:

Calculated Concentration (fibres/mL)	Reported Concentration (fibres/mL)
0.0049	< 0.01
0.0054	0.01
0.063	0.06
0.356	0.4
2.34	2
12.2	12

Example:

A 400 litre sample with a 25 mm diameter filter count of 3 fibres for 100 graticule fields yielded a calculated concentration of 0.0036 fibres/mL. However, because the actual fibre count is below the lower limit of detection of 10 fibres/100 graticule areas, the concentration when recalculated using this limit is < 0.0121 fibres/mL. When rounded off as required in Table 3, the result shall be quoted at the reporting limit of the method as <0.01 fibres/mL.

PART 10. LABORATORY TECHNIQUES AND ANALYSIS

This Part details the analytical procedures to be used for both types of monitoring as described in Part 6 and Part 7. For convenience, aspects common to Part 6 and Part 7 (such as sampling equipment) are included in this Part of the method.

The following information on sampling equipment should be read in conjunction with Appendix A.

10.1 Sampling Equipment and Procedures

10.1.1 Sampling Pump

A portable battery powered pump must be used for exposure monitoring. The capacity of the battery must be sufficient to operate continuously over the chosen sample time. For control monitoring, a battery or mains operated pump can be used.

The pump chosen should be capable of maintaining the required flowrate with a variation within ±10 per cent for the entire sample duration, allowing for increasing filter loads. Pumps with automatic flow control facilities are strongly recommended, as they generally meet this requirement without difficulty. Pumps performing outside of the above requirement should not be used. The performance characteristics of field sampling pumps vary considerably and reference should be made to experienced laboratories for selection of pumps for specific monitoring applications.

The flow must be sufficiently free from pulsation. As a minimum and tentative criterion there must be no visible vibration of a rotameter float if such a flowmeter is connected to the filter holder with the filter inserted. It may be necessary to install a pulsation damper between the pump and the filter if an internal pulsation damper has not been included or if the pump shows significant pulsation.

Connecting tubing must be constriction-proof and the connections leak-proof.

Caution:	When monitoring in explosive gas or dust atmospheres, ensure that the sampling pump meets the requirements of AS 2380[9].

10.1.2 Filters

Membrane filters (mixed esters of cellulose or cellulose nitrate) of 0.8 micrometre pore size with printed grids must be used, and a diameter of 25 mm is preferred. Airborne dust should be collected on the upper (grid) surface of the filter.

It is acceptable to use other filter diameters, providing that the effective filter diameter is no less than 9.5 mm for a 13 mm diameter filter. It is not permissible to artificially reduce the effective filter diameter to any lesser diameter than that designed for the filter holder itself. Refer to Appendix A for the measurement of effective filter diameters.

For filters other than 25 mm diameter, the flowrate and sampling volume used should be adjusted in proportion to the effective filter area.. For example, if a 13 mm filter diameter is chosen, the flowrate and sample volume should be reduced by the ratio of areas represented by diameters of 10 mm (for the 13 mm filter) and 22 mm (for the 25 mm filter). This ratio is approximately five to one. As a result, the flowrate of 2 litres per minute would be reduced to 0.4 litres per minute, and a sample volume of 500 litres would be reduced to 100 litres.

10.1.3 Filter Holders

It is necessary to use an open-faced filter holder integral with a protective cowl. The cowl helps to protect the filter from accidental contamination. A metallic or conductive coated cowl is necessary because of the possible risk of fibre loss due to electrostatic charge when using plastic cowls. This is especially true when operated under conditions of low relative humidity.

Filter holders must be meticulously washed with detergent and water and then rinsed thoroughly. After exposure to high asbestos concentrations it may be necessary to dispose of the filter holders, or only re-use in environments with high dust concentrations where any potential contamination would not have a significant effect upon results. **Unless validated, filter holders which have previously been used with fibreglass filters should never be used for asbestos work because of the risk of cross-contamination**.

The design of the filter support utilised in some filter holders requires that a secondary support pad should be used. The purpose of this support pad is to ensure an even distribution of air passing through the primary membrane. These support pads are usually made of pure cellulose and have a much larger pore size than the primary filter upon which the fibres are collected.

10.1.4 Storage and Transport of Samples

Fixatives must not be used to adhere fibres to the filter. Experience has shown that fixing fibres to the filter surface with cytological or other types of fixatives is detrimental and may remove fibres from the filter face.

Filters should be transported in the closed holders in which the samples were collected.

An alternative is to transfer the filter to a petri dish in the following way:

- In a dust-free area, using forceps, carefully remove each exposed filter from its holder, taking care to grasp only the unexposed filter edge.
- Place the filter, dust side up, in a plastic petri dish or similar container.
- Fasten the filter to the bottom of the dish with one or two pieces of adhesive tape attached to the unexposed edge.
- After transportation, the filter can easily be removed from the dish with a surgical scalpel.

Samples should be clearly and unambiguously labelled, taking care to ensure that filters cannot be accidentally re-used. The filters should not be marked for this purpose because of

the risk of damaging the filter. The filter holders or petri dishes should be packed into a rigid container with some soft packing material to prevent both crushing and vibration of the filter.

10.2 Sample Preparation

10.2.1 Cleaning Slides and Equipment

Clean conditions should be maintained at all times. A dirty preparation area may result in sample contamination and erroneous results. Particular care should be taken to ensure that the presence of bulk asbestos samples in the laboratory does not cause contamination.

The slides should be cleaned with lens tissue or lint free tissue and laid out on a clean surface such as a sheet of lens tissue or clean paper. Each coverslip should be cleaned with lens tissue or lint free tissue immediately before use to ensure that the surfaces are free from contamination.

The scalpel and non-serrated forceps should be wiped with lens tissue or lint free tissue and placed on a clean surface (for example, lens tissue or clean paper). When mounting a series of filters, the mounting tools must be wiped clean before dealing with each sample.

10.2.2 Filter Sample Cutting

If a 13 mm diameter filter is used, the total filter must be mounted. It is preferable to mount only one half of a 25 mm diameter filter so that the second half can be retained or used if the first half becomes damaged. All cutting should be done to give a single clean cut, with no disturbance to the filter face. Either a curved bladed scalpel (usually a No. 24) used with a rolling action or a very sharp razor has been found satisfactory.

10.2.3 Mounting the Sample

For mounting, use the acetone-Triacetin (glycerol triacetate) method, as described in Appendix A.

If permanent slides are desired, it is permissible to use Euparal (MSR grade only), a synthetic resin alternative to triacetin.

WARNING: ACETONE VAPOUR IS HIGHLY FLAMMABLE, AND MOUNTING SHOULD BE CARRIED OUT WITH ADEQUATE VENTILATION. ON NO OCCASION SHOULD IT BE USED IN THE VICINITY OF AN OPEN FLAME OR OTHER IGNITION SOURCES.

10.3 Optical Requirements

10.3.1 Microscope Equipment

Microscopes with identical specifications can give quite different performances; therefore it is necessary that the performance of proposed and existing microscopes be assessed by means of a Detection Limit Test Slide (see Appendix F). It is important that experienced practitioners be consulted before selecting microscopes for asbestos dust determination. It is recommended that the following specification be used to select a microscope suitable for asbestos dust counting. It is important that the sensitivity of the method remains constant to aid appropriate interpretation of dust concentration measurements taken over the years. The sensitivity of the method has increased at least 10 times over the first ten of so years of the method's development, thus making it difficult to evaluate historical dust exposures from an epidemiological perspective. Therefore, no further attempts should be made to improve the performance of the microscope because the method is an empirical one, and was designed to provide consistent counts from different analysts and different microscopes.

- **Light Source** - Koehler or pseudo-Koehler illumination is preferred. It is preferable for the illuminator to be built-in together with an illuminator field diaphragm. An external lamp with a plane mirror can be satisfactory. A variable light intensity control is necessary for both methods of illumination.

- **Substage Assembly** - An Abbe or achromatic phase-contrast condenser incorporated into a substage unit is required. There must be a means of centering each phase condenser annulus with respect to the phase plate in the corresponding objective and a means of focusing the condenser.

- **Stage** - A built-in mechanical specimen stage fitted with slide clamps and x-y displacement is required.

- **Objective** - A rotating nose-piece fitted with a 40x parfocal phase-contrast achromatic objective is required. The 40x objective must have a numerical aperture (NA) of 0.65 to 0.75. It should have a phase ring of not less than 65 per cent and not greater than 85 per cent absorption. Either positive or negative phase-contrast is suitable. A 10x phase contrast objective or a 3x to 10x objective can be used provided it operates in a dark-field or pseudo dark-field manner

- **Eyepiece** - Binocular eyepieces of the compensating type are recommended. They should be chosen to give a total magnification of between 400x and 650x. At least one eyepiece must permit insertion of a graticule and should be of the focusing type. The use of body magnification changers and wide-field 10x eyepieces is not recommended.

- **Graticule** - The graticule for this method is the Walton-Beckett circular eyepiece graticule (Pyser-SGI Type G22). When using the 40x phase objective and an appropriate eyepiece, the image plane diameter of the graticule circle must be 100 micrometres $\pm$ 2 micrometres. See Appendix A for graticule specification, source of supply and ordering information.

10.3.2 Microscope Accessories

Points relevant to the selection of microscope accessories:

- A Centering Telescope or Bertrand Lens is essential for checking that the phase rings in the condenser are centred with respect to those in the objective.
- The phase contrast microscope is designed for monochromatic light of 530 nm wavelength (ie green light). A green filter is preferable, and it is permissible to use a blue filter. Do not use unfiltered light.
- The stage micrometer should be from a reputable source, preferably one millimetre in length and must be subdivided into at least 10 micrometre intervals, and preferably into 2 micrometre intervals. Some stage micrometres are divided into 10 and 2 micrometre divisions.
- High quality microscope slides should be used.
- The coverslip thickness should be that for which the microscope is designed, usually 0.17 mm thickness (that is, No. $1\frac{1}{2}$). Incorrect coverslip thickness will detract from the quality of the final image, because of the presence of spherical aberration.

10.3.3 Microscope Adjustment Principles

Microscope adjustments and testing with the Detection Limit Test Slide must be part of the daily counting routine. Follow the manufacturer's instruction while observing the following guidelines:

- The object for examination must be in focus.
- The illuminator field iris must be in focus, centred on the sample and opened only to the point where the field of view is illuminated.
- The image of the light source must be in focus and centred on the condenser iris or annular diaphragm for true Koehler illumination.
- The phase rings (annular diaphragm and phase shifting elements) must be concentric.
- Each of the oculars should be in focus so that each eye sees an identical image.
- The eyepiece graticule must be in focus.

See Appendix H for more detailed information.

10.3.4 Eyepiece Graticule Calibration

Each combination of eyepiece, objective and graticule must be calibrated with a stage micrometer. Should any of the three be changed, the combination must be re-calibrated. For some microscopes, calibrations will change for analysts with different interoccular distances (See Appendix A for eyepiece graticule calibration procedures).

10.3.5 Microscope/Analyst Performance Assessment

Past experience has shown that differences in counts arise from differences in microscope quality, setting up and cleanliness. It is therefore necessary that laboratories following this method should maintain contact with experienced laboratories.

A Detection Limit Test Slide (see also section 10.3) will assist in the regular assessment of microscope and analyst performance. If Block 5 on the Detection Limit Test Slide (Mark 2) cannot be distinguished, the microscope (or analyst) is not suitable for work with this method and should not be used until this deficiency has been investigated and corrected. Block 7 should not be detected. If it is detected, one or more optical components of the microscope exceeds the specifications required, and should not be used.

10.4 Counting and Sizing Fibres

Airborne asbestos fibres collected on membrane filters can be present in a wide variety of forms ranging from simple single fibres to very complex configurations of fibres or aggregates. When presented with these various forms, the analyst may experience difficulty in defining and counting the fibre content in a dust sample. The following notes (and drawings in Appendix A) have been prepared to assist and guide the analyst in assessment and interpretation of asbestos dusts collected on membrane filters. It must be recognised that the use of this method has limitations when applied to samples containing plate-like or acicular particles (for example, vermiculite, mica, talc, gypsum and certain other minerals and fibres), and consequently should not be implemented without a full qualitative understanding of the sample.

10.4.1 Low Power Scanning

With a total magnification of 30x to 150x (that is, a 3x to10x objective together with a 10x to 15x eyepiece), scan the entire filter area.

The margin normally covered by the filter holder should be free of dust and fibres. All viewing fields should have similar appearances with respect to total dust loading. If the observed fields show marked differences in loading, or gross aggregation of fibres or dust, the filter must be rejected.

At least half of the mounted filter area must be countable, otherwise it must be rejected.

10.4.2 Graticule Field Selection

After a satisfactory low power scan, change the microscope objective to 40x phase contrast and focus on the dust plane.

Ensure that the phase rings remain concentric. While most of the fibres and dust will be found on the upper surface of filter, it will be necessary to focus below (up to 10 micrometres) and slightly above the surface.

When counting and sizing, constant use of the fine focus is necessary because of the small depth of field of a 40x objective (that is, 2 to 3 micrometres).

Graticule fields should be examined throughout the entire countable area of the filter or filter segment ensuring that the choice is not biased by the lack or presence of fibres. Countable area is defined as the dust deposit area of the filter, but not within 3 mm of the filter edge or within 2 mm of the cutting line. Do not count fields that lie outside of this area. If the grid of a filter obstructs the view, move the stage to another field.

10.4.3 Laboratory Working Conditions

The working environment in a laboratory may systematically influence the accuracy of the actual counting. Subjective factors such as lighting, seating and noise should be suitable for the task.

10.4.4 Counting Criteria

Criteria 1. A countable fibre with both ends within the graticule area shall count as one fibre; a countable fibre with only one end within the area shall count as half a fibre; a fibre with both ends outside the area must not be counted.

Criteria 2. Accuracy for determining fibre length and diameter is critical, and full use must be made of the eyepiece graticule. Estimate the length of curved fibres along the curve of the fibre (that is, true length).

Criteria 3. Graticule areas for counting shall be examined as in section 10.4.2.

Criteria 4. An agglomerate of fibres, which at one or more points on its length appears to be solid and undivided but which at other points appears to divide into separate strands, is known as a split fibre. Any other agglomerate in which fibres touch or cross one another is known as a bundle.

Criteria 5. A split fibre is regarded as a single countable fibre where the width across the undivided part, not the split part, meets the definition of a countable fibre.

Criteria 6. Fibres in a bundle are counted individually if they can be distinguished sufficiently to determine that they meet the definition of a countable fibre. If no individual fibres can be distinguished as meeting the definition, the bundle is a counted as a single countable fibre if the bundle as a whole meets the definition of a countable fibre.

Criteria 7. If more than one-eighth of a graticule area is covered by an agglomerate of fibres and/or particles, the graticule area must be rejected and another counted.

Criteria 8. Count as many fields as is necessary to yield a total fibre count of 100 but count a minimum of 20 fields even if more than 100 fibres are counted. Do not count any more than 100 fields if a total of 100 fibres is not reached.

Criteria 9. All relevant information must be recorded. It is good practice to record each field and fibre as it is observed. (See Appendix A for an example of a fibre counting form.)

10.4.5 Blanks

Part 8 requires that analytical blank filters are used. If any analytical blank yields a fibre count more than 2 fibres/100 graticule areas, additional analytical blanks should be selected. In general, analytical blanks should have a count of zero fibres/100 graticule areas, and it may be necessary to reject the batch if further blanks yield positive results. If any analytical or field blank yields fibre counts greater than 2 fibres/100 graticule areas, the entire sampling and analytical procedure should be examined carefully to find the cause of the contamination. When the analytical or field blank count exceeds 2 fibres/100 graticule areas, and also exceeds 10 per cent of the actual sample fibre count/100 graticule areas, the samples to which the particular blank is appropriate should be rejected..

For example, if the fibre count of a blank filter was 4 fibres/100 graticule areas, while the sample yielded 15 fibres in 100 graticule areas.

$$\frac{\text{Blank Count}}{\text{Sample Count}} = \frac{4}{15} \times 100 = 27\%$$

As this ratio exceeds 10 per cent, the sample is rejected. Furthermore, because the blank count exceeded 2 fibres/graticule area the cause of contamination must be found and corrected.

10.4.6 Acceptable Fibre Loadings on Filters

10.4.6.1 Minimum Loading

Traditionally, for reliable counting, a fibre loading of a filter should exceed 40 fibres/100 Walton-Beckett graticule areas. In special circumstances (for example, when an indication of concentration with low precision is acceptable) it is permissible to lower the acceptable fibre loading to 10 fibres/100 Walton-Beckett graticule areas. With increasingly better dust control and less asbestos work being conducted, it is not uncommon to have sample counts of zero fibres/100 graticule areas.

If less than 10 fibres/100 graticule areas is observed, then the figure of 10 fibres/100 graticule areas is the minimum that can be used to calculate airborne fibre concentration.

The lowering of the acceptable fibre loading to 10 fibres/100 graticule areas gives high uncertainty. The limitations as described in Part 9 should also be considered when measuring very low fibre concentrations.

Note that a sample count of 10 fibres/100 Walton-Beckett graticule areas can just be distinguished from the background blank count of 2 fibres/100 graticule areas for typical sampling/analytical uncertainties prevailing in this method. For this reason, it is mandatory to ensure that blank counts are not greater than 2 fibres/100 graticule areas before accepting 10 fibres/100 graticule areas as a minimum loading.

10.4.6.2 Maximum Loading

Experience shows that the filter loading should not exceed a maximum of 5 fibres/graticule area (average value for all counted fields) for the majority of sampling situations. This may need to be reduced to an average of about 1 fibre per graticule area when mixed dusts or

agglomerates are present, and can sometimes be doubled or even quadrupled when only fibres are present on a clear background. Average filter loadings between 5 and 10 fibres/graticule area tend to result in an under-estimation, due to problems of obscuration, and should be treated with caution. Average filter loadings exceeding 10 fibres/graticule area can be accepted, providing that the fibrous and non-fibrous dust loading is sufficiently light so that it does not obscure or interfere with any of the countable fibres.

10.4.7 Calculation of Dust Concentration

When the following calculations are applied, the limitation imposed upon the data by the sampling and fibre counting methods must not be disregarded. Results should not be interpreted or reported with false precision.

10.4.7.1 Single Values

The fibre concentration for each single sample duration is determined according to the following formula:

$$C = \frac{A}{a} \cdot \frac{N}{n} \cdot \frac{1}{r} \cdot \frac{1}{t} \qquad \ldots\ldots (1)$$

where

$C =$ concentration (fibres/mL)

$A =$ effective filter area (mm^2)

$a =$ projected eyepiece graticule area (mm^2) (see Appendix A)

$N =$ total number of fibres counted

$n =$ number of graticule areas observed

$r =$ flowrate of air through filter (mL/min)

$t =$ Single Sample Duration (minutes)

Results should be presented in the manner detailed in either Part 7 or Part 9.

10.4.7.2 Time Weighted Average Values

When several consecutive samples of different sample duration are taken, calculate the time-weighted average values from the single sample concentrations and single sample durations as follows:

$$C_{TW} = \frac{\sum c_i . t_i}{} = \frac{c_1 t_1 + c_2 t_2 + \ldots + c_n t_n}{} \qquad \ldots\ldots (2)$$

$$\sum t_i \qquad t_1 + t_2 + \ldots + t_n$$

where:

C_{TW} = time weighted average concentration (fibres/mL)

c_i = single value of concentration (fibres/mL)

t_i = Single Sample Duration (minutes)

t_i = Total Sample Duration (minutes)

n = total number of samples

If the Single Sample Durations (t_i) referred to above is of equal duration, then equation 2 is simplified as follows:

$$C_{TW} = \frac{\sum c_1}{n} = \frac{c_1 + c_2 + \ldots + c_n}{n} \qquad \ldots\ldots (3)$$

Results should be presented in the manner detailed in either Part 7 or Part 9.

10.5 Quality Assurance and Quality Control

A good quality control/quality assurance procedure is essential because of the high variability in the results obtained by manual fibre-counting methods. Variation in the results for the same sample can be observed between different laboratories (inter-laboratory variation) or within the same laboratory (intra-laboratory variation).

Laboratories using the method should participate in systematic checks to assess inter-laboratory variation. The National Association of Testing Authorities (NATA) maintains an excellent inter-laboratory proficiency testing program known as NAP, the National Asbestos Program.

It is important to provide a measure of the reproducibility and stability of an analyst's performance in relation to other analysts and other laboratories. These exchanges should be supplemented by checks of internal consistency, which should aim to measure the mean and reproducibility of each analyst's difference from the average of the laboratory. It is unsatisfactory for an analyst to have an average result equal to the laboratory mean if that analyst's average performance conceals significant variation from sample to sample relative to ones colleagues.

In a large laboratory, a satisfactory quality control system involves having all the analysts recount a specified fraction of the routine slides. The fraction should be chosen to provide a quality control sample about once every week or two, and to ensure that these slides are fully representative of the laboratory's routine samples. For example, a laboratory counting 5000 samples a year could select every hundredth filter (whatever its type) for recounting by all of its analysts, and could keep a running check of the mean and standard deviation of each individual's difference from the laboratory mean.

A laboratory with only one or two analysts would have to maintain a stock of permanently mounted and well-characterised slides for periodic check counting, and could again calculate the mean and standard deviation of the counts in relation to those accepted for the stock slides. Otherwise, several small laboratories can join together in the participation of a suitable quality assurance scheme.

Systematic records of quality control results should be kept and regularly examined to assess individual analyst and overall laboratory performance. It should be remembered that, in common with sampling for other particulates, errors will be introduced in monitoring and analysis.

PART 11. SAMPLING AND ANALYTICAL UNCERTAINTY

Sampling and analytical uncertainty [10] [11] can be minimised by strict adherence to the method and by participating in intra and inter-laboratory quality assurance schemes. The following lists describe some of the common sources of uncertainty.

11.1 Sources of uncertainty

Some sources of uncertainty are introduced through errors that are predictable and repeatable. These are known as systematic errors and may include errors in method parameters like sampling duration and flowrate. Other sources of uncertainty may be introduced through unpredictable and unrepeatable effects. These are known as random errors and may include effects like the variability of a dust cloud in time and space. Random errors are more difficult to allow for in determining the overall uncertainty of the result.

11.2 Sources of Systematic Errors (bias)

Systematic errors cause a repeatable bias in the estimation of airborne asbestos fibre concentrations. For example, if a flowmeter indicates a flowrate of 2.0 L/min when the true flowrate is 2.5 L/min, this introduces a bias where the estimated airborne asbestos fibre concentration is overestimated by 25%.

11.2.1 Sampling

- Flowrate.
- Sample time.
- Non-representative or biased sampling.
- Contamination - deliberate or accidental.

11.2.2 Analytical

- Effective filter area.
- Counting area.
- Filter mounting.
- Microscope.
- Analyst.
- Contamination.

11.3 Sources of Random Errors

Random errors exhibit as unexplained and irregular estimates of airborne asbestos fibre concentrations.

For example, due to the Poisson error, repeat counting of the same filter by the same analyst leads to randomly different values of the fibre count and consequently of airborne asbestos fibre concentration.

11.3.1 Sampling

- Flowrate variability.
- Random fluctuations of the airborne dust cloud.

11.3.2 Analytical

- Fibre distribution on the filter: non-random deposition of dust on the filter leads to gross errors, the magnitude of which cannot be estimated. Twenty or more fields must be counted to ensure that minor divergence from randomness does not bias the result.
- Poisson error.

Note: As only a small proportion of the fibres deposited on the filter are counted, errors arise in the estimation of the total number of fibres on the entire filter surface. Theoretically, the Poisson Distribution defines the variation in fibre counts resulting from the viewing of randomly selected counting fields on the filter. If a minimum of 100 fibres is counted, and if a Poisson Distribution were appropriate to the counting results, the standard deviation of the fibre counts would not exceed 10 per cent of the average. This percentage is defined as the Coefficient of Variation (CV).

The Poisson error is the minimum inherent error of the Membrane Filter Method and in many other practical situations such as particle counting, electron microscope methods and blood counts.

11.4 Uncertainty

Appendix K describes the various sources and magnitudes of uncertainty in the sampling and analytical process.

In summary, more than 80% of the estimated combined uncertainty was found to be attributable to the inter-laboratory variability experienced in the NATA Program. The remaining 10 to 20% was shared relatively equally by the uncertainties associated with the estimation of sample duration, sample flowrate, effective filter diameter and graticule diameter. More importantly, for most common combinations of flow rates and sampling

durations, the 95% expanded uncertainty was found to be approximately equal to the numerical value of the airborne asbestos fibre concentration.

In other words, a concentration of 0.01 fibres per millilitre of air has an expanded uncertainty of 0.01 fibres per millilitre, calculated using a coverage factor of 2 which gives a level of confidence of approximately 95%. In essence, this means that the true concentration could be as low as zero and as high as 0.02 fibres per millilitre. As stated previously, there are additional errors to the those mentioned above that relate to the airborne dust cloud, that have not been taken into account, and which only increase the uncertainty further.

From a practical point of view, after every effort is made to reduce all known sources of uncertainty, airborne asbestos fibre concentrations estimated by this Method can be validly and directly compared to various relevant control levels or exposure standards. Whilst these concentration estimates are subject to significant uncertainties, it may only be necessary to take these uncertainties into account for a small handful of critical situations. The remainder of situations embody major safety factors that allow adequate decisions to be made without taking the magnitude of uncertainties directly into account.

APPENDIX A. FLOWRATE CALIBRATION AND CORRECTIONS

FOR FLOWRATES 0.4 - 2.0 L/min

Flowmeters used for sample flow rate determinations must be calibrated with a primary calibration device. One suitable calibration procedure makes use of a soap film flowmeter. In general, commercially available electronic soap film or sliding piston flowmeters are not primary calibration devices because they cannot be checked directly against Australian National Measurements Laboratory derived standards of time and distance (ie volume).

The flowmeters described in this section are of the variable area type (that is, rotameters).

1. Choose a burette (or similar measuring device) of 500-1,000 mL capacity that has been calibrated against a primary standard. This is known as a Soap Film Flowmeter. Attach a tube to the Soap Film Flowmeter, and then clamp it in an inverted vertical position in a stand.

2. Set up the sampling pump, and allow flow to stabilise complete with connecting tube, filter holder and filter as used in the field.

3. Connect the Soap Film Flowmeter to the filter holder. Ensure that the system is leak-proof. It is advisable to rinse the Soap Film Flowmeter thoroughly in water immediately prior to the test - this assists in wetting the inside of the burette. The Soap Film Flowmeter should be regularly cleaned with a cleaning fluid suitable for volumetric glassware.

4. Switch on the pump, allow the flow to stabilise and adjust the flowrate to the nominal desired figure.

5. Partly fill a beaker or petri dish with water plus the minimum amount of detergent necessary to permit bubbles to be formed.

6. By momentarily placing the beaker against the bottom of the Soap Film Flowmeter, create a bubble such that it will travel the entire length of the burette without bursting.

7. With a stopwatch, measure accurately the time that the bubble requires to traverse the tube between the appropriate graduated marks.

8. Repeat steps 6 and 7 at least twice, or more, until good repeatability of the times is achieved.

9. Average the times and calculate the true flow (Q_c) as follows:

Note:	Theoretically, the water vapour content in the soap film flowmeter air should be taken into consideration in determining the true flowrate. However, for practical purposes acceptable accuracy is maintained without this correction.

$Q_c = V/T$ where Q_c = true volumetric flowrate (mL/min) at calibration conditions
V = volume of burette (mL)
T = average time required for bubble to traverse the tube (minutes)

10. If the external or internal rotameter is used under different temperature conditions than those during calibration, it is generally not possible to calculate the different flowrate that will inevitably result.

As all air sampling measurements are concerned only with volumetric flowrate (that is flowrate measured and expressed at the prevailing temperature and pressure) and not mass flowrate (that is flowrate corrected to standard temperature and pressure conditions), re-calibration of the pump flowrate is essential if it is operated under conditions substantially different to those of calibration. `Substantial' implies a difference in altitude or temperature by more than 500 m or 15 ^{o}C respectively compared to the calibration conditions.

Example:

During the calibration of a pump with an internal flowmeter a soap film flowmeter of 500 mL volume gave an average of 31.7 seconds for the bubble to traverse its length.

What is the flowrate under these conditions?

Using the equation in this appendix:

$$Q_c = \frac{V}{T} = \frac{500}{31.7/60} = 946 \text{ mL/min}$$

The flowrate, under the temperature and pressure conditions as stated above, was 946 mL/min.

FOR FLOWRATES EXCEEDING 2.0 L/min

It is possible to calibrate a flowmeter up to 8 L/min by using a Soap Film Flowmeter of 1,000 to 2,000 mL. In any case, when manually timing the passage of the bubble, significant errors are introduced if the time interval over the measured volume is less than approximately 10 seconds. A Soap Film Flowmeter of volume greater than 2 litres can also introduce significant errors.

As an example, if a calibrated Soap Film Flowmeter of 1,000mL capacity is chosen, then flowmeters up to approximately 6 L/min can be calibrated.

Photocell activated electronic timed Soap Film Flowmeters can be used if it is proven that no added artefacts are introduced which can cause inaccuracy.

At high flowrates, pressure drops across restrictions in the calibration train may cause major calibration problems, and must be avoided or taken into account.

If secondary standard flowmeters (for example, rotameters) are used, it is necessary that they are regularly calibrated against a suitable primary standard, giving due consideration for pressure drop and pulsation problems.

APPENDIX B. EXPOSURE MONITORING SAMPLING RECORD (EXAMPLE ONLY)

All data necessary for the determination of the fibre concentration must be recorded in a monitoring record. Furthermore, as much data as available should be recorded for control design and epidemiological studies.

SAMPLING DETAILS

- Sampling pump type and number.
- Flowmeter type and number.
- Measured Flowrate: (initial, intermediate and final).
- Flowrate Correction Data or Factor
- Start and stop time of sample.
- Sampling strategy used.
- Time and date.
- Sampled by.

SAMPLING ENVIRONMENT DETAILS

- Designation: (job title and work location).
- Harmful substances: (for example, types of asbestos.).
- Brief description of working process.
- Variable parameters which can exercise an influence on dust formation.
- Work practices: (if applicable)
    - working conditions: (normal, abnormal)
    - material: (for example, type, size, condition)
    - airflow: (worker in dust airflow - yes/no)
    - obvious influence on adjoining working places.
- Methods of dust control: (if applicable)
    - exhaust ventilation
    - other methods

    - visual impression.

- Number of employees for which the measuring value is representative.
- Personal protection (yes/no) type.
- Hours per shift.
- Days per week.

APPENDIX C. SPECIFICATIONS FOR FILTERS, FILTER HOLDERS AND SAMPLING PUMPS

FILTERS

Membrane filter (mixed ester cellulose or cellulose nitrate), 13 or 25 mm diameter, pore size 0.8 µm, with grid.

SUPPORT PADS

Most filter holders require support pads between the filter holder support grid and the filter.

FILTER HOLDER AND COWL

Filter holders should be made from conductive material, for example, metal or conductive plastic.

Some cowls are supplied with an end piece, which has a small opening of approximately 4 mm in diameter. These end pieces must be removed during sampling such that a large opening approximately the size of the effective filter area is used.

SAMPLING PUMPS

Sampling pumps used for estimating airborne asbestos fibres should be capable of maintaining the appropriately chosen flow rate within $\pm$ 10% for the entire sample duration. Pumps with automatic flow control facilities are recommended. Because performance characteristics of field sampling pumps can vary considerably, reference should be made to experienced laboratories for selection of pumps for specific sampling applications.

When sampling in explosive gas or dust atmospheres, ensure that the sampling pump meets the requirements of AS 2380[12].

APPENDIX D. MEASUREMENT OF EFFECTIVE FILTER AREA

One convenient way in which to determine the area of the dust deposit (that is, the effective filter area) is as follows:

1. Place a small quantity of dark coloured dust (for example, carbon, cement or road dust) into a 2 to 5-litre container with a lid.

2. Shake the container, remove the lid and draw air through a membrane filter and its holder until the airborne dust in the container forms an obvious visible deposit on the filter.

3. Remove the filter from the holder, and mount on to a microscope slide in the normal manner as described in Appendix A.

4. Measure at least two different diameters at right angles to each other of the resultant dust spot to within $\pm$ 0.2 mm. Alternatively four different diameters can be measured if the slide can be turned at 45˚ angles in reference to the stage. Among other methods of measurement, microprojection, or the use of calibrated microscope object stage verniers have been found satisfactory.

5. Provided that the measured diameters of the filter differ by no more than 0.5 mm, a simple arithmetical average is sufficient to provide a good estimate of the effective filter diameter.

6. At least three individual filters must be prepared and measured as described above to give assurance that the final calculated area is sufficiently accurate.

7. Provided that the three individual filter diameters differ by no more than 0.5 mm, an arithmetical average (D) should be taken and the area calculated from the equation:-

   Effective Filter Area, $A = \pi.D^2/4$

   This area is then the Effective Filter Area (A) to be used for calculations in this method.

8. If steps 5 or 7 produce differences greater than 0.5 mm, close attention should be paid to the sampling of the dust or to the filter clearing technique.

9. It is necessary to repeat the measurement of the effective filter area if the type of filter or holder, or if any aspect relating to filter clearing, is changed.10. It is advisable to repeat the entire measurement procedure every twelve months to ensure that the correct effective filter area is known.

APPENDIX E. ACETONE-TRIACETIN MOUNTING PROCEDURE

To allow counting of fibres under a microscope, the filter material must be rendered transparent. The acetone-triacetin mounting procedure is commonly used for this purpose.

Most Australian laboratories use the `hot-block' method for generating acetone vapour[12], which has certain advantages in terms of filter preparation and safety. This method uses a heated metal block in which a small amount of acetone is rapidly vaporised and directed on to the filter.

Inject approximately 0.1 mL of liquid acetone into the 'hot-block', which causes a stream of acetone vapour to impinge on a microscope slide through a membrane filter placed on top of the slide. This renders the filter transparent.

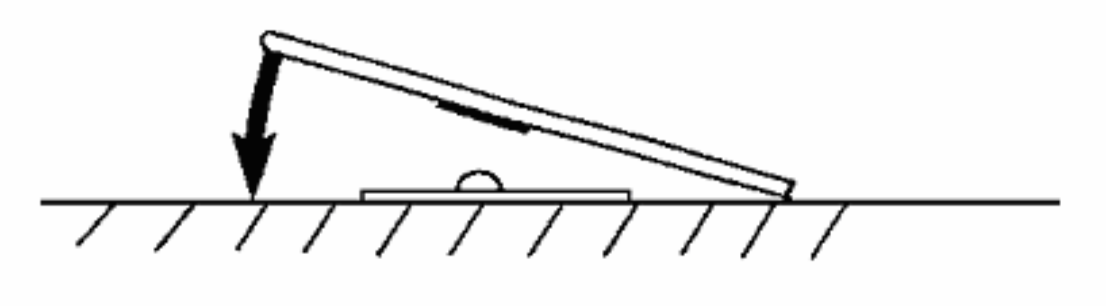
Note: Acetone vapour condenses on the top of the slide and rises in a controlled and uniform manner through the filter. Because acetone dissolves cellulose esters based material, the porous membrane filter collapses into a thin layer without pores, thus adhering to the slide and becoming transparent. Because the edges of the former pores have a different density (and therefore different refractive index) from the remainder of the filter, phase contrast microscopy shows the presence of granularity, which interferes with the counting process. Therefore, a slower acting solvent in the form of Triacetin or Euparal is used to form a homogeneous gel of the top layer of the filter that contains any dust and fibres.

After acetone clearing, leave the cleared filter for at least two minutes so that any remnant acetone can evaporate, and permit the cleared filter to stabilise.

Lay a freshly cleaned coverslip on a clean horizontal surface and using a variable dispenser capable of consistently delivering a quantity between 5-10 µL (for half of a 25 mm diameter filter) of glycerol triacetate (triacetin) on the coverslip. Lower the already (acetone) cleared filter gently on to the coverslip and allow the weight of the slide to spread the Triacetin evenly. See Figure 1.

Too much triacetin (as indicated by excess liquid emerging from the edges of the filter) can cause the outside edge of the filter to eventually disintegrate to some degree. Insufficient Triacetin will result in uneven clearing of the granularity left from the acetone vapour clearing. Further, the refractive index of the mounted sample will not be suitable for optimum visibility of very fine chrysotile fibres.

FIGURE 1



Heating the cleared filter to approximately 50 ^{o}C for two or more minutes accelerates the clearing process and enables analysis to proceed almost immediately thereafter. Otherwise it may be necessary to delay counting for up to ten hours until the entire filter has dissolved under the action of the Triacetin. Provided the above procedures are followed, the finished product should be stable, should not disintegrate, nor be subject to significant particle migration.

If the slide is to be kept indefinitely, it is desirable to paint nail polish, or similar lacquer, around the edge of the coverslip.

When a permanent slide is desired, an alternative to triacetin is to use Euparal, originally developed and used extensively by the United Kingdom Health and Safety Executive Laboratories. Euparal includes sandarac, a resin that is derived from a Moroccan pine (*callitris quadrivalvis)*, plus primaric acid and callitrolic acid. Only a grade known as Membrane Sealing Resin (MSR) should be used, because other grades do not possess the correct refractive index nor stability.

A volume of around 25 microlitres of Euparal should be used, which allows the resin to cover the entire space between the coverslip (ie 20 x 32 mm) and the slide so as to provide better and longer lasting adhesion. Because Euparal sets hard within a week, it does not generally lead to disintegration of the filter. Placing in an oven at about 40 ˚C hardens the resin in approximately 12 hours.

Euparal is relatively difficult and expensive to use, and considerable experience is necessary to produce good slides.

APPENDIX F. DETECTION LIMIT TEST SLIDE

DESCRIPTION

The standard test slides consist of epoxy replicas of a Master Slide produced and certified by the National Physical Laboratory (UK). The replicas are mounted on a 75 x 25 mm glass slide which is either 1.2 or 0.8 mm thick. The slide is covered by a coverslip 0.17 mm thick with a layer of another resin with a different refractive index in between.

The test objects consist of a series of seven blocks of grooves of length 8.5 mm filled with a resin of refractive index 1.58 in a medium of refractive index 1.485. The grooves have a V-shape profile and have a depth-to-width ratio of about 0.1. The blocks are separated by gaps 20 micrometres wide. A set of four deep marker grooves is placed on either side of the array and a further two sets of two marker grooves spaced at an interval of 120 micrometres intersect the array at right angles. The zone of the test objects to be used is delineated by the rectangle bounded by these marker grooves. This zone can easily be located, as the field of view in which it is found is engraved on the coverslip. This is illustrated in Figure 2.

The widths of the grooves within each block and the calculated phase change (in degrees) associated with the maximum path difference in the light rays passing through the test objects are in Table 4.

METHOD OF USE

Set up the microscope for phase contrast microscopy as recommended for the membrane filter method.

Locate Block 1 (the coarsest set) of the test objects and move the slide to observe adjacent blocks. Determine the block of the finest grooves that can be seen. It is unlikely that all seven blocks of grooves will be detected using optical phase contrast techniques, even on the best research microscope. On the basis of present information, a satisfactory system will detect Block 5.

Full details are supplied with the slide.

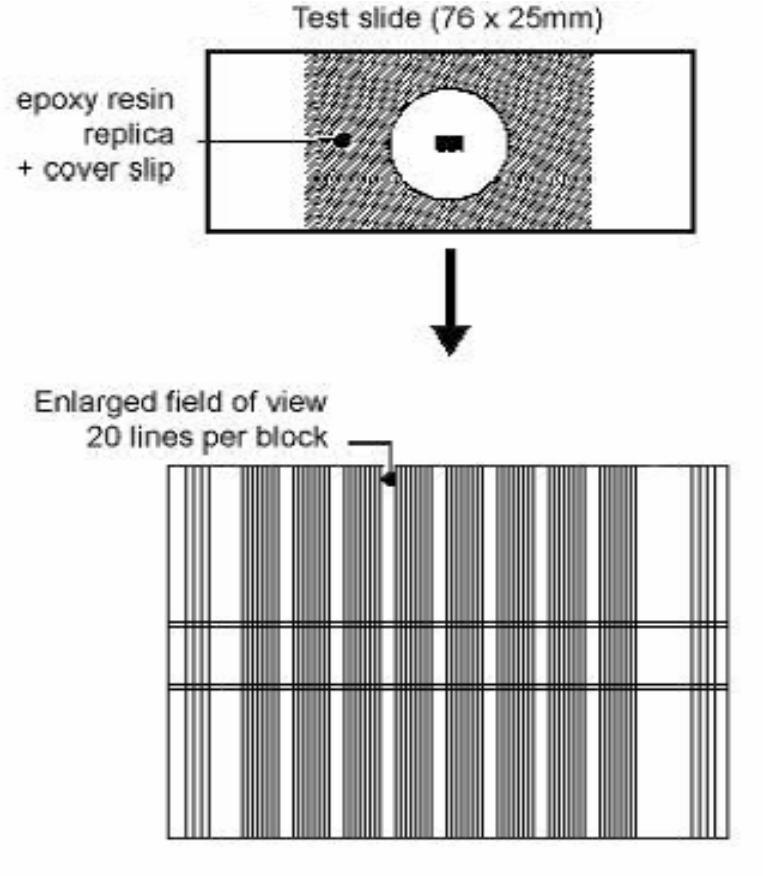
TABLE 4 – WIDTHS OF TEST OBJECTS AND CALCULATED MAXIMUM PHASE CHANGE INDUCED IN LIGHT RAYS PASSING THROUGH TEST OBJECTS OF HSE/NPL TEST SLIDE

Block Number	Groove Width (micrometres)	Maximum Calculated Phase Change (in degrees) for light rays*
1	1.08	6.6
2	0.77	4.7
3	0.64	3.9
4	0.53	3.2

5	0.44	2.7
6	0.36	2.2
7	0.25	1.5

* wavelength = 530 nanometres passing through test objects.

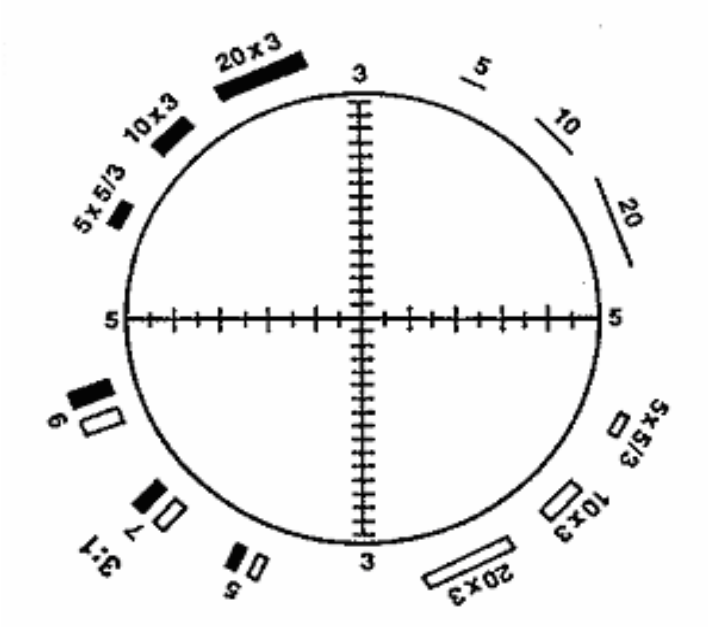
FIGURE 2 – HSE/NPL TEST SLIDE FOR PHASE CONTRAST MICROSCOPY



APPENDIX G. SPECIFICATIONS FOR EYEPIECE GRATICULE AND CALIBRATION

SPECIFICATIONS OF EYEPIECE GRATICULE, ORDERING INFORMATION AND CALIBRATION

FIGURE 3 – WALTON-BECKETT GRATICULE FOR EVALUATING FIBROUS DUST



A technical description of this graticule can be found in a paper in the Annals of Occupational Hygiene[13].

For most microscopes, the relationship between the actual graticule diameter (l) and the projected graticule diameter (d) in the image plane depends on the actual magnifications achieved by a the specific ocular and objective used.

The desired actual graticule diameter (l) of the circle to appear as 100 ± 2 micrometres in the image plane, and the overall diameter of the glass disc (L) should both be specified in millimetres when ordering. The graticule can be referred to by the Reference No.G22.

The following procedure is one of several methods for determining the desired actual diameter (l) of the circular counting area such that the desired projected diameter (d) of 100 micrometres is achieved:

1. Insert any available graticule into the eyepiece and focus so that the graticule grid is sharply in focus.

2. Set the appropriate interpupillary distance and, if applicable, reset the binocular head adjustment so that the tube length (and thus magnification) remains constant.

3. Ensure that the 40 phase objective is in place, and that any magnification changer position (if used) is known and recorded.

4. Place a stage micrometer on the microscope object stage and focus the microscope on to the graduated lines.

5. Measure the overall object length (l_0) of the graticule grid, using the stage micrometer.

6. Remove the graticule from the microscope and measure its actual overall grid length (l_a). This can be done by using a stage fitted with verniers.

7. Use the following equation:

   diameter to be specified (d) = $(1_a/1_o)/10$

   It is also necessary to specify the overall diameter of the glass disc as required for each specific microscope ocular.

Example:

Step 5 produced an object length of a Porton graticule of 108 micrometres

Step 6 produced an actual length of 4.50 mm

Step 7: (4.50/0.108)/10 = 4.17 mm

For this example, the graticule disc diameter necessary for microscope, Brand X, Model Y ocular was 17 mm.

Thus a 17 mm diameter, Type G22 Walton-Beckett graticule of circle diameter 4.17 mm, should be specified for the above example.

CALIBRATION OF EYEPIECE GRATICULES

1. Obtain a stage micrometer, preferably with a scale having two micrometre divisions, or at maximum ten micrometre divisions, and place on the object stage of the microscope.

2. Make sure interpupillary distance of eyepieces is set correctly.

3. Note the objective magnification and any intermediate magnification used.

4. Focus the microscope on to the graduated marks of the stage micrometer.

5. Line up the eyepiece graticule with the graduated divisions on the micrometer so that the number of whole micrometer divisions can be counted from one side of the eyepiece graticule graduations to the other.

6. If less than a whole division remains, estimate this fraction to the nearest micrometre and add to the number of whole divisions of the stage micrometer after converting to micrometres.

This totalled result is the projected diameter (d) of the eyepiece graticule at the image plane.

The actual projected area of the graticule (a) of the circular counting area is calculated using the projected graticule diameter (d) as follows:

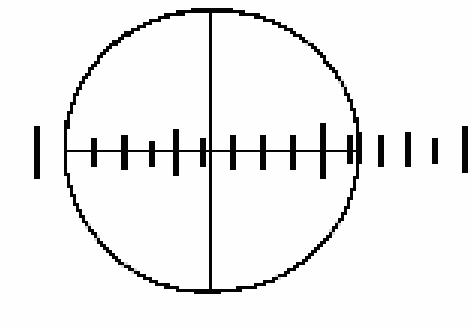
Projected area of the graticule, $a = \pi.d^2/4$

Example:

A stage micrometer with ten micrometre divisions was placed on the stage of a microscope.

The following diagram depicts the view of the superimposed eyepiece graticule and stage micrometer.

FIGURE 4



Note that 10 whole divisions span across the graticule (that is 10 x 10 micrometres).

The remainder of the 11th division is estimated as being one-fifth of a whole division (that is, two micrometres).

Adding these together yields 102 micrometres, which is the object dimension of the eyepiece graticule.

Note that if the interpupillary distance, objective, intermediate magnification, or even in some microscopes the eyepiece is changed, then this usually changes the object dimension of the eyepiece graticule, thus necessitating recalibration.

APPENDIX H. MICROSCOPE ADJUSTMENT PROCEDURE

Good quality phase contrast microscope equipment should be used (see section 10.3). The equipment should be maintained in first-class condition. Most manufacturers operate a routine maintenance service that includes the stripping down and cleaning of all optical components and the replacement of worn traverse mechanisms. Such services should be used unless skilled maintenance services can be provided in-house.

In general, the following setting-up procedure should be adopted to obtain Koehler or pseudo-Koehler illumination and good phase contrast conditions. The detail may vary according to manufacturer's instructions and the type of equipment.

1. Place membrane filter specimen slide on microscope stage.

2. Open both the field diaphragm (sometimes referred to as the illuminator diaphragm or field iris) and the substage condenser diaphragm (also known as the iris diaphragm).

3. (Note: at this stage it is usual that the condenser phase annuli is not inserted. The phase annuli is usually housed in a rotating disc fitted into the substage condenser unit.)

4. Raise condenser to its upper limit, usually within 1mm of lower face of specimen slide.

5. If the objectives are parfocal, use a 40x objective as a gauge and raise the microscope slide to approximately 0.5 to 1 mm below the front objective lens.

6. Using a convenient level of illumination and 3x to 10x objective, focus on the specimen. Change to 40x objective and refocus on the specimen.

7. Close down the field diaphragm and focus this in the field of view by lowering and raising the condenser. Centre the diaphragm and re-open to fill the field of view.

8. Observe the back focal plane of the objective by removing the eyepiece and using an auxiliary telescope. Alternatively, some microscopes have a Bertrand lens fitted to the body of the microscope, which can be used. Care must be taken to ensure that the Bertrand lens assembly does not embody an unknown magnification change which can result in an unacceptable Walton-Beckett graticule diameter.

9. Observe the image of the bulb (removing the diffusing disc if one is fitted if possible) and centre the bulb filament, focusing the bulb if possible with the adjustment provided. The image of the bulb filament should fill the back focal plane of the objective. Re-insert the diffusing disc if appropriate. (Note: if the filament cannot be focused, adjust the bulb to give uniform bright illumination.)

10. If using a low power phase contrast objective, insert the correct phase annulus into the condenser system and centre this, using the appropriate adjusting screws so that the phase plate in the objective and the image of the annulus coincide

exactly. *Slightly* adjust the condenser focusing if this is necessary. Ensure that the bright annulus image does not extend beyond the phase ring.

11. Revert to normal viewing and change to 40x objective with no phase annuli in the condenser system. Close down the field diaphragm and re-focus this by appropriate adjustment of the condenser. Re-centre if necessary and re-open to fill field of view.

12. Repeat stages 6 and 8 after inserting the phase annulus appropriate to the 40x objective.

13. Revert to normal viewing.

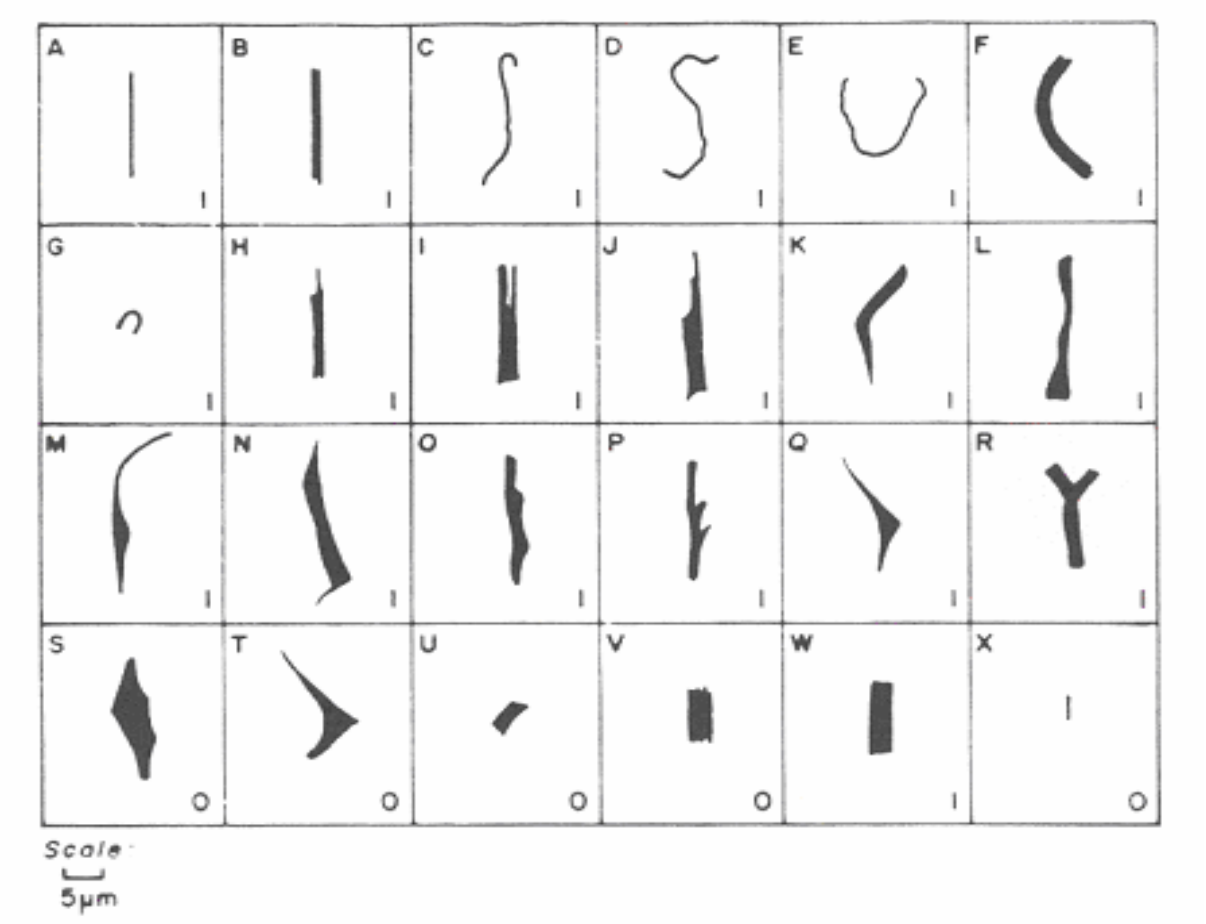
APPENDIX I. DRAWINGS OF VARIOUS ASBESTOS FIBRES

Note: All drawings are the same scale (1mm represents one micrometre). The number in the right bottom corner of each drawing indicates the number of fibres (as defined) counted.

SINGLE FIBRES

These are the simplest of the fibres to identify and count. They are also the most common measurable fibres seen on the membrane filter. Amosite and crocidolite fibres generally assume a straight needle-like form. Chrysotile fibres, while sometimes straight, often assume a curved or curly outline. Fibres, which appear irregular and perhaps `unfibre-like', are counted if they conform to the basic requirements of fibre definition.

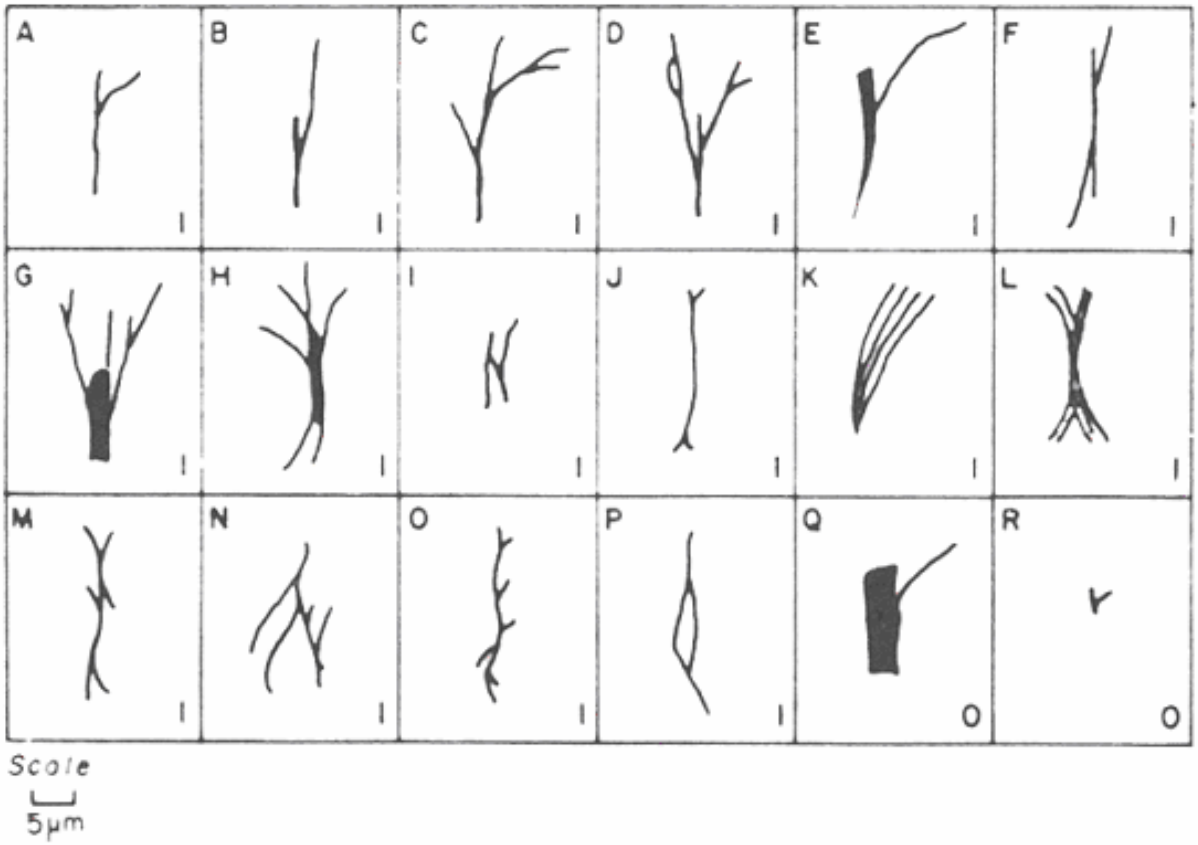
FIGURE 5



SPLIT FIBRES

These appear generally as a fibre or fibres splitting away from a single stem.

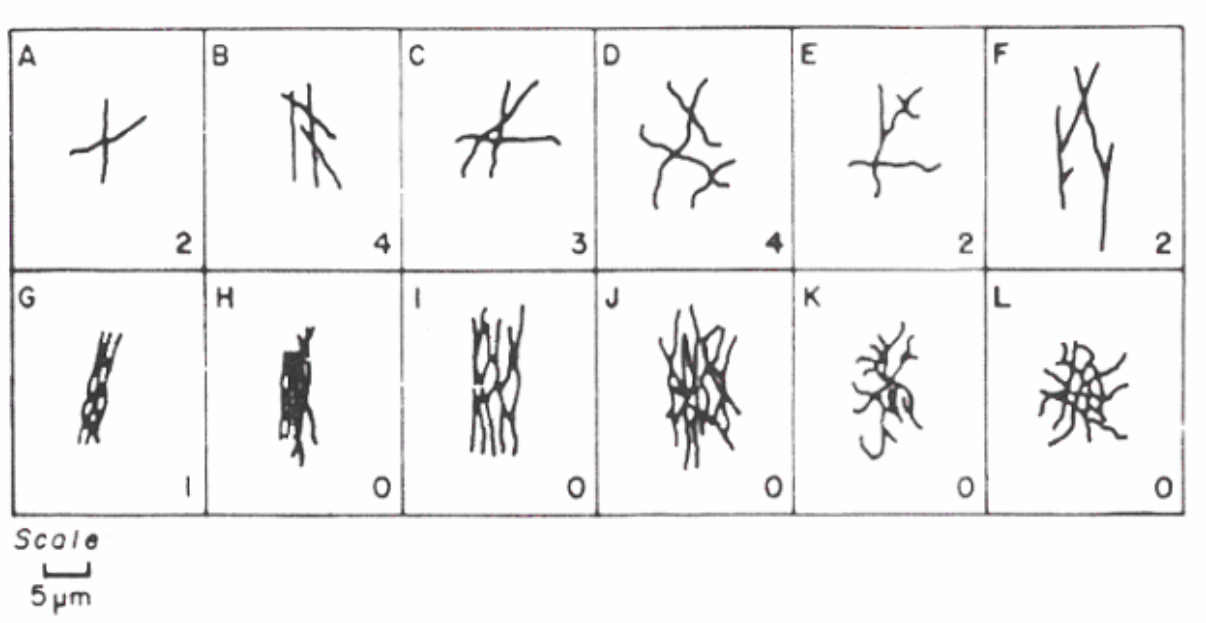
FIGURE 6



GROUPED FIBRES

These are formed when fibres overlap, intertwine or pack together. The simplest form is when two fibres overlap and cross each other. In this case, each fibre in the group appears as a discrete entity. In more complex form, fibres lie nearly parallel and appear to originate from the same bundle.

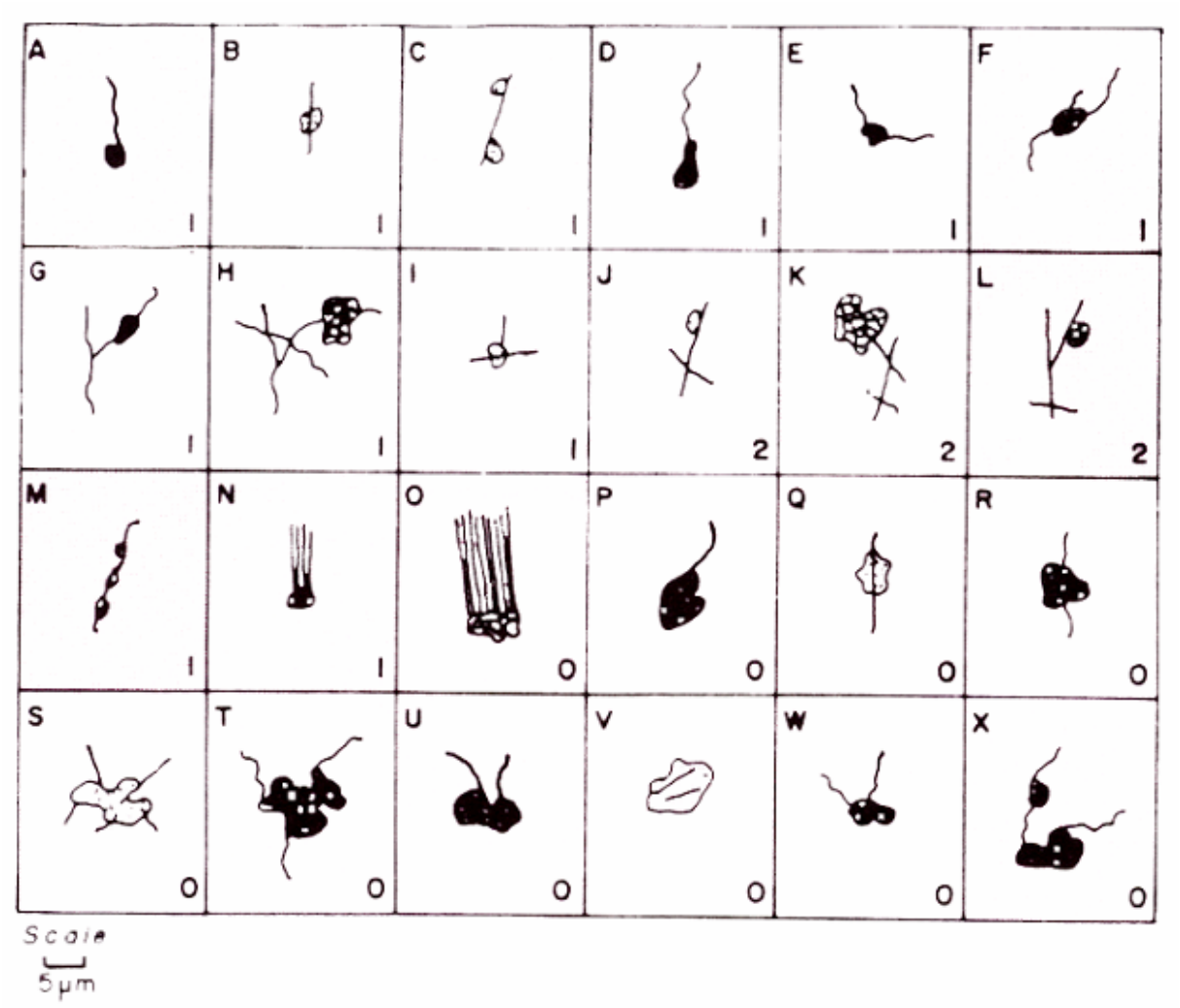
FIGURE 7



FIBRES WITH OTHER PARTICLES

This group consists of fibres attached to, or embedded in, particulate matter. For example, this latter material could be parent asbestos rock, or resins, cement, silicates used in manufactured products. Under the microscope some fibres, especially chrysotile, appear to project from the particulate matter with only part of the fibre seen. Other fibres (often amosite) are seen as embedded in the particulate matter.

FIGURE 8



APPENDIX J. EXAMPLE OF A FIBRE COUNTING RECORD

Name of job	Date
	Pump No.
Location of Sample	Filter No.
	Flow
Additional Remarks	Time off
	Time on
	Total time
	Sample taken by

LAB USE ONLY

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	TOTAL
Fibres Per Field																					
Accum. Total																					

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Fibres Per Field																					
Accum. Total																					

	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	
Fibres Per Field																					
Accum. Total																					

	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
Fibres Per Field																					
Accum. Total																					

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	
Fibres Per Field																					
Accum. Total																					

Scanner's remarks

A simplified formula for calculating dust concentration is:

$$\text{Dust concentration } C = 1000 \times \frac{\text{No. of fibres}}{\text{No. of fields}} \times \frac{\text{effective filter diameter(mm) squared}}{\text{graticule diameter(µm) squared}} \times \frac{1}{\text{volume(L)}}$$

$$C = 1000 \times \frac{\square}{\square} \times \frac{\square}{\square} \times \frac{1}{\square}$$

$C = \square$ fibres/mL

Sample analysed by	Date / /	Checked

APPENDIX K. UNCERTAINTY

Because of the nature of the Membrane Filter Method, it is not possible to know the *true* airborne fibre concentration of a given dust cloud. The result ultimately determined will be greatly influenced by uncertainty in two areas. First is the uncertainty as to what is happening in the workplace, and the second is the uncertainty surrounding the method of sampling and counting. The concentration of dust around a dust source may be influenced by a number of environmental variables including air speed and direction, humidity, geometry of dust source and measuring point, and type of dust generating activities. To overcome the uncertainties produced by all of these environmental, process and workplace variables, it is usual to take a number of samples to average out those influences. In the rare case of any occupational exposure monitoring which is still undertaken, multiple sampling may still be achievable.

In the case of control monitoring, nearly all testing procedures will be restricted to single samples obtained at any test location. As a consequence, it will be almost impossible to make any statement about the uncertainty due to workplace environmental influences, and these will remain unascertained. On the other hand, it has been possible to make some estimates of uncertainty on the sampling and counting processes.

But even then, the uncetainty of the method is difficult to quantify because of bias, which tends to arise both within and between laboratories. Taken as a whole, by randomly selecting analysts and laboratories, these various sources of bias tend to take on a random nature such that it is beginning to be possible to provide estimates of empirical precision (that is the closest approach possible to a statement of accuracy for a method with known *true* values).

However, such estimates still provide only for the uncertainties related to the sampling and counting, not to workplace variability.

Much work has been done in an attempt to arrive at these estimates, and to date only partial conclusions have been reached.

The minimum uncertainty that is associated with the counting process is obtained from the Poisson Distribution as presented in Table 5 below:

TABLE 5 – THEORETICAL UNCERTAINTY FOR RESULTS USING POISSON DISTRIBUTION

Number of Fibres Counted per 100 Graticules Areas	Uncertainty at 95% Confidence Interval	
	Lower Limit	Upper Limit
0	0	3.7
5	1.6	11.7
10	4.8	18.4
20	12.2	30.9
50	37	66
100	81	122

Table 5 shows that if a total of 10 fibres have been observed, this could be as high as 18 fibres, or as low as 5 fibres at the 95% confidence level. This range represents the smallest error likely to occur on average. Expressed in percentage terms, for 10 fibres counted, the true result may be in the range of 48 to 184% of the calculated result.

Example:

Table 6 shows the lowest and greatest possible concentration for a 500 L sample, 22.5 mm countable area and 100 µm graticule:-

TABLE 6

Calculated value in fibres/mL	Lowest possible fibre/mL concentration value based on uncertainty	Greatest possible fibre/mL concentration based on uncertainty
0.005	0.0016	0.0117
0.01	0.0048	0.0184
0.015	0.0072	0.0276
0.02	0.012	0.0309
0.05	0.037	0.066
0.1	0.081	0.122

From the above table for a calculated value of 0.015 fibres/mL, the uncertainty considerations on sampling and counting alone could place the sample either below 0.01 fibres/mL or above 0.02 fibre/mL. In the first it would not be requiring any control activities, and in the second it would necessitate some control activity.

These uncertainties apply to the measured result and not the final reported result, which is a rounded-off representation of the measured result. Those sources of errors resulting from environmental and process factors which are not able to be reflected in a single measurement strategy add significantly to the uncertainty in estimating the airborne asbestos fibre concentration. Such variability considerations which govern the dispersion of individual dust concentrations are known to increase the above uncertainties by up to a factor of 2 or 3 but the extent of their influence on the overall uncertainty cannot be easily ascertained simply by reviewing collected data. Nonetheless, in 1988, the National Association of Testing Authorities (NATA)* commenced the National Asbestos Program (NAP) which supplies six mounted test slides to applicant and participating analysts for two rounds each year. The NAP program is designed to assess and approve analysts as part of a mandatory proficiency testing scheme for accredited laboratories. Analysis from this program now assists in the attribution of the components of uncertainty to different parts of the overall assessment process.

Until the end of 2002, the NAP program processed a total of 25,840 individual counts using a total of 1,588 slides. On average, each slide was counted by an average of 16 analysts, with a minimum of two, a maximum of 76 and a median of 11 analysts per slide.

Without rejecting any outliers, which are defined in this case by a Coefficient of Variation (CV) exceeding 1.0, the results are as follows-

Total Fibres Counted/100 Fields	**CV***
<20	0.42
20-49	0.34
50-100	0.30
>100	0.28

* CV is defined as the standard deviation divided by the arithmetic mean

When the outliers were rejected, the effect on the CVs was insignificant.

The following standard uncertainties were used to calculate the 95% combined uncertainty of airborne concentration:-

Sample duration: rectangular distribution, semi-range = 3 minutes

Sample Flowrate: rectangular distribution, semi-range = 0.2 L/min

Effective Filter Diameter: rectangular distribution, semi-range = 0.2 mm

Graticule Diameter: rectangular distribution, semi-range = 2 µm

Fibre Count: coefficient of variation as per NATA data

Rectangular distributions were used because it was considered that there were equal probabilities of the true values lying anywhere within the given ranges. For example, semi-range for Sample Duration implies that all values lie between ± 3 minutes of the measured Duration.

More than 80% of the estimated combined uncertainty was found to be attributable to the inter-laboratory variability seen in the above NATA table. The remaining 10 to 20% was shared relatively equally by the uncertainties associated with the estimation of sample duration, sample flowrate, effective filter diameter and graticule diameter. More importantly, for most common combinations of flow rates and sampling durations, the 95% expanded uncertainty was found to be approximately equal to the numerical value of the airborne asbestos fibre concentration.

NATA is a private, not-for-profit company, owned and governed by its members and representatives from industry, government and professional bodies. NATA is Australia's Government-endorsed provider of accreditation for laboratories and similar testing facilities.

In other words, a concentration of 0.01 fibres per millilitre of air has an expanded uncertainty of 0.01 fibres per millilitre, calculated using a coverage factor of 2 which gives a level of confidence of approximately 95%. In essence, this means that the true concentration could be as low as zero and as high as 0.02 fibres per millilitre. As stated previously, there are additional errors to the those mentioned above that relate to the airborne dust cloud, that have not been taken into account, and which only increase the uncertainty further.

It should be added that the CV decreases as the count becomes higher. However, observing significantly more than 100 graticule areas, or more than 100 fibres in an attempt to improve the uncertainty generally results in no real gain due to operator fatigue and other subjective errors.

GLOSSARY

ACM	Asbestos-containing material
ANTA	Australian National Training Authority
ABS	Australian Bureau of Statistics
ACTU	Australian Council of Trade Unions
ANZSIC	Australian and New Zealand Standard Industrial Classification
ASCO	Australian Standard Classification of Occupations
EU	European Union
IARC	International Agency for Research on Cancer
ICD-10	International Classification of Disease
MFM	Membrane Filter Method
MOSS	Musculoskeletal Occupational Surveillance Scheme
NAP	National Asbestos Program
NCIS	National Coronial Information System
NCSCH	National Cancer Statistics Clearing House
NDS	National Data Set for Compensation-based Statistics
NIOSH	National Institute for Occupational Safety and Health
NODS	Notifiable Occupational Disease System
NOHSC	National Occupational Health and Safety Commission
OHS	Occupational Health and Safety
PLM	Polarising Light Microscopy
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
WHO	World Health Organization
XRD	X-ray Diffractometry

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