Size-Selective Samplers for Respirable Dust Sampling – Guidance Information

Technical Paper

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Contact: AIOH: 03 9338 1635 | admin@aioh.org.au

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Australian Institute of Occupational Hygienists, Inc.

The Australian Institute of Occupational Hygienists Inc. (AIOH) is the association that represents professional occupational hygienists in Australia. Occupational hygiene is the science and art of anticipation, recognition, evaluation and control of hazards in the workplace and the environment. Occupational hygienists specialise in the assessment and control of:

- Chemical hazards (including dusts such as silica, carcinogens such as arsenic, fibrous dusts such as asbestos, gases such as chlorine, irritants such as ammonia and organic vapours such as petroleum hydrocarbons);
- Physical hazards (including heat and cold, noise, vibration, ionising radiation, lasers, microwave radiation, radiofrequency radiation, ultra-violet light, visible light); and
- Biological hazards (including bacteria, endotoxins, fungi, viruses, zoonoses).

AIOH members are the professionals most likely to be asked to identify hazards associated with respirable dust concentrations in the workplace using size-selective sampling cyclones to assess exposure risks. Therefore, the AIOH has a keen interest in the accuracy of size-selective sampling cyclones for collecting the respirable dust fraction according to standards.

The Institute was formed in 1979 and incorporated in 1988. An elected governing Council, comprising the President, President Elect, Secretary, Treasurer and three Councillors, manages the affairs of the Institute. The AIOH is a member of the International Occupational Hygiene Association (IOHA).

The overall objective of the Institute is to help ensure that workplace health hazards are eliminated or controlled. It seeks to achieve this by:

- Promoting the profession of occupational hygiene in industry, government and the general community.
- Improving the practice of occupational hygiene and the knowledge, competence and standing of its practitioners.
- Providing a forum for the exchange of occupational hygiene information and ideas.
- Promoting the application of occupational hygiene principles to improve and maintain a safe and healthy working environment for all.
- Representing the profession nationally and internationally.

More information is available at our website – http://www.aioh.org.au.

Exposure Standards Committee Mission Statement

The AIOH established the Exposure Standards Committee to provide expert guidance and comment to the exposure standards setting process at a State and National level and internationally where appropriate, through development of AIOH Position Papers, AIOH guidance publications or comment on relevant Standards, Regulations and Codes of Practice. The Committee's remit is to confirm that the revision of exposure standards, and other relevant Standards and Codes of Practice, are valid and based on good occupational hygiene and scientific principles. The Committee is also concerned with the integrity of the exposure assessment process whereby sampling results for airborne contaminants are compared against exposure standards.

Statement of Position Regarding AIOH Technical Papers

The AIOH is not a standard or method setting body. Through its Technical Papers, the AIOH seeks to provide relevant technical information on equipment and methodologies with regard to ensuring the integrity of the process of evaluating workplace hazards. The information herein is supplementary to published and validated methods for sampling and is provided as a resource where the information is not available elsewhere, such as from Australian Standards (AS) or the National Association of Testing Authorities (NATA), or in methods published by Regulatory organisations (e.g. Safe Work Australia).

The information included in this document attempts to provide practical and pertinent information to assist occupational hygienists or laboratory personnel to use correct sampling or analytical techniques and equipment for collecting valid samples, which can be used to compare against the relevant workplace exposure standards (WES) where personal sampling has been conducted. Data quality is an important aspect of the workplace exposure assessment process, particularly when it is necessary to demonstrate compliance with a WES.

Consultation with AIOH members

AIOH activities are managed through committees drawn from occupational hygienists nationally. This Technical Paper has been prepared by the Exposure Standards Committee based on published information and comments sought from AIOH members with interest and/or expertise in this area. The AIOH acknowledges the following contributors to this Paper: AIOH Members Linda Apthorpe, Robert Golec, Geoff Pickford, Laurie Glossop and Ian Firth.

Thirty-eighth AIOH Council

List of Abbreviations and Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AIOH	Australian Institute of Occupational Hygienists
AS	Australian Standard
BCIRA	British Cast Iron Research Association
BS EN	British Standard European Standards (European Norms)
CEN	European Committee for Standardisation (Comité Européen de Normalisation)
HD	Higgins and Dewell
IOM	Institute of Occupational Medicine
ISO	International Standards Organisation
L/min	Litres per minute
mm	millimetres
NATA	National Association of Testing Authorities
PPI	Parallel Particulate Impactors
SIMPEDS	Safety in Mines Personal Equipment for Dust Sampling (or sometimes referred to as Safety in Mines Research Establishment Personal Dust Sampler)
WES	Workplace Exposure Standard

Competent Person

AIOH recommends the following definition of a *Competent Person* for the purposes of this document:

- A person with the relevant experience (at least 5 years) and proven competence in workplace exposure assessment, particularly as related to workplace sampling of airborne contaminants.

AIOH Technical Paper: Size-Selective Samplers for Respirable Dust Sampling – Guidance Information

1. Introduction

This Technical Paper was prepared to provide guidance on choosing sampling equipment for respirable dust sampling. The need for this Paper became apparent due to questions raised by occupational hygienists regarding the validity of a number of size-selective cyclones in common use that may not meet the required respirable dust size-selective criteria required by various Standards.

This situation presents problems whereby respirable dust sampling results obtained may underestimate or overestimate the actual concentration, with either alternative being unacceptable for occupational hygienists.

It is envisaged that this Technical Paper will be updated when further information regarding the performance of respirable dust sampling cyclones becomes available.

Size-selective cyclone samplers are primarily used to collect airborne aerosol contaminants in the respirable size range to determine their concentrations. The samplers may be placed in the breathing zone of a worker to estimate worker exposure, or in a static (i.e. fixed) location to determine airborne concentrations in strategic locations. The results may be used to provide guidance on engineering control effectiveness, risk assessments, epidemiological purposes or determining compliance against the relevant workplace exposure standards (WES).

The information provided in this Technical Paper should be used in conjunction with the methodology provided in Australian Standard (AS) 2985:2009 *Workplace atmospheres - Method for the sampling and gravimetric determination of respirable dust*.

It is essential that the cyclone samplers used meet established performance requirements of the sampling curve in order to sample the specific fraction of dust known as respirable dust. Samplers which do not meet these requirements should not be used.

2. Background

Guidance for selecting a sampling system suitable for respirable dust is provided in AS 2985:2009. This Standard indicates that several samplers are available which, when used, will sample the defined fraction of dust that penetrates to the unciliated airways and into the lower regions of the lungs. This size fraction of dust is known as Respirable Dust. Further information on this particle size fraction of dust can be found in ISO 7708:1995 *Air quality – Particle size fraction definitions for health-related sampling* (or BS EN 481 1993: *Workplace atmospheres: Size fraction definitions for measurement of airborne particles*).

By using the information in AS 2985:2009, the respirable fraction of dust as defined by the ISO 7708:1995 Standard can be sampled, and subsequently analysed. Therefore, correct selection and operation of the sampler is essential.

AS 2985:2009 was prepared on the basis of the information available at the time regarding the available size-selective samplers and the specific flowrates to be used in order to meet the sampling efficiency curve which will sample airborne respirable dust. Information from the manufacturer of one type of size-selective cyclone sampler regarding a change in the recommended flowrate in order to meet the ISO 7708:1995 Standard became available in September 2018.

It is possible that the variety of cyclones previously and currently available do not comply with the sampling efficiency curve as required in AS 2985:2009 (and ISO 7708:1995) at their recommended operating flowrate, because their size selecting performance has not been recently determined. Caution should be taken in the use of these samplers until their performances are independently verified by the manufacturers, including, but not limited to, peer reviewed research in order to satisfy that the device is appropriate for use (Belle, 2018).

It should also be noted that the use of general correction factors are not recommended due to the complex relationship between the particle size distribution of the dust, and the nature of the size selection classification. For example, if the device measures +30% in relation to the ISO 7708:1995 Standard, it is not appropriate to simply correct historical results by applying a 130% weighting. It is only possible to say that a non-compliant cyclone either 'over' or 'under' samples. This may be further complicated based on the type and particle size distribution of the dust being sampled. For example, some samplers over sample below the 50% cut point and under sample above it, so may be either over or under sampling depending on the particle size distribution of the aerosol being sampled (refer to Section 6). Additional information on samplers can be found in the EN 13205 *Workplace Exposure – Assessment of Sampler Performance for Measurement of Airborne Particle Concentrations* series of documents.

The information contained herein may be useful in assisting Occupational Hygienists to ensure their sampling methods are suitable for health-based workplace airborne aerosol monitoring purposes, which is to be fit for purpose for sampling respirable dust.

The AIOH will endeavour to provide additional information on the compliance or otherwise of specific cyclone samplers as it becomes available.

3. Airborne Dust Sampling

The AIOH recognises the inherent variability in sampling. Therefore, it is critical that appropriate devices and sampling equipment (i.e. pumps) are selected that best ensure accuracy of the sample.

The purpose of airborne sampling for respirable dust is to determine the airborne concentration of a substance that may potentially affect the lungs. Depending upon the purpose of the sampling, this can either be conducted in a worker's breathing zone (i.e. personal sample) or in an area (i.e. fixed location or static sample). The results of long-term personal sampling can often be used to determine the risk to worker health and/or compliance to the relevant WES. As the results of personal sampling directly relate to potential worker exposures and consequent health effects, it is important that the sampling is conducted by persons suitably qualified and experienced in this sampling technique using approved and validated methods such as those published by Australian Standards. In addition, air sampling for determining compliance with a relevant WES is a requirement of Work, Health and Safety/Occupational Health and Safety Legislation across all jurisdictions in Australia (Safe Work Australia, 2013; Grantham and Firth, 2014)).

The AIOH recommends that the analysis of collected samples be conducted by laboratory facilities accredited by National Association of Testing Authorities (NATA) for the specific test using appropriate validated methods. Based on results obtained from the air sampling, correct interpretation of the sampling results by a competent person is essential in order to determine compliance or otherwise with a WES and whether control strategies are required to eliminate or reduce exposures to acceptable levels.

Please refer to AIOH Technical Papers: *Flow Measuring Equipment: Calibration Requirements* and *Air Sampling Pumps: Equipment Calibration Requirements* for recommended equipment checks and calibration requirements for air flow measuring equipment used to sample respirable dust.

4. Size-Selective Samplers

In order to carry out sampling for respirable dust, a filter is placed inside a sampler and air is drawn through the filter by a suitable sampling pump. The sampling device is specifically designed to enable sampling of airborne dust which meets the sampling efficiency curve for respirable dust; the CEN-ISO-ACGIH respirable fraction curve. SKC (2018b) demonstrates an appropriate testing protocol for determining whether there is reasonable conformance with the CEN-ISO-ACGIH respirable fraction curve.

There are a variety of respirable dust size-selective samplers available and these are colloquially known as miniature cyclone samplers (i.e. cyclone elutriators) as they operate by employing rapid circulation (i.e. cyclonic action) to separate out particles according to their aerodynamic diameters.

The devices must be operated within narrow tolerances of their specified flowrates in order to sample the respirable fraction of dust as defined in the AS 2985.

Devices which are specified in AS 2985:2009 include:

- BCIRA – British Cast Iron Research Association Higgins and Dewell (HD) sampler (Higgins and Dewell, 1967)
- SIMPEDS – Safety in Mines Personal Equipment for Dust Sampling (or sometimes referred to as Safety in Mines Research Establishment Personal Dust Sampler) (Harris and Maguire, 1968)
- Aluminium Cyclone sampler

5. Background Information on Cyclone Samplers

Since the original invention, design and manufacture of the first cyclone samplers in the 1960's, there have been various modifications over the years. Some of these modifications have arisen due to practicability (e.g. lighter versions to wear), others due to changes/advancements in manufacturing technologies and materials, with some slight changes due to equipment such as dies and presses used to manufacture the samplers over time.

The BCIRA sampler was the first commercial version of the original HD design. This sampler was manufactured using machined metal components and was very heavy to wear when compared to other newer versions.

The SIMPEDS cyclone was developed by the United Kingdom Safety in Mines Research Establishment who used the BCIRA cyclone design and adapted it for use on a miner's cap-lamp. This version was much lighter and easier to wear.

The manufacturing company SKC Inc (SKC) also produced their versions of the HD design, and they currently have two plastic sizes available, one each for 25 mm and 37 mm filter cassettes. SKC also manufacture aluminium cyclones in 25 mm and 37 mm sizes.

Casella manufacture various types of cyclone samplers including plastic versions of the HD cyclone (25 mm and 37 mm sizes), and aluminium cyclones (25 mm and 37 mm).

The use of the terms SIMPEDS, Higgins-Dewell and BCIRA to describe modern cyclones no longer has any meaning because of a multitude of variants with different size-selective characteristics to each other. The Casella and SKC versions commonly in use are now best described as 'modified' Higgins-Dewell cyclones (including specific manufacturer's brand and model number).

Refer to the photographs in Table 1 for various types of cyclone samplers (Note: not all types of cyclones available are depicted).

Other cyclones such as the Dorr-Oliver, BGI, SKC GS-1, SKC GS-3, SKC HD and CIP10-R[1] are also used for size-selective sampling for specific applications. These cyclones were originally designed to meet the ACGIH sampling efficiency curve.

Due to the changes in cyclone design and manufacturing technologies over time, unless recent testing has been conducted for a specific sampler model number and manufacturing date, it is not known whether the cyclones listed above meet the CEN-ISO-ACGIH respirable sampling efficiency curve requirements.

It should be noted that all cyclone samplers (including those listed in Table 1) have some type of inherent bias due to internal flow and turbulence issues within the devices themselves. This is primarily due to the different particle types and shapes which are sampled in real-world scenarios as compared to laboratory testing using unit density sphere equivalents and monodisperse aerosols. In addition, particles of different shapes and densities tumble within the cyclone, some of which spin out and are discarded, while others may be captured onto the filter. Further variability may also occur

[1] More information on the CIP10-R can be found at https://airsamplingdevices.com/cip10-literature/

when the sampler is worn by a worker who moves around and where the orientation of the cyclone may not always be vertical.

Table 1 – Photographs of various miniature cyclone samplers, note the names of devices listed.

			
1 - Casella Modified Higgins-Dewell Cyclone	2 - Casella Modified Higgins-Dewell Cyclone	3- SKC (Plastic) Modified Higgins-Dewell Cyclone	4 - Casella (metal) Modified Higgins-Dewell Cyclone
			
5. BCIRA Higgins-Dewell Cyclone	6. Aluminium Cyclone	7. Dorr-Oliver Cyclone	

Another issue is that no single miniature cyclone sampler works effectively over all dust types. While manufacturers work to overcome these issues, in fact, there is no such thing as an ideal universal respirable dust sampler.

The 50% cut-point is also used to establish performance criteria for size-selective samplers. This is the particle size which the device collects with a 50% efficiency. Particles that are smaller than the 50% cut-point are collected with an efficiency of greater than 50%, whereas larger particles are collected with an efficiency of less than 50%. The 50% cut-point is 4 micrometres for cyclone samplers which meet the requirements of the CEN-ISO-ACGIH curve. In order to achieve this 50% cut-point, it is essential that the cyclone is operated at the manufacturers' specified flowrate. It is also important that the cyclones are not modified in any way that may alter the sampling efficiency, including copying or replicating any component of the device, or interchanging components from other models or brands.

In selecting the specific cyclone sampler to use, various factors must be considered such as electrostatic effects, workplace parameters (e.g. underground mines), constituents of the dust to be sampled, and specific methodology or jurisdictional requirements for the sampling. A competent Occupational Hygienist should consider the above before selecting an appropriate sampling device. However, it should be noted that there is no easy way to field check that a sampling head is working to its design specifications.

Other factors which may impact the ability of samplers to capture dust according to the ISO/CEN/ACGIH curve include wear of internal components, which can occur when the samplers are used consistently over many years.

6. Differences Between Samplers

There have been a number of published studies on the differences between samplers for respirable particulates. A study of 15 respirable aerosol samplers by Görner *et al* (2001) using polydisperse coal dust found serious deviations for some samplers from the conventional target CEN-ISO-ACGIH respirable fraction curve, whereas other samplers met the convention quite well. The flow rate of certain cyclone-separator-based instruments needed to be optimised to adjust sampling efficiency.

Stacey *et al* (2014) assessed the relative collection efficiencies of 13 respirable dust samplers, involving nine laboratories from eight countries, with samplers exposed to airborne concentrations of ultrafine and medium Arizona road dust in a calm air chamber. All methods and analytical approaches applied in this study for the sampling and analysis of respirable crystalline silica by X-ray diffraction obtained comparable results (most were within 12 %). When following good analytical practice, the main factors affecting the comparability of results for respirable crystalline silica were significant differences in sampler efficiencies. In particular, the conductive sampler from SKC obtained a higher concentration of respirable dust (1.3-1.4 times) when compared with the average air concentration. The Dorr-Oliver, SKC aluminium, CIP10-R and IOM head (with polyurethane foam separator) samplers all reported lower respirable dust air concentrations than average with the ultrafine Arizona road dust. Their lower collection efficiency compared with other samplers was explainable from published sampler information. The Dorr-Oliver sampler also had a tendency to collect a lower proportion of crystalline silica in the respirable dust than others. Verpaele and Jouret (2013) similarly reported that the SKC conductive black plastic sampler over sampled. They also noted that the CIP10-R under sampled.

Belle (2018) highlighted the significant differences between various cyclone samplers. Some samplers, such as the SKC plastic cyclone, showed a sampling bias as high as 59% against the size-selective curve, significantly overestimating respirable dust concentrations. These differences could, in part, be attributed to the ‘un-auditable’ inherent design and manufacturing quality, or unverifiable data on the size-selective sampling curve.

There are also Parallel Particulate Impactors (PPI) which are available for sampling respirable dust according to the ISO/CEN/ACGIH efficiency curve where higher flowrates and lower detection limits are required. These samplers deposit the dust in four discrete locations on the filter rather than being dispersed over the entire filter surface, as cyclone style samplers do. Caution is recommended when using these samplers as the resultant filter may be incompatible with secondary analysis techniques (e.g. direct on filter analysis for respirable crystalline silica).

7. Recent Information

Manufacturers of commonly used miniature cyclones in Australia include SKC and Casella. Based on the manufacturers’ information at the time, for sampling to meet the sampling efficiency curve as defined in ISO 7708 and AS 2985, specified operating flowrates for the cyclones were provided.

As per AS 2985:2009, Table 2 provides the following information regarding flowrates for each cyclone sampler.

Size-Selective Sampler	Designated Flowrate (L/min)
BCIRA cyclone (Higgins-Dewell)	2.2
SIMPEDS (modified HD) cyclone	2.2
Aluminium cyclone	2.5

Table 2 – Cyclone Sampler Flowrates (from AS2985:2009)

Information was released in August 2018 by one manufacturer, SKC Limited, regarding testing conducted on their plastic cyclones (based on their modified HD design, SKC Catalogue Nos 225-69 and 225-69-37)[2]. It should be noted that this recent information is most likely only related to the current versions of the SKC plastic modified HD cyclone sampler, and all other miniature cyclone samplers should be operated at the flowrates nominated in AS 2985:2009 (as described in Table 2 above or as recommended by the manufacturer).

Current information from SKC for their modified HD cyclone (SKC 2018a and 2018b) indicates that it should be operated at a flowrate of 3.0 L/min in order to sample dust according to the sampling efficiency curve for respirable dust. Previously, the recommended flowrate for this cyclone sampler was 2.2 L/min. SKC Limited has indicated that samples collected with 2.2 L/min may have oversampled by approximately 30%. The AIOH recommends that samples previously collected using the SKC modified HD cyclone at 2.2 L/min are not adjusted by any 'factor' to account for change in the flowrate when analysing historic data, unless there is good representative side-by-side sampling data available to verify the use of a correlation/correction factor. Note though, that a number of variables will influence the derived correlation/correction factors and hence at least 5 to 6 side-by-side samples would need to be collected for each type of site and process-generated respirable dust contaminant to provide sufficient validation of the factors.

It is not presently known if any older versions of the SKC modified HD cyclones, or any Casella HD cyclones, aluminium style cyclones or other types (e.g. Dorr-Oliver, SKC GS-1, SKC GS-3, SKC HD and CIP10-R) comply with the CEN-ISO-ACGIH respirable fraction curve.

8. Airborne Contaminants

There are many types of airborne aerosol contaminants that can be sampled using size-selective cyclone samplers. For respirable dust, the following examples are provided:

- Respirable dust (i.e. dust which is not otherwise classified)
- Respirable crystalline silica (including cristobalite and α-quartz)
- Graphite
- Coal dust
- Soapstone

It is important to note that whilst fibres such as asbestos, man-made vitreous fibres (synthetic mineral fibres), cotton fibres/dust may be respirable, they cannot be sampled using size-selective cyclone samplers as per AS2985:2009. It is essential to select the correct and validated method in order to sample these types of airborne contaminants.

[2] Note, it is assumed that the 25 and 37 mm versions tested were from current manufacturing dates, as older versions are unlikely to meet the CEN-ISO-ACGIH curve due to changes in manufacturing over time.

9. Sampling Guidance Recommendations

When preparing to carry out respirable dust sampling, it is important to read and understand the detailed requirements in AS 2985:2009 as there is very little latitude for deviation. In particular, pre and post sampling flowrate acceptance criteria and sampling filter selection are critical.

While AS 2985:2009 indicates that 25 mm and 37 mm filters can be used, in most circumstances 25 mm filters are utilised. Should 37 mm filters be required, it is advised to check with the analytical laboratory to ensure that they are compatible with the gravimetric analysis method (and any subsequent analysis, i.e. for respirable crystalline silica) used. For example, the 37 mm diameter filter leads to less sensitivity due to a thinner dust deposit and may also impact secondary analysis techniques (e.g. for respirable crystalline silica).

When conducting personal sampling for respirable dust for comparison against an established WES, it is critical that the samples are representative of the workers' shift. AS 2985:2009 recommends a sampling duration of not less than 4 hours – even though this has generally been based on a typical 8-hour shift. Many workplaces now employ longer shift lengths, and therefore sampling should be conducted for at least half of the shift length, and longer if practical to ensure the sample is representative of the workers' exposure. Shorter sampling times may be used in specific circumstances such as when task or process-based sampling is required to characterise exposure. Detailed knowledge of the exposure patterns are required in order to determine the appropriate sampling period. The AIOH recommends that near full shift sampling be carried out, where possible, for personal sampling.

In some cases, not only should the sampling period be chosen to be representative of the shift, it must also take into account the desired detection/reporting limits for the analysis of the filters (e.g. for respirable crystalline silica). Samples of longer duration also ensure a heavier dust deposit (to assist with analytical detection limits) and reduces inaccuracies with the sampling.

Other recommendations when sampling using cyclone samplers include:

- Ensure that the sampler is assembled correctly, including checking all 'O' rings are in place and serviceable;
- Ensure that grit pots are not perished and are firmly fitted to the cyclone;
- Check for leaks in the cyclone itself as this will impact air flows and flowrate through the cyclone;
- Conduct pre (and post) flowrate calibration measurements of the sampling train with the actual sampler to be used in line (i.e. not with the use of a 'dummy' sampler);
- Ensure that the sampler remains affixed to the worker and in an upright orientation at all times during sampling;
- Ensure that the sampler is not inverted and is transported upright after sampling (and remove the grit pot to prevent large particles falling onto the filter) or remove that sampling filter cassette at the completion of sampling for transportation. If the cassette is removed from the sampler, ensure that it is transported in a manner so as to avoid deposited dust from dislodging from the sample filter;
- After sampling, it is important to thoroughly clean (and dry) the cyclone sampler prior to reloading with a filter cassette for next use; and
- Ensure that the flowrate variations and pulsation effects are minimised by careful selection of the sampling pump utilised, otherwise it may impact the effective operation of the sampler.

It is important that the sampling and analytical methodology selected and utilised considers the specific contaminant to be determined. The sampling/analytical efficiency of the method chosen may also vary based on the actual aerosol of concern and the workplace conditions during sampling. There will always be uncertainties associated with exposure assessments. The important factor is to control as many of the sampling and analytical variables as possible through the use of validated and standardised techniques and good practices, in order to minimise the uncertainties.

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Search

- The NATA website (www.nata.com.au) for accredited laboratory facilities who can undertake testing and analysis of workplace airborne contaminants.
- The AIOH website for Occupational Hygiene consultants (www.aioh.org.au).