PD CEN/TR 16013-1:2010

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Workplace exposure — Guide for the use of direct-reading instruments for aerosol monitoring

Part 1: Choice of monitor for specific applications

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee EH/2/2, Work place atmospheres.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 69045 7

ICS 13.040.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 July 2010

Amendments issued since publication

Date	Text affected

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16013-1

May 2010

ICS 13.040.30

English Version

Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 1: Choice of monitor for specific applications

Exposition au poste de travail - Guide d'utilisation des instruments à lecture directe pour la surveillance des aérosols - Partie 1: Choix du moniteur pour des applications spécifiques

Exposition am Arbeitsplatz - Leitfaden für die Anwendung direkt anzeigender Geräte zur Überwachung von Aerosolen - Teil 1: Auswahl des Monitors für besondere Anwendungsfälle

This Technical Report was approved by CEN on 13 March 2010. It has been drawn up by the Technical Committee CEN/TC 137.

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Foreword

This document (CEN/TR 16013-1:2010) has been prepared by Technical Committee CEN/TC 137 "Assessment of workplace exposure to chemical and biological agents", the secretariat of which is held by DIN.

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CEN/TR 16013, *Workplace exposure — Guide for the use of direct-reading instruments for aerosol monitoring*, consists of the following parts:

— *Part 1: Choice of monitor for specific applications*

— *Part 2: Evaluation of airborne particle concentrations using Optical Particle Counters*

— *Part 3: Evaluation of airborne particle concentrations using photometers* (in preparation)

Introduction

The assessment of aerosols in the workplace can have several aims, including:

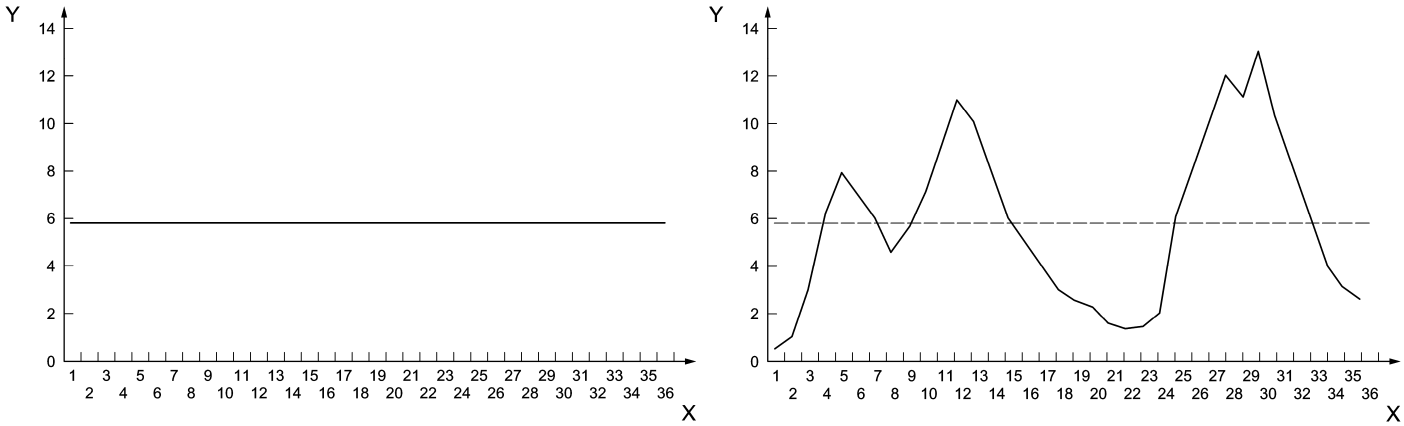
a) estimation of the mean concentration of health-related aerosol particles (see EN 481) during a working shift period (workplace characteristics or personal exposure by static or personal sampling);

b) sampling to provide a sample of airborne particles for later analysis (gravimetric, morphological, chemical, physical, mineralogical, etc., see EN 482);

c) evaluation of almost instantaneous concentrations produced by various work activities using automatic instruments (photometers, β-attenuation instruments, vibrational mass balance instruments);

d) evaluation of almost instantaneous concentrations and particle size distributions (optical particle counters – OPC).

This Technical Report concerns items c) and d), gives the principles, and details the general conditions to be satisfied. In occupational hygiene, no measurement procedure recommends exposure monitoring using direct-reading aerosol monitors. These instruments should instead be considered as permitting a complementary approach to the conventional filter-based gravimetric method. The different types of information obtained are explained in Figure 1.



a) b)

Key

X sample number (time) Y concentration (arb units)

Figure 1 — Information from integrated filter sampling vs. continuous monitoring

There is a wide range of portable and personal direct-reading aerosol monitors available.

Recent advances in modern electronics and battery technology means direct-reading dust monitors are becoming smaller and lighter and of relatively low price. In addition to reliance on compliance with Occupational Exposure Limits, emphasis is now also being placed on control banding and advice on suitable control systems. This has led to new roles being identified for direct-reading aerosol monitors in ensuring that systems deployed to control exposure to airborne dusts actually work. Some types of direct-reading aerosol monitors appear to be well suited to evaluate prevention action efficiency and to space- and time-related monitoring of concentration.

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All instruments mentioned in this document (see, in particular, Tables 2, 4, 6, 8 and 10) are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report only and does not constitute an endorsement by CEN of these products.

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1 Scope

This Technical Report describes the principles underlying the evaluation of one or more aerosol fractions using direct-reading aerosol monitors. The currently available methods for monitoring levels of aerosols in workplaces for a range of different purposes are described and details are given of their limits and possibilities in the field of occupational hygiene.

The document does not cover the sampling of aerosols for compliance with occupational exposure limits or the collection of aerosol particles for subsequent analysis.

2 Abbreviations

For the purposes of this document, the following abbreviations apply.

DRAM	direct-reading aerosol monitor
LOD	limit of detection
OEL	occupational exposure limit
OPC	optical particle counter
PM	particulate matter
TEOM	tapered element oscillating microbalance
TSP	total suspended particulate

3 Principles of direct-reading aerosol monitoring methods

3.1 General

There are many methods, based on different physical principles, for the instantaneous measurement of aerosols. Instruments used are generally called direct-reading or continuous monitoring instruments. Depending on their design, they can give the instantaneous or sequential concentration and can sometimes even measure particle size distribution.

Instantaneous measurement has several advantages:

a) immediate knowledge of the result without going through the laboratory, whence the possibility of rapid intervention (e.g. implementation of a ventilation system);

b) continuous measurement, long-distance surveillance, concentration record over time, mean concentration integration and calculation in selected periods, maxima and minima determination, source location, etc.;

c) measurement of concentration for particles of unstable composition (e.g. volatile substances);

d) monitoring and control of aerosol concentration.

Depending on the principles used, automatic methods can be classed into the following three main groups:

— vibrational mass method (see 3.2);

— beta attenuation method (see 3.3);

— optical methods (see 3.4).

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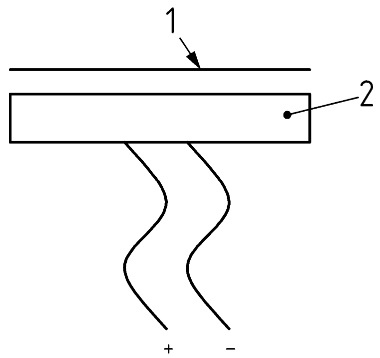
3.2 Vibrational mass methods

3.2.1 Piezoelectric mass monitors

3.2.1.1 Operating principle

Particles drawn into the instrument are collected on the surface of a piezoelectric crystal, forming part of a quartz crystal-based oscillating circuit (see Figure 2).



Key

1 piezoelectric crystal

2 frequency

Figure 2 — Schematic of piezoelectric mass monitor

The mass of deposited particles causes a reduction in the oscillation frequency f. The changed frequency is compared with the previous recorded initial frequency or a control circuit frequency. The frequency reduction is directly proportional to the particle mass (see [8]). The proportionality factor k_f expresses the crystal sensitivity with respect to the deposited weight. It is constant for each crystal (see [7]) and its value varies, in most cases, by approximately 200 Hz/µg. If the frequency change during sampling, for a time t, is Δf, the weight of collected dust will be $\frac{\Delta f}{k_f}$ and the aerosol mean concentration can be calculated according to Equation (1):

$$C = \frac{\Delta f}{Q \times t_s \times k_f} \quad (1)$$

where

C is the aerosol mean concentration, in milligrams per cubic metre;

Δf is the change resonance frequency, in Hertz;

Q is the sampling flow rate, in litres per minute;

t_s is the sampling time, in minutes;

k_f is the crystal mass sensitivity, in Hertz per microgram

The method is very sensitive and allows low concentrations of the order of several tens of micrograms per cubic metre to be measured. However, it is limited to fine particles (usually smaller than 10 µm) because of the small mechanical force between the particle and the crystal surface: if its mass is high, the particle cannot follow the vibration frequency. This is also a problem for high loads when there is lack of coupling between the outermost layers of particles and the crystal. This requires the crystal to be regularly cleaned and may limit the monitoring duration.

3.2.1.2 Determination of mass concentration of health-related fractions

The change in frequency of crystal is directly proportional to the mass of particles deposited and is therefore largely independent of the physical and chemical properties of the particles. There is no need therefore to use on-site calibration factors, providing that the crystal is not overloaded. Because of particle size limitations on particle/sensor coupling (mentioned above) only the mass concentration of the respirable fraction is measurable. Respirable size selection can be achieved using any suitable size selector; one instrument uses a single stage impactor with the respirable particles deposited on the crystal by electrostatic precipitation. Another instrument uses multiple crystals as the collection substrate for size separated particles in a 10-stage cascade impactor.

3.2.1.3 Calibration of piezoelectric instruments

Each crystal sensor has its own frequency response and so the instrument incorporating the crystal will be calibrated in the factory to give the required mass response. Provided that the crystal is not damaged, no further calibration is required.

3.2.1.4 Advantages/disadvantages of piezoelectric instruments

Table 1 gives advantages and disadvantages of piezoelectric instruments.

Table 1 — Advantages/disadvantages of piezoelectric instruments

Advantages	Disadvantages
— direct measurement of dust mass	— usage limited by dust loading on crystal
— no on-site calibration required	— regular cleaning of crystal required
— response independent of chemical composition and particle size (below 10 µm)	— only suitable for respirable particles
— relatively easy to use	

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3.2.1.5 Currently available piezobalance instruments

Table 2 gives an overview on currently available piezobalance instruments.

Table 2 — Currently available piezobalance instruments

Name [a]	Portable/ personal	Size mm	Weight kg	Size selection	Flow rate l/min	Response time s	Accuracy	Measure-ment range mg/m^3
Kanomax Piezo-balance dust monitor Model 3511®	portable	311 × 170 × 130	2	respirable fraction by impactor	1	from 0 mg/m^3 to 1 mg/m^3: 24 s from > 1 mg/m^3 to 10 mg/m^3: 120 s	± 10 % of reading	0,02 to 10
California Measure-ments Inc, PC-2HX QCM® real-time cascade impactor	portable, but mains-operated (battery-powered version by special order)	cascade impactor: 35 × 12,5 × 32 control unit: 18 × 43 × 32	5,4 10	10 stages (0,1 µm to 14 µm)	2	for average concentration 0,05 mg/m^3: 30 s	not given	0,005 to 1

NOTE "Accuracy" is defined by the manufacturers.

[a] Kanomax Piezo-balance dust monitor Model 3511® and California Measurements Inc, PC-2HX QCM® real-time cascade impactor are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.

3.2.2 TEOM − Tapered Element Oscillating Microbalance

3.2.2.1 Operating principle

This device is similar in principal to the piezoelectric microbalance but the oscillating frequency is applied to a tapered glass tube equipped with sampling filter at its narrow end (see Figure 3).

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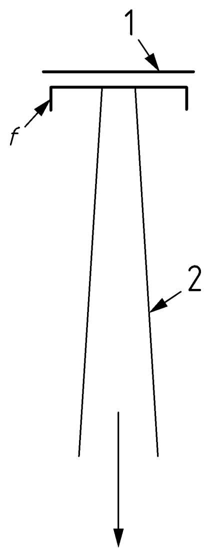

Key

1 filter

2 tapered glass tube

f frequency

Figure 3 — Schematic of the TEOM device

The 13 mm diameter filter responsible for collecting the sampled aerosol particles is held inside a plastic cassette that is a close push-fit to the glass tube. The top part of the tapered tube is coated with an electrically conducting layer and it is placed between two flat electrodes, which maintain a continuous electric field. An oscillating current flows through the conducting layer, prompting vibration of the tapered tube. The vibration frequency is measured by an optical system comprising an LED photo-emitting diode and a phototransistor. The pulsating current linked to the tapered tube oscillations is amplified and returned to the conducting layer, thereby creating a closed loop system. At equilibrium, the electrical oscillation frequency is equal to the tapered tube's natural mechanical vibration frequency. This frequency depends on the mass of the filter cassette positioned at the narrow end of the tube and, thus, on the mass of deposited particles, see [6]. The mass of particle collected on filter is calculated according to Equation (2):

$$\Delta m = K_0 \left(\frac{1}{f_\mathrm{b}^2} - \frac{1}{f_\mathrm{a}^2} \right) \tag{2}$$

where

Δm is the mass of particle collected on filter, in micrograms;

f_b is the frequency of the oscillating tube after particle collection, in Hertz;

f_a is the frequency of the oscillating tube before particle collection, in Hertz;

K_0 is a constant (spring constant) unique to each tapered tube, in micrograms per square second.

The control unit calculates the mass of particles collected on the filter based on the oscillation frequency difference before and after sampling as given in the above equation. The 13 mm diameter Pallflex® [1)] filter used is made from glass fibres coated with plastic and is relatively insensitive to changes in humidity which

1) Pallflex® filter is an example of a suitable product available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of this product.

can modify the particle mass. However, in order to minimize collection of water droplets when used in the outdoor atmosphere the whole sensing unit is held at a temperature of 50 °C. However, this has the disadvantage of vaporising some collected semi-volatile aerosol particles (e.g. some organic species and ammonium nitrate) and therefore providing reliable consistent results only for those particles that are non-volatile at and below 50 °C.

3.2.2.2 Determination of mass concentration of health-related fractions

Change in the oscillation frequency of the tapered glass tube is directly proportional to the mass of particles deposited on the filter and is therefore independent of the physical and chemical properties of the particles. There is no need therefore to use on-site calibration factors. With particle collection onto the filter, there is no limitation, in principle, on the size of particles that can be detected (unlike the piezoelectric crystal). Different health-related fractions can be sampled using particle size selective inlets, such as cyclones, impactors or porous foam plugs. The mains-powered TEOM is widely used to monitor ambient particle levels and sampling inlets for PM_{10}, $PM_{2,5}$ and PM_1 fractions are available.

3.2.2.3 Calibration of TEOM

Each tapered glass tube sensor has its own frequency response (K_0) and so the instrument incorporating the sensor is calibrated in the factory to give the required mass response. Provided that the sensor is not damaged and the filter is fitted correctly on to the tapered glass tube, no further calibration is required. However, as a check on the stability of the performance of the sensor, reference filters of known mass can be used as part of a quality control audit system

3.2.2.4 Advantages and disadvantages

Table 3 gives advantages and disadvantages of TEOM instruments.

Table 3 — Advantages/disadvantages of TEOM instruments

Advantages	Disadvantages
— direct measurement of dust mass	— detector system held at 50 °C so mass measurement does not include liquid or semi-volatile aerosols
— no on-site calibration required	— mains-operated instrument, although personal monitor available for use in mines
— response independent of chemical composition and particle size	— requires > 30 min warm up time at start of monitoring.
— only monitor capable of monitoring all three aerosol fractions without calibration factors (not at the same time)	— large multi unit device not easy to move, although personal monitor available for use in mines
	— not easy to use

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3.2.2.5 Currently available TEOM instruments

Table 4 gives an overview on currently available TEOM instruments.

Table 4 — Currently available TEOM instruments

Name [a]	Portable/ personal	Size	Weight	Size selection	Flow rate	Response time	Accuracy	Measure-ment range
		mm	kg		l/min	s		mg/m³
Thermo TEOM 1400 series®	static	two units: sensor unit: 360 × 280 × 330 control unit: 430 × 380 × 220	 18 15	can use any size selective inlet for inhalable, thoracic or respirable aerosols	16,7	depends upon concentration − real time mass concentration averages: 10 min default (10 s to 3 600 s by choice)	± 0,75 %	0,000 1 to 5 000
R & P PDM®	personal	TEOM unit incorporated into cap lamp battery 243 × 87 × 193	2,8	uses currently cyclone for respirable fraction	2,2	depends upon concentration – real time mass concentration averages: 30 min default (10 min to 60 min by choice)	± 25 % at 0,2 mg/m³	0,05 to 200

NOTE "Accuracy" is defined by the manufacturers themselves and in some cases the definitions are different.

[a] Thermo TEOM 1400 series® and R & P PDM® are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.

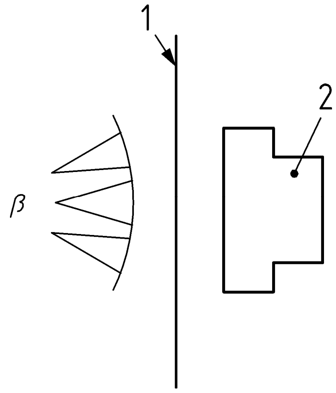
The personal version of the TEOM is available (R&P PDM® [2)]), although this was originally developed for the mining industry and is linked to the cap lamp used by miners. It would therefore require considerable modification to be used in general workplace environments. However, researchers are currently investigating its use for this purpose.

3.3 Beta mass monitors

3.3.1 Operating principle

In this case, the weight of dust particles sampled on the filter (or collection substrate) is estimated by attenuation of beta rays crossing the filter positioned between a source and a Geiger-Müller counter (see Figure 4).

2) R&P PDM® is an example of a suitable product available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of this product.



Key

1 aerosol particle collection substrate

2 Geiger-Müller counter

β beta radiation source

Figure 4 — Schematic of beta mass monitor

Beta ray attenuation by a substance is proportional to the ratio between the atomic number and the atomic mass of that substance. As this ratio does not vary much between the elements (apart from hydrogen), this means that the attenuation relates to the mass of particles collected per filter unit area (see [4]). Measurement involves recording and comparing numbers of pulses detected by the Geiger-Müller counter before and after sampling. If N_1 is the number of pulses per unit time for a clean filter, then:

$$N_1 = N_0 \exp\left(-k_\beta \times m_1\right) \tag{3}$$

and if N_2 is the number of pulses per unit time for a particle-loaded filter:

$$N_2 = N_0 \exp\left[-k_\beta\left(m_1 + \Delta m\right)\right] \tag{4}$$

where

N_0 is the pulse count without a filter, in numbers per second;

k_β is the mass absorption coefficient, in square centimetres per milligram;

m_1 is the surface mass of clean filter, in milligrams per square centimetre;

Δm is the surface mass of collected particles, in milligrams per square centimetre.

The pulse ratio is calculated according to Equation (5):

$$\frac{N_2}{N_1} = \exp\left(k_\beta \Delta m\right) \tag{5}$$

whence the surface mass of collected particles is calculated according to Equation (6):

$$\Delta m = \frac{\left(\ln N_2 - \ln N_1\right)}{k_\beta} \tag{6}$$

Finally, the aerosol mean concentration during sampling is given by Equation (7):

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$$C = 1\,000 \frac{\Delta m \times S}{Q \times t_s} \tag{7}$$

where

- C is the aerosol mean concentration, in milligrams per cubic metre;
- Δm is the surface mass of collected particles, in milligrams per square centimetre;
- S is the filter effective area, in square centimetres;
- Q is the sampling flow rate, in litres per minute;
- t_s is the sampling time, in minutes.

Using this method, the measurement result depends on the uniformity of the deposition of the particles on the filter and their chemical composition. It has been shown that the influence of particle chemical composition is low for most urban pollutants (see [9]). This problem should be taken into account in the workplace where a large variety of pollutants is encountered.

3.3.2 Determination of mass concentration of health-related fractions

Particles are normally collected on suitable filter materials and so in principle there are no particle collection or deposition problems. However, as mentioned above, the response is affected by the uniformity of particle deposition on the filter and so the method is normally limited to the thoracic (PM_{10}) or respirable particle fractions. Particle size selective inlets connected to the mass sensing head are used to select the thoracic or respirable fractions.

3.3.3 Calibration of beta mass monitors

In order to determine the mass of particles deposited on the filter it is necessary to take into account the attenuation of the beta radiation by the filter and by the particles. This is described above and in practical direct-reading instruments is determined by alternately scanning areas of clean and mass-deposited filter. Other complications arise from the effect associated with the geometry of the beta source and detection system. Careful calibration against known gravimetrically assessed reference samples is therefore required. This is initially carried out by the manufacturer and can then be routinely checked in the laboratory.

3.3.4 Advantages and disadvantages

Table 5 gives advantages and disadvantages of beta mass monitors.

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Table 5 — Advantages/disadvantages of beta mass monitors

Advantages	Disadvantages
— direct measurement of dust mass	— includes radioactive source, which causes problems for transportation to and from site and for disposal
— no on-site calibration required	— long integration periods so time resolution poor
— response independent of chemical composition and particle size for most common industrial aerosols	— mostly mains-operated
— filter collection can be used for chemical analysis	— naturally occurring radioactive materials may influence the result
— once on-site relatively easy to use	

3.3.5 Currently available beta mass monitors

Table 6 — Currently available beta mass monitors

Name [a]	Portable/ personal	Size mm	Weight kg	Size selection	Flow rate l /min	Response time	Accuracy	Measure-ment range mg/m^3
Met One Instru-ments BAM 1020®	static	310 × 430 × 400	—	can use any size selective inlet for inhalable, thoracic or respirable dust	0 to 20	1 h depending upon sampled mass	± 8 % of indication for 1 h mode	0 to 10
Thermo FH62 I-R Beta Atten-uation Monitor®	static	not mentioned	—	can use any size selective inlet TSP, PM_{10}, $PM_{2,5}$, human health effects	16,7	30 min, 1 h, 3 h, 24 h	0,001 mg/m^3 for 24 h sample	two ranges: 0 to 5, 0 to 10
Verewa F-701 Beta gauge particle monitor®	static	320 × 450 × 500	26	can use any size selective inlet TSP, PM_{10}, $PM_{2,5}$	16,7	selectable from 15 min to 24 h	± 2 % full scale	selectable: from 0 to 0,1 and from 0 to 10

NOTE "Accuracy" is defined by the manufacturers themselves and can be different.

[a] Met One Instruments BAM 1020®, Thermo FH62 I-R Beta Attenuation Monitor® and Verewa F-701 Beta gauge particle monitor® are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.

3.4 Methods of optical measurement of aerosols

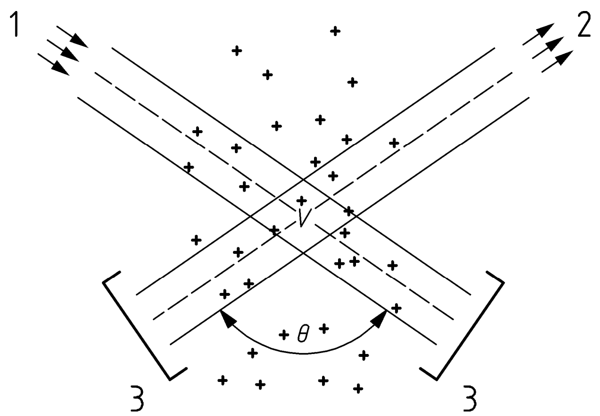
3.4.1 General

Several measuring methods have been developed based on the principle of light scattering by aerosol particles. Various incident light sources are used: white light emitted by incandescent lamps, visible near-infrared monochromatic light emitted by photoelectric diodes (LEDs) or laser sources, distinguished by their high intensity. Scattered light detectors are usually sensitive photomultipliers or photodiodes with response spectra covering approximately the source emission spectra. In practice, there are many different light scattering instruments.

3.4.2 Photometers

3.4.2.1 Operating principle

The light scattered by particles contained within a finite volume V can be used to determine the concentration of those particles (see Figure 5).



Key

1 incident light

2 scattered light

3 light trap

V optical sensing volume

θ angle of detection (scattering angle)

Figure 5 — Schematic of photometer optical cell

A wide range of instruments is available that use this principle, and they are generally called photometers or Tyndallometers. They can operate either with an open cell (in passive mode), in which the measured aerosol penetrates an optical zone by natural movement of the surrounding air, or with a sampling system (pumped mode). In the former case, there is no sampling aspiration pump, but the open cell can be disturbed by ambient light. A modulated monochromatic beam is often used to limit the measurement influence of ambient light, visible light being absorbed by a filter in front of the photo detector (see [1]).

This technique allows a wide range of particle concentrations to be measured (from several micrograms per cubic metre to hundreds of milligrams per cubic metre in different instruments) but it has a number of drawbacks. Although the signal is proportional to particle concentration, scattered light intensity increases as the particles become finer and the observation angle is small. For example, at a 30° scattering angle, particles smaller than 1,5 µm are grossly over-estimated (see [2]). Changing aerosol particle size distribution will therefore significantly alter the concentration response. Instruments allowing measurement of a certain particle size fraction can be reached by technical means (observation angle, incident light wavelength, e.g. the respirable fraction measured in occupational hygiene, see [10]). More details are given in Part 3 of CEN/TR 16013.

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3.4.2.2 Determination of mass concentration of health-related fractions

For most currently available photometers, the instrument setup is such that the scattered light intensity is at a maximum for particles from 1 µm to 2 µm, and is close to zero for particles greater than 10 µm. They are therefore ideally suited to the respirable fraction and become successively inaccurate for the coarser particles within the thoracic and inhalable aerosol conventions (see [3]). Determination of the mass concentration of the respirable fraction requires careful on-site calibration for the aerosol being sampled as described in 3.4.2.3.

3.4.2.3 Calibration of photometers

Photometers are graduated in mg/m^3 of respirable dust and require calibration with respect to this fraction. This is normally carried out by the manufacturer using a polydisperse test dust such as A 2 fine test dust following procedures laid out in standards such as ISO 12103-1. There are others given in Table 8. The reading given is then only valid for a specific dust and the instrument usually need to be recalibrated to measure an aerosol of particles with different refractive indices or particle shape or a different particle size distribution (see [11]). On-site calibration is performed by comparison with gravimetric sampling using a reference gravimetric sampler (such as a personal cyclone positioned side-by-side) or by comparison with mass concentration obtained by weighing the particles collected on a special filter-based attachment (see [10]). Either of these two methods will give the reference mass concentration (C_r). The mass concentration given by the photometer (C_m) is then corrected by multiplying by the correction coefficient (C_r/C_m.). However, it is only valid for the identical and stable aerosols and recalibration should be performed when either nature of the aerosol particles changes (size, shape, density or refractive index) or the workplace site is changed.

For more detailed treatment of photometers see Part 3 of CEN/TR 16013.

3.4.2.4 Advantages and disadvantages

Table 7 gives advantages and disadvantages of photometers.

Table 7 — Advantages and disadvantages of photometers

Advantages	Disadvantages
— very fast response	— response not directly proportional to mass, but is dependent upon particle size, shape and refractive index
— very wide concentration range	— need factory and on-site calibration for mixed or varying aerosols
— portable and personal models available	— response drops off for particles > 10 µm, so only suitable for respirable fraction
— passive models require very little power	— oversensitive to fine aerosols (e.g. water mist, fume and cigarette smoke)
— pumped models may have filter collection that can be used for analysis	
— very simple use (most simple of all types of monitor described)	

There are many photometers available for a wide range of applications. The list given in Table 8 includes only those that are battery-powered and suitable for use in occupational hygiene settings.

The responses for large particles in thoracic and inhalable fractions are very low due to lack of sensitivity (see [10]).

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Table 8 — Currently available photometers

Name [a] (of instrument)	Pumped flow rate passive l/min	Personal or portable	Size mm	Weight kg	Particle size range µm	Measure-ment range mg/m³	Precision mg/m³	Accuracy	Resolution	Calibration	Display and data logging
Casella Microdust Pro®	passive	portable	245 × 95 × 50 probe 290 × 35 ø	1,0	not mentioned	0 to 2 500	not mentioned	not mentioned	0,001 mg/m³	factory calibrated with ISO 12103-A2 (fine test dust); can be calibrated on-site using add-on pump/filter system	128 × 64 pixel screen gives rolling averages of concentration, 15 700 points data logger
SKC Haz-dust 1®	passive	portable	229 × 70 × 63	0,5	0,1 to 50	0,01 to 200	± 0,02	± 10 % according to NIOSH 0600	not mentioned	factory calibrated with SAE fine dust according to NIOSH 0600	1-line LCD, optional data logger
SKC Split 2®	pumped 2 l/min or passive	personal	180 × 80 × 45	0,8	0,1 to 10 (R) 0,1 to 50 (T) 0,1 to 100 (I)	0,01 to 200	± 0,02	± 10 % according to NIOSH 0600	not mentioned	factory calibrated with Arizona road dust according to NIOSH 0600. Has inhalable entry and back-up filter as standard and calibration post for on-site	4-line LCD, 21 500 points data logger
TSI Sidepak®	pumped 0,7 to 1,8	personal	130 × 92 × 70	0,5	0,1 to 10 built-in impactors to choose "none", 1,0, 2,5 or 10	0,001 to 20	not mentioned	not mentioned	0,001 mg/m³ (min.)	factory calibrated to respirable fraction with ISO 12103-A1 (ultrafine test dust)	2-line LCD, 31 000 points data logger
TSI Dustrak®	pumped 1,4 to 2,4	portable	221 × 150 × 87	1,5	0,1 to 10 (approx.)	0,001 to 100	not mentioned	not mentioned	0,1 % of reading or 0,001 mg/m³	factory calibrated with ISO 12103-A1 (ultrafine test dust)	1-line LCD, 31 000 points data logger

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Table 8 *(continued)*

Name [a] (of instrument)	Pumped flow rate passive l/min	Personal or portable	Size mm	Weight kg	Particle size range µm	Measure-ment range mg/m³	Precision mg/m³	Accuracy	Resolution	Calibration	Display and data logging
Thermo DataRAM 4®	pumped 1 to 3	portable	134 × 184 × 346	5,3	0,08 to 10	0,000 1 to 400	± 0,01	± 2 % of reading ± precision	0,1 % of reading or 0,000 1 mg/m³	factory calibrated with SAE fine test dust; has an in-built optical scattering element	8-line LCD, 50 000 points data logger
Thermo personal DataRAM®	passive or pumped 1 to 5 with add-on pump/filter system	personal	153 × 92 × 63	0,5 (passive)	0,1 to 10 (max. response)	0,001 to 400	± 0,005	± 5 % of reading ± precision	0,1 % of reading or 0,001 mg/m³	factory calibrated with SAE fine test dust; can be calibrated on-site using add-on pump/filter system	2-line LCD, 13 000 points data logger
Sibata PDS 2®	pumped 2 l/min	personal	sensor 100 × 36 × 95 control unit 98 × 43 × 106	0,3 0,5	not mentioned	0,001 to 100	not mentioned	± 10 % to calibrated latex particles	0,001 mg/m³	factory calibrated with 0,6 µm latex spheres	1-line LCD, 60 000 points data logger
Hund TM-µP®	passive	portable	200 × 110 × 40	1,0	respirable	0 to 100	0,01 (LOD)	not mentioned	—	factory calibrated with respirable coal dust; can be calibrated with other dusts	4-digit display in mass concentration
TSI Respicon®	pumped 3 to 11	personal	sensor 110 × 63 × 69 data logger 210 × 100 × 55	0,48 0,58	three fractions via virtual impactors	0 to 250 for each of the three stages	0,05 (LOD)	≤ 30 % following EN 13205 procedures	0,01 %	—	—

NOTE "Precision", "accuracy" and "resolution" are defined by the manufacturers themselves and can be different.

[a] Casella Microdust Pro®, SKC Haz-dust 1®, SKC Split 2®, TSI Sidepak®, TSI Dustrak®, Thermo DataRAM 4®, Thermo personal DataRAM®, Sibata PDS 2®, Hund TM-µP® and TSI Respicon® are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.

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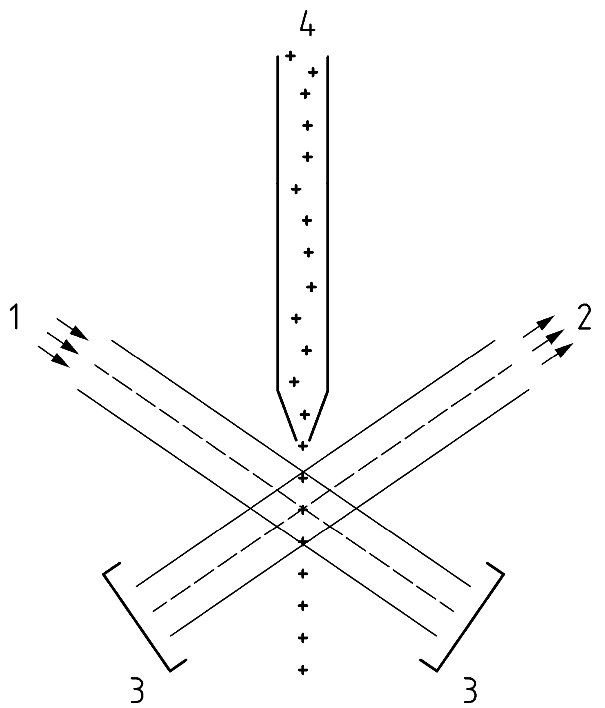
3.4.3 Optical particle counters

3.4.3.1 Operating principle

The particle counting method involves passing particles one by one through a small illuminated volume (see Figure 6).



Key

1 incident light

2 scattered light

3 light trap

4 aerosol stream

Figure 6 — Schematic of optical particle counter measuring cell

The scattered light intensity from each particle is detected and converted into an electrical signal by a photosensitive component. The electrical signal is then amplified and recorded. Signal analysis allows particles to be counted and their size to be estimated. This method requires sampling of the aerosol by a pump. Part of the main airflow is filtered, then recycled as a clean air stream surrounding the aerosol flow, thereby preventing particle deposition on instrument optical components. Only low concentrations can be measured using this method, in particular because of coincidence errors in the measured volume. The coincidence occurs when two or more particles pass simultaneously through the optical sensing volume (see Figure 6). Maximum measurable concentration is of the order of a few hundred particles per cubic centimetre. Standard optical particle counters for use in industrial workplaces can provide reliable results for aerosol particles in the size range from 0,3 µm to 10 µm. Certain instruments can measure particles down to 0,1 µm (even 0,05 µm) using a laser source rather than an incandescent source (see [5] and [12]), but these are mains-operated special instruments that are not normally used for workplace measurements. More details are given in Part 2 of CEN/TR 16013.

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3.4.3.2 Determination of mass concentration of health-related fractions

It is possible to determine the mass concentration of the respirable fraction of workplace aerosols from the particle number concentrations given in the various size channels of an OPC. It is to be assumed that the particles are spherical and have the same known density. For the thoracic fraction, the mass concentration results are less reliable. It is not recommended using OPCs to measure the mass concentration of the inhalable fraction.

For more details see Part 2 of CEN/TR 16013.

3.4.3.3 Calibration of optical particle counters

Optical particle counters require calibration of both the particle count response and the particle diameter response. Full details on this are given in Part 2 of CEN/TR 16013.

3.4.3.4 Advantages and disadvantages

Table 9 gives advantages and disadvantages of optical particle counters.

Table 9 — Advantages and disadvantages of optical particle counters

Advantages	Disadvantages
— very fast response	— response not directly proportional to mass, but dependent upon particle size, shape and refractive index
— portable and personal models available	— limitation on maximum particle counts in each channel can restrict use in high concentrations
— can select boundaries of size channels and, therefore, can focus on specific particle sizes	— response drops off for particles > 15 μm, therefore, only suitable for the respirable and thoracic fraction
— relatively simple to use on-site, although interpretation can be difficult	

3.4.3.5 Currently available battery-powered optical particle counters

There are many optical particle counters available for a wide range of applications. The list given in Table 10 includes only those that are battery-powered and suitable for use in occupational hygiene settings.

NOTE 1 Instruments designed specifically for use in clean rooms have been excluded from Table 10.

NOTE 2 The particle size range given in Table 10 is for counting and not a function of aerodynamic size selection.

NOTE 3 The concentration range (see Table 10) quoted by the manufacturer is a very important parameter to consider when choosing an OPC. Care needs to be taken to avoid using an OPC where high concentrations are likely to lead to errors from coincidence.

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Table 10 — Currently available optical particle counters

Name [a]	Hand-held/ personal	Size mm	Weight kg	Flow rate l/min	Particle size range µm	Size channels µm	Concentration range parts/ml	Counting efficiency	Additional features mg/m^3
TSI Aerotrak 8220®	hand-held	254 × 114 × 76	1,0	2,8	0,3 to 10	six channels adjustable by the user: 0,3, 0,5, 1, 3, 5, 10	1 to 70 at 5 % coincidence	(50 ± 10) % at 0,3 µm 100 % at 0,45 µm	—
TSI Aerotrak 8240®	portable	254 × 178 × 241	5,8	28,3	0,3 to 10	six channels adjustable by the user: 0,3, 0,5, 1, 3, 5, 10	1 to 18 at 5 % coincidence	(50 ± 10) % at 0,3 µm 100 % at 0,45 µm	—
MET ONE HHPC-2®	hand-held	114 × 210 × 57	1,0	2,8	0,3 to 20	two channels factory set: 0,3, 0,5, 1,0, 5, 10, 15, 20	1 to 70 at 5 % coincidence	(50 ± 10) % at 0,3 µm 100 % by 0,45 µm	—
GRIMM 1.101 Workplace®	portable	240 × 120 × 60	2,5	0,6	0,5 to 15	three channels factory set according to EN 481: inhalable, thoracic, respirable	0,1 mg/m^3 to 10 mg/m^3	not mentioned	has in-built back-up filter for on-site calibration and subsequent chemical analysis of particles
GRIMM 1.109 Research®	portable	240 × 120 × 60	2,5	1,2	0,25 to 32	31 channels in size range	1 to 2 × 10^3 0,1 mg/m^3 to 100 mg/m^3	not mentioned	has in-built back-up filter for on-site calibration and subsequent chemical analysis of particles
BIONTECH HPC600®	hand-held	185 × 90 × 48	0,8	2,8	0,3 to 25	six channels fixed: 0,3, 0,5, 0,7, 1,0, 2,0, 5,0; user adjustable in size range	1 to 70 at 5 % coincidence	(50 ± 20) % at 0,3 µm (100 ± 10) % at 0,45 µm	main base unit to download data, data printing, battery charging etc.
GRAYWOLF GW3016®	hand-held	222 × 127 × 64	1,0	2,8	0,3 to 25	six channels factory set from 0,3, 0,5, 0,7, 1,0, 2,5, 3,0, 5,0, 10,0, 25,0.	1 to 140 at 5 % coincidence	50 % at 0,3 µm 100 % by 0,45 µm	—

[a] TSI Aerotrak 8220®, TSI Aerotrak 8240®, MET ONE HHPC-2®, GRIMM 1.101 Work place® , GRIMM 1.109 Research®, BIONTECH HPC600® and GRAYWOLF GW3016® are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.

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4 Requirements for different applications of direct-reading dust monitors

4.1 General

Depending on its foreseen application a suitable direct-reading dust monitor need to fulfil specific provisions which are listed in 4.2 to 4.7 as attributes for six different cases of potential uses of DRAMs. Comparing these provisions with the characteristics of the available instruments described in Clause 3, will enable the user of this Technical Report to select the most suitable DRAM for his purposes.

4.2 Walk through surveys

For walk through surveys the DRAM should have the following attributes:

— portable (battery-powered);

— response preferably independent of particle characteristics;

— fast response time;

— concentration displayed on a screen;

— particle size selection not important.

Walk through surveys can provide additional information for inclusion in the "Basic Survey" outlined in EN 689:1995.

4.3 Identification of main process or source emitting aerosols

For identification of the main process or source emitting aerosols, the DRAM should have the following attributes:

— can be mains-operated or battery-powered monitor;

— response preferably independent of particle characteristics;

— relatively fast response time, but depends upon duration of processes being monitored;

— needs to run and record data for shift length period to monitor all possible aerosol emitting processes.

These studies can provide additional information for inclusion in the "Basic Survey" outlined in EN 689:1995.

4.4 Use with video visual techniques

For use with video visual techniques the DRAM should have the following attributes:

— personal and unobtrusive;

— particle size selectivity related to the potential health effects from the process being monitored;

— fast response time;

— signal from DRAM needs to be capable of being integrated with video images.

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4.5 Assessing efficiency of control systems

For use in assessing the efficiency of control systems, the DRAM should have the following attributes:

- can be mains-operated and static monitor;
- particle size selectivity related to the potential health effects from the process being monitored;
- response should have wide dynamic range especially for testing the efficiency of filters;
- may need two identical instruments calibrated to give equivalent results;
- fast response not necessarily required.

4.6 Watchdogs to monitor levels in workplaces and ensure controls are working

For use as watchdogs to monitor levels in workplaces to ensure that control are working, the DRAM should have the following attributes:

- simple, cheap (passive) monitors for distribution around workplaces;
- can be battery-powered or mains-operated static;
- response calibrated against reference monitors, possibly personal monitors for specific processes;
- information tele-metered to central hub system;
- alarm function set to go off when agreed level exceeded;
- fast response not necessary.

4.7 Surrogate personal exposure assessment

Direct-reading aerosol monitors cannot currently be used to measure exposure to determine compliance with occupational exposure limits (OELs). However, there are a number of situations where an indication of exposure is important:

a) use with video visual techniques to demonstrate changes in techniques to minimise exposure for worker training;

b) for situations where there is no OEL and relative changes in exposure as measured with DRAMs can be used to demonstrate improvements in control.

For this purpose, the DRAM should have the following attributes:

- personal and unobtrusive;
- particle size selectivity related to the potential health effects from the process being monitored;
- response calibrated on-site against in-built filter or suitable compliance sampler worn alongside DRAM;
- fast response time for video visual work, but not necessary for demonstrating overall reduction in exposure.

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