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Workplace atmospheres — Guidance for sampling of inhalable, thoracic and respirable aerosol fractions

ICS 13.040.30

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National foreword

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- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

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English Version

Workplace atmospheres - Guidance for sampling of inhalable, thoracic and respirable aerosol fractions

Atmosphères de lieux de travail - Guide pour l'échantillonnage des fractions d'aérosols inhalables, thoraciques et alvéolaires

Arbeitsplatzatmosphäre - Leitfaden zur Probenahme der einatembaren, thorakalen und alveolengängigen Aerosolfraktion

This Technical Report was approved by CEN on 10 July 2005. It has been drawn up by the Technical Committee CEN/TC 137.

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Foreword

This Technical Report (CEN/TR 15230:2005) 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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0 Introduction

0.1 Background

A number of materials hazardous to health occur in the workplace in the form of aerosols, i.e. suspensions of solid or liquid particles in air. Dust is generally understood to be an aerosol of solid particles, mechanically produced, with individual particle diameters of 0,1 µm upwards. Dust particles can be compact in shape, or can have extreme shapes, as for example in the case of airborne fibres. Fume is an aerosol of solid particles generated by condensation from the vapour state usually following the evaporation of molten metals. Smoke is an aerosol of solid and or liquid particles generated by condensation or nucleation of vapours after burning of carbonaceous material. In both fumes and smokes the primary particle diameters are typically less than 0,1 µm which form larger aggregated particles. Mists are aerosols formed from liquid droplets. In this document the term ''aerosol' is used to describe any suspension of particles in air, whether the airborne particles constitute a solid dust, airborne fibres or droplets, a fume, a smoke or a mist.

Aerosol sampling at workplaces can be performed for many reasons using different sampling strategies: These include comparison of the measured concentration with the occupational exposure Limit Value (LV), exposure assessment for epidemiological studies and evaluation of control measures. Occupational Exposure Limits have been defined for many types of aerosol. In order to demonstrate that personal exposure is adequately controlled it is usually necessary to determine the concentration of the aerosol by means of personal sampling. In some cases a direct determination of the aerosol concentration is all that is needed. In other cases a subsequent analytical technique is applied for the determination of a particular harmful element or compound present in the aerosol.

0.2 Sampling instruments

Many instruments have been developed over the years for sampling airborne particles for the purpose of assessing exposure or for determining the efficacy of dust control measures (see [6]). In the past, sampling instruments were often inadequately standardised in terms of their collection characteristics. Modern standards for monitoring exposure to airborne particles are performance based, i.e. they require that the instruments used meet agreed performance criteria with respect to target specifications. This document is intended to help those responsible for making measurements to select and use instruments that meet these modern performance standards.

0.3 Inhalable, thoracic and respirable fractions of airborne particles

Most industrial aerosols contain particles of a wide range of sizes. The behaviour, deposition and fate of any particle after entry into the human respiratory system, and the response that it elicits, depends on the nature and size of the particle. For the purposes of occupational hygiene it is important to consider the concentrations of particles present in different size fractions.

Inhalable dust corresponds to the fraction of airborne material that enters the nose and mouth during breathing, and is therefore available for deposition anywhere in the respiratory tract. The target specification for sampling the inhalable fraction is given in EN 481. In reality the inhalable fraction depends on the prevailing air movement around the exposed person (wind speed and direction), and on whether breathing is by nose or mouth. It has, however, been possible to define a target specification for sampling instruments that approximates to the inhalable fraction, for representative values of breathing rate, and for a person exposed equally to all wind directions.

Thoracic dust corresponds to the fraction of airborne material that passes through the nose or mouth of the exposed person, and enters the branching airways of the lungs. The target specification for sampling the thoracic fraction is given in EN 481. In reality the thoracic fraction depends on breathing rate and varies for different individuals, however it has been possible to define a target specification for sampling instruments which approximates to the thoracic fraction for an average person.

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Respirable dust corresponds to the fraction of airborne material that penetrates to the gas exchange region of the lung. The target specification for sampling the respirable fraction is given in EN 481. The respirable fraction varies for different individuals, however it has been possible to define a target specification for sampling instruments, which approximates to the respirable fraction for an average person.

NOTE 1 The PM 10 fraction is defined by US Environmental Protection Agency (and adopted in EN 12341). It also corresponds to the fraction of material that passes through the nose or mouth of the exposed person, and passes the larynx. However, it is based on other experimental data than the scientific basis for the thoracic fraction, and is therefore slightly different. The main difference between the PM 10 and thoracic sampling conventions is that at 15 µm the sampling efficiency for a sampler for PM 10 should be zero whereas it for a sampler for the thoracic fraction should be 19 %.

NOTE 2 The PM 2,5 fraction sampler is defined by US Environmental Protection Agency (see also EN 14907). It corresponds to the fraction of material in the accumulation and nuclei modes of the ambient particle size distribution.

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1 Scope

This Technical Report describes methods that are suitable for the determination of the health-related fractions of most aerosols in the workplace.

For more complex aerosols such as bioaerosols, fibres, radioactive aerosols and particle-vapour mixtures further considerations are necessary (see e.g. relevant standards).

This Technical Report is not applicable to the monitoring of airborne particle concentrations using direct-reading instruments.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 481, *Workplace atmospheres – Size fraction definitions for measurement of airborne particles*

EN 482, *Workplace atmospheres – General requirements for the performance of procedures for the measurement of chemical agents*

EN 689, *Workplace atmospheres – Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy*

EN 1232, *Workplace atmospheres – Pumps for personal sampling of chemical agents – Requirements and test methods*

EN 1540, *Workplace atmospheres – Terminology*

EN 12919, *Workplace atmospheres – Pumps for the sampling of chemical agents with a volume flow rate of over 5 l/min – Requirements and test methods*

EN 13098, *Workplace atmospheres – Guidelines for measurement of airborne micro-organisms and endotoxin*

EN 13205, *Workplace atmospheres – Assessment of performance of instruments for measurement of airborne particle concentrations*

ISO 15767, *Workplace atmosphere – Controlling and characterizing errors in weighing collected aerosols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in the standards listed above, if applicable, apply.

4 Sampling strategy

No sampling strategy can provide comprehensive information for all objectives. The sampling strategy should be carefully tailored to meet the required objectives. Before a measurement survey is started in the workplace a number of fundamental questions like these have to be answered:

- why sample?

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- how to sample?
- whose exposure should be measured?
- where to sample?
- when to measure?
- how long to sample for?
- how many measurements?
- how often to sample?

The reason being that time, money and sampling technology constraints are such that not every worker's dust exposure can be measured on every single day of his working career. An optimal sampling strategy will have to be designed given the limited budget available. The actual sampling strategy used will be largely determined by the reasons for the measurement survey. Several objectives can be mentioned:

- to provide information on personal exposure to evaluate compliance with limit values;
- to provide information on personal exposure in the framework of an epidemiological study;
- to provide information on the location and intensity of a source;
- to provide information on prevailing concentrations and trends in the general workplace atmosphere;
- to provide information on the effectiveness of control measures;
- to provide samples of airborne particles for subsequent analytical or toxicological investigations.

For the first two objectives personal sampling is well suited to measure or to monitor individual exposure of workers to airborne particles. The aerosol is sampled in the breathing zone of individual workers. The other objectives on the other hand are often met through static sampling. The aim of static sampling is usually to measure and to analyse the workplace atmosphere in terms of aerosol concentration, particle size-distribution and chemical or mineralogical composition. Another purpose of static sampling is monitoring of time-variations in aerosol concentration at fixed locations. There can be special situations which need the application of a static-sampling strategy, for example, when higher air volume flow rates are needed, or when the system of compliance control measurements depends on that approach. All deviations from a personal sampling strategy should be specifically justified.

When checking compliance often so-called "worst-case" sampling is performed, but these measurements are of limited use for assessing exposure epidemiological purposes. Strategies like "worst-case" sampling can be cost-effective for compliance testing. However, special care should be taken when measurement results coming from a "worst-case" strategy have to be used for epidemiological purposes. Nevertheless this is done in many cases.

Studies focusing on temporal and personal patterns of occupational exposure concentrations, have shown that assumptions of homogeneous or similar exposure groups made up of workers performing the same tasks in one location are often not met. Efficient and effective measurement strategies therefore should take into account temporal and personal variations in exposure concentrations.

Guidance for the assessment of exposure to inhalation to chemical agents for comparison with limit values can be found in EN 689. The strategies described in EN 689 assume that homogeneous exposure groups exist. Rappaport *et al.* (see [4]) have described more recently a measurement strategy taking into account between-worker variability in long-term exposure. This strategy uses an observational group approach, but recognises that exposure varies both within and between workers. The strategy proposed by Rappaport *et.al*. is only suitable for situations where we seek to evaluate and control long-term exposures, which can give rise

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to chronic health effects. It would be inappropriate to employ this approach to evaluate and control short-term exposures or scenarios where acute effects are likely. Additionally, in short-term sampling the limit of quantitation has to be considered.

5 Method performance

5.1 Limit of detection and limit of quantitation

Both the limit of detection and the limit of quantitation of the methods described in this document depend on the volume of air sampled, and on the analytical method used to quantify the dust collected on the sampling substrates used within the sampling instruments described. Further information on the determination of the limits of detection and quantitation for gravimetric analysis of airborne dust samples is given in ISO 15767.

5.2 Sampling bias

Sampling bias arises primarily from two sources:

a) Concentration bias is minimised by carefully siting the sampler within the breathing zone of the worker, close to the nose and mouth (see 8.2). The concentration to which the sampler is exposed is not necessarily the same as the concentration to which the person is exposed. This is a particularly difficult problem for sampling the inhalable fraction, as larger dust particles are very non-uniformly distributed and are typically produced by localised sources in the workplace.

b) The samplers listed in this Technical Report have been demonstrated to match the target specifications over a reasonable range of conditions, as laid down by the test procedures and requirements of EN 13205. There are no sampling instruments in existence that closely match the target specifications given in EN 481 under all possible workplace conditions.

5.3 Sampling precision

The main source of lack of precision in the measurement of workplace dust concentrations is the non-uniformity (in time and space) of the aerosol cloud surrounding the worker. Analytical and sampling precisions are generally better in comparison. Workplace-based studies using pairs of samplers on each worker have been used to determine the real precision in dust sampling results. For sampling of the inhalable aerosol fraction for example, a second contemporaneous sample on a worker was found to lie within a factor of two of the first sample, on 95 % of occasions (see [5]). Precision in the measurement of thoracic or respirable dust is lower than this figure as smaller particles become more uniformly mixed in workplace air.

Lack of precision caused by the sampling instrument itself is limited by the requirements of EN 13205. See 5.5 of this document.

5.4 Analytical bias and precision

Relevant standards, for example ISO 15767 for gravimetric analysis, should be consulted for details of the analytical bias and precision. Compared to the variability of the workplace aerosol itself, analytical bias and lack of precision generally have (with adequate laboratory quality control) minor impact on the error in the measurement of airborne particle concentrations.

5.5 Expanded uncertainty

Sampling instruments meeting the requirements of EN 13205 will have an accuracy better than or equal to 30 %. Note however, for complete measurement procedures for airborne particles, the expanded uncertainty (see EN 482) is a combination of the uncertainty of the sampled volume, the uncertainty of the sampled fraction, the uncertainty of the transportation, storage, sample preparation, etc. and the uncertainty of the analytical method employed.

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The measured concentration will be a good approximation of the concentration to which the worker is exposed, only, if the sampler meets the requirements of EN 13205, if it has been correctly sited (see 8.2), if the sampling time corresponds to or is representative of the exposure time and if the transportation, storage and analytical methods used are appropriate. The temporal, spatial and personal variability of the workplace aerosol concentration often far exceeds the variability of sampling and analysis procedures. The sampling strategy used needs to accommodate the large variability of workplace concentrations.

6 Sampling instruments

6.1 Personal and static samplers

Workplace aerosols can be sampled for different purposes, which determine the choice of an appropriate sampler (personal or static).

Static samplers often use high flow rates (> 10 l min^{-1}) in order to collect a high amount of particulate matter, sufficient for further analysis.

A high flow rate pump shall not be allowed to exhaust more than a small fraction of the air flow through a room.

Personal sampling systems are worn by the persons themselves, and for this reason a personal sampler should be small and light and therefore its flow rate is usually also small.

In practice, it is also possible to use personal samplers for static sampling but a personal sampler might not be a validated static sampler. Static samplers are usually not suitable for personal sampling because of their weight, except for special cases, e.g. samplers mounted in a driving cabin for sampling the exposure of the driver.

NOTE Static samplers are sometimes called stationary samplers, area samplers or fixed-point samplers.

Personal and static samplers should meet the same sampling performance criteria as given in EN 13205. See 5.2 b).

6.2 Personal and static samplers for the inhalable aerosol fraction

Samplers for the inhalable aerosol fraction with the potential to meet the requirements of EN 481 and EN 13205 for several environmental conditions are listed in Table B.1. With each sampler name, references are given to reports and papers that demonstrate the performance of the sampler. These references should be consulted for detailed information on the field conditions for which satisfactory performance is obtained.

For samplers of the inhalable aerosol fraction, the instruments listed have most difficulty to meet the requirements in field situations where there are

- high external winds, e.g. in underground mines or out doors;
- large particles generated with high momentum (“projectiles”), e.g. as produced in woodworking or textile manufacture;
- losses during transportation of samples, e.g. when samples are taken remotely from the analytical laboratory and shipped by mail.

In general these problematic situations lead to undersampling of the inhalable aerosol fraction, except for “projectiles”.

NOTE The concentration of the inhalable aerosol fraction is usually very localised and therefore static samplers are unlikely to give a valid indication of personal exposure.

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6.3 Personal and static samplers for the thoracic aerosol fraction

Samplers for the thoracic aerosol fraction with the potential to meet the requirements of EN 481 and EN 13205 for several environmental conditions are listed in Table B.2. With each sampler name, references are given to reports and papers that demonstrate the performance of the sampler. These references should be consulted for detailed information on the field conditions for which satisfactory performance is obtained.

For samplers of the thoracic aerosol fraction, the instruments listed have most difficulty to meet the requirements in field situations where there are

- high external winds;

- high concentrations, i.e. some samplers have a tendency to become overloaded, either at the separation stage or the collection stage;

- pulsating flow, i.e. some samplers are sensitive to flow pulsation in older models of sampling pumps (i.e. pumps not specified according to EN 1232).

- losses during transportation of samples, e.g. when samples are taken remotely from the analytical laboratory and shipped by mail;

In general these problematic situations lead to undersampling of the thoracic aerosol fraction of airborne dust.

NOTE 1 The concentration of thoracic dust is usually localised and therefore static samplers are less likely to give a valid indication of personal exposure.

NOTE 2 In many cases a sampler for the PM 10 aerosol fraction will only give a minor bias relative to the thoracic aerosol fraction.

6.4 Personal and static samplers for the respirable aerosol fraction

Samplers for the respirable aerosol fraction with the potential to meet the requirements of EN 481 and EN 13205 for several environmental conditions are listed Table B.3. With each sampler name, references are given to reports and papers that demonstrate the performance of the sampler. These references should be consulted for detailed information on the field conditions for which satisfactory performance is obtained.

For samplers of the respirable aerosol fraction, the instruments listed have most difficulty to meet the requirements in field situations where there are:

- high concentrations, i.e. some samplers can become overloaded, either at the separation stage or the collection stage;

- pulsating flow, i.e. some samplers are sensitive to flow pulsation in older models of sampling pumps (i.e. pumps not specified according to EN 1232);

- losses during transportation of samples, e.g. when samples are taken remotely from the analytical laboratory and shipped by mail.

In general these problematic situations lead to undersampling of the respirable aerosol fraction of airborne dust.

6.5 Personal samplers simultaneously collecting the inhalable, thoracic and respirable aerosol fractions

Samplers for two or all three aerosol fractions with the potential to meet the requirements of EN 481 and EN 13205 for several environmental conditions are listed in Table B.4. With each sampler name, references are given to reports and papers that demonstrate the performance of the sampler. These references should be consulted for detailed information on the field conditions for which satisfactory performance is obtained.

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Multifraction samplers have most difficulty to meet the requirements in field situations where there are

- high external winds, e.g. in underground mines or out doors;
- large particles generated with high momentum (“projectiles”), e.g. as produced in woodworking or textile manufacture;
- high concentrations or narrow size distributions, i.e. parts of the samplers have a tendency to become overloaded and this can distort the separation characteristics of the sampler;
- low concentrations, for one or two fractions the deposit might be below the limit of quantitation;
- losses during transportation, e.g. migration of deposit from one aerosol fraction to another, which can occur when samples are taken remotely from the analytical laboratory.

In general these problematic situations lead to incorrect collection of the inhalable aerosol fraction, or to incorrect subdivision of the airborne dust between aerosol fractions, typically manifested as overestimation of the respirable aerosol fraction and underestimation of the inhalable aerosol fraction.

7 Ancillary equipment required for field use

7.1 Sampling pumps

Sampling pumps used for dust sampling should comply with the requirements of EN 1232 and EN 12919, and should have as a minimum the following features:

- an automatic flow control which keeps the volumetric flow rate constant (within ± 5 % of the initial flow rate)in the case of changing back pressure;
- either a malfunction indicator, which following the completion of sampling indicates that the air flow has been reduced or interrupted during sampling; or an automatic cut-out, which stops if the pump flow is reduced or interrupted;
- a facility for adjustment of the flow rate such that it can only be actuated with the aid of a tool (e.g. a screw driver) or requires special knowledge for operation (e.g. software), so as to prevent inadvertent adjustment of the flow rate during use.
- For some samplers, e.g. cyclones, pulsation damped flow is particularly important and an external pulsation damper must be used if the pump does not contain an integral damper.

7.2 Other equipment required

- A portable flow meter, capable of measuring the desired volumetric flow rate to within 2,5 % of the nominal flow rate of the sampler, and calibrated against a flow meter whose accuracy is traceable to national standards. Bubble flow meters are preferred for measuring the volumetric flow rate because the readings they give are independent of temperature and pressure. For other flow meters, it can be necessary to measure the temperature and pressure at the time of use and apply corrections if these differ from the conditions under which the flow meter was calibrated.

  A special adapter between the sampler and the flow meter are in some cases required in order to measure the flow rate correctly. The flow rate shall always be determined as the volumetric flow of air (of local ambient temperature and pressure) into the sampler inlet.
- For personal sampling, belts or harnesses to which the sampling pumps can conveniently be fixed, unless they are small enough to fit inside workers' pockets.

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- A means to transport the samples from the workplace to the laboratory, which minimises the possibility of accidental transfers of collected dust to or from the collection substrate. Transportation will usually require caps or covers for the samplers, filter cassettes or other substrates, as detailed in the manufacturer's instructions for use of the instruments.

7.3 Choice of collection substrates

The choice of collection substrates (e.g. filters, foams) will normally be dictated by the choice of sampling instrument and by analytical considerations. Factors affecting substrate choice for gravimetric analysis are discussed in ISO 15767. In some types of sampler the collection substrate is held within a sampling cassette that is intended to be analysed along with the filter, i.e. dust collected on the inner walls of the cassette forms part of the sample. In other instruments the collection substrate is held within a holder that is not intended to be weighed along with the filter. The operating instructions supplied by the manufacturer should be consulted to find out exactly what parts of the sampler should be included in the analytical procedure. All collection substrates, including blanks, must have unique identification numbers.

NOTE It is important to contact the analytical laboratory before a collection substrate is selected.

8 Sampling procedure

8.1 Preparation of sampling equipment

Set the volumetric flow rate in a clean area.

Connect each sampler equipped with a collection substrate to a sampling pump, ensuring that no leaks can occur.

Remove the protective cover from the sampler, switch on the sampling pump, attach the calibrated flow meter to the inlet of the sampler so that it measures the flow through the inlet orifice(s).

Note that for some sampler types a different procedure can be required; refer to the manufacturer's instructions.

Allow the pump to stabilise before measuring and adjusting the flow.

NOTE 1 The stabilising time depends on pump design and can be up to 30 min.

Set the flow rate reading to within ± 5 % of the required value.

NOTE 2 This can be done with collection substrates not intended for subsequent analysis.

Switch off the pump and replace the protective cover on the sampler. Note that if the temperature and pressure in the environment where the samplers are used differ from where the flow rate was set, the volumetric flow rate can change, and needs to be re-adjusted before sampling.

For most types of flow measuring devices the reading of the flow rate will be in error if the device is used at an actual atmospheric temperature T_a (K) and actual pressure p_a (kPa) differing from that at which it was calibrated (T_c (K) and p_c (kPa)). For example, for a variable area volumetric flow meter the actual flow rate, Q_a (l min^{-1}), can be calculated from the indicated flow rate, Q_i (l min^{-1}) by the following equation (see [2]):

$$Q_\mathrm{a} = Q_\mathrm{i}\sqrt{\frac{T_\mathrm{a}}{T_\mathrm{c}}\frac{p_\mathrm{c}}{p_\mathrm{a}}} \qquad (1)$$

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NOTE 3 If the samplers, collection substrates, and pumps were transported to the sampling site at temperatures below zero, and will be used at room temperature or elevated temperatures, condensation of water vapour can occur on and inside the equipment, (possibly causing sampling errors) if sufficient time for equilibration is not allowed.

8.2 Deploying samplers

Follow the manufacturer's instructions for siting the samplers. In general, personal sampling instruments are attached to the worker preferably on his or her lapel, not more than 30 cm away from the nose-mouth region ("breathing zone", see EN 1540). Pumps are attached to a belt or harness, unless they are small enough to fit inside the worker's pocket, so they cause minimum inconvenience to the worker. Any tubing used to connect the sampler and pump should be safely secured to the harness or clothing.

When deciding where to position samplers, give consideration to the nature of the processes being undertaken by the worker and whether these can cause differences in the dust concentration within the breathing zone. This is particularly important where the sources of dust are close to the breathing zone, where large particles are generated by the process, and where the concentration of the inhalable aerosol fraction is to be measured (see [3]). Ensure that as far as possible the position at which the sampler is mounted will reflect the exposure of the worker. The sampling of welding fume can require sampling inside (see EN ISO 10882-1) or outside the visor (depending on national regulation).

When ready to begin sampling, remove the protective cover or cap from the sampler and switch on the pump. Record the time and volumetric flow rate at the beginning of the sampling period. If the pump is fitted with an integral timer, ensure that this is reset to zero. Check the sampler and pump periodically during sampling to see that the equipment is still working, and if necessary re-measure and adjust the flow rate.

At the end of the sampling period, carefully remove the sampling equipment from the worker without subjecting it to mechanical shocks

NOTE 1 Some types of sampler need be retained upright when switched off; refer to manufacturer's instructions.

Measure the volumetric flow rate at the end of the sampling period using the calibrated flow meter. Consider the possibility that the sample could be invalid if the flow rates before and after sampling differ by more than 5 %. Record the flow rate and the sampling time, and calculate the duration of the sampling period. If the pump is fitted with an integral timer, check that the indicated period agrees with the calculated period. Consider the possibility that the sample could be invalid if the two sampling times differ by more than 5 %, since this indicates that the pump did not operate for the entire period.

NOTE 2 Certain workplace environments can require specialized equipment, e.g. intrinsically safe pumps.

8.3 Information to be recorded in the field

Carefully record the sample identity and all relevant sampling data. In general, calculate the mean volumetric flow rate by averaging the flow measurements made at the beginning and end of the sampling period. Consider the sample to be invalid if the two measured flow rates differ by more than 5 %.

An example of information to be collected in the field for each sample taken is given in Annex A.

8.4 Transportation of samples and equipment

The method of transporting samples from the workplace to the analytical laboratory should form part of a written procedure, as required by ISO 15767. The method should be evaluated for losses and bias as described in ISO 15767 or EN 13205.

Transport the samples to the laboratory in a container designed to prevent damage in transit, and labelled to ensure proper handling. Carefully inspect the transport containers, clips etc. for signs of loose material lost from the filters. In cases where losses are suspected it can be necessary to develop and document special transport procedures for the used samplers. Special precautions to recover lost material, for example the use of weighable cassette covers and filter containers, are likely to be needed where samples are sent by post.

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8.5 Field blanks

Retain as blanks one unused loaded sampler (or loaded cassette) from each batch of ten prepared; a minimum of three blanks should always be kept. Treat these as far as possible in the same manner as those actually used for sampling, in respect of transport to and from the sampling site, but do not draw air through them. For instructions on the use of field blanks, see ISO 15767.

8.6 Cleaning and maintenance of instruments

Clean the samplers after use. Disassemble parts that come into contact with dust, soak in detergent solution, rinse thoroughly with water and allow to dry before reassembly. Refer to the manufacturer's instructions before disassembly, and check for any special cleaning instructions. Discard the sampler if the inside is visibly scored or otherwise damaged.

9 Analysis of samples

9.1 General

The sampling and methodology should have been chosen under consideration of the intended analysis. The quantity of sampled material (which depends on the aerosol concentration, sampling time and flow rate) need to be adequate for the intended analysis. Analytical requirements on the sample, not analytical procedures themselves, will be described in this clause.

The results of sample quantity analysis along with the sampling flow rate and sampling time are used to calculate the aerosol concentrations.

Further analysis can be performed to supply information about the quality and composition of sampled matter. Several physical, chemical and biological characteristics of particles can be measured

a) physical characteristics:

- particle size, shape, specific surface, morphology of surface, mineralogical composition, optical properties, solubility, radioactivity, etc.

b) chemical characteristics:

- organic or inorganic composition, speciation, pH, chemical reactivity, etc.

c) biological characteristics:

- toxicity of particulate matter, identification of micro-organisms, their viability, ability of reproduction, metabolic activity, etc.

The sampling results can be expressed on the basis of the whole sample quantity or on the basis of one specifically analysed compound.

Except the case of direct-reading analytical methods (which are not mentioned here), the sampled particles should be collected onto an appropriate substrate so as not affect the quality of the sample.

Procedures for the gravimetric analysis of the collected aerosol by weighing are given in ISO 15767.

In the case of particle *number analysis* by counting, the sampler should provide a homogenous layer of particles without any concentration gradient on the surface of the collecting substrate. A preferential deposition of particles onto some part of the sampling surface should be avoided. When the particles are counted, the filter surface should be smooth and flat, and the sampled particles should not have penetrated into the depth of filter material. The number of sampled particles should be high enough to meet the statistical

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requirements for significant counting, but low enough to be able to identify single particles. Procedures for counting and sizing particles with an image analyser are given in ISO 13322-1.

NOTE Preferential deposition of particles can occur when particles are impacted onto the substrate, deposited in the presence of a highly turbulent flow, or when the particles or the collecting substrate are electrically charged.

In the case of *physical, chemical or biological analysis* of particles, a sampler and a collecting substrate free from interfering materials should be used, e.g.

- non-metallic sampler for samples intended for analysing metals (if appropriate);
- filters not releasing polymers or organic solvents for the analysis of organic compounds, or elemental carbon;
- non-biotoxic materials for collecting viable micro-organisms;
- membrane filter collecting particles on its surface for alpha radioactivity counting (see [1]).

The specific analytical methods are described in specialised standards or guidelines. E.g. fibres are analysed according to the recommendations by WHO (see [7]), lead is analysed according to ISO 8518, metals and metalloids are analysed according to EN 13890, ISO 15202-1 and ISO 15202-2 respectively, diesel particulates are analysed according to EN 14530, particle and vapour mixtures are analysed according to ENV 13936, endotoxins are analysed according to EN 14031. See also EN 14042.

In some types of samplers the collection substrate is held within a cassette intended to be analysed along with the filter, i.e. particles collected on the inner walls of the cassette form part of the sample. In this case, these particles should also be recovered for the analysis.

9.2 Calculating concentrations

If the sample is collected during time t (in min) at the mean flow rate Q_m (in l min^{-1}), the quantity of particulate matter sampled is mass m (in mg, when weighing) or number n (dimensionless, when counting). The measured aerosol concentration C is then calculated either as mass concentration, C_m (in mg m^{-3}), according to equation (2) or as number concentration, C_n (in m^{-3}), according to equation (3):

$$C_\mathrm{m} = 1000 \frac{m}{Q_\mathrm{m}\ t} \tag{2}$$

$$C_\mathrm{n} = 1000 \frac{n}{Q_\mathrm{m}\ t} \tag{3}$$

Depending on the analytical measurement used, the measured aerosol concentration can be expressed as other characteristics of particles, e.g.:

- particulate volume V : C_V (in m^3 m^{-3});
- particulate surface S : C_S (in m^2 m^{-3});
- mass of analysed substance i : C_{m_i} (in mg m^{-3});
- activity of radioactive particles A: C_A (in Bq m^{-3}).

The particle concentration of the occupational exposure should be given as the actual volumetric concentration and not corrected to any reference temperature and pressure.

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9.3 Minimum sampled quantity for analysis – limit of detection and limit of quantitation

When analysing several times the same substance *i* at concentrations near or below the measuring range, and when any systematic error is excluded, the mass of the analysed substance m_i can be determined along with its standard deviation s_m (mg). If the analytical *limit of detection* is conventionally considered to be three times the value of s_m (see ISO 15767), the minimal sampling time t_min (min) to collect a detectable amount of the substance can be calculated according to equation (4):

$$t_\mathrm{min} = 3000 \frac{s_\mathrm{m}}{C_\mathrm{e}\, Q_\mathrm{s}} \tag{4}$$

where

C_e is an estimated aerosol concentration in mg m^{-3};

Q_s is the flow rate of the sampler in l min^{-1}.

Similarly, if the analytical *limit of quantitation* is conventionally considered to be ten times the value of s_m (see ISO 15767), the minimal sampling time t_min to collect a quantifiable amount of the substance can be calculated according to equation (5):

$$t_\mathrm{min} = 10000 \frac{s_\mathrm{m}}{C_\mathrm{e}\, Q_\mathrm{s}} \tag{5}$$

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Annex A
(informative)

Basic information to be recorded when sampling and afterwards

All necessary information needed to identify samples shall be recorded. This Annex contains a list of the basic information needed for the report:

a) purpose of the measurement;

- premises (name and address of the undertaking and the location of the workplace);
- activity and number of employees affected by the air contaminant which is the cause of the measurement;

b) product/substance;

- product;
- the substance(s) measured, including substance code, e.g. CAS (Chemical Abstracts Service) number;
- production data;

c) exposure modifiers/determinants of exposure;

- exposure pattern;
- job rotation, if any, and if it affects the exposure;
- personal protective equipment used, if any, and when;
- occurrence of physically strenuous work;
- pattern of technical control;
- ventilation data;
- workspace (confined, inside or outside);
- sketch or photograph of the workplace;
- average duration of each working operation per day, week and year, if this can be judged;
- names of persons, or identification number;
- climatic data (temperature, pressure, humidity and velocity of air movement);

d) sampling procedure;

- date of sampling;
- nature of sampling (e.g. multiplicate, serial);

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- sampling sites and sampling times for each sample;

e) sampling method, sampling equipment;

- analytical method;

- name of occupational hygienist carrying out the measurement;

- analytical laboratory engaged;

f) results;

- units of measurement;

- all measured concentrations;

- compilation of measurements obtained, showing daily averages and working operations, together with the current occupational exposure limit value;

- assessment, together with commentaries, comparisons with any previous measurements, other enquiries, etc, actions recommended and conclusions.

NOTE 1 This table is mainly directed towards the needs of a comparison of a measured concentration with the occupational exposure Limit Value and exposure assessment for epidemiological studies. Evaluation of technical control measures can have a different content.

NOTE 2 This Annex is partially based on the following papers:

Rajan, B., Alesbury, R., Carton, B., Gérin, M., Litske, H., Marquart, H., Olsen, E., Scheffers, T., Stamm, R. and Woldback, T. (1997). European proposal for core information for the storage and exchange of workplace exposure measurements on chemical agents, *Appl. Occup. Envion. Hyg.* 12(1):31-39.

Brederode, D., Linker, F., Marquart, H., Pothuis, J., Slijpen, J. and Timmermans, H. (2001). Recording of data of individual measurements of occupational exposure: Guideline of the Dutch society of occupational hygiene, *Appl. Occup. Envion. Hyg.* 16(2):122-127.

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Annex B
(informative)

Examples of samplers for the inhalable, thoracic and respirable aerosol fraction, which are or have been available on the market up to 2004, and published reports on their performance

B.1 General

The samplers listed in Tables B.1 to B 4 have the potential to meet the requirements of EN 482 and EN 13205 for several environmental conditions. However, no sampler fulfils the requirements for all possible environmental conditions. The extent of the validations performed on the listed samplers differ considerably. The user shall evaluate the sampler (e.g. on the basis of the reports listed in the table, other reports, or contacts with e.g. national research institutes on occupational health) in order to verify that it has acceptable performance in the environment in which it is intended to be used.

The trade names/designations of products mentioned in Tables B.1 to B 4 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.

NOTE 1 The Tables B.1 to B 4 contain references only published up to 2004.

NOTE 2 Samplers nominally identical, but from different manufacturers or manufactured from different materials, could have different performance characteristics.

Table B.1 — Samplers for the inhalable aerosol fraction

Mode of use	Sampler designation	Manufacturer	Supporting references
Personal	IOM	SKC	1, 2, 3, 4, 5, 6, 7
	PGP-GSP	GSM	2, 5, 6, 7,
	PGP-GSP10	GSM	48, 49
	CIP10-I	Arelco	2, 5, 8, 9
	Button	SKC	6, 7, 10, 11, 12, 13
	PAS-6	IRAS-UU	2, 5
Static	Cathia-I	Arelco	56, 57
	PM 4	GSM	50
	ESK50	DEHA	51
	VC-25 G	GSM	14
	IOM Static	no longer available	52

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Table B.2 — Samplers for the thoracic aerosol fraction

Mode of use	Sampler designation	Manufacturer	Supporting references
Personal	CIP10-T	Arelco	15,20
	GK2.69	BGI	15
	PEM200	MSP	21
Static	Cathia-T	Arelco	15, 20, 22, 23
	MPG III-T	DEHA	51

Table B.3 — Samplers for the respirable aerosol fraction

Mode of use	Sampler designation	Manufacturer	Supporting references
Personal	IOM MultiDust	SKC	16, 17, 18, 19, 24
	CIP10-R	Arelco	25, 26, 27, 28
	GK2.69	BGI	29
	BCIRA	no longer available	35
	SIMPEDS	Casella	28, 30, 32, 35, 36, 37
	Respirable dust cyclone	BGI	30, 31, 34, 37
	Aluminium cyclone	SKC	28, 33, 37
	Conductive plastic cyclone	SKC	28
	PGP-FSP 2	GSM	43
	PGP-FSP 10	GSM	53, 54
	10 mm Nylon	Panametrics	26, 28, 31, 33, 34, 38, 39
Static	Cathia-R	Arelco	28
	PM4 F	GSM	40
	MPG II	DEHA	40, 43
	MPG III	DEHA	40
	MRE 113A	Casella	27, 28, 41, 42
	VC25 F	GSM	44
	VC25 I	GSM	55

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Table B.4 — Samplers for more than one health-related aerosol fraction

Mode of use	Sampler designation	Manufacturer	Supporting references
Personal:			
• inhalable and respirable	IOM MultiDust	SKC	16, 17, 18, 19
• inhalable, thoracic and respirable	Respicon	Hund, TSI	11, 45, 46
	Perspec	No longer available	2, 47

Table B.5 — Vendors of samplers

Vendor	Address
Arelco	Arelco, Avenue Ernest Renan 2, F-94134 Fontenay sous Bois Cedex, France www.arelco.fr
BGI	BGI, 58 Guinan Street, Waltham MA 02451, USA, www.bgiusa.com
Casella	Casella, Regent House, Wolseley Road, Kempston, Bedford MK42 7JY, United Kingdom, www.casella.co.uk
DEHA	DEHA Haan+Wittmer Birkenstrasse 31, D-71292 Friolzheim, Germany, www.deha-gmbh.de
GSM	Gesellschaft für Schadstoffmesstechnik, Gut Vellbrüggen, D-41469 Neuss-Norf, Germany, www.gsm-neuss.com
Hund	Helmut Hund, Wilhelm-Will-Strasse 7, D-35580 Wetzlar, Germany, www.hund.de
IRAS-UU	Institute of Risk Assessment Sciences, PO Box 80.176, NL-3508 TD Utrecht, the Netherlands, www.iras.uu.nl
JS Holdings	JS Holdings, Unit 6, Leyden Road, Stevenage SG1 2BW, United Kingdom, www.jsholdings.co.uk
MSP	MSP, 5910 Rice Creek Parkway, Suite 300, Shoreview MN 55126, USA, www.mspcorp.com
Panametrics	Panametrics, Rue du Renard 11, F-92250 La Garenne Colombes, France, www.panametrics.fr
SKC	SKC, 11 Sunrise Park, Higher Shaftesbury Road, Blandford Forum, Dorset DT11 8ST, United Kingdom, www.skcltd.com
TSI	TSI Instruments, 1 Beach Road West, Portishead, Bristol BS20 7HR, United Kingdom, www.tsiinc.co.uk
NOTE This is not an exhaustive list. Some samplers can have distributors in several European countries. Only a main European vendor is listed above.	

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[13] EN 14042, *Workplace atmospheres – Guide for the application and use of procedures for the assessment of exposure to chemical and biological agents*

[14] EN 14530, *Workplace atmospheres – Determination of diesel particulate matter – General requirements*

[15] EN 14907, *Ambient air quality – Standard gravimetric measurement method for the determination of the PM 2,5 mass fraction of suspended particulate matter*

[16] ISO 8518, *Workplace air – Determination of particulate lead and lead compounds – Flame or electrothermal atomic absorption spectrometric method*

[17] ISO 13322-1, *Particle size analysis – Image analysis methods – Part 1: Static image analysis methods*

[18] ISO 15202-1, *Workplace air – Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry – Part 1: Sampling*

[19] ISO 15202-2, *Workplace air – Determination of metals and metalloids in airborne particulate matter by inductively coupled plasma atomic emission spectrometry – Part 2: Sample preparation*

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