BS EN 13205-2:2014

BSI Standards Publication

Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations

Part 2: Laboratory performance test based on determination of sampling efficiency

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National foreword

This British Standard is the UK implementation of EN 13205-2:2014. Together with BS EN 13205-1:2014, PD CEN/TR 13205-3, BS EN 13205-4:2014, BS EN 13205-5:2014 and BS EN 13205-6:2014 it supersedes BS EN 13205:2002, which will be withdrawn upon publication of all parts of the series.

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.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Workplace exposure - Assessment of sampler performance for measurement of airborne particle concentrations - Part 2: Laboratory performance test based on determination of sampling efficiency

Exposition sur les lieux de travail - Évaluation des performances des dispositifs de prélèvement pour le mesurage des concentrations de particules en suspension dans l'air - Partie 2: Essai de performances en laboratoire par détermination de l'efficacité de prélèvement

Exposition am Arbeitsplatz - Beurteilung der Leistungsfähigkeit von Sammlern für die Messung der Konzentration luftgetragener Partikel - Teil 2: Laborprüfung der Leistungsfähigkeit basierend auf der Bestimmung des Probenahmewirkungsgrads

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Foreword

This document (EN 13205-2:2014) 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.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2014 and conflicting national standards shall be withdrawn at the latest by December 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document together with EN 13205-1, CEN/TR 13205-3, EN 13205-4, EN 13205-5 and EN 13205-6 supersedes EN 13205:2001.

EN 13205, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations*, consists of the following parts:

— *Part 1: General requirements;*

— *Part 2: Laboratory performance test based on determination of sampling efficiency* (the present document);

— *Part 3: Analysis of sampling efficiency data* [Technical Report];

— *Part 4: Laboratory performance test based on comparison of concentrations;*

— *Part 5: Aerosol sampler performance test and sampler comparison carried out at workplaces;*

— *Part 6: Transport and handling tests.*

Significant technical changes from the previous edition, EN 13205:2001:

— This part of EN 13205 is based on Annex A of the previous edition, EN 13205:2001.

— The scope has been limited to aerosol samplers, and the current version of the standard is not (directly) applicable to other types of aerosol instruments.

— As this is now a standard in its own right, a clause on symbols used has been added. Almost all definitions are now given either in EN 1540, *Workplace exposure — Terminology* or in Part 1 of this standard.

— The method of calculating the uncertainty of a sampler or a measuring procedure has been revised in order to comply with ENV 13005. The concept of “accuracy” is no longer used, instead the concept of “expanded uncertainty” is used.

— The five major sources of uncertainty due to aspects of the sampling performance of an aerosol sampler (calibration of sampler test system, estimation of sampled concentration, bias relative to the sampling convention, individual sampler variability and excursion from nominal flow rate) are described with equations on how to incorporate these uncertainties into the expanded uncertainty of a sampler. CEN/TR 13205-3 gives recommendations how these entities may be calculated from measured sampling efficiency data.

— The list of the particle size distributions (per sampling convention) to be used for the evaluation of sampler performance has been restricted at the lower end to reflect that particles with an aerodynamic

diameter less than 0,5 µm are not sampled due to aerodynamic forces. In the current version, an additional requirement on the size distributions is that at least 84 % of the aerosol mass consists of particles exceeding 0,5 µm.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

EN 481 defines sampling conventions for the particle size fractions to be collected from workplace atmospheres in order to assess their impact on human health. Conventions are defined for the inhalable, thoracic and respirable aerosol fractions. These conventions represent target specifications for aerosol samplers, giving the ideal sampling efficiency as a function of particle aerodynamic diameter.

In general, the sampling efficiency of real aerosol samplers will deviate from the target specification, and the aerosol mass collected will therefore differ from that which an ideal sampler would collect. In addition, the behaviour of real samplers is influenced by many factors such as external wind speed. In many cases there is an interaction between the influence factors and fraction of the airborne particle size distribution of the environment in which the sampler is used.

EN 13205 (all parts) enables manufacturers and users of aerosol samplers to adopt a consistent approach to sampler validation, and provide a framework for the assessment of sampler performance with respect to EN 481 and EN 482.

It is the responsibility of the manufacturer of aerosol samplers to inform the user of the sampler performance under the laboratory conditions[1)] specified in this part of EN 13205. It is the responsibility of the user to ensure the actual conditions of intended use are within what the manufacturer specifies as acceptable conditions according to the performance test.

1) The inhalable convention is undefined for particle sizes in excess of 100 µm or for wind speeds greater than 4 m/s. The tests required to assess performance are therefore limited to these conditions. If such large particle sizes or wind speeds actually existed at the time of sampling, it is possible that different samplers meeting this document give different results.

1 Scope

This European Standard specifies a laboratory performance test for samplers for the inhalable, thoracic and respirable aerosol fractions, based on determining the sampling efficiency curve of a candidate sampler at a minimum of nine particle sizes. It specifies methods for testing aerosol samplers under prescribed laboratory conditions in order to test whether the performance of a candidate sampler fulfils the requirements of EN 13205-1:2014.

This part of EN 13205 is applicable to all samplers used for the health-related sampling of particles in workplace air.

2 Normative references

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

EN 1540, *Workplace exposure — Terminology*

EN 13205-1:2014, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations — Part 1: General requirements*

CEN/TR 13205-3:2014, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations — Part 3: Analysis of sampling efficiency data*

EN 13205-5:2014, *Workplace exposure — Assessment of sampler performance for measurement of airborne particle concentrations — Part 5: Aerosol sampler performance test and sampler comparison carried out at workplaces*

EN ISO 13137, *Workplace atmospheres — Pumps for personal sampling of chemical and biological agents - Requirements and test methods (ISO 13137)*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in EN 1540, EN 13205-1:2014 and the following apply.

NOTE With regard to EN 1540, in particular, the following terms are used in this document: total airborne particles, respirable fraction, sampling efficiency, static sampler, thoracic fraction, inhalable fraction, measuring procedure, non-random uncertainty, random uncertainty, expanded uncertainty, standard uncertainty, combined standard uncertainty, uncertainty (of measurement), coverage factor and precision.

3.1
relative concentration
concentration expressed as a fraction of the total airborne concentration

3.2
total airborne particle concentration
concentration of aerosol particles present in the air before the particles are affected by the presence of the sampler, or in the case of a personal sampler by the presence of the person wearing the sampler

4 Symbols and abbreviations

4.1 Symbols

4.1.1 Latin

$A\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}, D\right)$ relative lognormal aerosol size distribution, with mass median aerodynamic diameter D_{A} and geometric standard deviation σ_{A}, [1/µm]

NOTE The word "relative" means that the total amount of particles is unity [-], *i.e.* $\int_0^\infty A\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}, D\right)\mathrm{d}\,D = 1$.

C_{std} target sampled relative aerosol concentration, expressed as a fraction of the total airborne aerosol concentration, that would have been sampled using an ideal sampler with a sampling efficiency identical to the sampling convention, $F(D)$, for aerosol size distribution A, [-]

$\bar{C}_i$ mean sampled relative aerosol concentration, expressed as a fraction of the total airborne aerosol concentration, calculated to be obtained when using the candidate sampler, for aerosol size distribution A at influence variable value ς_i, [-]

c candidate sampler correction factor for bias correction, either prescribed by sampler manufacturer or measuring procedure, or assigned the value c = 1.00, [-]

D aerodynamic diameter, [µm]

D_{A} mass median aerodynamic diameter of a lognormal aerosol size distribution A, [µm]

D_{A_a} mass median aerodynamic diameter a of a lognormal aerosol size distribution A, [µm]

D_{max} diameter of the end of the integration range of the sampled aerosol, [µm]

D_{min} diameter of the beginning of the integration range of the sampled aerosol, [µm]

D_p aerodynamic diameter of test particle p (p = 1 to N_P), [µm]

$\bar{E}_i\left(D_p\right)$ mean sampling efficiency of the candidate sampler for test particle size p at influence variable value ς_i, [-] – (polygonal approximation method)

$\bar{E}_i\left(Q, D_p\right)$ mean sampling efficiency curve of the candidate sampler at flow rate Q for test particle size p at influence variable value ς_i, [-] – (polygonal approximation method)

$^{\mathrm{est}}E_{is}(D)$ fitted sampling efficiency curve of the candidate sampler individual s at influence variable value ς_i, [-] – (curve-fitting method)

$^{\mathrm{est}}E_{is}(Q, D)$ fitted sampling efficiency curve of the candidate sampler individual s at flow rate Q for influence variable value ς_i, [-] – (curve-fitting method)

$e_{ipr[s]}$ and $e_{ips[r]}$ experimentally determined efficiency value, with notation for polygonal approximation and curve-fitting methods, respectively. The subscripts are for influence variable value ς_i, particle size F (p = 1 to N_P), sampler individual s (s = 1 to N_S) and repeat r (r = 1 to N_R), [-] – (notation for polygonal approximation and curve-fitting methods, respectively)

$F(D)$ target sampling convention, [-]

$g_{ipr[s]}$ and $g_{ips[r]}$	aerosol concentration sampled by the candidate sampler. The subscripts are for influence variable value ς_i, particle size *p* (*p* = 1 to N_P), sampler individual s (s = 1 to N_S) and repeat r (r = 1 to N_R), [mg/m^3] or [1/m^3] – (notation for polygonal approximation and curve-fitting methods, respectively)
h_{ipr} and $h_{ips[r]}$	corresponding total airborne aerosol concentration estimated from the sharp-edged probe values. The subscripts are for influence variable value i (i = 1 to N_{IV}), particle size p (p = 1 to N_P), sampler individual s (s = 1 to N_S) and repeat r (r = 1 to N_R), [mg/m^3] or [1/m^3] – (notation for polygonal approximation and curve-fitting methods, respectively)
$m_i(D_A, \sigma_A, Q)$	mean sampled aerosol mass, expressed as a fraction of the total airborne aerosol mass, calculated to be obtained when using the candidate sampler with flow rate Q, to sample aerosol size distribution A at influence variable value ς_i, [-]
N_{IV}	number of values for the other influence variables at which tests were performed,
N_P	number of test particle sizes
N_{Rep}	number of repeats at particle size p for candidate sampler individual s at influence variable value ς_i – (in the polygonal approximation method N_{Rep} equals the number of repeats, whereas in the curve-fitting method it equals the number of repeats per candidate sampler individual)
N_S	number of candidate sampler individuals – (In the polygonal approximation method N_S equals the number of sampler individuals tested per repeat, whereas in the curve-fitting method it equals the total number of sampler individuals tested.)
Q	actual flow rate of candidate sampler, [l/min]
Q^0	nominal flow rate of sampler, [l/min]
q_0	parameter expressing whether the nominal or actual flow rate is used for the calculation of sampled respirable and thoracic aerosol fractions, [-]
$q_i(D_A, \sigma_A)$	flow rate dependence of sampled mass for aerosol size distribution A at influence variable value ς_i, [-]
$s_{\text{CandSampl-Flow}_{ia}}$	non-random uncertainty (of measurement) of the calculated sampled concentration, due to excursion from nominal flow and/or deviation from initial flow, for the a^{th} aerosol size distribution A at influence variable value ς_i, [-]
$s_{(\delta_{\text{FlowSet}} + \delta_{\text{Pump}})}$	random uncertainty for combined rectangular distribution based on allowed initial flow deviation from nominal flow rate and pump flow deviation, [-]
$U_{\text{CandSampl}}$	expanded uncertainty (of measurement) of the calculated sampled concentration due to the candidate sampler, [-]
$u_{\text{CandSampl}}$	combined uncertainty (of measurement) of the calculated sampled concentration due to the candidate sampler, [-]
$u_{\text{CandSampl}_i}$	combined uncertainty (of measurement) of the candidate sampler, at influence variable value ς_i, [-]
$u_{\text{CandSampl-Bias}_i}$	standard uncertainty (of measurement) due to bias (non-random errors) in relation to the sampling convention of the candidate sampler at influence variable value ς_i, [-]
$u_{\text{CandSampl-Calibr}_i}$	standard uncertainty (of measurement) (non-random and random errors) of the

	calculated sampled concentration, due to the calibration uncertainty of the experiment, calculated as the RMS of the corresponding relative uncertainties over all N_{SD} aerosol size distributions A at influence variable value ς_i, [-]
$u_{CandSampl\text{-}Flow_i}$	standard uncertainty (of measurement) of the calculated sampled concentration, due to flow rate deviation at influence variable value ς_i, [-]
$u_{CandSampl\text{-}ModelCalc_i}$	standard uncertainty (of measurement) of the calculated sampled concentration (random errors), due to the uncertainty of the fitted model, calculated as the RMS of the corresponding relative uncertainties over all N_{SD} aerosol size distributions A at influence variable value ς_i, [-]
$u_{CandSampl\text{-}nR}$	combined uncertainty (of measurement) of the sampled concentration (non-random errors) due to the candidate sampler, [-]
$u_{CandSampl\text{-}nR_i}$	combined uncertainty (of measurement) of the sampled concentration (non-random errors) due to the candidate sampler, at influence variable value ς_i, [-]
$u_{CandSampl\text{-}R}$	combined uncertainty (of measurement) of the sampled concentration (random errors) due to the candidate sampler, [-]
$u_{CandSampl\text{-}R_i}$	combined uncertainty (of measurement) of the sampled concentration (random errors) due to the candidate sampler, at influence variable value ς_i, [-]
$u_{CandSampl\text{-}Variability_i}$	standard uncertainty (of measurement) of the sampled concentration (random errors) due to differences among candidate sampler individuals at influence variable value ς_i, [-]
W_p	weighted average of integration of aerosol size distribution A between two particle sizes, [-] – (polygonal approximation)

4.1.2 Greek

Δ_i	bias or relative error in the aerosol concentration measured using the candidate sampler, for aerosol size distribution A, at influence variable value ς_i, [-]
$\delta_{FlowSet}$	maximum relative error allowed in setting the flow rate, [-]
δ_{Pump}	maximum relative change in flow rate allowed by pump flow rate stability, [-]
$\varepsilon_{ipr[s]}$ and $\varepsilon_{ips[r]}$	Random experimental error at particle size p, repeat r and candidate sampler s at influence variable value ς_i, [-] – (notations for polygonal approximation and curve-fitting methods, respectively)
ς	value of other influence variable values, as for example wind speed and mass loading of sampler, with values for i = 1 to N_{IV}, [various dimensions]
ς_i	i^{th} value of any other influence variable NOTE The dimension of each ς_i depends on the influence variable. The dimension selected, however, is not critical, as the values are never part in any calculation.
σ_A	geometric standard deviation of a lognormal aerosol size distribution A from Table A.2 [-]
σ_{A_a}	geometric standard deviation a of a lognormal aerosol size distribution A, [µm] –

4.2 Enumerating subscripts

a for test aerosols

I for selected value of distinguishable values of an influence variable

i for influence variable values, ς

$i0$ for selected value of non-distinguishable values of an influence variable which causes the largest combined standard uncertainty for the candidate sampler

p for test particle size

r for repeats

s for candidate sampler individual

4.3 Abbreviations

RMS Root Mean Square

5 Principle

The test method described in this part of EN 13205 is based on the measurement of the candidate sampler's sampling efficiency as a function of particle aerodynamic diameter, whether all aspirated particles are part of the sample (as for most inhalable samplers) or if a particle size-dependent penetration occurs between the inlet and the collection substrate (as for thoracic and respirable samplers). The bias versus the sampling convention is calculated based on the measured sampling efficiencies. Other sampling errors due to non-random and random sources of error are also determined, e.g. individual sampler variability, excursion from nominal flow rate, estimation of sampled concentration and experimental errors.

The purpose of the laboratory experiments is to determine the sampling efficiency as a function of particle aerodynamic diameter over the relevant size range, and also as a function of any other relevant variables (as determined in the critical review, see EN 13205-1:2014, 6.2). Mathematical modelling is used to estimate the concentrations that would be sampled from a range of ideal log-normally distributed aerosols, using both the measured sampler efficiency and the target sampling convention. From these data, the sampler performance is estimated.

6 Test method

6.1 General

The sampling efficiency values are calculated from dividing the aerosol concentrations measured using the candidate sampler, by measured values of the total airborne particle concentration. An experimental design shall be devised that gives due attention to randomization and to estimation of the main effects. The design, and its associated statistical model, shall be explained in the test report. An example of a suitable design is given in CEN/TR 13205-3:2014.

6.2 Test conditions

Experiments to test samplers for the inhalable fraction shall be carried out in a wind tunnel or in an aerosol chamber. Personal inhalable samplers for the inhalable particle fraction, intended for use outdoors or in environments with strong forced ventilation (i.e. wind speeds in excess of 0,5 m/s), shall be tested while mounted on a life-size mannequin, or on a simulated torso. The mannequin or simulated torso set-up shall reproduce the aerodynamic effects of the presence of a life-size, human-shaped head and torso[2)]. In a wind-tunnel of size (1,2 × 1,8) m it has been shown that a simulated torso with the width, height and depth equal to 33 cm, 21 cm and 21 cm, respectively, with samplers mounted on all four vertical planes give similar results as a life-size mannequin[3)]. The size and nature of the mannequin/ simulated torso used shall be described in

2) For examples of performance evaluations of personal inhalable samplers, see Bibliography, references [2] to [5].

3) See for example Bibliography, references [6] and [7], for reported experiments.

the test report. If a candidate sampler is tested as a personal sampler in moving air, the results do not apply to its use as a static sampler (and vice versa).

The sampling efficiencies of samplers for the thoracic or the respirable fractions are combinations of the samplers' inlet efficiency and of the internal penetration. They may be tested as a whole as described above, except that the particle size range for testing is restricted to that specified for the fraction of interest in Table 1. Alternatively the sampling efficiencies in these cases may be measured by combining the results from two separate experiments, one to test the sampler's inlet efficiency, and one to determine its internal penetration. For tests of the inlet efficiency the same considerations apply as for inhalable samplers, except that the particle size range for testing is restricted to that specified for the fraction of interest in Table 1. Tests of the penetration may be carried out in a low-wind aerosol chamber using isolated samplers.

6.3 Test variables

6.3.1 General

The laboratory tests of sampling efficiency shall be designed to quantify the effects of those influence variables which the critical review indicates are important for the sampler under test. Table 1 lists the most important influence variables and identifies those for which testing is compulsory (C), compulsory for some sampler types or uses only (C*), or optional (O). Excluded variables shall be clearly identified in the section of the test report that describes the scope of the test.

Table 1 — Influence variables to be tested

Variable	Status	Range	Number of values	Subclause
Particle aerodynamic diameter	C C C	Inhalable: 1 µm to 100 µm Thoracic: 0,5 µm to 35 µm Respirable: 0,5 µm to 15 µm	≥ 9: spaced to cover important features of the efficiency curve	6.3.2
Wind Speed	C	Indoor workplaces only:	1: ≤ 0,1 m/s	6.3.3
	C	Indoor or outdoor workplaces, 0 m/s to 4,0 m/s:	2: ≤ 0,1 m/s and 1 m/s	
Wind Direction	C	Omnidirectional average	Continuous revolution or ≥ 4 values stepwise	6.3.4
Aerosol composition	O	Phase: solid and/or liquid; Particles of known shape	Choose suitable materials	6.3.5
Aerosol agglomeration	O	Unagglomerated dust; Highly agglomerated dust	Choose and document	6.3.5
Collected mass and/or internally separated mass	O	Collected mass corresponding to: up to maximum concentration x nominal flow rate x sampling time Internally separated mass corresponding to: maximum uncollected concentration x nominal flow rate x sampling time	≥ 3	6.3.6
Aerosol charge	O	Charged or neutralised aerosol; Conducting or insulating sampler	Choose and document	6.3.7
Sampler specimen variability	C*	Test group to be as large as possible	≥ 6	6.3.8
Excursion from the nominal flow rate	C*	Nominal flow rate plus lower and higher flow rates at one wind speed	≥ 6 specimen tested at 3 flow rates	6.3.9
Particle collection substrates	O	Choice of materials (e. g. filters, foams) and details of any surface treatments to be stated		6.3.10

C compulsory

C* compulsory for some samplers for the respirable and thoracic aerosol fractions only

O optional

Table 1 also summarises the ranges of values for which the selected variables shall be tested, and the number of values within these ranges. In general, the values chosen need not include the extremes of the range, although specific requirements are stated in some cases. Where the experimental design requires a choice to be made, for example the composition of the aerosol used for the tests, or the type of collection substrate used, the effect of the choices made on the applicability of the test results to routine sampling shall be considered in the critical review and the noted in the test report.

This part of EN 13205 only gives specific information on how to calculate the uncertainty components, and how to add them into the expanded uncertainty, for uncertainty components pertaining to compulsory test influence variables. For optional test influence variables, the user will need to specify the tests, how they are evaluated and how the corresponding uncertainty components are added into the expanded uncertainty.

6.3.2 Particle size

For inhalable aerosol samplers, the largest particle size tested shall be no smaller than 90 µm. For samplers for the respirable and thoracic aerosol fractions, at least one particle size shall be in the range from 0,5 µm to 0,9 µm and the largest particle size shall be chosen so that the lowest measured sampling efficiency is lower than 0,04.

NOTE For the respirable and thoracic sampling conventions a sampling efficiency of 0,04 corresponds to approximately 8 µm and 22 µm, respectively.

6.3.3 Wind speed

In indoor work environments the average speed of air movement is quite low, 0,1 m/s to 0,3 m/s or lower[4)]. The 'outdoor workplace' range of wind speeds shall also apply to samplers intended for use in forced ventilation (>0,25 m/s). The highest wind speed value recommended here may be altered if the critical review identifies a more suitable upper limit, depending on the intended use of the sampler.

6.3.4 Wind direction

In accordance with the definition of the inhalable convention, the effects of wind direction shall be averaged out by rotating the mannequin/simulated torso or samplers during the course of each test run, either slowly and continuously, or stepwise, with four or more steps. For static samplers, an exception to this requirement may be made when the sampler is designed such that its inlet always takes up a preferred orientation to the external wind, or is omnidirectional, or when its use is limited to fixed sampling positions with respect to forced ventilation.

6.3.5 Aerosol composition

Particles used for tests to classify samplers shall be spherical (solid or liquid), or approximately isometric. The degree of agglomeration of the test aerosol itself may be verified by the visual microscopic inspection of particles collected by sedimentation onto slides placed in the working section of the wind tunnel or test chamber used. In general it is assumed that the chemical composition of the test aerosol is not influential. But in cases where the critical review suggests a possible composition-related effect (e.g. on particle retention on sampler surfaces), this can influence the choice, and this shall be noted in the test report.

6.3.6 Sampled or internally separated mass

The purpose of the test is to determine any dependency of the sampler efficiency curve on the collected mass or the internally separated mass, not to evaluate analytical errors. The amount of dust sampled (=aerosol concentration times sampled volume) shall not exceed typical values encountered during workplace sampling if it cannot be shown that this is not significant. If a test is carried out, a maximum concentration and sampling time relevant to the intended measurement tasks shall be chosen.

NOTE An example of such a test is given in EN 13205–5:2014, 6.5.5 and its evaluation in EN 13205–5:2014, 7.4.7.

6.3.7 Aerosol charge

If the sampler is non-conducting it shall be tested with a neutralised aerosol (unless it can be demonstrated that the results for aerosols charged during mechanical generation and dispersal into the test system are not significantly different)[5)]. However the results cannot reflect the performance obtained in routine sampling situations where charged aerosols are present. Electrostatic influences shall be reduced where possible, by

4) See Bibliography, reference [8], for the data presented by BALDWIN and MAYNARD.

5) See, for example, Bibliography, reference [9] on a study regarding the electrical charge on dry airborne particles produced by mechanical aerosol generators and Bibliography, reference [10] on a study regarding the effect of electrical particle charge on cyclone penetration.

choosing samplers made from conducting materials, cleaning them thoroughly, and earthing them during the tests where the information for use requires it.

6.3.8 Specimen variability

NOTE The given requirements are compulsory for personal thoracic and respirable samplers only.

Specimens chosen for testing shall be commercial samplers, not prototypes. Used specimens are preferred to new ones; the age of the selected specimens shall be stated. Where specimen variability is likely to be insignificant at least six test results shall be obtained, but tests may be repeated on two specimen (see EN 13205-1:2014, Tables 2 and 3).

6.3.9 Excursion from the nominal flow rate

NOTE The given requirements are compulsory for thoracic and respirable samplers only.

The flow dependence shall be tested at the wind speed most representative of the conditions of use. Tests to obtain this information need not be carried out where reliable data are available in published literature. The non-nominal flow rates shall be identical for all candidate sampler specimen, and be in a range from ± 5 % to ± 10 % of the nominal flow rate.

6.3.10 Surface treatments

Examples of surface treatments are the greasing and cleaning of collection substrates, the neutralising of filters and foams, and the method of sampler cleaning. Differences between the surface treatments actually tested and those recommended in the sampler's information for use shall be clearly stated and explained.

7 Experimental requirements

7.1 The experimental system shall have the characteristics as described in 7.2 to 7.12.

7.2 The experiments shall be carried out in an environment with temperature from 15 °C to 25 °C, pressure 960 hPa to 1050 hPa and relative humidity 20 % to 70 %, unless the sampler is to be used in more extreme environments, in which case the conditions of use shall be reproduced as closely as possible. A full description of the test environment shall be given in the test report, and the actual conditions existing at the time of testing documented.

7.3 Tests may be carried out with either polydisperse or monodisperse aerosols, or a combination of both[6)]. When monodisperse test aerosols are used, a single experiment gives rise to a single measurement of sampling efficiency at a single aerodynamic diameter. Therefore it is necessary to use (at least) nine different aerosols in order to obtain sampling efficiency values corresponding to at least nine particle sizes, covering the desired range (as required in Table 1). Correction factors for particle shape and particle density, where used, shall be determined for each aerosol[7)] or obtained from appropriate reliable literature. With a polydisperse aerosol a single experiment gives rise to several sampling efficiency values corresponding to adjacent aerodynamic diameters within the desired range. Correction factors for particle density and shape, where used, shall be determined as functions of particle size. The test aerosols shall consist of non-condensing, non-evaporating and non-coagulating particles.

7.4 The choice of aerosol depends on the availability of a suitable method for the measurement of particle aerodynamic diameter; this may be done by any method having a unique, monotonic calibration curve over

6) For examples of published performance evaluations using polydisperse aerosols (generally for respirable or thoracic samplers) see Bibliography, references [11] to [18].

7) See, for example, Bibliography, references [19] to [21].

the appropriate size range. Direct-reading instrumentation used shall be capable of providing particle size information specifically in terms of particle aerodynamic diameter. Alternatively, however, an instrument that provides particle size in terms of some other metric would be acceptable provided that it can either be calibrated in terms of particle aerodynamic diameter or the particle size it provides can be converted to particle aerodynamic diameter by the application of other information (for example, particle density or shape) according to established aerosol science principles. If the latter approach is adopted, full details of the conversion method (including uncertainty) shall be stated in the test report. Full details of the calibration method shall be stated, particularly where correction factors for particle density, particle shape or other test aerosol characteristics are used. The measured aerodynamic diameters and their precision (including uncertainty in any correction factors used) shall be calculated and stated in the test report.

7.5 Monodisperse test aerosols shall have geometric standard deviations less than 1,1 for experiments on respirable or thoracic samplers. For tests on inhalable samplers, only nearly-monodisperse test aerosols with a geometric standard deviations less than 1,3 is required. Where polydisperse aerosols are used, the particle size distribution shall extend well beyond the largest aerodynamic diameter at which sampler efficiency is to be measured, in order to keep measurement errors within acceptable limits[8)].

7.6 Within the testing section the test aerosols shall be spatially homogeneous with a standard deviation less than 10 % with respect to both size distribution and concentration. With some experimental designs, temporal stability can also be important. The temporal stability (after any correction) shall have a standard deviation less than 10 %. The aerosol concentration and size distribution during the tests shall be carefully chosen for compatibility with the limitations of the aerodynamic diameter measurement method, and shall be documented. For polydisperse test aerosols the sampled aerosol concentration shall be in the range that is (a) large enough to provide sufficient individual particle counts across the whole range of particle size of interest, in order that particle concentration can be defined with sufficient statistical accuracy, but (b) not so large that particle counting artefacts can occur due to counting coincidences or other apparent ‘phantom’ particles. The aerosol size distribution and concentration shall be sufficient to ensure that analytical errors in the measurement of the sampled aerosol are less than 2 % for analysis by weighing or chemical methods, and less than 1 % for analysis by particle counting. Details of the particle (number and mass) statistics shall be noted in the test report.

7.7 The test aerosol concentration shall be determined by sampling with thin-walled sharp-edged probes. In the case of a wind tunnel the probes shall be operating isokinetically. (Alternatively, anisokinetic operation of the probes may be used provided that a validated aspiration and transfer efficiency model is determined and used for correction of the measured aerosol concentrations.) In the case of an aerosol chamber (for tests in calm air or very slow wind) the probes shall either be circling and operating pseudo iso-kinetically[9)] or with aspiration efficiency calibrated according to the theory of Su and Vincent (see Bibliography, references [26] and [27]. Sharp-edged probes shall be situated at representative positions within the area in which the test samplers are placed, so that spatial variations in the test aerosol can be identified. The method used to calculate the sampler efficiency shall be clearly stated, and shall take into account where possible temporal and spatial variations in concentration. The method used to estimate the test aerosol concentration from the sharp-edged probe data shall demonstrated to be unbiased, and each estimate shall have relative standard deviation less than 10 %.

7.8 The actual values of wind speed (or any other environmental variable) during the test runs shall not differ by more than 10 % from the target value, over the area in which test specimens are situated. Where a wind tunnel is used the blockage by the mannequin or samplers shall be less than 20 %. The turbulence length scale and intensity in the wind tunnel shall be measured if possible and documented in the test report; the values shall be kept constant for each of the test wind speeds[10)].

8) Useful guidance on the generation of suitable test aerosols is given by VDI 2066, VDI 3489 and VDI 3491.

9) See, for example, Bibliography, reference [25].

10) The effects of turbulence on sampler performance are not yet well understood and the documentation of turbulence length scales and intensities will enable a study to be carried out. However, turbulence intensity and length scale are

7.9 Several sampler specimens may be tested together provided they are not so close that they interfere. The experimental design shall be capable of isolating and eliminating any positional effects from the experiment. Samplers shall be tested together with their appropriate holders; the plane of the inlet shall be orientated as in field sampling. The positions and orientations used shall be documented. The positions at which personal samplers are placed on a mannequin or simulated torso (if used) during testing shall be representative of where they are designed to be used, unless it can be shown that such positional effects are not significant.

7.10 Any test method involving the use of a direct-reading instrument to determine sampling efficiency requires consideration of the particle losses that will occur after passing through the position of the sampler where the collection substrate is mounted (in ordinary use of the sampler) before arrival at the sensing zone of the direct-reading instrument. This applies to both the candidate sampler and the sharp-edged probes. Particle losses may either be corrected quantitatively, or the measurement system designed so that such losses cancel out between the candidate sampler and the sharp-edged probe respectively. In addition, sampler flow rates appropriate to the candidate sampler (after appropriate scaling) and the sharp-edged probe can need to take account of the flow rate specified for the direct-reading instrument used, such that appropriate flow matching can be required (e.g. by the addition or subtraction of air from the sampler air flow).

7.11 The test report shall contain details of the methods used to process and analyse the samples taken during the tests, and of the procedures used to clean samplers between experimental runs.

7.12 Samplers shall be tested together with suitable, properly maintained pumps. For test purposes the sampler volumetric flow rates shall be very carefully adjusted to within ± 2 % of the intended flow rate and measured, using e.g. a bubble flow meter or gas meter, and recorded. The pumps used shall meet general requirements (EN ISO 13137), or the requirements in 5.1, and any more stringent requirements specified in the information for use for the sampler. Samplers with an integral pump or air mover shall be tested under flow conditions having the same characteristics as the integral pump or air mover.

NOTE In order to obtain less scatter in the determined internal penetration in tests of samplers for the thoracic and respirable aerosol fractions, is advisable to use either pumps with better performance than required of sampling pumps by EN ISO 13137 or critical orifices or mass flow regulators.

8 Calculation of sampler bias and expanded uncertainty

8.1 General

A sampler is evaluated based on its bias and expanded uncertainty. CEN/TR 13205-3 presents two methods for calculating these quantities from the experimental data. The two methods are termed polygonal approximation and curve-fitting. The former is generally used when several candidate sampler individuals are tested simultaneously using monodisperse test aerosols. The latter is generally used when several candidate sampler individuals are tested sequentially using polydisperse test aerosols. (References are included to published papers containing worked examples of various parts of the calculations.)

The experimental data consist of aerosol concentration values measured with both the candidate sampler and sharp-edged probes as a function of particle aerodynamic diameter. Similar data sets can be available for a number of values of other influence variables such as external wind speed, mass loading of sampler, etc. If so, the calculations described shall be repeated for each set of measured efficiency values for each of the tested influence variables.

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difficult to measure, and require sophisticated equipment. For good estimates for grid-generated turbulence, see Bibliography, reference [28].

8.2 Determination of the sampling efficiency

Determine the sampling efficiency value, e, for each particle size, each influence variable, all tested candidate sampler individuals and all repeats

$$\begin{cases} e_{ipr[s]} = \dfrac{g_{ipr[s]}}{h_{ipr}} & \text{polygonal approximation} \\ e_{ips[r]} = \dfrac{g_{ips[r]}}{h_{ips[r]}} & \text{curve - fitting} \end{cases} \quad (1)$$

where

$e_{ipr[s]}$ is the calculated efficiency value for the polygonal approximation method [-];

$e_{ips[r]}$ is the calculated efficiency value for the curve-fitting method [-];

g is the concentration measured by the candidate sampler [mg/m^3 or 1/m^3];

h is the concentration measured by the sharp-edged probe(s) [mg/m^3 or 1/m^3].

The subscripts i, p, r and s enumerate influence variable values, particle size, repeat experiment and tested candidate sampler individual, respectively.

The concentrations sampled by the sharp-edged probe, h, may have been subject to corrections, either before the sampling efficiency values, e, are calculated according to Formula (1), or before they are modelled by curve-fitting as for example described in CEN/TR 13205-3.

Determine sampling efficiency curves from the individual values $e_{ipr[s]}$ and $e_{ips[r]}$, respectively, using, for example, one of the methods described in CEN/TR 13205-3. If polygonal approximation is used, determine one mean sampling efficiency value for each test particle size and per value for an influence variable, $\bar{E}_i\left(D_p\right)$. If curve-fitting is used, fit one sampling efficiency curve per value for an influence variable for each candidate sampler individual, $^{\text{est}}E_{is}\left(D\right)$. If a curve is fitted to the experimental data, the fitted curve shall be physically reasonable, i.e. approach an efficiency value of unity at an aerodynamic diameter value of zero and an efficiency value of zero at very large aerodynamic diameters, unless the sampler is known to behave otherwise. The curve shall have minimal lack of fit.

NOTE A regression curve with a shape that is not physically reasonable, usually occurs when the fitted curve is extrapolated outside the particle size interval over which the curve was fitted. Any non-physical part of the curve can be exchanged for a linear extrapolation.

8.3 Calculation of sampler bias

8.3.1 Calculation of the sampled aerosol concentration

8.3.1.1 General

Two methods for the calculation of the sampled aerosol concentration are presented. Use the method most appropriate for the data from the experiment. CEN/TR 13205-3 further explains how they can be employed in order to perform the necessary calculations.

In the case of samplers for the inhalable fraction, the upper size limit for the calculations according to 8.3.1.2, 8.3.1.3 and 8.3.2 is the largest particle size of the test aerosol, which shall exceed 90 µm. Irrespective of

whether a candidate sampler actually collects larger particles, this is the upper limit, as the inhalable fraction is undefined for particles exceeding 100 µm [11)].

8.3.1.2 Polygonal approximation

Calculate the mean sampled relative concentration, $\bar{C}_i$, which can be approximately calculated for each aerosol size distribution A using the summation according to Formula (2):

$$\bar{C}_i = \bar{C}_i\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}\right) \approx \sum_{p=1}^{N_P} \bar{E}_i\left(D_p\right) W_p \tag{2}$$

where

$\bar{C}_i$ is the mean sampled relative concentration and is a function of the sampled aerosol size distribution, A;

D_{A} is the mass median aerodynamic diameter of the sampled aerosol, A;

$\bar{E}_i\left(D\right)$ is the mean sampling efficiency of the candidate sampler for influence variable value ς_i;

N_{P} is the number of test particle sizes;

W_p is a function of the aerosol size distribution A; and

σ_{A} is the geometric standard deviation of the sampled aerosol, A.

NOTE For information on how the W_p values can be calculate over the whole of the summation range, see FprCEN/TR 13205–3:2012, 5.4.1.

8.3.1.3 Curve-fitting

Calculate the mean sampled relative concentration, $\bar{C}_i$, which can be calculated for each aerosol size distribution A using the integral according to Formula (3):

$$\bar{C}_i = \bar{C}_i\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}\right) = \frac{1}{N_{\mathrm{S}}} \sum_{s=1}^{N_{\mathrm{S}}} \left[\int_{D_{\min}}^{D_{\max}} A\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}, D\right)^{\mathrm{est}} E_{is}\left(D\right) \mathrm{d}D \right] \tag{3}$$

where

$A\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}, D\right)$ is the relative lognormal aerosol size distribution, with mass median aerodynamic diameter D_{A} and geometric standard deviation σ_{A}, [1/µm];

$\bar{C}_i$ is the mean sampled relative concentration and is a function of the sampled aerosol size distribution, A;

D_{A} is the mass median aerodynamic diameter of the sampled aerosol, A;

$D_{\min}$ is the lower limit of the integral;

$D_{\max}$ is the upper limit of the integral;

11) For a discussion of the potential difference between an inhalable sampler that has a sharp (impactor-like) cut off at 100 µm and a more realistic sampler, see Bibliography, reference [29].

$^{\text{est}}E_{is}(D)$	is the mean sampling efficiency of the candidate sampler for influence variable value ς_i;
N_{S}	is the number of candidate sampler individuals; and
σ_{A}	is the geometric standard deviation of the sampled aerosol, A.

The integral may be evaluated numerically using any suitable method [12)] having a numerical error of less than one part in 10^4. The limits of the integration, D_{min} and, D_{max} are reached when the value of the integrand $A\ ^{\text{est}}E_{is}(D)$ is less than $0{,}5 \times 10^{-3}$, or for inhalable samplers when D_{max} is equal to the maximum aerodynamic diameter value tested in the experiments. For more information, see CEN/TR 13205-3:2014, 5.5.1.

8.3.2 Calculation of the ideal sampled aerosol concentration

The sampled concentration, C_{std}, that would be obtained for aerosol size distribution *A* using an ideal sampler is calculated from numerical integration as in Formulae (2) and (3), substituting the sampling convention relevant to the candidate sampler, $F(D)$, in place of the measured sampling efficiency, see Formula (4):

$$C_{\text{std}} = C_{\text{std}}(D_{\text{A}}, \sigma_{\text{A}}) \begin{cases} \approx \sum_{p=1}^{N_{\text{P}}} F(D_p) W_p \\ = \int_{D_{\text{min}}}^{D_{\text{max}}} A(D_{\text{A}}, \sigma_{\text{A}}, D) F(D) \text{d}D \end{cases} \quad (4)$$

where

$A(D_{\text{A}}, \sigma_{\text{A}}, D)$	is the relative lognormal aerosol size distribution, with mass median aerodynamic diameter D_{A} and geometric standard deviation σ_{A}, [1/µm];
C_{std}	is the concentration that would be sampled by a sampler that perfectly follows the sampling convention and is a function of the sampled aerosol size distribution, A;
D_{A}	is the mass median aerodynamic diameter of the sampled aerosol, A;
D_{max}	is the upper limit of the integral;
D_{min}	is the lower limit of the integral;
$F(D)$	is the sampling convention relevant to the candidate sampler;
N_{P}	is the number of test particle sizes;
W_p	is a function of the aerosol size distribution A; and
σ_{A}	is the geometric standard deviation of the sampled aerosol, A.

For the case of using polygonal approximation, CEN/TR 13205-3:2014, 4.4.1 gives information for how the values of the integral at the ends of the summation range can be determined. For the case of using the curve-fitting method, the integration limits shall be the same as in Formula (3).

12) For example by using Romberg integration, see Bibliography, reference [30].

8.3.3 Calculation of the sampler bias

For any aerosol size distribution A, the bias in the sampled concentration is defined according to Formula (5) as

$$\Delta_i = \Delta_i\left(D_{\mathrm{A}}, \sigma_{\mathrm{A}}\right) = \frac{c\,\bar{C}_i - C_{\mathrm{std}}}{C_{\mathrm{std}}} \tag{5}$$

where

C_{std} is the concentration that would be sampled by a sampler that perfectly follows the sampling convention and is a function of the sampled aerosol size distribution, A;

c is the correction factor stated either in the manufacturer's instructions for use or in the relevant measuring procedure;

$\bar{C}_i$ is the mean sampled relative concentration and is a function of the sampled aerosol size distribution, A;

D_{A} is the mass median aerodynamic diameter of the sampled aerosol, A;

Δ_i is the bias or relative error in the aerosol concentration measured using the candidate sampler, for aerosol size distribution A, at influence variable value ς_i; and

σ_{A} is the geometric standard deviation of the sampled aerosol, A.

Only a correction factor stated either in the manufacturer's instructions for use or in the relevant measuring procedure may be used for correcting the bias of a sampler. No other correction factor may be applied to the sampled concentrations. If no correction factor is stated, c is assigned a value of 1,00. The value chosen for *corr* shall be clearly stated in the sampler test report.

Calculate the bias values for the aerosol size distributions specified in Table 2. The calculated bias values shall be tabulated in the test report, and also plotted in the form of a bias map, which is a two dimensional diagram showing the σ_{A} and D_{A} values on the axes, and points of equal bias joined to form contours. One diagram shall be drawn for each tested wind speed or other influence variable. The aerosol size distributions of interest when assessing the performance of the sampler (see Table 2) shall be indicated on the bias maps.

8.4 Calculation of the expanded uncertainty of the sampler

8.4.1 General

The sources of uncertainty components of an aerosol sampler associated with the sampler, its calibration and flow deviations from nominal flow rate are

— calibration of sampler test system (see 8.4.2);

— estimation of sampled concentration (see 8.4.3);

— bias relative to the sampling convention (see 8.4.4);

— individual sampler variability (see 8.4.5);

— excursion from the nominal flow rate (see 8.4.6).

All these sources of uncertainty depend on the aerosol size distribution A and other influence variables, as for example wind speed or sampler loading. To compact the data, the calculations proceed in several steps:

a) for each of the influence variable values, and for each of the five uncertainty components listed above, calculate the RMS of the uncertainty component for all aerosol size distributions A in Table 2 (or possibly a restricted set if the performance of the sampler is to be determined only for this restricted set of aerosol size distributions) for each influence variable values;

b) for each of the influence variable values, add the variances of the five uncertainty components into a combined standard uncertainty squared;

c) if the sampling/analytical situation makes it feasible to distinguish between different values of the influence variables, associate one combined standard uncertainty squared with each influence variable values;

d) if the sampling/analytical situation does not make it feasible to distinguish between different values of the influence variables, determine for which of the influence variable values the combined standard uncertainty squared is largest, and select this value as the combined standard uncertainty squared of the sampler;

e) The combined standard uncertainty of the sampler is the square root of the combined standard uncertainty squared.

NOTE The following data are expected values for reasonably good experiments and samplers that are reasonably well optimized to the intended sampling convention. The data are only presented to indicate the magnitudes to be expected and cannot be taken as presented for any sampler. The uncertainty of the calibration of the experimental test system is expected to result in a uncertainty (of measurement) component of 0,01 to 0,02. The uncertainty of the calculated concentration is expected to result in a uncertainty (of measurement) component of 0,01 to 0,02. The difference amongst sampler individuals is expected to result in a uncertainty (of measurement) component of 0,03 to 0,07. The bias relative to the sampling convention is expected to result in a uncertainty (of measurement) component of 0,05 to 0,10 depending on how well the sampler is optimized to the sampling convention. (Samplers not well optimized can have an uncertainty component of 0,20 to 0,25.) For samplers for the respirable and thoracic aerosol fractions the uncertainty due to excursion from nominal flow rate is expected to result in a uncertainty (of measurement) component of 0,02 to 0,05 if the nominal flow rate is used in the calculation of sampled concentration and 0,05 to 0,09 if the actual flow rate is used in the calculation of sampled concentration. For samplers for the inhalable aerosol fraction the uncertainty of the sampler flow deviation from nominal flow rate is expected to be ~0,03.

In addition to the sampling per se, a measuring procedure for an aerosol fraction consists additionally of the three stages: 1) Flow measurement, 2) Transport of samples back to the analytical laboratory and 3) (chemical) Analysis. A complete evaluation of a measuring procedure requires knowledge of the losses/ biases (and possible corrections) and the uncertainties of these stages. EN 13205-1:2014, Annex A specifies how the expanded uncertainty is calculated for a measuring procedure.

8.4.2 Calibration of sampler test system

In a properly designed and performed experiment, the uncertainty components associated with calibration of the sampler test system shall be very small. They can be calculated from propagation of errors from the uncertainty of the diameter of the calibration particles (and possibly by the use of calibration functions for particle sizers) to the uncertainty in sampled mass fraction.

The calibration uncertainty stems from how well the actual absolute sizes of the test particles are known, and it is calculated as this particle size uncertainty translates into the uncertainty of the calculated concentration. The calibration uncertainty consists of both non-random and random uncertainties from (for example): 1) The (monodisperse) test aerosols, 2) The calibration particles for the particle counter/sizer used with (polydisperse) test aerosols, and 3) A conversion function for particle size (for example used to recalculate volume equivalent diameters into aerodynamic diameters).

The mixed non-random and random uncertainty of the mean sampled aerosol concentration due to calibration uncertainty, and expressed as a fraction of C_{std}, is calculated for each influence variable value as a RMS over all N_{SD} aerosol size distributions A. It is designated $u_{\text{CandSampl-Calibr}_i}$. CEN/TR 13205-3:2014, 5.4.3.2 and

5.5.3.2, give examples of how this is calculated for the polygonal approximation and the curve-fitting methods, respectively, based on the uncertainty of the sizes of the test particles.

8.4.3 Estimation of sampled concentration

The uncertainty of the estimate of the sampled concentration stems from how well the model for the sampling efficiency describes the sampling efficiency data. In the case of the polygonal approximation method it incorporates the crudeness of polygonal approximation, the uncertainties of the concentrations measured by the candidate sampler and the sharp-edged probes, respectively. In the case of the curve-fitting method, it incorporates the uncertainty of the estimated regression models and any correction of measured sampling efficiencies due to temporal or spatial variation. For both methods it is calculated (by propagation of errors) as how these uncertainties translate into the uncertainty of the calculated concentration.

The random uncertainty of the mean sampled aerosol concentration due to the uncertainty of the models used, and expressed as a fraction of C_{std}, is calculated for each influence variable value as a RMS over all N_{SD} aerosol size distributions A. It is designated $u_{\text{CandSampl-ModelCalc}_i}$. CEN/TR 13205-3:2014, 5.4.3.3 and 5.5.3.3, give examples of how this is calculated for the polygonal approximation and the curve-fitting methods, respectively, based on the uncertainty of the model for the sampling efficiency.

8.4.4 Bias relative to the sampling convention

The bias variability of the sampled concentration stems from the difference between the average actual sampling efficiency of the candidate sampler and the sampling convention.

The non-random uncertainty of the mean sampled aerosol concentration due to the difference of the average sampling efficiency curve of the candidate samplers and the sampling convention, and expressed as a fraction of C_{std}, is calculated for each influence variable value as a RMS over all N_{SD} aerosol size distributions A. It is designated $u_{\text{CandSampl-Bias}_i}$ and is calculated from Formula (6):

$$\begin{cases} u_{\text{CandSampl-Bias}_i}{}^2 = \dfrac{1}{N_{\text{SD}}} \sum_{a=1}^{N_{\text{SD}}} \left(\dfrac{c\,\bar{C}_i - C_{\text{std}}}{C_{\text{std}}} \right)^2 = \dfrac{1}{N_{\text{SD}}} \sum_{a=1}^{N_{\text{SD}}} \left(\Delta_i \left(D_{\text{A}_a}, \sigma_{\text{A}_a} \right) \right)^2 \\ \bar{C}_i = \bar{C}_i \left(D_{\text{A}_a}, \sigma_{\text{A}_a}, \varsigma_i \right) \\ C_{\text{std}} = C_{\text{std}} \left(D_{\text{A}_a}, \sigma_{\text{A}_a} \right) \end{cases} \tag{6}$$

where

C_{std} is the target sampled relative aerosol concentration;

$\bar{C}_i$ is the mean sampled relative aerosol concentration;

c is the candidate sampler correction factor for bias correction;

D_{A_a} is mass median aerodynamic diameter of the a^{th} lognormal aerosol size distribution A;

N_{SD} is the number of aerosol size distributions A according to Table 2;

$u_{\text{CandSampl-Bias}_i}$ is the standard uncertainty (of measurement) due to bias (non-random errors) in relation to the sampling convention of the sampler at influence variable value ς_i;

Δ_i is the bias in the aerosol concentration measured using the candidate sampler, for aerosol size distribution A, at influence variable value ς_i;

ς_i is the i^{th} value of another influence variable;

σ_{A_a} is the geometric standard deviation of the a^{th} lognormal aerosol size distribution A.

NOTE Formulae (2) and (3) describe how $\bar{C}_i$ is calculated for the polygonal approximation and the curve-fitting methods, respectively.

8.4.5 Individual sampler variability

This random error uncertainty is calculated from the measured/calculated standard deviations of the aerosol concentration sampled by the candidate sampler individuals. It can only be calculated when there exists a complete set of sampling efficiency data for at least six sampler individuals. For the method of polygonal approximation it is based on the variability of the concentrations sampled by the candidate sampler individuals. For the curve-fitting method it stems from the differences in sampling efficiency curves amongst the candidate sampler individuals. For both methods it is calculated as how the differences in sampling efficiency between sampler individuals translate into the uncertainty of the calculated concentration.

NOTE These differences mainly occur for samplers of the respirable and thoracic aerosol fractions with internal penetration that depends on geometry and surface smoothness, e.g. cyclones, horizontal elutriators and impactors.

The random uncertainty of the mean sampled aerosol concentration due to the variability of the measured/ calculated concentrations, and expressed as a fraction of C_{std}, is calculated for each influence variable value as a RMS over all N_{SD} aerosol size distributions A. It is designated $u_{\text{CandSampl-Variability}_i}$.

CEN/TR 13205-3:2014, 5.4.3.4 and 5.5.3.4, give examples of how this is calculated for the polygonal approximation and the curve-fitting methods, respectively, based on the measured differences in sampling efficiency.

8.4.6 Excursion from the nominal flow rate

8.4.6.1 Candidate samplers without any coupling between flow rate and internal penetration, e.g. samplers for the inhalable aerosol fraction

The flow deviation effect on the calculated fractional concentration is identical to the ability of the pump to keep the flow rate constant, within a maximum allowed flow rate deviation, $\pm\delta_{\text{Pump}}$. For a pump specified to the requirements of EN ISO 13137, $\delta_{\text{Pump}} = 0,05$.

The random uncertainty of the mean sampled aerosol concentration due to flow rate deviations, for aerosol size distribution A and other influence variables, and expressed as a fraction of C_{std}, is calculated for each influence variable value as a RMS over all N_{SD} aerosol size distributions A. Assuming a rectangular distribution the corresponding RMS source of uncertainty $u_{\text{CandSampl-Flow}_i}$ is calculated from Formula (7):

$$\begin{cases} u_{\text{CandSampl-Flow}_i}{}^2 = \dfrac{\delta_{\text{Pump}}{}^2}{3} \dfrac{1}{N_{\text{SD}}} \sum_{a=1}^{N_{\text{SD}}} \left(\dfrac{\bar{C}_i}{C_{std}} \right)^2 \\ \bar{C}_i = \bar{C}_i \left(D_{\text{A}_a}, \sigma_{\text{A}_a}, \varsigma_i \right) \\ C_{\text{std}} = C_{\text{std}} \left(D_{\text{A}_a}, \sigma_{\text{A}_a} \right) \end{cases} \quad (7)$$

where

C_{std} is the target sampled relative aerosol concentration;

$\bar{C}_i$ is the mean sampled relative aerosol concentration, for aerosol size distribution A, at influence variable value ς_i;

D_{A_a} is mass median aerodynamic diameter of the a^{th} lognormal aerosol size distribution A;

N_{SD} is the number of aerosol size distributions A according to Table 2;

$u_{\text{CandSampl-Flow}_i}$ is the standard uncertainty (of measurement) due to flow rate deviation at influence variable value ς_i;

ς_i is the i^{th} value of another influence variable; and

σ_{A_a} is the geometric standard deviation of the a^{th} lognormal aerosol size distribution A.

8.4.6.2 Candidate samplers with a coupling between flow rate and internal penetration, e.g. samplers for the respirable and thoracic aerosol fractions

The penetration of samplers for the respirable and thoracic sampling conventions is highly dependent on the sampling flow rate. The non-random uncertainty component associated with flow excursion from the nominal flow rate is calculated from propagation of error in flow rate to variability in sampled mass fraction.

The flow excursion effect on the calculated sampled concentration stems from two (in most cases, competing) effects of flow rate deviations from the nominal flow rate: 1) An increased volumetric flow rate increases the mass flow of aerosol entering the sampler, and 2) An increased volumetric flow rate changes (in most cases, increases) the separation power of the sampler.

NOTE 1 Examples of samplers that decrease the penetration with increased flow rate are samplers whose separation is based on inertia, e.g. cyclones and impactors. On the other hand, the penetration of horizontal (or vertical) elutriators (which is based on sedimentation) is increased with increased flow rate.

For any actual measurement with the sampler, the flow rate deviation has two parts: 1) The flow rate was not set exactly at the nominal flow rate (allowed *relative* flow rate deviation, $\pm\delta_{\text{FlowSet}}$), and 2) During the sampling time the pump is only able to keep the flow rate constant within a maximum allowed *relative* flow rate deviation, $\pm\delta_{\text{Pump}}$. For a pump specified to the requirements of EN ISO 13137, $\delta_{\text{Pump}} = 0,05$. If a measuring procedure specifies a more stringent requirement for pump flow stability, or if such a requirement is specified in a sampling protocol that will be used in conjunction with the sampler, this value shall be used for δ_{Pump} in the calculations below.

The non-random uncertainty of the mean sampled aerosol concentration due to flow rate deviations, for aerosol size distribution A and other influence variables, and expressed as a fraction of, C_{std} is calculated for

each influence variable value as a RMS over all N_{SD} aerosol size distributions A. It is designated $u_{\text{CandSampl-Flow}_i}$ and calculated according to Formulae (8) to (12).

The dependence on the flow rate of the mass that is sampled by the sampler (expressed as a fraction of the mass aspirated into the sampler), $m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right)$, can be expressed according to Formula (8) as

$$m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right) = m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q^0\right)\left(\frac{Q}{Q^0}\right)^{q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right)} \tag{8}$$

where

D_{A_a} is mass median aerodynamic diameter a of lognormal aerosol size distribution A;

$m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right)$ is the mass collected when sampling from the a^{th} lognormal aerosol size distribution A using flow rate Q (see Formula (10));

Q^0 is the nominal flow rate;

Q is the a flow rate (other than the nominal flow rate) for which the sampling efficiency was determined;

$q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right)$ is the coefficient expressing the influence of the flow rate on the collected mass (see Formula (9)); and

σ_{A_a} is the geometric standard deviation of the a^{th} lognormal aerosol size distribution A.

$q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right)$ is the regression coefficient estimated from the regression model without intercept, see Formula (9):

$$q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right) = \frac{\sum_{a=1}^{N_{\text{SD}}} \ln\frac{m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right)}{m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q_0\right)} \ln\frac{Q}{Q^0}}{\sum_{a=1}^{N_{\text{SD}}}\left[\ln\frac{Q}{Q^0}\right]^2} \tag{9}$$

The calculation of m_i depends on whether the polygonal approximation or the curve-fitting method is used, see Formula (10):

$$m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right) \begin{cases} \approx \sum_{p=1}^{N_P} E_i\left(Q, D_p\right) W_p \\ = \int_{D_{\text{min}}}^{D_{\text{max}}} A\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, D\right)^{\text{est}} E_i\left(Q, D\right) \text{d}D \end{cases} \tag{10}$$

where

$A\left(D_{\text{A}}, \sigma_{\text{A}}, D\right)$ is the distribution function of the lognormal aerosol size distribution A;

D_{A_a} is mass median aerodynamic diameter a of lognormal aerosol size distribution A;

$E_i\left(Q, D_p\right)$ is the sampling efficiencies at sampler flow rate Q estimated with the polygonal approximation method;

$^{\text{est}}E_i\left(Q, D\right)$ is the sampling efficiencies at sampler flow rate Q estimated with the curve-fitting methods;

$m_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, Q\right)$ is the mass collected when sampling from the a^{th} lognormal aerosol size distribution A using flow rate Q (see Formula (10));

Q is the actual flow rate for which the sampling efficiency was determined;

W_p is a function of the aerosol size distribution A. See CEN/TR 13205–3:2012, 5.4.1 for information on how the W_p values can be calculated over the whole of the summation range; and

σ_{A_a} is the geometric standard deviation of the a^{th} lognormal aerosol size distribution A.

For each aerosol size distribution a and tested influence variable value, the standard deviation for the uncertainty due to flow deviation $s_{\text{CandSampl-Flow}_{ia}}$ can approximately be calculated from Formula (11) as:

$$s_{\text{CandSampl-Flow}_{ia}} \approx \left| q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right) - q_0 \right| \sqrt{\frac{\delta_{\text{FlowSet}}{}^2 + \delta_{\text{Pump}}{}^2}{3}}\, \bar{C}_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, \varsigma_i, Q^0\right) \tag{11}$$

where

$\bar{C}_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}, \varsigma_i, Q^0\right) = \bar{C}_i$ is calculated according to Formulae (2) and (3) for the polygonal approximation and the curve-fitting methods, respectively.

$q_i\left(D_{\text{A}_a}, \sigma_{\text{A}_a}\right)$ is the coefficient expressing the influence of the flow rate on the collected mass;

q_0 is a parameter whose value depends on whether, the measurement procedure according to which the sampler will be used requires that, the sampled concentration shall be calculated based on the actual flow rate ($Q \Rightarrow q_0 = 0$) or the nominal flow rate ($Q^0 \Rightarrow q_0 = 1$);

$s_{\text{CandSampl-Flow}_{ia}}$ is the uncertainty (of measurement) of the calculated sampled concentration, due to excursion from nominal flow and/or deviation from initial flow, for the a^{th} aerosol size distribution A at influence variable value ς_i,

δ_{FlowSet} is the maximum relative error allowed in setting the flow rate;

δ_{Pump} is the maximum relative change in flow rate allowed by pump flow rate stability.

NOTE 2 It is only for samplers with decreased penetration with increased flow rate that it makes sense to calculate the concentration based on the nominal flow rate.

$u_{\text{CandSampl-Flow}_i}$ is finally calculated from Formula (12):

$$u_{\text{CandSampl-Flow}_i}{}^2 = \frac{1}{N_{\text{SD}}} \sum_{a=1}^{N_{\text{SD}}} \left(\frac{s_{\text{Sampl-Flow}_{ia}}}{C_{\text{std}}} \right)^2 \tag{12}$$

where

C_{std} is the target sampled relative aerosol concentration;

N_{SD} is the number of aerosol size distributions A according to Table 2;

$s_{CandSampl\text{-}Flow_{ia}}$ is calculated from Formula (11); and

$u_{CandSampl\text{-}Flow_i}$ is the standard uncertainty (of measurement) due to flow rate deviation at influence variable value ς_i.

8.4.7 Combined uncertainty (of measurement)

8.4.7.1 General

The combined standard uncertainty consists of two components, arising from the random, $u_{CandSampl\text{-}R_i}$, and non-random, $u_{CandSampl\text{-}nR_i}$, sources of error, respectively. Their calculation depends on whether there is no coupling between the flow rate and internal penetration of the candidate sampler (e.g. samplers for the inhalable aerosol fraction) or whether such a coupling exists (e.g. samplers for the respirable and thoracic aerosol fractions).

8.4.7.2 Candidate sampler without any coupling between the flow rate and internal penetration

For a candidate sampler without any coupling between the flow rate and internal penetration, separately for each influence variable value, add the variances of the random and non-random sources of uncertainty according to Formula (13):

$$\begin{cases} u_{CandSampl\text{-}R_i}{}^2 = u_{CandSampl\text{-}ModelCalc_i}{}^2 + u_{CandSampl\text{-}Variability_i}{}^2 + u_{CandSampl\text{-}Flow_i}{}^2 \\ u_{CandSampl\text{-}nR_i}{}^2 = u_{CandSampl\text{-}Calibr_i}{}^2 + u_{CandSampl\text{-}Bias_i}{}^2 \end{cases} \quad (13)$$

where

$u_{CandSampl\text{-}Bias_i}$ is the candidate sampler's standard uncertainty (of measurement) due to bias relative to the sampling convention, at influence variable value ς_i [see Formula (6)];

$u_{CandSampl\text{-}Calibr_i}$ is the candidate sampler's standard uncertainty (of measurement) due to the calibration uncertainty of the experiment, at influence variable value ς_i (see 8.4.2);

$u_{CandSampl\text{-}Flow_i}$ is the candidate sampler's standard uncertainty (of measurement) due to flow rate deviation, at influence variable value ς_i [see Formula (7)];

$u_{CandSampl\text{-}ModelCalc_i}$ is the candidate sampler's standard uncertainty (of measurement), due to the uncertainty of the fitted model, at influence variable value ς_i (see 8.4.3);

$u_{CandSampl\text{-}nR_i}$ is the candidate sampler's combined uncertainty (of measurement) due to non-random errors, at influence variable value ς_i;

$u_{CandSampl\text{-}R_i}$ is the candidate sampler's combined uncertainty (of measurement) due to random errors, at influence variable value ς_i; and

$u_{CandSampl\text{-}Variability_i}$ is the candidate sampler's standard uncertainty (of measurement) due to differences among sampler individuals, at influence variable value ς_i (see 8.4.5).

8.4.7.3 Candidate sampler with a coupling between the flow rate and internal penetration

For a candidate sampler with a coupling between the flow rate and internal penetration, separately for each influence variable value, add the variances of the random and non-random sources of uncertainty according to Formula (14):

$$\begin{cases} u_{\text{CandSampl-R}_i}{}^2 = u_{\text{CandSampl-ModelCalc}_i}{}^2 + u_{\text{CandSampl-Variability}_i}{}^2 \\ u_{\text{CandSampl-nR}_i}{}^2 = u_{\text{CandSampl-Calibr}_i}{}^2 + u_{\text{CandSampl-Bias}_i}{}^2 + u_{\text{CandSampl-Flow}_i}{}^2 \end{cases} \quad (14)$$

where

$u_{\text{CandSampl-Bias}_i}$ is the candidate sampler's standard uncertainty (of measurement) due to bias relative to the sampling convention, at influence variable value ς_i [see Formula (6)];

$u_{\text{CandSampl-Calibr}_i}$ is the candidate sampler's standard uncertainty (of measurement) due to the calibration uncertainty of the experiment, at influence variable value ς_i (see 8.4.2);

$u_{\text{CandSampl-Flow}_i}$ is the candidate sampler's standard uncertainty (of measurement) due to flow rate deviation, at influence variable value ς_i [see Formula (12)];

$u_{\text{CandSampl-ModelCalc}_i}$ is the candidate sampler's standard uncertainty (of measurement), due to the uncertainty of the fitted model, at influence variable value ς_i (see 8.4.3);

$u_{\text{CandSampl-nR}_i}$ is the candidate sampler's combined uncertainty (of measurement) due to non-random errors, at influence variable value ς_i;

$u_{\text{CandSampl-R}_i}$ is the candidate sampler's combined uncertainty (of measurement) due to random errors, at influence variable value ς_i; and

$u_{\text{CandSampl-Variability}_i}$ is the candidate sampler's standard uncertainty (of measurement) due to differences among sampler individuals, at influence variable value ς_i (see 8.4.5).

8.4.7.4 Combined uncertainty per influence variable value

For each of the influence variable values, calculate the combined uncertainty (of measurement) according to Formula (15):

$$u_{\text{CandSampl}_i} = \sqrt{u_{\text{CandSampl-R}_i}{}^2 + u_{\text{CandSampl-nR}_i}{}^2} \quad (15)$$

where

$u_{\text{CandSampl}_i}$ is the candidate sampler's combined uncertainty (of measurement) due to both random and non-random errors, at influence variable value ς_i;

$u_{\text{CandSampl-nR}_i}$ is the candidate sampler's combined uncertainty (of measurement) due to non-random errors, at influence variable value ς_i;

$u_{\text{CandSampl-R}_i}$ is the candidate sampler's combined uncertainty (of measurement) due to random errors, at influence variable value ς_i.

8.4.7.5 Distinction between different values of the influence variables

In cases where it is feasible to distinguish between different values of the influence variables (at the sampling and/or the analytical stage), the combined standard uncertainty of the sampler depends on the actual value of the influence variable at the time of sampling, e.g. wind speed.

NOTE This implies that the reported expanded uncertainty will be a function of the distinguishable values of the other influence variables, ς .

For these cases the combined standard uncertainty (for example for influence variable value I) can be given by Formula (16) as:

$$\begin{cases} u_{\text{CandSampl}} = u_{\text{CandSampl}}(\varsigma_I) = u_{\text{CandSampl}_I} \\ 0 \le I \le N_{\text{IV}} \end{cases} \quad (16)$$

where

I is the value of the enumerating subscript for a selected value of influence variable value, ς;

N_{IV} is the number of values for the other influence variables at which tests were performed;

$u_{\text{CandSampl}}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, to be used in the calculation of the expanded uncertainty [see Formula (19)];

$u_{\text{CandSampl}_I}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, for the specific influence variable value ς_i; and

ς is the value of other influence variable values.

Determine also the corresponding combined measurement uncertainties due to random and non-random errors, respectively, at influence variable value ς_I, namely $u_{\text{CandSampl-R}_I}$ and $u_{\text{CandSampl-nR}_I}$.

8.4.7.6 Non-distinction between different values of the influence variables

In cases where it is not feasible to distinguish between different values of the influence variables (at the sampling and/or the analytical stage), the maximum combined standard uncertainty for any influence variable value is selected as the combined standard uncertainty for all influence variable values, e.g. wind speed.

NOTE This means that the reported expanded uncertainty will be independent of the indistinguishable values of the other influence variables, ς.

For these cases the combined standard uncertainty is calculated from Formula (17) as:

$$u_{\text{CandSampl}} = \max_{i \le N_{\text{IV}}} \left\{ u_{\text{CandSampl}_i} \right\} \tag{17}$$

where

N_{IV} is the number of values for the other influence variables at which tests were performed;

$u_{\text{CandSampl}}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, to be used in the calculation of the expanded uncertainty [see Formula (19)];

$u_{\text{CandSampl}_i}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, at influence variable value ς_i; and

ς is the value of other influence variable values.

If this maximum occurs for influence variable value number $i = i0$ then the combined standard uncertainty for the candidate sampler is calculated from Formula (18) as

$$u_{\text{CandSampl}} = u_{\text{CandSampl}_{i0}} \tag{18}$$

where

$i0$ is the value of the enumerating subscript for the influence variable, ς, which causes the largest combined standard uncertainty for the candidate sampler;

$u_{\text{CandSampl}}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, to be used in the calculation of the expanded uncertainty [see Formula (19)];

$u_{\text{CandSampl}_{i0}}$ is the candidate sampler's combined standard uncertainty due to both random and non-random errors, for the specific influence variable value ς_{i0}; and

ς is the value of other influence variable values.

Determine also the corresponding combined measurement uncertainties due to random and non-random errors, respectively, at influence variable value ς_{i0}, namely $u_{\text{CandSampl-R}_{i0}}$ and $u_{\text{CandSampl-nR}_{i0}}$.

8.4.8 Expanded uncertainty

The expanded standard uncertainty for the aerosol sampler, $U_{\text{CandSampl}}$, is calculated from the combined standard uncertainty using a coverage factor of 2

$$U_{\text{CandSampl}} = 2\,u_{\text{CandSampl}} \tag{19}$$

where

$U_{\text{CandSampl}}$ is the candidate sampler's expanded uncertainty (of measurement); and

$u_{\text{CandSampl}}$ is the candidate sampler's combined uncertainty (of measurement)

NOTE In cases where it is feasible to distinguish between different values of the influence variables (at the sampling and/or the analytical stage), the expanded uncertainty of the sampler depends on the actual value of the influence variable at the time of sampling.

The calculation of the expanded uncertainty for a complete measuring procedure, i.e. incorporating also the stages transport, storage, sample preparation and sample analysis, is described in EN 13205-1:2014, Annex A.

9 Test report

9.1 General

The test report shall contain all information required in various parts of this standard for a type A test, even if not explicitly listed below (see EN 13205-1:2014, 7.1). The test report shall be divided into sections as described.

9.2 Testing laboratory details and sponsoring organisation

— name and address of testing laboratory, personnel carrying out the tests and date of the work;

— name of the organisation sponsoring the test.

9.3 Description of the candidate sampler

— sampler name;

— generic type, i.e. cyclone, elutriator;

— sampling convention(s) against which test is made;

— definition of which collection substrate(s) constitutes the sample(s);

— scope of the test, and any limitations to the field of application of the sampler that arise from the limited nature of the test;

— number, age and origin of the candidate sampler specimen;

— nominal flow rate for candidate sampler, including source of information e.g. constructions for use.

9.4 Critical review of sampling process

NOTE See EN 13205–1:2014, 6.2.

— description of the sampling process for the sampler under test;

— factors influencing the sampling process;

— reasoning behind the inclusion or exclusion of optional variables listed in Table 1.

9.5 Laboratory methods used

Details of the methods used at all stages of the laboratory tests shall be given, making particular reference to methods traceable to international standards. The report shall usually include:

a) schematic diagram and description of test facilities, i.e. wind tunnel or aerosol chamber, including dimensions, and showing the locations of samplers;

b) for wind tunnels, details of velocity profiles, blockage and turbulence,

c) for personal samplers, description of the mannequin, simulated torso or alternative experimental arrangement; position and orientation of samplers;

d) aerosol(s) used and description of generation system;

e) measurements of aerosol stability and homogeneity;

f) mass and number (if relevant) concentrations of test aerosol, as well as aerodynamic modal diameter and geometric standard deviation;

g) calibration of aerodynamic diameter measurements and error in the determination of aerodynamic diameter;

h) in the case of using direct-reading instruments for sizing and counting particles, a description of the instrument and its application in the test;

i) method of reference sample collection;

j) details of sampler flow measurement;

k) details of any external sampling pumps used;

l) details of temperature, pressure and humidity during the tests;

m) methods of sample analysis and errors in analysis;

n) calculation of test aerosol concentrations; relative standard deviation of test aerosol concentrations;

o) choice and treatment of collection substrates, and sampler cleaning procedures.

9.6 Details of experimental design

The test report shall contain a table that clearly shows the design of the experiment in terms of the number of specimens tested, particle sizes tested, external factors such as wind speed that have been included, and the number of levels for each factor. The order in which the experiments were actually carried out shall be recorded. This section shall also give details of any supplementary experiments, such as those to determine the flow dependence of the sampling efficiency, that were carried out. The configuration in which the main test was carried out shall be clearly stated.

9.7 Presentation of experimental results

For all specimens, a complete tabulation of all the sampler efficiency values measured at stated aerodynamic diameters shall be given. The table(s) shall clearly identify the sampler specimen, torso position (if applicable) and wind speed or other factors tested. The results of supplementary tests shall be tabulated separately.

9.8 Data analysis

The methods used to calculate the sampler bias and sampler performance shall be explained and the results of the calculations tabulated. Diagrams of the sampler bias and the expanded uncertainty for the sources of error (see 8.3), as a function of aerosol size distribution parameters, shall be shown for each tested wind speed or other influence variable.

9.9 Candidate sampler performance

— state the aerosol size distributions and wind speeds for which the sampler bias exceeds ± 0,1;

— the following components of the uncertainty (of measurement) shall be listed in the test report: calculated standard measurement uncertainties for all the sources of uncertainty for all influence variable values ($u_{\text{CandSampl-Calibr}_i}$, $u_{\text{CandSampl-ModelCalc}_i}$, $u_{\text{CandSampl-Variability}_i}$, $u_{\text{CandSampl-Bias}_i}$ and $u_{\text{CandSampl-Flow}_i}$); the calculated combined measurement uncertainties for all influence variable values ($u_{\text{CandSampl-R}_i}$, $u_{\text{CandSampl-nR}_i}$ and $u_{\text{CandSampl}_i}$), the corresponding the maximum values if not it is possible to distinguish between different other influence variable values during sampling and/or analysis ($u_{\text{CandSampl-R}}$, $u_{\text{CandSampl-nR}}$ and $u_{\text{CandSampl}}$);

— for all tested influence variable values (e.g. wind speed, collected mass or other condition), state the expanded uncertainty of the sampler, and whether it has the required expanded uncertainty (see EN 13205-1:2014, 5.2a);

— state any prescribed correction factor (c) that shall be applied to all concentrations measured with the sampler, according to either the sampler manufacturer or the relevant measuring procedure;

— state any special restrictions on the operational characteristics of the sampler, for example, the conditions for which it does not meet the requirements of this standard.

9.10 Report of workplace comparison

Include a report according to EN 13205-5:2014, Annex A.

9.11 Summary and information for the user of the sampler

Give a summary of the test report, explaining the scope of the tests and the main findings. Include the sampler performance and restrictions on its use. Describe any practical difficulties in the routine use of the sampler that are known to exist.

Table 2 — Size distributions of interest when assessing the performance of aerosol samplers

MMAD	GSD									
(µm)	1,75	2,00	2,25	2,50	2,75	3,00	3,25	3,50	3,75	4,00
1	R, T, I	R, T, I	–	–	–	–	–	–	–	–
2	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
3	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
4	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
5	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
6	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
7	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
8	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
9	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
10	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
11	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
12	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
13	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
14	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
15	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
16	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
17	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
18	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
19	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
20	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
21	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
22	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
23	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
24	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
25	T,I	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	R, T, I
26	T,I	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	R, T, I	–
27	T,I	T,I	T,I	T,I	T,I	R, T, I	R, T, I	R, T, I	–	–
28	T,I	T,I	T,I	T,I	T,I	T,I	R, T, I	R, T, I	–	–
29	T,I	T,I	T,I	T,I	T,I	T,I	R, T, I	–	–	–
30	T,I	T,I	T,I	T,I	T,I	T,I	R, T, I	–	–	–
31	T,I	T,I	T,I	T,I	T,I	T,I	–	–	–	–
32	T,I	T,I	T,I	T,I	T,I	T,I	–	–	–	–
33	T,I	T,I	T,I	T,I	T,I	T,I	–	–	–	–
34	I	T,I	T,I	T,I	T,I	–	–	–	–	–

35	I	T,I	T,I	T,I	T,I	–	–	–	–	–
36	I	T,I	T,I	T,I	T,I	–	–	–	–	–
37	I	T,I	T,I	T,I	–	–	–	–	–	–
38	I	T,I	T,I	T,I	–	–	–	–	–	–
39	I	I	T,I	T,I	–	–	–	–	–	–
40	I	I	T,I	T,I	–	–	–	–	–	–
41	I	I	T,I	–	–	–	–	–	–	–
42	I	I	T,I	–	–	–	–	–	–	–
43	I	I	T,I	–	–	–	–	–	–	–
44	I	I	T,I	–	–	–	–	–	–	–
45	I	I	–	–	–	–	–	–	–	–
46	I	I	–	–	–	–	–	–	–	–
47	I	I	–	–	–	–	–	–	–	–
48	I	I	–	–	–	–	–	–	–	–
49	I	I	–	–	–	–	–	–	–	–
50	I	I	–	–	–	–	–	–	–	–

R = samplers for the respirable aerosol fraction

T = samplers for the thoracic aerosol fraction

I = samplers for the inhalable aerosol fraction

The range of Mass Median Aerodynamic Diameter (MMAD) and Geometric Standard Deviation (GSD) values covered by this table includes the aerosol size distributions of most interest for workplace aerosol sampling. The criteria for including specific aerosol size distribution for respirable, thoracic or inhalable samplers are as follows:

1) More than 84 % of the aerosol mass consists of particles with aerodynamic diameters below 100 µm, i.e. MMAD × GSD ≤ 100 µm
2) In the case of the respirable and thoracic fractions, the fraction of interest contains at least 5 % of the total aerosol mass
3) More than 84 % of the aerosol mass consists of particles exceeding 0,5 µm, i.e. MMAD / GSD ≥ 0,5 µm.

There are 354 size distributions of interest for inhalable samplers, 325 for thoracic samplers and 216 for respirable samplers.

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