PD CEN/TS 16976:2016

BSI Standards Publication

Ambient air — Determination of the particle number concentration of atmospheric aerosol

National foreword

This Published Document is the UK implementation of CEN/TS 16976:2016.

The UK participation in its preparation was entrusted to Technical Committee EH/2/3, Ambient atmospheres.

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

Published by BSI Standards Limited 2016

ISBN 978 0 580 90926 9

ICS 13.040.20

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2016.

Amendments/corrigenda issued since publication

Date	Text affected

TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

CEN/TS 16976

August 2016

ICS 13.040.20

English Version

Ambient air - Determination of the particle number concentration of atmospheric aerosol

Air ambiant - Détermination de la concentration en nombre de particules de l'aérosol atmosphérique

Außenluft - Bestimmung der Partikelanzahlkonzentration des atmosphärischen Aerosols

This Technical Specification (CEN/TS) was approved by CEN on 26 June 2016 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

CEN members are required to announce the existence of this CEN/TS in the same way as for an EN and to make the CEN/TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the CEN/TS) until the final decision about the possible conversion of the CEN/TS into an EN is reached.

CEN members are the national standards bodies of 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 United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TS 16976:2016 E

Contents

Page

European Foreword

This document (CEN/TS 16976:2016) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

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

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to announce this Technical Specification: 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

There is a growing awareness of the significance of aerosol particles with diameters of $D < 1$ μm for human health as well as for their climatic impact. To assess air quality, it appears necessary to supplement gravimetrically determined mass concentrations such as PM_{10} or $PM_{2.5}$ with a measurement of the particle number concentration. Since ultrafine particles with diameters of $D < 0{,}1$ μm make an almost insignificant contribution to the mass of atmospheric aerosol particles, they can best be detected with counting measuring methods of sufficient sensitivity.

As particle measurement instrumentation allows determining either the particle number concentration or the particle number size distribution two Technical Specifications will be established:

- one dealing with the determination of the single parameter number concentration (a measure of “total” number concentration),
- one dealing with the determination of number concentration within a limited number of size ranges.

Clauses 5 and 6 contain general information about the method and the expected properties of the aerosol to be measured.

Clause 7 sets out the performance criteria for CPCs. Specifically, these are the relevant performance characteristics of CPC instruments (without any sampling system), the respective criteria that shall be met, and a description of how the tests shall be carried out. In general these tests are expected to be carried out by test houses or CPC manufacturers rather than users, and could form the basis for type testing of CPCs in future.

Clause 8 sets out the performance criteria and test procedures for the sampling and conditioning system (e.g. dilution). These may be applied by manufacturers of sampling systems, test houses or users (network operators).

Clause 9 sets out requirements for the installation, initial checks and calibrations, and operation of a CPC and sampling system at a monitoring site, including routine maintenance, data processing (including use of QA/QC data) and reporting. In general these will be the responsibility of users (network operators), though calibrations requiring test aerosols shall only be carried out by suitably qualified laboratories.

Clause 10 sets out Quality Assurance and Quality Control procedures, i.e. the ongoing checks and calibrations that are required on the CPC and sampling system during operation at a monitoring site. It is expected that these will be the responsibility of users (network operators), though calibrations requiring test aerosols shall only be carried out by suitably qualified laboratories. The main sources of measurement uncertainty are described.

1 Scope

This Technical Specification describes a standard method for determining the particle number concentration in ambient air in a range up to about 10^7 cm^{-3} for averaging times equal to or larger than 1 min. The standard method is based on a Condensation Particle Counter (CPC) operated in the counting mode and an appropriate dilution system for concentrations exceeding the counting mode range. It also defines the performance characteristics and the minimum requirements of the instruments to be used. The lower and upper sizes considered within this document are 7 nm and a few micrometres, respectively. This document describes sampling, operation, data processing and QA/QC procedures including calibration parameters.

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.

ISO 27891, *Aerosol particle number concentration — Calibration of condensation particle counters*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
actual flow rate
volumetric flow rate of an individual instrument, measured at its inlet under the actual air conditions

3.2
aerosol
a multi-phase system of solid and/or liquid particles suspended in a gas, ranging in particle size from 0,001 µm to 100 µm

3.3
calculation flow rate
flow rate which directly relates count rate and particle number concentration

Note 1 to entry: This flow rate is used for instrument internal calculation of the particle number concentration. It depends on the instrument type and may be nominal, factory-certified or actual inlet flow rate. It may also include a calibration factor unless the total inlet flow is analysed.

3.4
coincidence error
error that occurs with counting measuring methods when two or more particles are counted simultaneously as a single particle

Note 1 to entry: Coincidence error is related to particle number concentration, flow velocity through the sensing zone and size of sensing zone.

3.5
detection efficiency

ratio of the particle number concentration determined by the measuring instrument to the reference particle number concentration of the aerosol at the instrument's inlet

Note 1 to entry: The detection efficiency depends on particle size and may depend on particle number concentration.

3.6
factory-certified flow rate

volumetric flow rate of an individual instrument at the time of factory calibration, measured at its inlet under the actual air conditions, and documented on a check out certificate

3.7
nominal flow rate

volumetric flow rate indicated on the instrument specification sheet by the manufacturer

Note 1 to entry: The nominal flow rate is that flow rate, which a specific CPC model is designed for by the manufacturer. The real flow rate of individual instruments may differ from the nominal flow due to manufacturing tolerances.

3.8
number size distribution

frequency distribution of the particle number concentration represented as a function of particle size

3.9
particle

small piece of matter with defined physical boundary

Note 1 to entry: The phase of a particle can be solid, liquid, or between solid and liquid and a mixture of any of the phases.

[SOURCE: ISO 27891:2015, modified]

3.10
particle number concentration

number of particles related to the unit volume of the carrier gas

Note 1 to entry: For the exact particle number concentration indication, information on the gaseous condition (temperature and pressure) or the reference to a standard volume indication is necessary.

[SOURCE: ISO 27891:2015]

4 Atmospheric aerosol

Atmospheric aerosols are strongly dependent on their local and regional sources. Especially, the size distribution in number and mass, as well as the size-resolved chemical composition are highly variable. Aerosol particles are either emitted directly (primary aerosols) or formed by nucleation and condensation from pre-cursor gases (secondary aerosol). Combustion processes lead to both primary and secondary aerosols.

Mass-wise, the global direct emission of aerosol particles is dominated by sea salt, biological material as well as by desert and volcanic dust. These particles are generally larger than 1 µm. Anthropogenic emissions in this size range play a minor role on a global scale. Submicrometer natural aerosols consist mainly of marine sulfate, biogenic organics, and wildfire carbonaceous particles. Submicrometer anthropogenic aerosols are complex mixtures of primary and secondary particles, consisting mainly of sulfate, nitrate, organics and elemental carbon.

Particle number concentrations of atmospheric aerosols cover several orders of magnitude. While remote marine or free tropospheric aerosols have number concentrations as low as tens or a few hundred per cubic centimetre, anthropogenically influenced aerosols can contain a few thousand up to one million particles per cubic centimetre. The number concentration of the anthropogenic aerosol over land, especially in urban areas is dominated by particles in the size range smaller than 0,1 µm. Major sources for high number concentrations in this size range are regional new particle formation and local combustion processes. Average background concentrations in an urban area are several tens of thousands of particles per cubic centimetre.

For details see Annex E.

5 Description of the method

5.1 Sampling and conditioning

5.1.1 Sampling

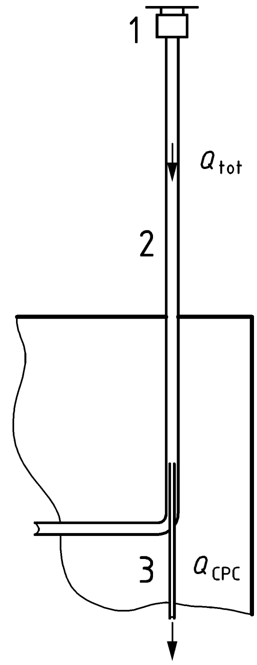
The measurement of atmospheric aerosols will always necessitate sampling and the transport of the sample to the measuring instrument. Moreover, in certain cases the sample has to be processed in terms of temperature, relative humidity and particle concentration in order to adapt the aerosol to the measuring instrument's permissible operating conditions.

The information given on this issue in this document refers to stationary ambient monitoring sites. For mobile applications (e.g. measurements from aircraft), additional considerations have to be taken into account.

The measuring instruments shall be accommodated in a protected environment in controlled conditions (temperature 15 °C to 30 °C).

The sampling location depends on the measurement task. If the undisturbed atmospheric aerosol is to be measured, air intake should take place 5 m to 10 m above the ground level. Buildings, vegetation or the topography of the terrain may make an even higher sampling point necessary. By contrast, the measurement of aerosols close to the source (e.g. traffic) calls for much lower sampling points (1,5 m to 4 m above the ground, see Directive 2008/50/EC [1]).

The design of the intake port should permit representative sampling regardless of the direction of the wind for a broad range of wind velocities. However, this is not a critical condition for the small particles measured by the CPC. Steps shall be taken to avoid soiling of the sampling lines by particles larger than 10 µm. For this purpose a PM10 or PM2.5 inlet can be used (see Figure 1).



Key

1 PM sampling inlet

2 Primary sampling tube

3 Secondary sampling tube

Figure 1 — Basic design of the aerosol intake port

The sample should ideally be fed via a vertical primary sampling tube without bends to the measuring instruments. Since gas measuring methods have fundamentally different requirements regarding sampling, gas and aerosol sampling should be conducted independently of each other.

To reduce diffusion loss, it is necessary to intake aerosol with the aid of a pump at a primary flow rate (Q_{tot}) much higher than the secondary flow rate (Q_{CPC}). The CPC should sample isoaxially in the central area from this volumetric flow via a secondary sampling tube that is as short as possible. Flow in the primary sampling tube should be laminar in order to prevent additional particle loss due to turbulence. Ideally, a Reynolds number of about Re = 2000 shall be aimed for (see 7.2).

The diffusion losses in the sampling system for smallest relevant particle size of 7 nm shall be less than 30 % (see 7.2).

The intake port and lines shall be made of a conductive, corrosion-resistant material with a low surface roughness (e.g. stainless steel) and electrically earthed. This prevents chemical changes to the aerosol and particle losses due to electrostatic effects. Flexible tubing of electrically conductive material may also be used for small connections or short distances. The length of flexible tubing should be below 50 cm.

The inlet and the flow-splitter of the sampling system shall be checked regularly to detect obstructions, e.g. by insects, and cleaned, if necessary.

5.1.2 Drying

Aerosols with a high relative humidity (mist in extreme cases) should be dried, as the size of particles of hygroscopic materials is strongly influenced by humidity. The requirement is to keep the relative humidity of the primary flow at the CPC inlet lower than 40 % (see 7.2). The relative humidity at the inlet of the CPC shall be monitored.

With respect to the temperature conditions three cases are to be distinguished:

- In case the room temperature is higher than 22 °C no aerosol dryer is needed if the ambient dew point temperature never exceeds 10 °C.
- If the dew point temperature is between 10 °C and the room temperature, the secondary flow shall be dried.
- In case that the dew point temperature is above the room temperature, the primary flow shall be dried before entering the room. Additional drying of the secondary flow may be necessary.

There are three recommended methods to dry the aerosol:

- Aerosol diffusion dryer based on silica;
- Membrane dryer (e.g. Nafion® dryer);
- Dilution with dry particle-free air (only for high concentrations, see 5.1.3). In this case the exact dilution ratio shall be known in order to calculate the correct concentrations.

NOTE Heating is not recommended as this may change the aerosol (significant evaporation of volatile components above 40 °C).

5.1.3 Dilution

Preferably the CPC selected to measure at any particular site will have a concentration range in counting mode (with or without coincidence correction) that covers the expected concentrations. When this is not possible or the CPC would rely on photometric mode the sample shall be diluted with particle-free air.

The dilution step may introduce a high uncertainty which shall be estimated and specified in the report. Where dilution is not required this step should be avoided.

The minimum requirement with respect to accuracy of the dilution factor is given in 7.2, operation principles of suitable dilution systems are presented in Annex F.

5.2 Determination of the number concentration with a CPC

5.2.1 Condensation growth

In a CPC, particles are enlarged by condensation growth and then subjected to optical detection by scattered light.

To incite the condensation growth of particles of a given diameter, a certain minimum saturation ratio with respect to a condensable vapour must be present in accordance with the Kelvin Formula (1):

$$S = \exp\left(\frac{4 \cdot \sigma \cdot M}{\rho \cdot \mathrm{R} \cdot T \cdot d}\right) \tag{1}$$

Where

S is the saturation ratio (ratio of current vapour pressure to saturation vapour pressure);

σ is the surface tension of the vapour substance;

M is the molar mass of the vapour substance (relative molecular mass);

ρ is the density of the vapour substance in its condensed state;

R is the general gas constant;

T is the absolute temperature;

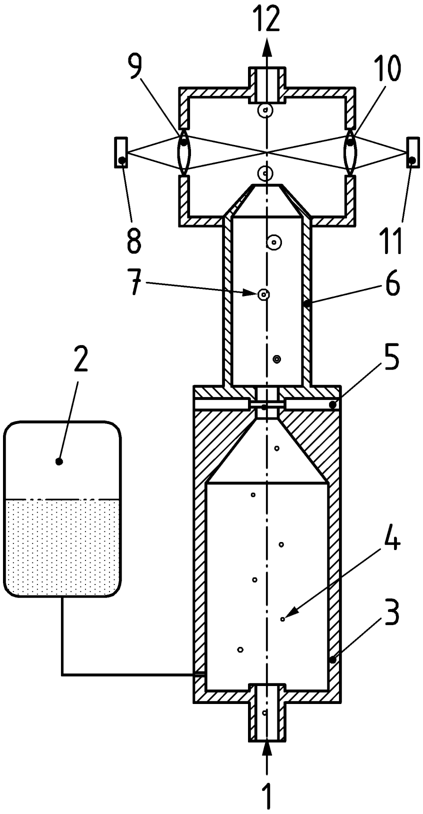
d is the Kelvin equivalent diameter.

Particle shape, surface structure and affinity of the particle material to the vapour phase are important factors influencing the Kelvin equivalent diameter.

NOTE The Kelvin equivalent diameter (with respect to the vapour substance) of an aerosol particle is defined as the diameter of a pure vapour substance drop that would start to grow at the same supersaturation as the particle in question.

Figure 2 shows the principle of a continuous flow CPC. The aerosol enters a heated saturator (3) in which it is saturated with the vapour substance at a constant temperature. Typical vapour substances used in CPCs are alcohols, e.g. n-butanol. It then flows into a cooled condenser (6) where the vapour condenses on the particles forming spherical droplets that consist mainly of the vapour substance and have a diameter of typically a few micrometres. These particles can be easily detected and counted optically.

The temperatures of the saturator and the condenser are important operating parameters that influence the smallest detectable particle size.



Key

1	Aerosol inlet
2	Vapour substance reservoir
3	Heated saturator
4	Nanoparticle (not true to scale)
5	Thermoelectric cooling and heating device
6	Condenser
7	Droplet (not true to scale)
8	Light source
9	Illumination optics
10	Receiving optics
11	Photodetector
12	Aerosol outlet

Figure 2 — Principle of a continuous flow CPC (see ISO 27891)

5.2.2 Optical detection

The droplets produced by the condensation process are then transported through a light beam. The light scattered by the droplets is collected by a receiving optic under a defined solid angle (receiver aperture) and guided onto a detector (e.g. photodiode). If the particle number concentration is low enough, the droplets cross the light beam one after the other, thus producing single electrical pulses at the detector output. From the count rate of these pulses and the calculation flow rate the total number concentration of the droplets can be determined. This number concentration is equal to the number concentration of the primary particles (condensation nuclei) with a size larger than the Kelvin diameter determined by the supersaturation achieved in the instrument.

For higher particle number concentrations more than one particle may cross the light beam at the same time (coincidence). This results in the coincidence error, which leads to a measured value lower than the actual concentration.

For even higher concentrations the detector cannot distinguish single pulses but measures the light scattered by the whole population of particles in the sensing volume as an analogue signal (photometric mode). Since in the ideal case droplet growth due to condensation yields the same size independently of the size of the condensation nuclei and since the optical properties of the droplets are determined essentially by the condensing material, there is in principle a linear relationship between this photometer signal and the particle number concentration which can be determined by calibration. On the other hand very high particle number concentrations lead to a depletion of the vapour concentration by the condensation process. This leads not only to nonlinearity of the calibration curve but also influences the lower detection limit for particle size.

The use of the photometric mode is not allowed in the standard method.

6 CPC performance criteria and test procedures

6.1 General

This clause sets out the performance criteria for the CPC. In general the tests described in 6.3 are expected to be carried out by test houses or CPC manufacturers to validate an instrument design, and could form the basis for type approval of CPCs in future.

6.2 General requirements of the CPC

1) The performance criteria all refer to the counting mode of the CPC, including counting with coincidence correction, after any pre-determined calibration factors have been applied.

2) The CPC shall have no internal flow splitting, which is not accessible to an external flow rate check, or internal dilution to avoid unnecessary sources of measurement uncertainty.

3) The working fluid shall be n-butanol.

4) The instrument shall produce concentration data averaged over a data reporting interval of 1 min.

5) The instrument's internal clock shall be externally synchronizable.

6) The instrument shall enable the following parameters to be recorded in 1 min time intervals:

   — Date, start time and end time of each reported concentration

   — Calculation flow rate

   — Raw concentration (count rate divided by the calculation flow rate), in cm^{-3}

   — Concentration with internal coincidence correction (based on the calculation flow rate), in cm^{-3}

   — Saturator temperature, in K

   — Condenser temperature, in K

- Temperature and absolute pressure at the point of flow rate measurement
- Warning and error flags:
  - Signal quality out of tolerance
  - Too high concentration
  - Flow problems
  - Saturator or condenser temperature out of range
  - Butanol liquid level too low
  - Light source malfunction

6.3 Test conditions

Before operating the CPC, the operating instructions of the manufacturer shall be followed, particularly with regard to the set-up of the equipment, the quality and quantity of consumable products necessary, and the CPC warm up time.

During the laboratory tests for each individual performance characteristic, the temperature of the air surrounding the instrument shall be between 20 °C and 23 °C, except for the tests in 6.5.1, 6.5.4 and 6.5.5, which are carried out at two temperatures (15 °C and 30 °C).

6.4 Performance characteristics and criteria

Table 1 lists the performance criteria of the CPC which shall be met in the performance tests specified in 6.5.

Table 1 — CPC performance criteria

	Performance characteristic	**Criteria**	**Clause**
1	Actual flow rate	≤ 5 % difference to the nominal flow rate ≤ 2 % difference to the factory-certified flow rate	6.5.1
2	Number concentration measurement range		6.5.2
	Lower limit	≤ 100 cm^{-3} (based on at least 1500 particle counts)	
	Upper limit	≥ 10 000 cm^{-3} (including coincidence correction)	
	Dynamic range	at least 3 orders of magnitude	
3	Number concentration detection limit	< lower limit of number concentration measurement range	6.5.3
4	Concentration response		6.5.4
	Slope	1 ± 0,05	
	Linearity	all residuals < 4 % of the measured value	
5	Detection efficiency at low particle size	D_{50} = 7 nm ± 0,7 nm D_{90} < 14 nm	6.5.5
6	Detection efficiency (at intermediate particle sizes)	> 95 % at (50 ± 10) nm	6.5.4
7	Upper particle size detection limit	> 90 % detection efficiency at 1000 nm ± 100 nm	6.5.6

8	Zero count rate	$< 1\ \mathrm{min}^{-1}$	6.5.7
9	Response time	$t_{\mathrm{rise}} < 5$ s $t_{\mathrm{fall}} < 5$ s $\left\lvert\frac{t_{\mathrm{rise}} - t_{\mathrm{fall}}}{t_{\mathrm{rise}}}\right\rvert < 10\ \%$ or $< 0,5$ s	6.5.8
10	Dependence of flow rate on supply voltage	≤ 5 %	6.5.9
11	Accuracy of temperature and pressure sensor calibration	$T \leq 3$ K $P \leq 1$ kPa	6.5.10
12	Effect of failure of mains voltage	Instrument parameters shall be secured against loss. On return of mains voltage, the instrument shall automatically resume functioning.	6.5.11

6.5 Test procedures

6.5.1 Inlet flow rate accuracy

The CPC inlet flow rate shall be measured using a calibrated reference flow meter at two temperatures (15 °C and 30 °C) and at atmospheric pressure above 900 hPa.

The pressure dependence shall be checked at two pressures (atmospheric pressure above 900 hPa and the second pressure at least 200 hPa lower) and at a temperature between 20 °C and 23 °C.

The reference flow meter shall measure with a relative expanded uncertainty (95 % confidence) of ≤ 2 % at the controlled flow rate. At each temperature at least 10 consecutive measurements shall be taken over a minimum period of 1 h. For each temperature, the mean of the measurement results shall be compared with the factory-certified flow rate as specified by the manufacturer, and the relative difference shall meet the criteria in Table 1.

6.5.2 Number concentration measurement range

The instrument shall demonstrably cover the range given in Table 1 within its counting mode (with or without coincidence correction).

6.5.3 Number concentration detection limit

The detection limit for the number concentration is the value that can be distinguished with a statistical certainty of 95 % from the concentration indicated on the basis of the instrument's zero count rate. The zero count rate states the number of indicated count events per unit of time that are not caused by particles. The detection limit shall be lower than the lower limit of the number concentration measurement range given in Table 1.

6.5.4 Linearity and slope of response

Linearity of response is determined by comparing the number concentrations determined by the CPC under test and the reference instrument at various particle number concentrations. An aerosol electrometer or a CPC can be used as reference instrument. This instrument shall meet the requirements of ISO 27891.

Following the ISO 27891 procedure for detection efficiency, using silver particles sized (40 ± 10) nm produced by the evaporation/condensation method, the instrument response shall be determined for particle number concentrations of approximately 1000 cm^{-3}, 2000 cm^{-3}, 4000 cm^{-3}, 8000 cm^{-3}, etc. Each new number concentration is derived by multiplying the last number concentration by factor 2, and a final measurement is made at approximately the highest concentration specified for the instrument in count mode. The instrument number concentration readings shall be coincidence corrected.

If an aerosol electrometer is used as reference instrument and if multiply charged particles are present, corrections according to ISO 27891 shall be made. ISO 27891 requires the fraction of multiply charged particles in this case to be less than 10 %.

With the number concentration from the CPC under test calculated using the actual flow rate as function of the number concentration of the reference instrument, a linear least squares regression analysis, forced through zero, shall be made. The result shall be graphically documented (reference instrument shown on the x-axis, logarithmic x- and y-axis). The slope and the residuals resulting from the regression analysis shall meet the specification given in Table 1.

The test shall be carried out at two temperatures (15 °C and 30 °C) and two pressures (atmospheric pressure above 900 hPa and the second pressure at least 200 hPa lower).

6.5.5 Detection efficiency curve at low particle size

The detection efficiency shall be measured according to ISO 27891, using silver particles produced by the evaporation/condensation method, and a particle number concentration between 3000 cm^{-3} and 10000 cm^{-3} for the following particle sizes: 5 nm, 6 nm, 7 nm, 9 nm, 12 nm, 15 nm, 20 nm and 30 nm.

The detection efficiencies shall meet the criteria specified in Table 1.

The test shall be carried out at two temperatures (15 °C and 30 °C) and two pressures (atmospheric pressure above 900 hPa and the second pressure at least 200 hPa lower).

6.5.6 Upper particle size detection limit

The detection efficiency at 1000 nm ± 100 nm shall be determined and shown to meet the requirements of Table 1. Any reasonable demonstration of this will be acceptable (e.g. comparison measurement, theoretical considerations).

NOTE The detection efficiency can be determined by applying a monodisperse test aerosol with the particle diameter in the desired particle size range and comparing the instrument's response with the response of a reference instrument (e.g. optical particle counter, time-of-flight spectrometer).

6.5.7 Zero count rate

For this zero count test run the CPC for a minimum of 60 min with a ULPA filter attached to its inlet. The zero count rate shall meet the requirement of Table 1.

6.5.8 Response time

The response time of the instrument shall be determined by applying a step function in the particle number concentration from less than 20 % to approximately 80 % of the measurement range of the instrument. The change in concentration shall be near-instantaneous, by the use of a suitable valve.

A cycle shall consist of the concentration being stepped up, at time $t = 0$, waiting for the response to stabilize (<2 % change over 1 min), stepping the concentration down, and waiting for the concentration to stabilize again. The cycle shall be repeated 4 times. The response time (rise) is the time taken for the response to rise between 10 % and 90 % of the difference between the stable values; similarly, the response time (fall) is the time taken for the response to fall between 90 % and 10 % of the difference between the stable values.

The results for response time (rise), response time (fall) and their difference shall meet the criteria given in Table 1.

6.5.9 Dependence of flow rate on supply voltage

The dependence of the flow rate on the supply voltage of the CPC and, if used, an external pump shall be determined by measuring the flow rate at voltages of 210 V, 230 V and 245 V.

The results shall meet the criteria given in Table 1.

6.5.10 Accuracy of temperature and pressure sensor calibration

The temperature and pressure sensors used to correct sampled volumes to standard temperature and pressure shall be calibrated by any appropriate method to confirm that the values meet the criteria given in Table 1.

6.5.11 Effect of failure of mains voltage

The instrument shall be checked for the effects of temporary mains voltage failure. The requirements given in Table 1 shall be met.

7 Performance criteria and test procedures for the sampling and conditioning system

7.1 General requirements

The sampling and conditioning system takes a sample of the ambient aerosol and transports it to the measuring instrument. Besides that it shall be able to modify the aerosol's temperature and humidity to adapt it to the range suitable for the measurement. For high concentrations it shall be able to dilute the aerosol by a defined factor. All this shall be done without significantly changing the size distribution of the aerosol.

The following sampling system parameters shall be recorded unless they are covered by CPC data protocol:

- Relative humidity, temperature and absolute pressure at CPC inlet
- Drying (yes/no), if yes: primary or secondary flow?
- Drying method (see 5.1.2)
- Dilution (yes/no), if yes: dilution factor
- Dilution method (see 5.1.3)
- Status of primary flow pump: error flag in case of malfunction

7.2 Performance characteristics and criteria

Table 2 lists the performance criteria for the sampling system which shall be met in the performance tests specified in 7.3 to 7.5.

Table 2 — Sampling system performance criteria

	Performance characteristic	**Criterion**	**Clause**
1	Diffusion losses for smallest relevant particle size of 7 nm	< 30 %	7.3
2	Relative humidity of secondary flow at CPC inlet	< 40 %, accuracy ± 3 %	7.4
3	Dilution factor	if applicable, accuracy ± 5 %, stable in time	7.5
4	Primary sampling flow	laminar ($Re \leq 2000$), accuracy ± 10 % of the nominal value	7.6

7.3 Diffusion losses

For simple tube geometries the diffusion losses may be calculated theoretically (see Annex A). For flow geometries for which the theoretical relations are not applicable (e.g. dryers or dilution systems) the diffusion losses shall be determined experimentally. Published (peer reviewed) data for the geometries in question may also be used.

7.4 Relative humidity

The relative humidity at the CPC inlet shall be monitored. It shall meet the requirement of Table 2 even if the maximum error of the measurement device is taken into account.

The relative humidity sensor shall be calibrated by any appropriate method to confirm that the relative humidity values between 20 % and 80 % are correct to within 3 %.

7.5 Dilution factor

Dilution means to reduce the number concentration of the aerosol by mixing an aerosol flow Q_a in a particle-free dilution air flow Q_d. The dilution air can be provided externally or produced internally by filtration of a part of the sample. For details see Annex F.

The dilution factor F_d of a dilution system shall be determined in one of the two ways:

- by measuring the volumetric flow rates of the aerosol flow and either the dilution air flow or the total air flow Q_t (both corrected for standard conditions, if necessary) and calculating the following ratios:

$$F_{\mathrm{d}} = \frac{Q_{\mathrm{a}} + Q_{\mathrm{d}}}{Q_{\mathrm{a}}} \tag{2}$$

or

$$F_{\mathrm{d}} = \frac{Q_{\mathrm{t}}}{Q_{\mathrm{a}}} \tag{3}$$

- by using a tracer gas (e.g. He in synthetic air) and determining its concentration both in the undiluted ($c_{T,ud}$) and in the diluted air ($c_{T,d}$) flow. This method cannot be applied to dilution systems that dilute by partial internal filtration of the aerosol, because filtration is not effective for the tracer gas.

$$F_{\mathrm{d}} = \frac{c_{\mathrm{T,ud}}}{c_{\mathrm{T,d}}} \tag{4}$$

Particle losses in the dilution system are not included in the above definition of the dilution factor since they are particle-size dependent. They shall be determined separately and shall be included in the overall diffusion losses of the sampling system.

7.6 Primary sampling flow

Laminar flow can be demonstrated by calculating the Reynolds number according to Annex G using the nominal flow rate and the inner diameter of the primary sampling tube.

The primary flow shall be measured using a flowmeter with an accuracy better than 5 %.

8 Measurement procedure

8.1 Measurement planning

Before a CPC and sampling system are chosen for a particular measuring task, their suitability shall be evaluated for the specific conditions that exist at the relevant monitoring site.

The evaluation is a trial measurement or estimate of maximum particle number concentrations that are likely to be encountered (affecting possible requirements for coincidence correction and dilution), and of high values of the ambient dew point temperature (affecting the design of the sampling system).

The requirements with respect to drying (see 5.1.2 and 7.2) and dilution (see 5.1.3 and 7.2) shall be observed.

8.2 Environmental operating conditions

The CPC shall be located in an environment that is sheltered, and shielded from dust, rain and snow, direct solar radiation, other sources of heat, and cooling (temperature requirements see 5.1.1).

8.3 Initial installation

The chosen CPC and sampling system shall be installed at a monitoring station in such a way that their normal operation is not compromised. After installation at the measuring station, the CPC and sampling system shall be tested for proper operation.

The results of these tests shall fulfil the requirements and limitations as set out by the manufacturer of the CPC and sampling system as well as the requirements given in this Technical Specification. The compliance with the requirements of the manufacturer and requirements set out in this Technical Specification shall be documented.

When the concentrations measured by a CPC at a monitoring station are collected by a datalogger/computer system, then the proper functioning of the data collection shall be checked. When the measured data are transmitted to a central computer system, the transmission process shall be checked as well. Checks shall be performed to an extent that ensures that the actual concentrations measured by the CPC are properly recorded in any data collection system.

Every time a part of the data registration/transmission process is changed, the proper functioning of the complete process shall be rechecked.

All checks on the proper functioning of the data collection/transmission system(s) shall be documented.

Subsequently, quality assurance and quality control procedures for ongoing monitoring shall be followed (see Clause 9).

8.4 Initial checks on site

Table 3 lists the initial checks on site.

Table 3 — Initial checks on site

Checks	**Clause**	**Comments**
CPC		
Zero check	9.2.5	
Number concentration check	9.2.6	Can also be done in the laboratory before transport to the site.
Flow rate calibration	9.2.7	
Status of internal diagnostics		Check if no internal error flag is set.
Sampling system		

Primary sampling flow	7.6	
Dilution factor (where applicable)	9.2.12	
Leak check	9.2.13	

8.5 Data processing and reporting

Corrections for particle coincidence may be provided directly by the condensation particle counter or have to be done by the user prior data reporting. A manual data quality check is recommended before reporting to the database.

Reported data shall include, as a minimum, data for instrument inlet temperature, pressure and relative humidity at the same time resolution as the number concentration data. Reporting of other operational parameters, as set out in the EBAS protocol (see Annex C), shall be encouraged. All relevant diagnostic information on the measurement system shall be available and stored routinely.

9 Quality control, quality assurance and measurement uncertainty

9.1 General

Quality control is essential to ensure that the uncertainties of the measured values for particle number concentration in ambient air are kept within stated limits during extended monitoring periods in the field. Maintenance, checking and calibration procedures shall be followed so that accurate and traceable data are obtained. The procedures for QA/QC checks on equipment are set out in this Section.

In general, regular checks should also be made on the final data, so that error flags produced by internal diagnostics and instances of, for example, unusually low concentrations, systematic concentration change over time, excess noise, or anomalous concentration spikes can be identified and investigated. Such data checks are not described in this Technical Specification.

This Section also sets out the main components of the measurement uncertainty of particle number concentration data, and how these can be estimated.

9.2 Frequency of calibrations, checks and maintenance

9.2.1 General

For instruments in continuous operation the maintenance, checks and calibrations, together with their minimum frequency, are summarized in Table 4. Criteria are also given for when action or adjustment are required. Where instruments are not in continuous operation the frequencies can be adjusted accordingly.

Table 4 — Calibration, checks and maintenance, and their minimum frequency

Calibration, checks and maintenance	**Clause**	**Frequency (minimum)**
CPC		
Maintenance of CPC	9.2.2	As required by the manufacturer, at least annually
Calibration of plateau region and linearity	9.2.3	Annually
Determination of low size cut-off	9.2.4	Annually
Zero check	9.2.5	Monthly
Number concentration check	9.2.6	Every 3 months
Flow rate calibration	9.2.7	Monthly

Temperature and pressure sensor calibration	9.2.8	Annually
Internal diagnostics	9.2.9	Weekly in case of remote data access, otherwise monthly
Sampling system		
Maintenance	9.2.10	As required by the manufacturer, at least annually
Relative humidity sensor	9.2.11	Annually
Dilution factor (where applicable)	9.2.12	Monthly
Leak check	9.2.13	Monthly
Primary sampling flow	7.6	Monthly

9.2.2 Maintenance of CPC

The CPC shall be maintained according to the manufacturer's instructions.

9.2.3 Calibration of CPC plateau region and linearity

Both in the "as found" condition and after any maintenance, the detection efficiency of the CPC shall be calibrated according to ISO 27891 using silver particles (30 nm to 50 nm, see 6.5.4):

- Measure CPC detection efficiency η at a particle size 30 nm ≤ D_p ≤ 50 nm; (40 ± 10) nm
- Result is accepted if 0,95 ≤ $\eta(D_\mathrm{p})$ ≤ 1,05, otherwise, further maintenance is required.

Linearity shall be checked, for example, to check for changes in coincidence correction, using the same procedure and size of particles as for the detection efficiency. The same number concentrations as specified in 6.5.4 shall be used. The data shall meet the 4 % residual criterion described in 6.5.4, or else further maintenance is required.

9.2.4 Determination of CPC low size cut-off

The low size cut-off of the CPC shall be determined according to ISO 27891 using silver particles as described in 6.5.5.

- Measure the CPC detection efficiency η at 6 nm and 8 nm. The result is accepted if η(6 nm) < 0,5 and η(8 nm) > 0,5.
- Determine D_{50} by linear interpolation. The result is accepted if 6,3 nm ≤ D_{50} ≤ 7,7 nm.
- Measure the CPC detection efficiency η at 14 nm. The result is accepted if η(14 nm) ≥ 0,9.
- If any of the results is not accepted, further maintenance is required.

9.2.5 CPC zero check

If a dryer or a dilution system is used, these devices shall be included in this zero check. Attach an ULPA filter either to the inlet of the CPC or to the inlet of the dryer or the dilution system. Run the CPC for at least 5 min to purge the filter and the CPC. Run the CPC for a minimum of 15 min. The zero count rate during this period shall be less than 15 counts per minute. If not, maintenance is required.

9.2.6 Number concentration check

A check on the performance of the CPC shall be carried out every 3 months. This can be less rigorous than the annual calibration, for example taking the form of a field comparison using a recently calibrated reference CPC connected to the secondary sampling tube via a Y-shaped connector. If the hourly average concentration determined by the field CPC deviates by more than 10 % from the reference, maintenance is required.

9.2.7 CPC flow rate calibration

Run a test similar to the one in 6.5.1, but only at ambient temperature and pressure: At least 5 consecutive measurements shall be taken over a minimum period of 5 min. The mean of the measurement results shall be compared with the flow rate as specified by the manufacturer, and the relative difference shall meet the criteria for the actual flow rate in Table 1 (difference ≤ 5 % to the nominal flow rate, difference ≤ 2 % to the factory-certified flow rate). If these criteria are not met, maintenance is required.

The result of the calibration shall be documented and used for further number concentration calculations or included in the calibration factor for correction.

9.2.8 Temperature and pressure sensor calibration

The temperature and pressure sensors used to correct sampled volumes to standard temperature and pressure shall be calibrated by any appropriate method to confirm that the values are correct to within 3 K for temperature and 1 kPa for pressure.

9.2.9 CPC internal diagnostics

Internal diagnostics, especially warning and error flags, shall be checked at least weekly in case of remote data access, otherwise monthly. Users shall develop procedures appropriate to their systems. For example, if data availability over last 7 days is less than 99 %, the error flags can be checked for recorded errors. Corrective action shall be taken if necessary (e.g. CPC maintenance).

9.2.10 Sample system maintenance

The sampling system shall be maintained according to the manufacturer’s instructions.

9.2.11 Relative humidity sensor

The relative humidity sensor in the sampling system shall be calibrated by any appropriate method to confirm that the relative humidity values between 20 % and 80 % are correct to within 3 %.

9.2.12 Dilution factor (where applicable)

If the sampling system includes dilution, the dilution factor shall be determined using one of the methods described in 7.5, and shall show agreement with the previously determined value to within 5 %. If the deviation is greater than 5 %, maintenance is required.

9.2.13 Leak check

Put an ULPA filter on the inlet to the system or via an optional three-way valve (see Figure B.1). Purge the system for at least 5 min. Leakage within the sampling system shall be checked for a minimum of 15 min. The zero count rate during this period shall be less than 15 counts per minute. This test includes the CPC zero count rate check according to 9.2.5, which, if this test is passed, does not need to be performed separately. Maintenance of the sampling system is required if the CPC zero count rate check is then passed.

9.3 Measurement uncertainty

9.3.1 General

The main components of the measurement uncertainty for one-minute-duration measurements are set out in Table 5. In practice, random noise is only significant for very low particle concentrations, and so the uncertainty for measurements averaged over a longer period will be similar.

Table 5 — Uncertainty components and how to estimate them

Uncertainty component	Symbol	Clause	Estimation
CPC plateau detection efficiency	u_η	9.3.2	As given on CPC calibration certificate
CPC detection efficiency drift	u_{drift}	9.3.3	From analysis of stability between calibrations
Flow determination	u_{flow}	9.3.4	From uncertainty of flow calibration, and long term stability
Correction of volume to standard temperature and pressure	u_{STP}	9.3.5	From uncertainty of T and p measurements
Sampling losses due to diffusion to walls	u_{loss}	9.3.6	A fixed value estimated theoretically
Dilution factor (where appropriate)	u_{dil}	9.3.7	From the uncertainty of the method used to determine the dilution factor, and from the stability of these determinations.

Many other factors will contribute to the uncertainty, but are here considered to be negligible. For example:

- CPC nonlinearity – this will be much more significant if the photometric mode is used;
- CPC low size cut-off – the effect will be highly dependent on the particle size distribution, but is generally small;
- Effect of hygroscopic growth – the growth of particles in the sampling system, even after control of relative humidity, will have some effect on the size distribution, but only a negligible effect on the total numbers, in effect by altering the low size cut-off;
- Repeatability – as noted above, random noise is only significant for very low particle concentrations;
- Leakage – with the criteria specified, the contribution of leakage to the uncertainty will be very small.

9.3.2 CPC plateau detection efficiency

Following ISO 27891, the annual calibration of the CPC will lead to a certificate that includes a value for the uncertainty in the detection efficiency determination. The component u_η is the 1 σ value, so that if the uncertainty is presented as $k = 2$ or 95 % confidence, u_η is half this value. The component shall be expressed as a percentage of the detection efficiency.

9.3.3 CPC detection efficiency drift

The CPC detection efficiency drift is estimated from the typical difference between the “post maintenance” and subsequent “as found” detection efficiencies, η_{diff}.

Calculate the mean of these differences, $\overline{\eta}_{\text{diff}}$. For the purposes of this Technical Specification, the uncertainty component $u_{\text{drift}} = 100 \cdot \overline{\eta}_{\text{diff}} / 2 \cdot \eta$ where η is the mean post maintenance detection efficiency.

9.3.4 Flow determination

If the QA/QC criteria are met, the actual flow rate can be taken to be within 2 % of the calculation flow rate. For the purposes of this Technical Specification, assume a rectangular distribution, so that the uncertainty component $u_{\text{flow}} = 2/\sqrt{3}$ % = 1,2 %. If the criteria are not met, or flow stability is demonstrably better than the criteria, the component shall be changed accordingly.

9.3.5 Correction to standard temperature and pressure

If the QA/QC criteria are met, the relevant temperatures can be taken to be correct within 3 K and the pressures to within 1 kPa. Both of these criteria represent deviations of close to 1 % in the corrected flow values. For the purposes of this Technical Specification, assume the two deviations are independent and have rectangular distributions. In this case the uncertainty component $u_{\text{STP}} = \sqrt{2}/\sqrt{3}$ % = 0,8 %. If the criteria are not met, or temperature and pressure measurements are demonstrably better than the criteria, the component shall be changed accordingly.

9.3.6 Sampling losses due to diffusion to walls

The actual reduction of particle numbers due to diffusion to the walls will depend both on the measurement system and the size distribution of the particles being measured. In principle this uncertainty component represents a typical difference that would be recorded by identical CPCs using compliant sampling systems of different designs at the same place and time.

Sampling losses may not exceed 30 % for 7 nm particles (see 7.3). For a typical sampling system with a primary flow rate of 16,67 l/min, effective length from the inlet section to the flow splitter of 3,5 m, a secondary flow rate of 1 l/min, built in dryer in the secondary flow to the CPC and no dilution, sampling losses at 7 nm of approximately 28 % can be expected, see example calculation in Annex B. For an optimized sampling system without a dryer, sampling losses at 7 nm can be reduced to approximately 10 %.

Since the particle losses in the sampling system are a function of the particle size, the deviation of the measured particle number concentration for differently designed sampling systems depends on the particle number size distribution to be measured. For situations, where both a nucleation mode and an accumulation mode are present in the particle number size distribution, deviations up to 5 % in measured particle number concentration between the worst case (30 % losses at 7 nm) and the ideal case (10 % losses at 7 nm) shall be expected, Without a nucleation mode, the before mentioned deviations between the worst and the ideal case are reduced to approximately 1,5 %.

For the purposes of this Technical Specification, the contribution of the design of the sampling system to the relative standard uncertainty shall be taken as 1,5 %. This is approximately the value for the maximum spread treated as having a rectangular distribution ($5/2\sqrt{3}$ %).

9.3.7 Dilution factor (where applicable)

Table 2 and 9.2.12 set the criteria for the accuracy of the dilution factor as ± 5 %. For the purposes of this Technical Specification, assume a rectangular distribution, so that the uncertainty component $u_{\text{dil}} = 5/\sqrt{3}$ % = 2,9 %. If the criteria are not met, or dilution factor accuracy is demonstrably better than the criteria, the component shall be changed accordingly.

9.3.8 Calculation of overall uncertainty

All of these uncertainty components contribute linearly to the reported result. For the purposes of this Technical Specification, they are assumed to be independent, so that the combined standard uncertainty (in %) is given by

$$u_{\mathrm{c}} = \sqrt{u_{\eta}^{2} + u_{\mathrm{drift}}^{2} + u_{\mathrm{flow}}^{2} + u_{\mathrm{STP}}^{2} + u_{\mathrm{loss}}^{2} + u_{\mathrm{dil}}^{2}} \qquad (5)$$

The coverage factor *k* shall be taken to be 2, so that the expanded uncertainty *U* (in %) is given by:

$U = 2 \cdot u_c$

An example of the calculation of measurement uncertainty for a one-minute-duration measurement is given in Annex D.

Annex A
(normative)

Determination of diffusion losses in sampling lines

Particle losses of ultrafine particles (<100 nm) in aerosol sampling lines are caused mainly by aerosol diffusion. Particles motion due to diffusion is random, but a gradient in concentration leads to a net transport towards any surface. Ultrafine particles that are deposited at a wall stick to that surface due to van-der-Waals forces. The diffusion behaviour of particles is governed by the diffusion coefficient D, which increases with decreasing particle size as described in following equation:

$$D = \frac{k \cdot T \cdot C_\mathrm{C}}{3 \cdot \pi \cdot \eta \cdot D_\mathrm{p}} = k \cdot T \cdot B \tag{A.1}$$

Where

k is the Boltzmann constant (k = 1,3806504 · 10^{-23} J/K);

T is the absolute temperature;

C_C is the Cunningham correction factor;

η is the gas viscosity;

D_p is the particle diameter;

B is the mechanical mobility of a particle.

The Cunningham correction factor for air can be calculated as follows:

$$C_\mathrm{C} = 1 + \frac{2 \cdot \lambda}{D_\mathrm{p}} \cdot \left(1{,}165 + 0{,}483 \cdot \exp\left(-0{,}997 \cdot \frac{D_\mathrm{p}}{2 \cdot \lambda}\right)\right) \tag{A.2}$$

Where

λ is the mean free path of the gas molecules.

The pressure and temperature dependency of the mean free path and the gas viscosity can be taken into account using following equations:

$$\lambda = \lambda_0 \cdot \left(\frac{T}{T_0}\right)^2 \cdot \left(\frac{p_0}{p}\right) \cdot \left(\frac{T_0 + 110{,}4}{T + 110{,}4}\right) \tag{A.3}$$

$$\eta = \eta_0 \cdot \left(\frac{T}{T_0}\right)^{1{,}5} \cdot \left(\frac{T_0 + 110{,}4}{T + 110{,}4}\right) \tag{A.4}$$

T_0 = 296,15 K

p_0 = 101,3 kPa

λ_0 = 0,0673 µm

η_0 = 18,3245 · 10^{-6} kg/(m·s)

The particle size-dependent particle penetration P for a tube with laminar flow can be estimated theoretically. The penetration depends on a dimensionless parameter μ that is defined as follows:

$$\mu = \frac{D \cdot L}{Q} \qquad \text{(A.5)}$$

Where

D is the diffusion coefficient;

L is the tube length;

Q is the volume flow rate of the aerosol.

The parameter μ does not depend on the inner diameter of the tube, which means, that diffusion losses only depend on the flow rate and the tube diameter can be used as a free parameter in the design of a sampling system, e.g. to obtain laminar flow conditions.

Depending on the value of the parameter μ, two different equations have to be used to determine the tube penetration.

for $\mu < 0{,}007$:

$$P = \frac{\eta_{\text{out}}}{\eta_{\text{in}}} = 1 - 5{,}50 \cdot \mu^{1{,}5} + 3{,}77 \cdot \mu \qquad \text{(A.6)}$$

for $\mu > 0{,}007$:

$$P = \frac{n_{\text{out}}}{n_{\text{in}}} = 0{,}819 \cdot \exp\left(-11{,}5 \cdot \mu\right) + 0{,}0975 \cdot \exp\left(-70{,}1 \cdot \mu\right) + 0{,}0325 \cdot \exp\left(-179 \cdot \mu\right) \qquad \text{(A.7)}$$

The equations given here are taken from [2]. The accuracy is better than 1 % for all values of the dimensionless parameter μ.

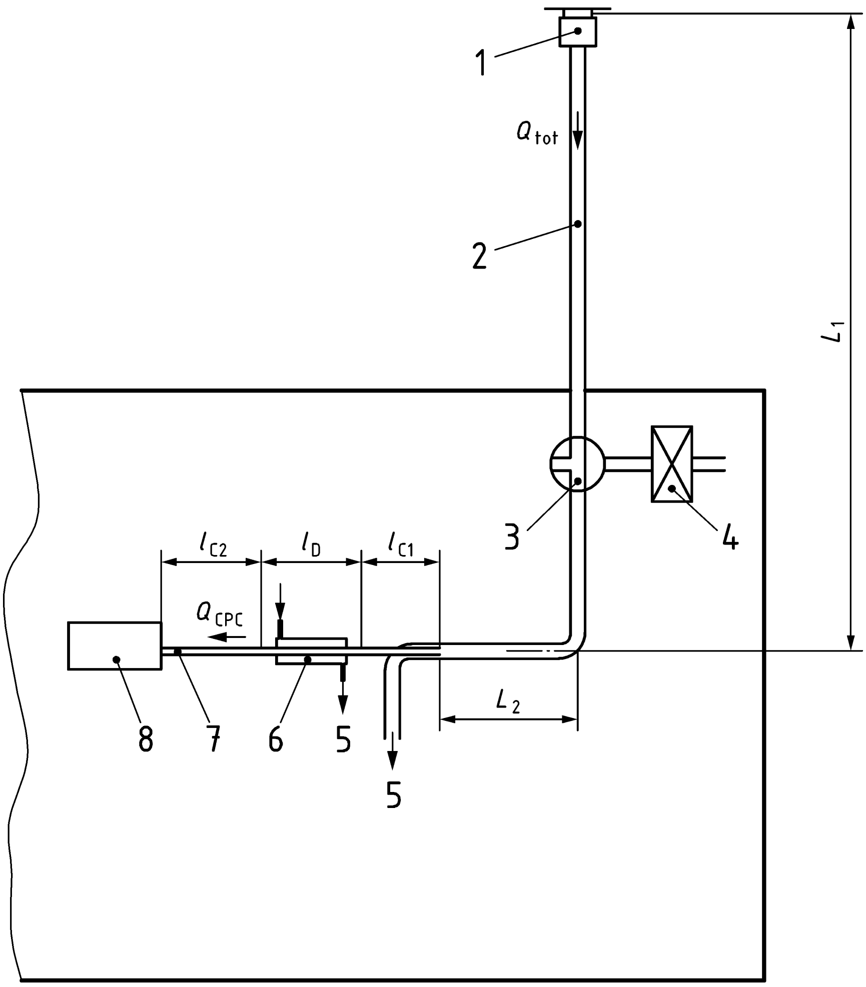
Size dependent diffusion losses can be determined experimentally by feeding monodisperse (e.g. size classified with a differential electrical mobility classifier (DEMC)) particles mixed with particle free carrier gas into the component of the sampling system to be investigated (e.g. a dilution system or a dryer). The penetration through this component is then determined by an upstream and downstream concentration measurement with a CPC. The ratio of downstream concentration to upstream concentration at a given particle size is the penetration P and $(1 - P)$ is the corresponding diffusion loss. To determine the penetration at 7 nm, silver particles produced by the evaporation/condensation method can be used.

Annex B
(informative)

Example of the calculation of diffusion losses in a sampling system

B.1 Description of the sampling system

Figure B.1 shows the model sampling system for which the diffusion losses will be calculated.



Key

1 PM10 / PM 2.5 sampling head

2 primary sampling tube

3 optional three-way valve for leak test and primary flow rate measurement

4 optional ULPA filter for leak test

5 to critical orifice and vacuum pump

6 Nafion® dryer

7 secondary sampling tube (CPC sampling tube)

8 CPC

Figure B.1 — Model CPC sampling system

The following dimensions and flow rates are assumed:

$L = L_1 + L_2 = 3{,}5$ m   total length of primary sampling tube

$l = l_{C1} + l_{C2} = 0{,}5$ m   total length of secondary sampling tube

l_D geometrical length of the dryer;

for a single tube Nafion® dryer of $l_D = 0{,}3$ m the effective length $l_{D,eff}$ with respect to diffusion losses is

$l_{D,eff} = 1{,}25$ m

$Q_{tot} = 1$ m^3/h = 16,67 l/min   primary flow rate

0,3 l/min < Q_{CPC} < 1 l/min   secondary flow rate

B.2 Air properties and diffusion coefficient

For reasons of simplicity for the temperature and pressure of the sampled air the standard values given in Annex A are used.

$T = T_0 = 296{,}15$ K

$P = p_0 = 101{,}3$ kPa

This means that for the mean free path of the gas molecules as well as for the gas viscosity also the standard values can be used.

$\lambda = \lambda_0 = 67{,}3$ nm   mean free path

$\eta = \eta_0 = 18{,}3245 \cdot 10^{-6}$ kg/(m·s)   gas viscosity

For a particle size of $D_p = 7$ nm the Cunningham correction factor now can be calculated according to Formula (A.2):

$C_C = 32{,}22$

The diffusion coefficient according to Formula (A.1) is then:

D = 1,090·10–7 m^2/s

B.3 Losses in the primary sampling tube

To determine the penetration of a tube, in a first step a dimensionless parameter μ has to be determined according to Formula (A.5):

$$\mu = \frac{1{,}090 \cdot 10^{-7}\,\frac{\mathrm{m}^2}{\mathrm{s}} \cdot 3{,}5\ \mathrm{m}}{2{,}78 \cdot 10^{-4}\,\frac{\mathrm{m}^3}{\mathrm{s}}} = 0{,}00137 < 0{,}007$$

For this value of μ the penetration of the primary sampling tube can be calculated according to Formula (A.6) to yield:

$P = 0{,}9373$

The losses are

$L = 1 - P = 0{,}0627$, corresponding to 6,27 %.

B.4 Losses in the secondary sampling tube and the dryer

Using the effective length of the Nafion® dryer, the total CPC sampling path can be regarded as one tube with an equivalent length of

$$l_{\mathrm{CPC}} = l_{\mathrm{D,eff}} + l = 1{,}75 \text{ m}$$

To show the influence of the CPC flow rate, the calculations are performed for three different values of that flow rate. Table B.1 shows the results.

Table B.1 — Penetration and losses in the secondary sampling tube for different CPC flow rates

CPC flow rate (Q_{CPC}) l/min	**CPC flow rate (Q_{CPC})** m^3/s	**Parameter μ**	**Penetration (P_{CPC})**	**Losses (L_{CPC})**
0,3	$5{,}00 \cdot 10^{-6}$	0,0382	0,5346	0,4654
0,5	$8{,}33 \cdot 10^{-6}$	0,0229	0,6495	0,3505
1,0	$1{,}67 \cdot 10^{-5}$	0,0114	0,7664	0,2336

As the value of the parameter μ is larger than 0,007 in all three cases, Formula (A.7) has to be used for the calculation of the penetration.

Due to the small flow rates and the large equivalent length of the dryer these losses are much higher than the losses in the primary sampling tube. A way to reduce these losses would be an additional flow splitting after the dryer just at the CPC inlet. Then a larger flow rate could be drawn through the dryer reducing the diffusion losses.

B.5 Overall sampling losses

The overall penetration of the sampling system can be calculated as the product of the primary sampling tube penetration and the secondary sampling tube penetration (including dryer). Table B.2 shows the results as overall penetration and overall losses for the three different CPC flow rates.

Table B.2 — Overall penetration and losses for different CPC flow rates

CPC flow rate (Q_{CPC}) l/min	**Penetration of secondary sampling tube (P_{CPC})**	**Total penetration (P_{tot})**	**Total losses (L_{tot})**
0,3	0,5346	0,5011	0,4989
0,5	0,6495	0,6088	0,3912
1,0	0,7664	0,7183	0,2817

In this example only at a CPC flow rate of 1 l/min the requirement for particle losses can be met.

Annex C
(informative)

Data reporting

C.1 Motivation

Observations of air quality parameters are often conducted as a part of national or international observation networks. While the purpose of all these networks is to collect the data in a central data centre for efficient subsequent analysis and dissemination, the network architectures vary between two extremes:

1. The instrument is operated by qualified personnel at the site who processes and quality ensures the data manually before it is submitted to the central data centre. This architecture is typical of scientific networks.

2. The instrument is operated fully unattended at the site. The data are transmitted to the data centre where it is processed and quality ensured centrally before publication. This architecture is more typical in environmental monitoring and near-real-time applications.

A well-defined data processing chain should accommodate both these cases. At the same time, the processing chain should make the measurement traceable back to the time of measurement. This implies a hierarchy of clearly defined data products and intermediate products, which are connected by an operating procedure describing the steps needed to process the data from one hierarchy level to the next. All metadata describing the measurement process needed to interpret or process the data needs to accompany the data. This opens the option of re-processing the data if such a need should arise. More specifically, a flagging system should be used to relay additional information to the user for judging whether the data are suitable for a specific purpose. Since a station is often part of several observation networks that differ in their architecture, the use of common data reporting formats and protocols should be encouraged to avoid frequent reformatting of the same data and duplication of effort.

The EBAS database, originally developed as data archive for the European Monitoring and Evaluation Programme (EMEP) for archiving air quality related surface data, is today a major archive for data on atmospheric constituents from surface stations worldwide. It hosts data of WMO Global Atmosphere Watch (GAW) programme, the Oslo and Paris Conventions (OSPAR) for protecting the North Atlantic environment, the Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM), and other frameworks. In collaboration with the European research infrastructure ACTRIS “Aerosols, Clouds, and Trace gases Network” common standard operating protocols and data reporting procedures for observations of atmospheric aerosol properties have been defined for EBAS that also have been adopted by the WMO GAW programme. While the resulting data format definitions are certainly not the only solution to the above mentioned objectives, they are one such solution that a large number of leading scientists in this field managed to agree upon, and are therefore included here as a recommendation.

In order to meet the needs of different network architectures, EUSAAR defined 3 data levels and corresponding data file formats:

C.2 Level 0 (annotated raw data)

This format contains essentially all parameters provided by the instrument, raw data values as well as instrument status parameters, in the native temporal resolution of the instrument (for environmental monitoring commonly minute averages). Volume concentrations are stated at instrument internal conditions of temperature and pressure. Since this data level is specific for the instrument type used, the mandatory parameters may be augmented by others provided only by a given instrument type. Level 0 would be used for data submission to the data centre if the quality assurance is performed centrally at the data centre.

C.3 Level 1 (data processed to final physical property, potential corrections applied, original temporal resolution)

In level 1, the raw parameters have been processed to the final physical variable, i.e. the size integrated particle number concentration. More specifically, this involves the following steps:

1. Correcting the raw particle concentration from level 0, which is often based on an assumed flow rate, to the true, calibrated flow rate;

2. apply the coincidence correction to the particle concentration, if not applied instrument internally;

3. checking that primary flow and operating temperature of the particle counter have been within the nominal range to meet the nominal lower size cut, and set the value to missing if this is not the case.

The reason for setting the value missing should be stated by a corresponding flag. Depending on the temporal resolution desired, level 1 can be used for data submission to the data centre in case quality assurance is performed at the site.

C.4 Level 2 (hourly averages, including measures of variability)

In processing the data from level 1 to level 2, hourly averages of the particle number concentration are calculated that span from one turn of the hour to the next. Also, the concentration is stated for standard conditions of temperature and pressure (273,15 K; 1013,25 hPa). As measures of variability, the level 2 format contains the 15,87 and 84,13 percentiles for each averaging period. Percentiles have been chosen over the standard deviation since use of the standard deviation assumes the variable to be predominantly normally distributed. For atmospheric aerosol particle concentrations however, the dominant statistical distribution is log-normal, i.e. asymmetric around the average value, which requires the use of at least two numbers for quantifying the statistical variability. The stated percentiles have been chosen for ease of interpretation since they correspond to average minus and plus one standard deviation in the limes of a normal distribution. Level 2 is another alternative for transferring data to the data centre that has been quality ensured at the site.

Subject of this document is the functionality of CPC instrument itself. Independent of what type of network the CPC is used in, it should be capable of providing output corresponding to data and metadata of data level 0 as described above. Below, the corresponding templates used in the WMO Global Atmosphere Watch network are given as a recommended example for implementing the stated objective of traceability in data reporting. These templates are based on the NASA Ames 1001 format standard with additional specifications concerning metadata items to meet these objectives. While there exist other ways of meeting these objectives, the following considerations led to this implementation and choice of format:

- **Simplicity:** The format consists of pure ASCII text that may be assembled and used with numerous, readily available spreadsheet applications, plotting applications, and numerical libraries. It is readable and understandable for a human reader. It is streamlined enough to make the instructions on assembling it fit on a few pages, but still contains the essential information for efficient data archiving, discovery, and documentation to make the data self-explaining.

- **Reduce format confusion:** Some features and specifications of NASA Ames 1001 are outdated and targeted at older IT environments. However, as long as necessary new features can be implemented within the existing format, defining an only slightly optimized new format would only add to the format confusion and prevent the use of existing routines and libraries.

- **Keep threshold low:** Other formats like NetCDF or HDF have come into use. However, these are binary formats, not plainly readable for a human, and special applications or routines and a steep learning curve are required for assembling them. NASA Ames 1001 is widely used in numerous observation networks

Below, two fully annotated examples of level 0 files for reporting particle number concentrations measured by a CPC to the WMO GAW World Data Centre for Aerosol are stated. The examples include one version without, and one with sample dilution. Line-by-line explanations of content and syntax are given for the first template, as well as a list of commonly used flags to indicate instrument conditions and errors. The latest version of this template is available online at:

www.gaw-wdca.org/SubmitData/AdvancedDataReporting/Level0/CondensationParticleCounterlevel0.aspx

C.5 GAW WDCA Condensation Particle Counter Level 0 (raw data) file format example (system without sample dilution):

```
90 1001
Fiebig, Markus; Someone, Else
NO01L, Norwegian Institute for Air Research, NILU, Instituttveien 18, 2007, Kjeller, Norway
Fiebig, Markus
EMEP EUSAAR GAW-WDCA
1 1
2014 01 01 2015 02 24
0
Days from the file reference point (start time)
14
1 1 1 1 1 1 1 1 1 1 1 1 1 1
9999.999999 9999 9999 9999.99 9999.99 9999.99 9999.99 9999.99 9999.999 9999.99 9999.99 9999999.999 9999999.999 9.99999999999999999999999999999999999999999999
end time of measurement, days from the file reference point
start time of measurement, year
end time of measurement, year
pressure, hPa, Location=instrument inlet
temperature, K, Location=instrument inlet
relative humidity, %, Location=instrument inlet
pressure, hPa, Location=flow measurement
temperature, K, Location=flow measurement
flow_rate, l/min, Location=sample line, Comment=calculation flow rate
temperature, K, Location=CPC saturator
temperature, K, Location=CPC condensor
particle_number_concentration, 1/cm3, Correction=uncorrected
particle_number_concentration, 1/cm3, Correction=coincidence, Measurement uncertainty=5%
numflag
0
62
Data definition:      EBAS_1.1
Set type code:        TI
Station code:         NO0002R
Platform code:        NO0002S
Timezone:             UTC
Startdate:            20140101000100
Timeref:              00_00
Revision date:        20150224000000
```

```
37   Component:                particle_number_concentration
38   Unit:                     1/cm3
39   Matrix:                   pm10
40   Period code:              1y
41   Resolution code:          1mn
42   Sample duration:          1mn
43   Laboratory code:          NO01L
44   Instrument type:          cpc
45   Instrument manufacturer:  TSI
46   Instrument model:         3772
47   Instrument name:          TSI_3772_BIR
48   Instrument serial number: 100235
49   Method ref:               NO01L_CPC_acquisition_lev0_0_0_1
50   Orig. time res.:          1mn
51   File name:                NO0002R.20140101000100.20150224000000.particle_number_concentration.pm10.1y.1mn.lev0.nas
52   Station name:             Birkenes II
53   Station latitude:         58.38853
54   Station longitude:        8.252
55   Station altitude:         219.0m
56   Station GAW-Name:         Birkenes Atmospheric Observatory
57   Station GAW-ID:           BIR
58   Station WDCA-ID:          GAWANO__BIR
59   Station AIRS-ID:
60   Station other IDs:
61   Station state/province:
62   Measurement latitude:     58.380
63   Measurement longitude:    8.250
64   Measurement altitude:     220m
65   Station land use:         Forest
66   Station setting:          Rural
67   Station GAW type:         R
68   Station WMO region:       6
69   Originator:               Fiebig, Markus, Markus.Fiebig@nilu.no, Norwegian Institute for Air Research, NILU, Atmosphere and Climate Department, Instituttveien 18,, 2007, Kjeller, Norway
70   Originator:               Someone, Else, Someone@somewhere.no, Some nice Institute, WOW, Super interesting division, Street 18,, X-9999, Paradise, Norway
71   Submitter:                Fiebig, Markus, Markus.Fiebig@nilu.no, Norwegian Institute for Air Research, NILU, Atmosphere and Climate Department, Instituttveien 18,, 2007, Kjeller, Norway
72   Data level:               0
73   Version:                  1
74   Version description:      initial revision, CPC_acquisition_lev0 v.0.0.1
75   Measurement height:       4m
76   Inlet type:               Impactor–direct
```

```
77    Inlet description:        PM10 at ambient humidity inlet, Digitel, flow 140 l/min
78    Humidity/temperature control: Nafion dryer
79    Humidity/temperature control description: sample dried to below 40% RH with Nafion dryer operated with reduced pressure sheath air
80    Volume std. temperature:    instrument internal
81    Volume std. pressure:     instrument internal
82    Detection limit:        0.001 1/cm3
83    Detection limit expl.:    Determined only by instrument counting statistics, no detection limit flag used
84    Measurement uncertainty expl.: typical value of unit-to-unit variability
85    Zero/negative values code:   Zero possible
86    Zero/negative values:     Zero values may appear due to statistical variations at very low concentrations
87    Standard method:        None
88    Comment:            Flow rate only covers part of primary flow actually evaluated
89    Acknowledgement:        Request acknowledgement details from data originator
90     start_time  end_time st_y ed_y  p_inl  T_inl  RH_inl  p_flw  T_flw   flow  T_sat  T_con  conc_raw    conc numflag
91      0.000694  0.001389 2014 2014  839.40  299.70   2.40  839.40  299.70   0.959  295.00  280.00   5864.250   5974.450 0.000000000000000000000000000000000000000000000
92      0.001389  0.002083 2014 2014 9999.99 9999.99 9999.99 9999.99 9999.99 9999.999 9999.99 9999.99 9999999.999 9999999.999 0.999000000000000000000000000000000000000000000
```

C.6 Line-by-line explanations:

1. Total number of header lines (here 85) and NASA-Ames file format number (fixed to 1001), separated by space. The total number of header lines needs to be adjusted for any changes made to the header affecting the total number of header lines.

2. Name of data originator, i.e. person who is responsible for providing the data (principle investigator), last name followed by first name separated by a comma. If several persons are to be named, names separated by a semi-colon. Assembled names are to be set in quotation marks, e.g.: “van Kassel”, Jan.

3. Details of sponsoring organization, syntax: < lab code > , < organization name > , < organization acronym > , < organization unit > , < organization address 1 > , < organization address 2 > , < organization ZIP > , < organization town > , < organization country > . Fields may be omitted if not needed, but number of commas separating the fields has to match. Lab code provided by database administrator. If a field content contains a comma, enclose field content in quotation marks.

4. Name of person submitting the data. For syntax, see comments for line 2.

5. Project associations for the data. Contact database administrator for possible options. Several projects may be mentioned, separated by a space.

6. Number of volumes and volume number of this file, separated by a space. Inherited from original NASA-Ames specification and kept for being backwards compatible. Always set to 1 and 1.

7. File reference date and revision date, both formatted as YYYY MM DD, separated by a space. The file reference date specifies the zero point of the time axis of the file. The time axis is stated in “days of the year”, where 0 is at 0 UTC of the file reference date. If the file reference date is e.g. 2010 01 01, day of year 0 would be at the turn of the year.

8. Time interval between begin times of measurement periods, 0 if irregular. Only defined for regular datafiles without holes and shifts in the time base, which by definition, is not the case for a level 0 file. Thus always 0 for level 0 files.

9. Description of the independent variable (leftmost column in data section) according to original NASA-Ames definition. For EUSAAR data files, this corresponds to the start time of a measurement period, and is stated as “Days from the file reference point”.

10. Number of dependent data columns in data section.

11. Multiplication factor, one for each dependent variable, space separated. Inherited from original NASA-Ames specification and kept for being backwards compatible. Usually set to 1 for all dependent variables.

12. Missing value code, one for each dependent variable, space separated. Number of digits left and right of the decimal point and choice of floating point or exponential notation has to match number format in data section. Usually, all digits are set to 9.

13. – 25. Titles of dependent variables, one line for each dependent variable. To stay within the NASA-Ames specification, the end time of the observation period (second column from left) and the flags column (rightmost column) are included as dependent variables. To allow for

recognition of the columns by name (string comparison), the column names should match exactly.

26. Flags column title. EUSAAR NASA-Ames uses a system of flag numbers where each flag number is a three digit integer. See http://www.nilu.no/projects/ccc/flags/flags.html for a complete list of flags, and table below for a list of commonly used flags with this template. Since the NASA-Ames specification only allows floating point numbers, the flags are coded into a floating point number by listing them as digits right of the decimal point. The number of digits right of the decimal point is thus an integer multiple of 3. For example, in a flags column with room for 3 flags, flags 620 and 772 would result in 0.772620000 as content in the numflag column in the data section.

27. Number of special comment lines, usually 0.

28. Number of normal comment lines. The normal comment lines hold metadata items not specified in the original NASA Ames format, but needed to meet today's data documentation standards. All these lines use the syntax < metadata item name > : < metadata item value > . The number of these lines is 62 in the example, but needs to be adapted since some metadata items may be added or omitted if not needed.

29. Definition of metadata format, does not vary.

30. Set type code is always TI for irregular data sets such a level 0 data.

31\. and 32. Station and platform code are assigned by the database administrator.

33. Timezone for all time values stated in the file. UTC time zone SHALL be used, field is kept to make this explicit and as a reminder to data submitters.

34. Start date and time at which the data in the file begins, formatted as YYYYMMDDHHMMSS. Not necessarily identical with the file reference point in header line 7.

35. Timeref states the time of sample changes (HH_MM). Only used for filter based measurements, 00_00 otherwise.

36. Revision date and time for the data file, formatted as YYYYMMDDHHMMSS. Renders the information in header line 7, whose format is fixed by the NASA-Ames specification, more precisely.

37. Component name, constant when reporting particle number concentrations.

38. Unit of main variable, constant.

39. "Matrix" describes the part of the sample the measurement refers to. Alternatives include aerosol (refers to total particle fraction), pm10 (when sampling through a PM10 head), pm1 (when sampling through a pm1 head).

40. Reporting period of the file. Common options include one hour (1h) and one year (1y). Data sets covering more than a year should be split into several files.

41. Target time interval between consecutive measurement intervals, i.e. interval between consecutive start times of data lines in file, most commonly 1 min (1mn).

42. Target duration of one sampling point, i.e. interval between start time and end time reported in one data line, most commonly 1 min (1mn).

43. The code of the lab responsible for the measurement is assigned by the database administrator.

44. Type of instrument used. “cpc” corresponds to CPC.

45. Manufacturer of the instrument used.

46. This field states the instrument model number / code.

47. The instrument name field serves 3 purposes:1) identify instrument manufacturer; 2) identify instrument model; 3) logically identify instrument uniquely within the network. Syntax: Instrument name: < manufacturer > _ < model > _ < additional ID > A change in the instrument name will be registered as start of a new time series, even if the same parameter has been measured before at the station. This is meant to ensure that a time series is internally comparable. The instrument name shall not contain spaces. The “additional ID” is supposed to make the ID unique within the GAW network and the WDCA database. Please choose a logical ID, e.g. the style “BIR_dry” identifying the instrument sampling the dry-state aerosol at Birkenes Observatory (Norway). That way, the instrument name won't need to change if you swap the instrument with one having a different serial number which is otherwise identical. The additional ID also allows to distinguish several instruments of the same type and model that may be run in parallel at a station for different purposes (e.g. dry-state vs. increased relative humidity) or intercomparison.

48. Serial number of the instrument used. If the instrument was replaced within the reporting period, please submit two different files, one covering the time before, and one after the replacement.

49. The method reference is managed by the reporting lab and identifies the standard operating procedure used for generating the reported data set. The standard operating procedure is a document that describes setup and steps necessary to make a comparable measurement, e.g. inlet design, primary flow, sample conditioning, calibration procedures, data processing steps. Since the method reference is managed by the reporting lab, it needs to begin with the lab code. Any change in instrument setup or data handling that could make the time series incomparable needs to result in use of a new method reference (will register as new time series in database).

50. Original time resolution of the data. Mostly relevant for data levels using aggregated data. For level 0, this value is identical with “Resolution code” in line 41.

51. File name, composed of metadata item values, syntax: < station code > . < start date / time > . < revision date / time > . < component > . < matrix > . < period code > . < resolution code > .nas

52. Station name.

53. Latitude of the station main buildings, may differ from instrument location, given in decimal degrees following WGS84. Use 6 digit accuracy right of the decimal point. Positive values for northern latitudes.

54. Longitude of the station main buildings, may differ from instrument location, given in decimal degrees following WGS84. Use 6 digit accuracy right of the decimal point. Positive values for northern latitudes.

55. Altitude of ground level above sea mean level at location of station main buildings in meters (m).

56. Official station name for GAW stations as registered in the GAW Station Information System (https://gawsis.meteoswiss.ch/GAWSIS/)

57. For stations in the GAW network, three letter station ID issued by GAWSIS

58. The World Data Centre for Aerosol (WDCA) previously used another set of station IDs in addition to the ones issued by the GAWSIS. Included to allow connecting older and newer data sets from the same station. Established GAW stations have this ID issued already. New stations will receive it when initially contacting WDCA for their first submission.

59. For North-American stations, this line contains the station ID issued by the Alliance of Information and Referral Systems (AIRS) if such an ID has been issued. If such an ID hasn't been issued, e.g. for all non-North American stations, this line may be left out. If you leave out this line, make sure to decrease the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1.

60. This line contains a space separated list of IDs the station has with other networks or databases. syntax:
    Station other IDs: < ID 1 > (<database acronym 1 >) < ID 2 > (<database acronym 2 >) ...
    The ID is immediately followed by the acronym of the issuing network or database in parenthesis. If the station doesn't have any other IDs, this line may be left out. If you leave out this line, make sure to decrease the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1.

61. For US and Canadian stations, this line contains the non-abbreviated name of the state or province. For all other stations, this line may be left out. If you leave out this line, please make sure to decrease the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1.

62. Latitude of the instrument location, may differ from location of station main buildings, given in decimal degrees following WGS84. Use 6 digit accuracy right of the decimal point. Positive values for northern latitudes.

63. Longitude of the instrument location, may differ from location of station main buildings, given in decimal degrees following WGS84. Use 6 digit accuracy right of the decimal point. Positive values for northern latitudes.

64. Altitude of ground level above sea mean level at instrument location in meters (m).

65. WMO has defined a list of accepted land use keywords to describe land use at stations. Please choose the option most applicable to your station from:

    Agricultural

    Airport

    Blighted area

    Commercial

    Desert

    Forest

Grassland

Gravel and stone

Industrial

Military reservation

Remote Park

Residential

Single point source area

Snowfield

Urban park

Wetland

Other

Not available

66. WMO has defined a list of accepted keywords to describe the setting of a stations. Please choose the option most applicable to your station from:

    Mountain

    Polar

    Coastal

    Rural

    Suburban

    Urban and centre city

    Other

    Not available

67. For GAW stations. GAW has defined 4 station types with corresponding key letters: G (for global), R (for regional), C (for contributing), and L (for local). Please choose the letter applicable to your station as registered in GAWSIS. If you leave out this line, make sure to decrease the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1.

68. WMO has defined 7 regions on the globe, together with corresponding key numbers: 1 (Africa), 2 (Asia), 3 (South America), 4 (North and Central America), 5 (South-West Pacific), 6 (Europe), 7 (Antarctica). Please choose the region where your station is situated. This may be different from the region where the institution operating the station is located.

69. For each data originator named in header line 2, one line of contact and affiliation information has to be present. The order needs to correspond to the order of names in header line 2.

syntax: < last name > , < first name > , < e-mail address > , < affiliation name > , < affiliation acronym > , < affiliation unit > , < affiliation address 1 > , < affiliation address 2 > , < affiliation ZIP > , < affiliation town > , < affiliation country > Fields are comma separated. All commas have to be present. Fields may be left empty if not needed. If a comma is part of field content, enclose field content in “”. If you include more or fewer originator names than in the example, make sure to adjust the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1.

71. For each data submitter named in header line 4, one line of contact and affiliation information has to be present. The order needs to correspond to the order of names in header line 4. syntax: < last name > , < first name > , < e-mail address > , < affiliation name > , < affiliation acronym > , < affiliation unit > , < affiliation address 1 > , < affiliation address 2 > , < affiliation ZIP > , < affiliation town > , < affiliation country > Fields are comma separated. All commas have to be present. Fields may be left empty if not needed. If a comma is part of field content, enclose field content in “”. If you include more or fewer originator names than in the example, make sure to adjust the total number of header lines in line 1 and the number of auxiliary comment lines in line 28 by 1

72. For raw data submission, the data level is always 0.

73. In case the data contained in the file has been processed several times into the same format, the versions receive a unique, sequential number.

74. This line (freetext) contains a few keywords on how this version was processed, e.g. as opposed to the previous version.

75. Height of inlet tip or instrument location above ground level at station.

76. A set of inlet type keywords has been defined. Please choose the most appropriate from:
    Cyclone
    Diffuser cone
    Elutriator
    Hat or hood
    Impactor–direct
    Impactor–virtual/concentrator
    Impactor–elutriator combination
    Isokinetic
    None–open-face filter
    Open conductive tubing
    Downward-facing tube
    Selective filtration

77. Since the values for the previous field are limited and may not convey all necessary information, this line may contain the essential keywords (e.g. size, size cut, brand, flow, diameter) describing the inlet system used.

78. A set of keywords for describing commonly used methods of sample temperature and humidity conditioning has been defined. Please choose the most appropriate from:
    Diffusion dryer
    Dilution drying
    Humidification
    Humidification with temperature condition at ambient
    Humidification with temperature conditioning at 50 °C

Heating to 40 % RH, limit 40 °C
Manual control (see metadata)
Nafion dryer
Nafion dryer with temperature conditioning at 30 °C
Temperature conditioning at 20 °C
Temperature conditioning at 25 °C
Temperature conditioning at 30 °C
Temperature conditioning at 40 °C
Temperature conditioning at 50 °C
Temperature conditioning at ambient
Temperature controlled
Other (see metadata)
None

79. Due to the limited selection of options in the previous line, this field (freetext) uses keywords to describe the temperature / humidity control implemented.

80. For raw data, volume concentrations are usually reported for instrument for internal instrument conditions of temperature and pressure as stated by corresponding variables. In this case, use keyword
    instrument internal
    If a standard temperature is used due to the type of flow regulation, state it here in K. A standard temperature of 273.15 K is preferred.

81. For raw data, volume concentrations are usually reported for instrument for internal instrument conditions of temperature and pressure as stated by corresponding variables. In this case, use keyword
    instrument internal
    If a standard pressure is used due to the type of flow regulation, state it here in hPa. A standard pressure of 1013.25 hPa is preferred.

82. State the detection limit of the main variable reported in the file. Please use the same unit as stated in line 38

83. Short key word statement how the detection limit was determined.

84. Short key word statement how the measurement uncertainty was determined.

85. Keyword declaring whether 0 and negative values may occur in the data section. The following keywords are allowed:
    zero possible
    zero/negative possible
    zero/negative impossible

86. Short statement why 0 or negative values may or may not occur.

87. The standard method refers to one of the recognized standard operating procedures (SOPs) for CPCs. If your measurement is according to this document, state “TS XXXXX”, and “None” otherwise.

88. This line allows to convey any additional information on how the data was processed, e.g. parameters used for processing the data according to the stated “Standard method”. Freetext.

89. Information on whom to contact in terms of acknowledgement for using the data in any form of publication. Freetext.

90. Line with column short headers for data section. Facilitates to use the file content in spreadsheet applications by simply removing the header.

Following lines:

Data section, columns separated by space, preferably constant width formatted. The number format (max. number of digits left and right of decimal point, floating point or exponential notation) shall correspond to the respective missing value code stated in header line 12. In a few columns, the missing value code, even though defined in header line 12, shall never be used, e.g. for end_time of measurement, start year of measurement, end year of measurement, and numflag column. Even though all other data items in a line may contain the missing value code, the numflag column shall always contain at least one allowed flag value, e.g. flag 999 (missing value) coded as 0.999000000 if all other data items contain the missing value code.

Table C.1 — Commonly used flags for indicating conditions which make the data invalid

Flag value	Description
610	Working medium supply problems, here butanol supply
611	Light source malfunction
620	Poor signal quality
635	Internal temperatures too far off target value, considered invalid
664	Secondary flow(s) too far off target value, considered invalid
699	Mechanical problem, unspecified reason.
772	Value above range, data element invalid
980	Missing due to calibration or zero/span check
999	Missing measurement, unspecified reason (avoid in favour of more specific flags)

Annex D
(informative)

Uncertainty calculation (example)

D.1 General

The procedure for calculating the uncertainty of one-minute duration measurements is set out in 9.3. This Annex gives a worked example of the uncertainty calculation.

D.2 CPC plateau detection efficiency

The calibration certificate for the CPC will include an uncertainty in the detection efficiency determination. For this example this is taken to be 7 %, presented as $k = 2$ or 95 % confidence. The component u_η is the 1 σ value, so that the uncertainty component u_η is half this value, i.e. 3,5 %.

D.3 CPC detection efficiency drift

Suppose that the last three years' "post maintenance" and subsequent "as found" detection efficiencies are as in Table D.1:

Table D.1 — Detection efficiency drift

"Post maintenance" efficiency	**Later "as found" efficiency**	**Difference η_{diff}**
0,846	0,867	0,021
0,953	0,929	0,024
0,864	0,883	0,019
mean η = 0,888		$\overline{\eta}_{\text{diff}}$ = 0,0213

The uncertainty component u_{drift} = 2,13/(2 · 0,888) = 1,2 %

D.4 Flow determination

As described in 9.3.4, the uncertainty component $u_{\text{flow}} = 2/\sqrt{3}$ % = 1,2 %, unless the criteria are not met, or flow stability is demonstrably better than the criteria, in which case the component is changed accordingly.

D.5 Correction to standard temperature and pressure

As described in 9.3.5, the uncertainty component $u_{\text{STP}} = \sqrt{2}/\sqrt{3}$ % = 0,8 %, unless the criteria are not met, or temperature and pressure measurements are demonstrably better than the criteria, in which case the component is changed accordingly.

D.6 Sampling losses due to diffusion to walls

As described in 9.3.6, the uncertainty component u_{loss} is taken to be 1,5 %.

D.7 Dilution factor (where applicable)

Where a dilution system is present, as described in 9.3.7, the uncertainty component $u_{\text{dil}} = 5/\sqrt{3}\ \% = 2{,}9\ \%$, unless the criteria are not met, or dilution factor accuracy is demonstrably better than the criteria, in which case the component is changed accordingly.

D.8 Calculation of overall uncertainty

Table D.2 — Uncertainty components

Uncertainty component	**Symbol**	**Estimation (%)**
CPC plateau detection efficiency	u_{η}	3,5
CPC detection efficiency drift	u_{drift}	1,2
Flow determination	u_{flow}	1,2
Correction of volume to STP	u_{STP}	0,8
Sampling losses due to diffusion to walls	u_{loss}	1,5
Dilution factor (assumed to be applicable in this example)	u_{dil}	2,9

The combined standard uncertainty is given by

$$u_{\text{c}} = \sqrt{u_{\eta}^{2} + u_{\text{drift}}^{2} + u_{\text{flow}}^{2} + u_{\text{STP}}^{2} + u_{\text{loss}}^{2} + u_{\text{dil}}^{2}} \tag{D.1}$$

In this case,

$$u_{\text{c}} = \sqrt{3{,}5^{2} + 1{,}2^{2} + 1{,}2^{2} + 0{,}8^{2} + 1{,}5^{2} + 2{,}9^{2}} = 5{,}1\ \%$$

The coverage factor *k* is taken to be 2, so that the expanded uncertainty *U* here is:

U = 10,2 %.

Annex E
(informative)

Atmospheric aerosols in Europe

E.1 General

Annex E provides a brief overview of particle number concentrations that were observed in Europe, and shows examples of number size distributions. It relies largely on findings derived from a series of European Aerosol Phenomenology publications [3; 4], and on contributions regarding number size distribution measurement results from some monitoring sites.

As described in the articles mentioned above, measurement sites are categorized mainly according to their distance from large pollution sources (e.g. cities, industrial areas, major motorways) and thus their expected pollution levels as natural background, rural, near-city, urban, industrial and kerbside sites. Measurement sites were further grouped into Northwestern, Southern and Central Europe locations; comprehensive data from Eastern European locations were unfortunately not available.

Particle number concentrations were either measured directly with Condensation Particle Counters (CPC) or integrated from particle number size distributions measured with Mobility Particle Sizing Spectrometers (MPSS).

Number concentrations of aerosol particles vary considerably in Europe across different categories of sampling sites, from high concentrations exceeding 100000 cm^{-3} during peak hours at kerbsides to concentrations as low as some 100 cm^{-3} at natural background sites during very clean conditions. In E.2, mean particle concentrations across Europe are presented; in E.3, examples of measurements of particle number concentrations and size distributions from selected sites are shown.

E.2 Mean concentrations

Table E.1 gives an overview of annual mean total particle number concentrations at various measurement sites across Europe. These measurements are not all strictly comparable, since they do not all encompass the same particle size range (typically from 8 nm – 10 nm to 500 nm – 800 nm), depending on the instruments' configuration. Annual mean particle number concentrations increase from a few thousand per cm^3 at rural / natural background sites (e.g. Aspvreten and Hyytiala) to several tens of thousands at kerbsides (e.g. London M. with 78000 cm^{-3}). These differences are much larger than the uncertainties related to measurements. In contrast, concentrations for the same category of sites are similar for the three European sectors (Northwestern, Southern and Central Europe).

Table E.1 — Annual mean particle number concentrations (CN) at different measurement sites in Europe [4]

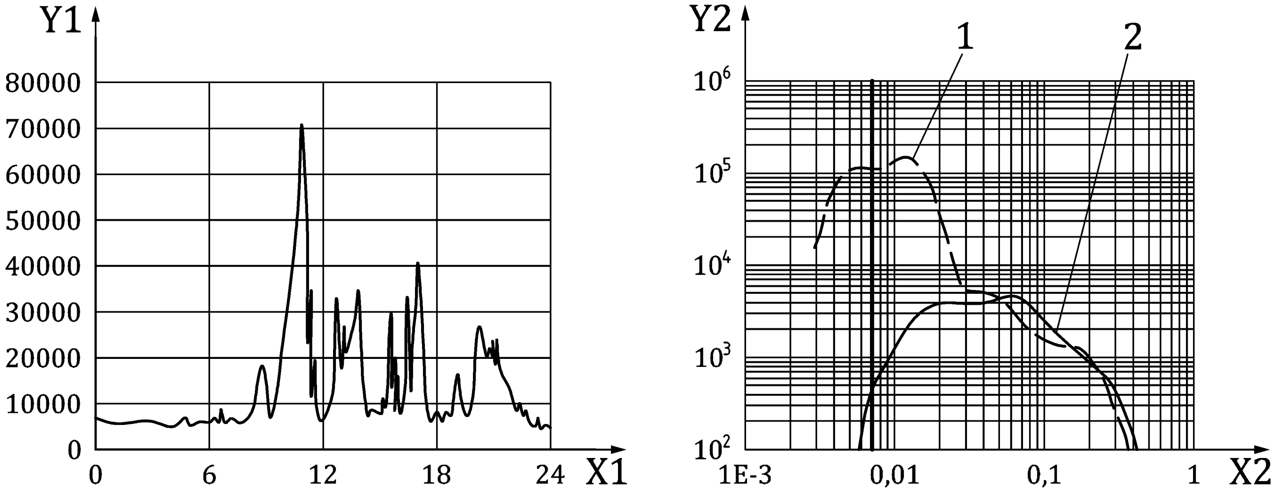
	Site	Country	Category	Period	CN total $10^3/cm^3$
Northwestern	Hyytiala	FI	natural background	2005	5,8
	Aspvreten	SE	natural background	2000	2,2
	Belfast	UK	urban	2000 – 2005	25,2
	Glasgow	UK	urban	2000 – 2005	19,4
	Manchester	UK	urban	2000 – 2005	20,8
	Birmingham	UK	urban	2001 – 2005	17,2
	London N	UK	urban	2001 – 2005	19,3
	London B	UK	urban	2002 – 2004	23,5
	Port Talbot	UK	industrial	2001 – 2005	15,7
	Helsinki V	FI	kerbside	1996 – 1997	19,6
	London M	UK	kerbside	2001 – 2004	78,4
Southern	Ispra	IT	near-city	2005	10,1
	Barcelona C	ES	urban	2003 – 2004	16,7
Central	Chaumont	CH	rural	2005 – 2006	3,7
	Hohenpeissenberg	DE	rural	1998 – 2000	2,7
	Melpitz	DE	near-city	2007 – 2008	5,0
	Basel	CH	urban	2005 – 2008	14,7
	Zuerich	CH	urban	2008	9,9
	Augsburg	DE	urban	2005 – 2007	11,7
	Leipzig	DE	urban	1998 – 2001	13,0
	Dresden	DE	kerbside	2003 – 2007	29,2
	Bern	CH	kerbside	2005 – 2008	30,8

E.3 Examples of measurements

In this section, examples of measurements are shown to give a flavour of the variations in particle number concentrations and size distributions that can be expected during measurements of ambient aerosols.

Figure E.1 (left) shows the variation in the number concentration which can be observed in Central Europe in a rural area under urban influence during the course of a day, taking the example of Melpitz, Germany. In this plot, the daily variation in the number concentration shows values ranging from 5000 cm^{-3} to 70000 cm^{-3}.

Figure E.1 (right) gives the number size distribution in Melpitz during the same day at two different times. In the very early morning, when the number concentration is roughly 5000 cm^{-3}, the maximum of the size distribution is broad and ranges from 10 to 100 nm. In this case, the size range in which particles are counted has little influence on the total particle number concentration (<3 %). When the number concentration rises to approximately 70000 cm^{-3} towards midday, the main part of the distribution shifts to very small particles between 5 nm and 20 nm. The increase of the number of very small particles involves a minor variation in the aerosol mass concentration, but makes the total particle number concentration very dependent on the lower limit of the particle size range since almost half of the particles have a diameter $D_\mathrm{p} < 7$ nm. In contrast, the number concentration decreases markedly for particles with $D_\mathrm{p} > 300$ nm (which is typical for European sites), and the upper limit of the particle size range has therefore no significant influence on the total particle number concentration.

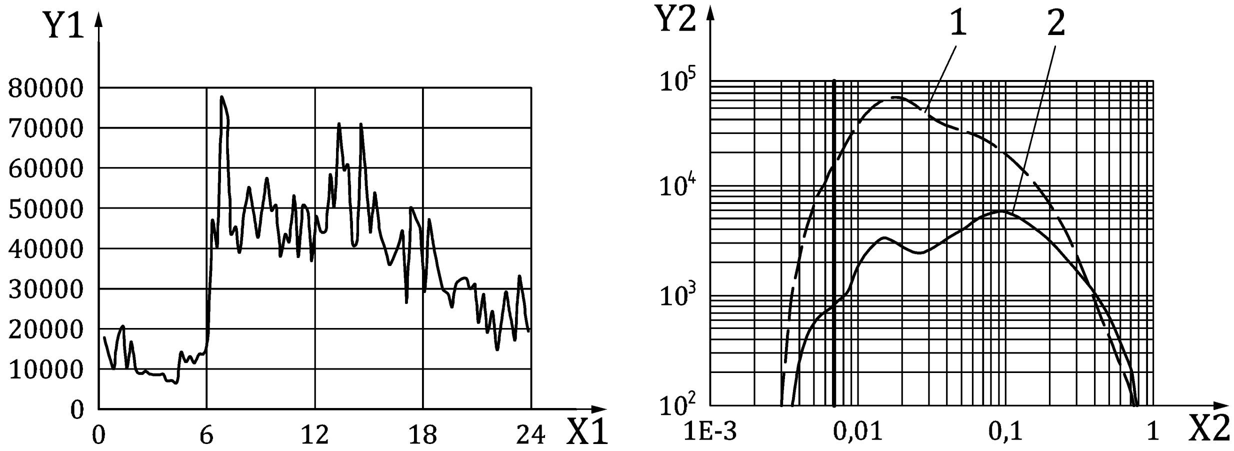


Key

X1	Time of day
Y1	Particle number concentration in cm^{-3}
X2	Diameter D_p in µm
Y2	dN/dlog(D_p) in cm^{-3}
1	11:00 h
2	04:00 h

Figure E.1 — Rural area under urban influence
Left: number concentration for particles $D_\mathrm{p} > 3$ nm (measured with a CPC, time resolution 1 min).
Right: number size distributions at different times of the same day, measured with an MPSS. The vertical bar shows the lower size cut at 7 nm

In Figure E.2, results from a kerbside measurement site in Leipzig, Germany, during a typical working day are illustrated. Particle number concentrations increase rapidly within an hour from low night time values (below 10^4 cm^{-3}) to peak rush hour values of more than 7×10^4 cm^{-3}. The corresponding number size distributions for night and day time measurements show that during daytime very small particles between 10 nm and 30 nm dominate the size distribution. Particles with $D_p < 7$ nm and $D_p < 10$ nm contribute 4 % and 10 %, respectively, to the total particle number concentration. During night time in contrast, particles with diameters around 100 nm are the main contributors to the particle population, and the lower size cut has little influence on the total particle number (<5 %).



Key

X1	Time of day
Y1	Particle number concentration in cm^{-3}
X2	Diameter D_p in µm
Y2	$dN/d\log(D_p)$ in cm^{-3}
1	11:00 h
2	04:00 h

**Figure E.2 — Kerbside measurements:
Left: number concentration on a week day in winter, measured with an MPSS.
Right: number size distributions for two different times of the same day. The vertical bar shows the lower size cut at 7 nm**

Annex F
(informative)

Dilution systems

F.1 Background

Measuring at concentrations higher than the maximum detectable number concentration of the CPC leads to an underestimation of the total particle number due to coincidence counts and shall be avoided.

In highly polluted areas where this limit is expected to be exceeded, a dilution system shall be used to reduce the concentration of the aerosol to a level suitable for the measurement range of the CPC in counting mode.

This annex describes the basic operation principles of dilution systems in which the dilution is carried out by mixing the aerosol with particle-free air in a continuous flow.

F.2 Criteria for dilution systems

The design criteria include the following:

- The dilution factor shall be accurately known (see 7.2) and stable in time.
- The volumetric flow rate of the aerosol available at the outlet of the dilution stage shall be compatible with the inlet flow rate of the CPC.
- Particle losses due to diffusion (see Annex A) shall be minimal.
- The dilution factor should be relatively independent of temperature, ambient pressure and humidity of the sample.
- The dilution factor or parameters indicating the status of the dilution system should be monitored.
- The particle number concentration in the dilution air should be less than 0,1 % of the number concentration of the diluted aerosol.
- The dilution system should be robust, easy to use and to service under real field conditions.

These criteria could have a strong impact and a correction of the final result could be necessary to take them into account. The uncertainty introduced by the dilution step shall be estimated and specified in the report. Where dilution is not required this step should be avoided.

F.3 Operation principles of dilution systems

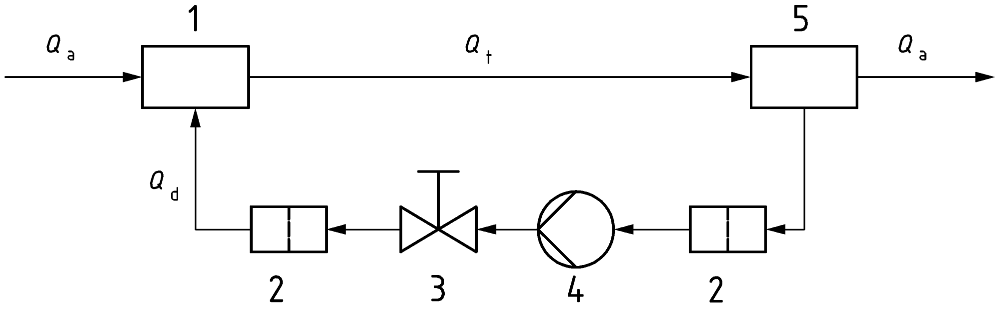
F.3.1 General

In a dilution system the aerosol flow Q_a is mixed in a particle-free dilution air flow Q_d. Different dilution systems differ in the design of the mixing section and in the way, the particle free air is generated. Dilution factors necessary in polluted areas may range from 10 to 100. Large dilution factors can be achieved by using two dilution systems in series.

In the design of a dilution system unnecessary flow restrictions like valves or capillaries in the aerosol path should be avoided, because they may clog or be the reason for particle losses. Homogeneous mixing of the aerosol and the particle free air is essential for a stable operation of the system.

F.3.2 Dilution systems with partial flow filtration

Figure F.1 shows a dilution system with partial flow filtration also referred to as dilution loop.



Key

1 Flow mixer

2 Filter

3 Valve

4 Pump

5 Flow splitter

Q_a Aerosol flow

Q_d Dilution air flow

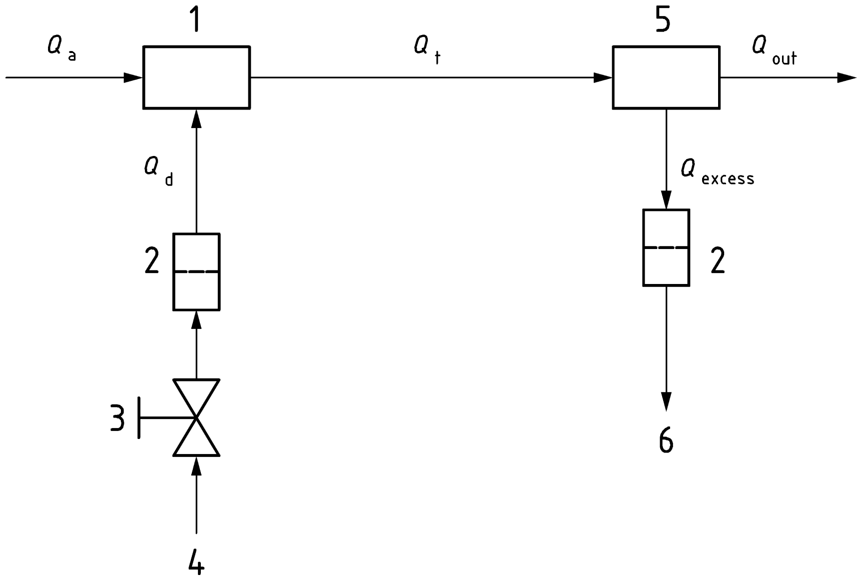
Q_t Total flow

Figure F.1 — Schematic of a dilution loop

In a dilution loop a part of the diluted total flow is filtered, optionally dried and pumped back to the flow mixer. A valve is used to set the dilution air flow and thus the dilution ratio. The flow between mixer and splitter is larger by the dilution factor so that diffusion losses are small. The aerosol flow Q_a is drawn by the measuring instrument. The dilution air flow Q_d has to be measured or controlled independently.

F.3.3 Dilution systems with external clean air supply

For this type of dilution system the clean air is supplied by some external pressurized air supply. This means, that the dilution air can be different from the aerosol in terms of humidity, gas composition and gas temperature. Figure F.2 shows the setup of such a system.



Key

1	Flow mixer
2	Filter
3	Valve
4	Compressed air
5	Flow splitter
6	To ambient air
Q_a	Aerosol flow
Q_d	Dilution air flow
Q_t	Total flow
Q_{out}	Output flow
Q_{excess}	Excess air flow

Figure F.2 — Schematic of a dilution system with external clean air supply

This type of dilution system has two input and two output flows which in principle can be adjusted independently from each other under the condition that

$$Q_t = Q_a + Q_d = Q_{out} + Q_{excess} \tag{F.1}$$

If the output flow Q_{out} is equal to the CPC input flow and the excess air flow Q_{excess} is produced by a pump and controlled by a valve, the aerosol flow will be the difference between the total flow Q_t and the dilution air flow Q_d. So the aerosol flow Q_a can be set larger than the output flow Q_{out} to reduce diffusion losses in the secondary sampling tube.

A much simpler way of operation can be achieved, if the flow mixer is designed as a Venturi ejector. The dilution air flow Q_d creates a static underpressure at the nozzle which draws in the aerosol flow Q_a. The ratio of the two flows depends strictly on the nozzle geometry and is relatively indifferent to variations in dilution air quantity or temperature, resulting in a quite stable dilution factor.

Annex G
(informative)

Laminar flow

Laminar flow is characterized by a Reynolds numbers below or equal to $Re = 2000$ while for Reynolds numbers much larger than that the flow is regarded to be turbulent.

The Reynolds number for tube flow is defined as

$$\mathrm{Re} = \frac{\rho \cdot D \cdot v}{\eta} \tag{G.1}$$

ρ gas density

D inner diameter of the tube

v mean flow velocity in the tube

η gas viscosity (see Annex A)

As normally the volumetric flow rate Q in the tube is known, it is convenient to express the flow velocity in terms of flow rate

$$v = \frac{4 \cdot Q}{\pi \cdot D^2} \tag{G.2}$$

With this, the Reynolds number is inversely proportional to the tube diameter:

$$\mathrm{Re} = \frac{4 \cdot \rho \cdot Q}{\eta \cdot \pi \cdot D}$$

As diffusion losses depend only on the flow rate Q and the length of the tube, the tube diameter D can be used as a free parameter to adjust the Reynolds number to a desired value.

Bibliography

[1] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

[2] HINDS W.C. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, 2*. Wiley, 1999

[3] VAN DINGENEN R. et al. A European aerosol phenomenology – 1: Physical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. *Atmos. Environ.* 2004, **38** pp. 2561–2577

[4] PUTAUD J.P. et al. A European aerosol phenomenology – 3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe. *Atmos. Environ.* 2010, **44** pp. 1308–1320

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Copyright in BSI publications

All the content in BSI publications, including British Standards, is the property of and copyrighted by BSI or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use.

Save for the provisions below, you may not transfer, share or disseminate any portion of the standard to any other person. You may not adapt, distribute, commercially exploit, or publicly display the standard or any portion thereof in any manner whatsoever without BSI's prior written consent.

Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than 1 device provided that it is accessible by the sole named user only and that only 1 copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than 1 copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright & Licensing team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email subscriptions@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 345 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK