INTERNATIONAL STANDARD

ISO 16170

First edition
2016-07-01

In situ test methods for high efficiency filter systems in industrial facilities

Méthodes d'essai in situ pour les systèmes filtrants à très haute efficacité dans les installations industrielles

Reference number
ISO 16170:2016(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 142, *Cleaning equipment for air and other gases*.

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Introduction

Methods for measuring the performance of high efficiency gas cleaning devices are described in a number of existing standards. These specify procedures for quality assurance following manufacture (e.g. ISO 29463 and EN 1822).

Some other standards specify the filter medium used in such devices, how they are constructed and how they are installed within industrial facilities.

Installations of high efficiency particulate filters are extensively used within nuclear and toxic material processing plants and laboratories to confine these materials within the facility and prevent their discharge to the environment.

Radioactive and other toxic materials are confined within processing facilities inside containment zones bordered by barriers. Air and gases vented from these zones are decontaminated by passage through a series of highly efficient particulate filters before final discharge to the environment. The membrane (filter medium) of the filters acts as part of the containment barrier. In view of its perceived fragility, confirmation of its integrity is required on a periodic basis because operational safety cases depend on the knowledge that the effectiveness of these filters is maintained at all times. These periodic checks are made by the procedure(s) known as “in-situ” or “in-place” testing.

The basic principles of *in situ* tests on installed filters are the same as for laboratory tests, such as those described in EN 1822 and ISO 29463, insofar as known quantities of a challenge aerosol are dispersed into the airstream upstream of the filter installation; the particulate contents of the unfiltered and filtered air are sampled and analysed to determine whether the integrity of the filters has been compromised.

In the case of testing a single unit (manufacturer’s production test or in the case of a laboratory testing on a single filter unit), the purpose is to confirm that the unit performance [efficiency/penetration at Most Penetrating Particle Size (MPPS) and other parameters] lies within specified limits, and further, that the results are globally reproducible. To achieve this requires the use of a laboratory test rig setup with full dispersion of a challenge aerosol, prescribed geometry of the test rig, and to obtain and analyse fully representative particulate samples both upstream and downstream of the test filter. Some ventilation systems are highly complex and it should be noted that many facilities use ventilation systems in which a high percentage of the air is recirculated.

The purpose of an *in situ* test is to detect any adverse change in the filtration performance of the installation and to compare it with the expected efficiency or decontamination factor. Such a change might be caused by deterioration of a unit or units or a faulty sealing system and would be manifested by the appearance of a proportion of unfiltered aerosol in the effluent airstream. Testing methodologies developed in this International Standard do not cover the other requirements that relate to filters in terms of mechanical resistance, burst strength or temperature and moisture resistance.

It is neither fully necessary nor useful for the results of an *in situ* test to replicate the results of production tests on the individual filters in the installation, nor is it necessary to confine the test aerosol size distribution to one which replicates that used in production tests.

No International Standard for general *in situ* testing of high efficiency filters has been produced before, explaining the needs for such an International Standard.

This International Standard describes the requirements for test equipment, data interpretation and reporting for the *in situ* testing of HEPA and ULPA air cleaning installations designed for the removal of airborne particulate contamination in high-integrity ventilation systems.

This International Standard includes specification of the test interval, aerosol type, aerosol mixing and measurement methods, i.e. the following:

— aerosol: solid or liquid, monodisperse or polydisperse;

— mixing: degree of mixing, mixing lengths, etc.;

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— method: injection, detection.

This International Standard proposes an outline testing philosophy to highlight the following:

— principle of the method;

— prerequisites;

— preparatory conditions;

— injected aerosol properties;

— qualification and selection of measuring devices;

— qualification of test personnel;

— test setup;

— test sequence;

— evaluation and reporting.

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In situ test methods for high efficiency filter systems in industrial facilities

1 Scope

This International Standard specifies *in situ* test methods for high efficiency particulate air filters used to limit releases towards the environment (e.g. from nuclear facilities or facilities with aerosol toxic or biological releases). This applies where installations of these filters are used to clean effluent air before discharge to the environment from industrial (including nuclear) installations where toxic/radioactive/biological materials are handled or processed.

This International Standard excludes the application already covered by ISO 14644-3.

The scope of this International Standard includes detail of two methods, either of which applies to the periodic testing of high efficiency filters which are used in demanding applications aiming at protecting the environment, such as the nuclear industry.

In the case of nuclear applications, this International Standard is applicable to installations covered by ISO 17873 (applications other than nuclear reactors) and ISO 26802 (nuclear reactors).

The two reference methods specified in this International Standard are not equivalent, but related to, the requirements to be addressed by the test results. The choice of which of the two methods is adopted in any specific case depends on whether the outcome requires an integrity test or a statutory efficiency accountancy test.

For industries handling or processing radioactive or toxic materials giving rise to a risk of possible release, the main goal of the tests is to confirm that the filter installation is fit for purpose. In the case of integrity tests (Annex B), this is to confirm that no significant leakage of toxic aerosols through the filter installation is possible.

In the case of efficiency accountancy tests (Annex C), the test is designed to make an accurate measurement of decontamination factor with respect to the MPPS size range of particles.

The reference method described in Annex B (integrity test) requires a test aerosol of dispersed oil particles mainly submicrometre in size range, which is stable during the test procedure and compatible with other installation components. Particle concentrations are measured in real time by light scattering instrumentation (optical detectors).

The reference method described in Annex C (efficiency accountancy test) requires a test aerosol of particles having a narrow size range centred on MPPS size range for HEPA filter media. Their concentration both upstream and downstream the filters is measured by fluorimetric analysis of aqueous solution obtained by washing the membrane sampling filters.

It should be noted that the requirements for an efficiency accountancy test also cover the requirements of an integrity test, which is considered to be a minimum requirement.

Test methods developed in this International Standard do not cover the other *in situ* performance requirements, such as mechanical resistance, bursting resistance or humidity resistance. Specific systems operating at high temperature or with specific gaseous effluents might require specific test methods.

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The engineering design of HEPA and ULPA filter installations does not fall within the scope of this International Standard.

NOTE In the field of filters for general ventilation applications, ISO 29462 is a detailed and comprehensive description of a method which uses scanning and particle counting methods to evaluate the performance of a filter in terms of particle grade efficiency, as well as pressure drop. Such a method and procedure would not be applicable in those nuclear installations where quantification of the decontamination factor at MPPS size is needed.

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 29463-1, *High-efficiency filters and filter media for removing particles in air — Part 1: Classification, performance testing and marking*

ISO 14644-3:2005, *Cleanrooms and associated controlled environments — Part 3: Test methods*

ISO 17873, *Nuclear facilities — Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors*

ISO 26802, *Nuclear facilities — Criteria for the design and the operation of containment and ventilation systems for nuclear reactors*

ISO 2889, *Sampling airborne radioactive materials from the stacks and ducts of nuclear facilities*

3 Terms and definitions

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

3.1
aerosol
system of solid or liquid particles suspended in gas

Note 1 to entry: In general, one divides the atmospheric aerosol into three size categories: the ultrafine range $x \leq 0{,}1$ µm, the fine range $0{,}1$ µm $< x \leq 1$ µm, and the coarse range $x > 1$ µm, where x is the particle diameter.

[SOURCE: ISO 29464:2011, 3.1.1]

3.1.1
monodisperse aerosol
aerosol (3.1), the width of whose distribution function, described by the geometric standard deviation σ_g, is less than 1,15 µm

[SOURCE: ISO 29464:2011, 3.1.2]

3.1.2
polydisperse aerosol
aerosol (3.1), the width of whose distribution function, described by the geometric standard deviation σ_g, exceeds 1,5 µm

[SOURCE: ISO 29464:2011, 3.1.3]

3.1.3
quasi-monodisperse aerosol
aerosol (3.1), the width of whose distribution function, described by the geometric standard deviation σ_g, is between 1,15 µm and 1,5 µm

[SOURCE: ISO 29464:2011, 3.1.4]

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3.1.4
test aerosol
aerosol (3.1) used for determining filter efficiency

3.2
decontamination factor
ratio between the concentration or particles number upstream the filter and the concentration or particles number contamination downstream the filter

Note 1 to entry: This ratio is also defined by 1/(1- *overall efficiency* (3.13)).

3.3
effective filter media area
area of the media contained in the filter (without adhesive spaces or ligament) and passed by air during operation

[SOURCE: ISO 29464:2011, 3.1.11]

3.4
efficiency
E
fraction of contaminant entering the filter which is retained

[SOURCE: ISO 29464:2011, 3.1.55]

3.5
efficiency accountancy test
in-situ test procedure meeting a requirement for an accurate system *overall efficiency* (3.13) determination at *MPPS* (3.11)

3.6
integrity test
in-situ test procedure meeting the requirement for confirming the absence of unfiltered leakage of the system

3.7
filter element
filtering material in a preformed shape being a part of a complete filter

[SOURCE: ISO 29464:2011, 3.1.67]

3.8
filter face area
frontal face area of the filter including the header frame

[SOURCE: ISO 29464:2011, 3.1.83]

3.9
HEPA filter
filter with performance complying with requirements of filter class ISO 35 – ISO 45 as per ISO 29463-1

[SOURCE: ISO 29464:2011, 3.1.88]

3.10
filter medium
material used for filtering

[SOURCE: ISO 29464:2011, 3.1.90]

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3.11
most penetrating particle size
MPPS
particle size at which the minimum of the *particle size efficiency* (3.14) curve occurs under test conditions

Note 1 to entry: This MPPS is media and ventilation conditions dependent. This MPPS is in the 0,1 µm to 0,2 µm medium aerodynamic size range for fibreglass type filters commonly used in nuclear applications.

[SOURCE: ISO 29464:2011, 3.1.129]

3.12
user nominal air volume flow rate
$q_{v,nom}$
air volume flow rate specified by the user, at which the *filter element* (3.7) is tested *in situ*

Note 1 to entry: This flow rate may be different from the one specified by the manufacturer.

3.13
overall efficiency
efficiency averaged over the whole *superficial face area* (3.15) of a *filter element* (3.7) under given operating conditions of the filter

Note 1 to entry: It is expressed in percentage (%).

3.14
particle size efficiency
efficiency for a specific particle diameter

Note 1 to entry: The efficiency plotted as a function of the particle diameter gives the fractional efficiency curve.

Note 2 to entry: It is expressed in percentage (%).

3.15
superficial face area
cross-sectional area of the *filter element* (3.7) through which the air flow passes

3.16
ULPA filter
filters with performance complying with requirements of filter class ISO 55 – ISO 75 as per ISO 29463-1

[SOURCE: ISO 29464:2011, 3.1.100]

3.17
user nominal filter medium face velocity
nominal air volume flow rate divided by the effective *filter medium* (3.10) area

4 Principle of the method

For industries handling radioactive and/or toxic materials, the main goals of the tests are the following.

a) For efficiency accountancy tests: to confirm that the overall filtration efficiency, in particular the decontamination factor for the MPPS size range and other performance parameters, remain within the operating envelope criteria authorized in the site operating licence.

b) For integrity tests: to detect any significant leakages of airborne particles bypassing the filter media.

The test procedure follows the following sequence:

— measure the main ventilation parameters (e.g. flow rates, pressure drops, temperature and humidity) of the system under test;

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— inject the appropriate quantity/quantities and type of the test aerosol into the airstream(s) upstream of the filter installation with a size distribution covering the MPPS range;

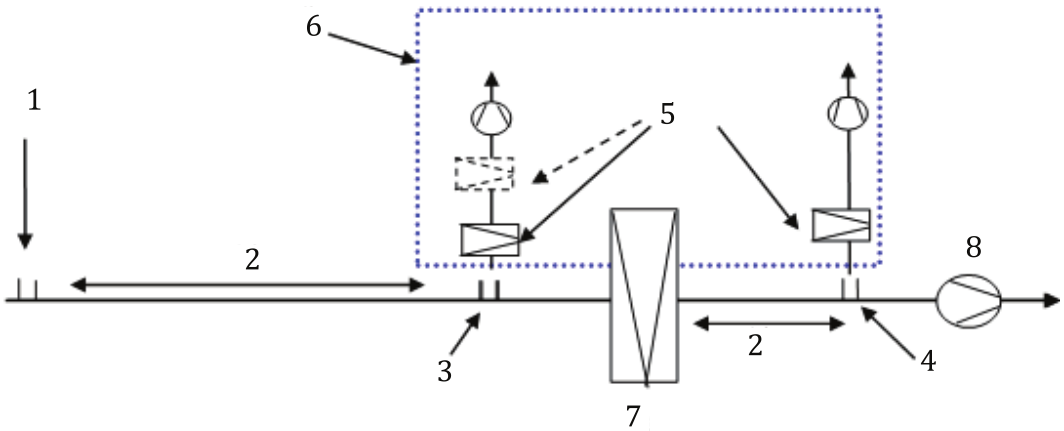
— measure the concentration of aerosol challenging the filter installation upstream of the filters;

— measure the quantity of aerosol present in the airflow downstream of the filter installation;

— calculate the efficiency or decontamination factor(s) within a size range covering the most penetrating particle size (MPPS);

— compare the measured value(s) against the required regulatory value(s) or other criteria, such as MPPS filter classification.

Figure 1 shows one general principle of the method, which is then further refined for the different methods.



Key

1 injected particles injection
2 provisions for homogenization
3 upstream representative sampling
4 downstream representative sampling
5 representative samples (this is done using different techniques in Annex B and Annex C)
6 mobile or fixed unit
7 filter(s) to be tested
8 fan (in many nuclear installations, it is customary to return the sample to the duct from which it was originally withdrawn downstream of the original sampling point)

Figure 1 — Principle of the method for representative sampling

According to ISO 29463-1, the MPPS range value should be obtainable from the media manufacturer for the typical media that are installed (e.g. 0,1 µm to 0,2 µm for HEPA filters constructed with glass microfibre media).

For efficiency accountancy tests, the chosen method shall be capable of measuring values within the range of 10 to 100 000 (efficiency range 90 % to 99,999 %), for particles sizes covering the MPPS range.

For integrity tests, an accurate measurement is not as important as for efficiency accountancy tests but the method shall cover ranges of efficiency between 90 % and 99,99 %.

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If it is needed to compare further the efficiency results, the parameters having an impact on the filter efficiency results should be reliably known for the test (e.g. flow rates, pressure drop, temperature, humidity).

Specific limitations on the applicability of the test results shall be detailed on the results sheet(s); for example, limitations on access to ideal sampling locations because of high dose rates, or difficulty in ensuring design flow rates, temperature, humidity, etc. within the ventilation system.

The results of the tests are provided only for the ventilation regime at which the test has been performed.

NOTE The specific case of continuous efficiency monitoring is rarely implemented in industrial facilities but obeys to the same principles.

5 Prerequisites

5.1 Filter initial characterization

The filter, bank of filters or filters in series to be tested shall have been initially certified in the manufacture according to a given standard (e.g. ISO 29463) for new filters or for filters already installed in the facilities according to relevant national standards.

ISO 29463-1 provides a classification of all filters with efficiencies ranging from 95 % to 99,999 999 5 %. Since the efficiencies are measured at the MPPS of the filter, the efficiency of a filter at any particle size is better than at the filter class. That is, these filters provide particle removal at, or better than, the filter class efficiency at *all* particle sizes. In addition, in this classification, filters with efficiencies higher than 99,95 % are tested for leaks. Although this document deliberately avoids prescribing specific filter classes for specific end use, the classification scheme provides a sound basis for selecting filters for nuclear protection where a minimum decontamination safety factor is required. For this end use, ISO Class 35H to 45H, and 50U (99,95 %, 99,995 % and 99,999 %, respectively at MPPS) generally provides commonly acceptable decontamination safety factors. For some specific applications where higher safety factors are required, ISO Class 55 to 75U filters may be specified for the last filtration stage.

NOTE The selection of the filter to be tested considers that the filter operating flow rate (user nominal flowrate) is as close as possible, or lower than, the nominal flow rate specified by the manufacturer in order to ensure that the filter performs as classified.

5.2 Preparatory conditions

5.2.1 General

To obtain the most valuable and useful in-situ test results, the test procedure shall be carried out when the plant is operating either at or as close as possible to its normal operating conditions.

Unlike production testing in industrial environments, access limitations may be created by factors such as radiation levels or even straightforward physical obstruction, preventing access to otherwise best possible sampling locations. These considerations should be addressed in advance to the best possible extent, e.g., by carrying out full system characterization tests before the introduction of radioactive/toxic materials, i.e., the following:

— qualification of injection and sampling locations to ensure fully mixed aerosol both upstream and downstream of the filter;

— conditions in the ventilation system and its operation during the test;

— apparatus selection and preparation;

— qualification of test personnel;

— test conditions;

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— climatic conditions of the air and rooms during the tests, if needed;

— aerosol preparation;

— health and safety.

Where this is no longer possible, more specialized means of addressing the problem need to be developed and implemented.

5.2.2 Choice of injection and sampling locations

The sampling location shall provide the ability to extract a representative sample. For existing plants, where it is not possible, sampling locations should be selected to provide representative samples to the best feasible extent. The injection and sampling locations shall be located in a way to ensure the optimum possible homogeneity of concentrations at sampling locations (ISO 14644-3 and ISO 2889) according to the guidelines defined in the annexes, particularly Annex C and Annex E. The expected homogeneity at the sampling point depends on the expected accuracy of the filter's decontamination factor.

The design of new injection and sampling ports/probes should, as far as possible, ensure that a suitable cross section of the duct can be accessed to extract representative samples to the best feasible extent and that sampling points are appropriately placed to assist fault identification. Representative sample(s) shall be extracted from location(s) where the contributing airstreams are blended to the greatest prevailing extent. If the sample is extracted from another location (e.g., because of accessibility conditions), then the uncertainties that are induced shall be assessed. The sample probe shall be located at the best available location (see Annex E). Consideration may be given to installing a device or devices to improve mixing. In this case, the sampling probe may contain a single or multiple sampling points. In circumstances where the well-mixed criteria are not achieved, a multi-sampling probe may be used or needed to get a representative sample.

For facilities that could not characterize fully the filtration system after careful evaluation, one or more of the following steps should be taken in circumstances where these previous criteria cannot be satisfied in effluent systems designed and constructed prior to the publication of this International Standard:

a) select another well mixed location for the sampling probe;

b) install features that promote mixing;

c) perform an *in situ* test or simulation demonstrating that a representative sample is being collected.

The values of the properties that signify a well-mixed location for sample extraction can be characterized by certain parameters that are specified in 5.2.5.

5.2.3 Conditions for the ventilation systems on which the test is performed

The ventilation systems on which the *in situ* test is performed should be under normal operating conditions (e.g. not in degraded mode) when the test is performed. If normal conditions are not achieved when the test is performed, then the effects on the tests results shall be evaluated. The results' validity depends on the chosen test conditions. Generally, for the filters meeting the specifications described in 5.1, the tests results show greater decontamination factors for lower flow rates.

5.2.4 Climatic conditions in the rooms where the injection/sampling is performed

Room air temperature and air humidity should be established under nominal conditions where the sampling is performed.

The conditions in the ventilation system during normal operations shall not exceed the following:

— during normal operations: the stated maximum rating for any component contained within the system;

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— during testing: the stated maximum rating of any apparatus used to undertake the test.

Additionally, if it is necessary to compare further the efficiency results,

— the climatic conditions of the air and rooms during the test should be compatible with the materials used for the test, and

— the background particulate levels in the air should be low enough to ensure sufficient detection sensitivity to the challenge aerosol (see Annex B).

5.2.5 Apparatus selection and preparation

5.2.5.1 General

The apparatus should be able to operate at the climatic conditions of the filtration system under test (5.2.4). The sampling flow rates for upstream and downstream shall not differ by greater than 5 % when connected to the system under test.

The tubing connecting the sampling probes (either installed or otherwise) to the sampling apparatus shall be as short as possible and the length for upstream and downstream shall be the same to minimize transit time and line losses.

All apparatus used for performing tests as described in this International Standard shall have a valid calibration certificate.

For the efficiency accountancy test, defined in Annex C, any apparatus shall be selected to work covering the MPPS range of the particular filtration system under test, and be able to determine, at a sufficient confidence level, the required efficiency/decontamination factor to satisfy the regulations or users' acceptance criterion.

5.2.5.2 Injected aerosol properties

The efficiency of filters varies with particle size and exhibits a minimum efficiency at a particle size which is typically close to 0,15 µm for HEPA filters made with glass microfibre media due to the influence of particle inertia and diffusivity, as well as other parameters of usually lesser influence such as fibre size and electrostatics.

In order to ensure that the filter is stringently tested, they are usually challenged with particles at, or close to, the MPPS. While the majority of clean new filters which use standard glass fibre filter media have an MPPS to test aerosols in the 0,1 µm to 0,2 µm range, this is not always the case and this changes as filters age, as local and average flow rates vary, and as lifetime conditions change.

While injecting a narrow range covering the MPPS is fundamental for the efficiency accountancy test method (in Annex C), this is less important for the integrity test.

It is nevertheless important that the test aerosol is carefully controlled with regards to its

— type,

— size (mass median diameter),

— standard deviation,

— generation method,

— electrostatic charge

— toxicity.

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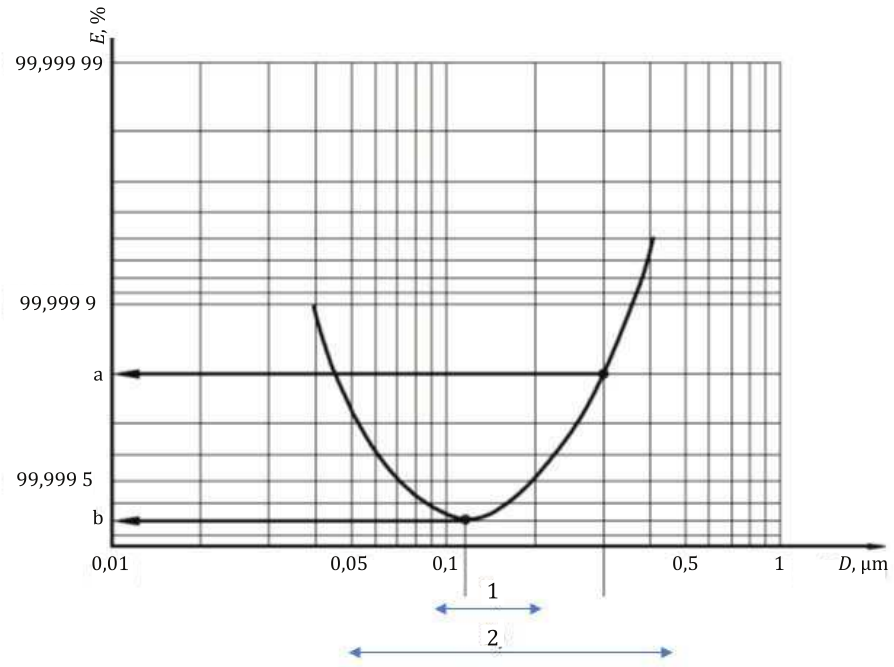
A list of suitable candidates is mentioned in Annex A (e.g. uranine, dispersed oil particulates such as di-2-ethyl hexyl sebacate (DEHS), Ondina oil or poly-alpha olefin (PAO)). Any other aerosol (e.g. sodium produced in a flame) would be suitable if it meets the requirements given in this International Standard.

The use of aerosols that would create other physical phenomena, such as electrostatic properties, that can interfere with the results shall be avoided. Test aerosols shall not carry significant electrostatic charge. In particular, aerosols with electrostatic properties (e.g. polystyrene latex) shall be avoided. When an aerosol is generated from aqueous or other polar solution or suspension, consideration should be given for diluting air through a neutralizer, i.e. a source of bipolar ions, immediately before mixing with the output from the aerosol generator.

The aerosol to be injected shall, therefore, be at a size that shall cover MPPS range (generally 0,1 µm to 0,2 µm, depending on flow rates and media). A broader range (typically 0,1 µm to 0,5 µm) should be accepted, in accordance with national agreement with the national regulations in force, if both aerosol selection and chosen method are proven to give adequate results with regards to the results needs.

NOTE Generally, a safety margin is already applied; a margin is implemented between the criteria used in the safety case and the results.



Key

1 MPPS range

2 acceptable aerosols range to inject

Figure 2 — Efficiency of a filter depending on an aerosol injection range (covering MPPS range)

The geometrical standard deviation of the challenge particle size distribution generated should be less than 2 for the method described in Annex C, and less than 2,5 for the method described in Annex B (see ISO 29463-2).

The quantity of injected particles at MPPS shall be enough to minimize uncertainties for the calculation of the efficiency/decontamination factor, taking into account the expected efficiency/decontamination factor. The total quantity of injected particles shall also minimize uncertainties for the calculation of the decontamination factors.

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The following conditions should be met:

a) the median mass particle diameter should be close to MPPS range, preferably around 0,15 µm; but a higher median mass particle diameter is acceptable if the apparatus and the methods are adequate to achieve the required conservative result;

b) the particles to be injected shall be measurable by the monitoring apparatus, otherwise, the test cannot be performed;

c) the concentration of the aerosol challenge upstream of the filter should be sufficiently high to achieve acceptable and measurable concentration downstream the filter.

5.2.5.3 Qualification and selection of testing apparatus

The devices used for the efficiency measurement (samplers, injectors, flow meters, particle counters) shall be qualified prior to the test measurements and should meet the requirements of ISO 14644-3:2005, Annex C.

The aerosol generator shall have the capacity to produce statistically enough particles with regards to air flow rate through the filter and filter expected efficiency/decontamination factor (see ISO 29463-4 and EN 1822-5). The aerosol properties are method-dependent.

For efficiency accountancy testing, the challenge aerosol measuring instrument shall have a linear range of at least 100 000 times the minimum detectible quantity of the instrument and an accuracy in accordance with the facility project specifications.

For integrity testing, the aerosol measuring system shall have a range capable of measuring penetrations down to 0,01 % (efficiencies between 99 % and 99,99 % with respect to the challenge aerosol).

The sampling device shall be able to sample at the specified flow rate and at the climatic conditions of the filtration system under test, and it shall be sufficiently leak-tight to prevent the dilution effects of in leakage and to reduce the risk of expelling contaminated air to the working environment. Provision shall be made for routing the device exhaust back to the ducts downstream of the sampling points when required. The sampling line lengths shall be sized to reduce the transit time to a minimum and the material shall be chosen to minimize sampling losses.

The injection point and upstream and downstream sampling points should be placed to ensure an adequate homogeneity of challenge and aerosol particle concentration (see Annex E).

5.2.6 Qualification of the test personnel

All personnel conducting the tests shall be deemed suitably qualified and experienced. This can be demonstrated by the completion of a relevant training programme (either internal or external), knowledge of test methods and equipment and ongoing demonstration of competence.

5.2.7 Health and safety

The health and safety of the test personnel shall be ensured by the completion of any relevant training courses required by the management systems of the test location.

Prior to commencement of testing, risk assessments shall be conducted that consider the following:

— test location (access, egress, temperature, radiological conditions, power requirements, etc.);

— aerosol generation (toxicity, propellants, etc.);

— compatibility of aerosol to plant components;

— sampling methods (probes, exhaust air, etc.).

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5.2.8 Test conditions

The test conditions for each of the test methods shall be recorded, for the following parameters:

— the climatic measurements for the system under test;

— the quantity of aerosol to inject;

— the upstream and downstream measurements to be performed;

— the test duration.

The flow rate shall be controlled or monitored.

The climatic conditions for the system under test should be recorded. In particular, where possible/appropriate, the following parameters should be measured:

— velocity profile at the upstream sampling position (when multi-point sampling);

— velocity profile at the downstream sampling position (when multi-point sampling);

— duct depression;

— filter differential pressure(s);

— temperature;

— humidity.

The effects of turbulent flows on velocity profiles are less important than for laminar flows.

Checks shall be made upstream and downstream of the sampling points to confirm the homogeneity of the challenge aerosol and to determine the downstream concentration levels. The required measurements are dependent on the configuration of the plant under test (i.e. mixing lengths, duct geometry, perturbations, etc.) and need to be assessed prior to commencement of testing (see Annex E).

6 Test sequence

6.1 Evaluation of filtration system under test

Prior to testing, the filtration system shall be assessed and the existing testing provisions evaluated (see Annex E). Where practicable, key features shall be identified such as the following:

— injection point (type, geometry and location);

— upstream velocity measurement and sampling point(s) (type, geometry and location);

— downstream velocity measurement and sampling point(s) (type, geometry and location);

— duct sizes and geometry;

— filtration plant (housing type, number of housings, differential pressure measurement provisions, design parameters, etc.);

— location of duct perturbations, grills, dampers, flow straighteners, mixing devices, filter housings, fans, etc.;

— distances from injection point to filters, injection point to upstream sampling point, filters to downstream sampling point, etc.

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A statement needs to be prepared examining the effectiveness of the existing testing provisions in relation to meeting the objectives of the test. Where a deficiency has been identified, further provisions shall be specified to ensure the requirements of Clause 5 are satisfied.

6.2 Preparation of test equipment

The test equipment selected shall enable the test to be performed using the provisions identified in 6.1.

All test equipment shall be prepared according to the manufacturer's recommendations, shall be within calibration (where applicable) and shall be tested as electrically safe (where applicable).

Equipment shall be transported to the test location in such a manner as to prevent damage.

6.3 Preparation of log sheets

Using the information obtained in 6.1, appropriate test sheets may be prepared specifying the system information, required measurements (climatic and upstream and downstream sampling) and test equipment details.

6.4 Monitoring of climatic conditions

The required climatic conditions shall be measured prior to commencement of testing. The data shall be recorded on the test sheet(s). Where filtration systems have a variable flow, care shall be taken over what flow the testing is performed at. In some cases for filter testing, additional air inlets may need to be opened to allow the test to be conducted.

6.5 Aerosol generation setup

The aerosol generation equipment shall be placed adjacent to the identified injection point. If necessary, the appropriate warm-up period shall be completed prior to commencing generation.

When generation commences, the generator shall be adjusted to produce the required output of particles with regards to air flow rate through the filter, as well as filter expected efficiency or decontamination factor. The output shall be limited in order to avoid saturation of the detection equipment and to minimize challenge to the filters.

6.6 Sampling equipment setup

The sampling equipment shall be placed in such a way that the upstream and downstream test points can be reached with sampling lines of equal and minimum length, as far as possible. If necessary, the appropriate warm-up period and pre-use checks shall be completed prior to commencing the test.

6.7 Monitoring of upstream challenge

The upstream challenge shall initially be measured at roughly the duct centre to ensure adequate challenge. The aerosol generator shall be adjusted to ensure that the challenge is within the optimum range.

The upstream challenge shall be measured at the locations determined in 5.2.2 and according to the test conditions mentioned in 5.2.8 to ensure homogeneity.

From the measurements taken, the average upstream sampling concentration shall be determined and, where appropriate, this serves as the datum point during downstream measurements.

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6.8 Monitoring of downstream

The downstream shall be measured at the locations determined in 5.2.2 and according to the test conditions mentioned in 5.2.8. Where appropriate, the upstream challenge shall be checked for adequacy and the sampling equipment zero reading shall be checked for drift.

6.9 Test performance

The objective of the test is to derive from the upstream and downstream aerosol particle concentration readings value/values of the installation *in situ* filter efficiency/penetration/decontamination factor(s) with accuracy within an acceptable confidence range to satisfy the user criteria. These values are then compared with values obtained in previous tests in order to validate ongoing filtration performance.

The test duration shall be such that the collection of particles downstream the filter is enough to reduce the results uncertainties and to be at least one order of magnitude above the particle background level.

The concentrations shall be such that the sensors are not saturated during the tests.

The test procedure is the following:

— connect the challenge aerosol generator to the qualified injection point;

— place the challenge aerosol-measuring instrument sample probes upstream and downstream the filter or filter bank to be tested;

— the sampling tubing should have the shortest length possible to minimize the measuring instrument response time;

— the downstream sample probe should be located close to the centre of the filter bank; it may be located in a downstream sample manifold or downstream of a mixing source;

— start the system and verify stable flow rate within qualification parameters;

— measure the upstream/downstream aerosol background concentration (“blank” measurement), (specific for Annex B);

— start the injection;

— ensure of the adequate collection of aerosol on upstream/downstream samples.

6.10 Calculations

On completion of testing, the efficiency/decontamination factor shall be calculated and compared to the required efficiency/decontamination factor to satisfy the regulations or users’ acceptance criterion.

$$DF = \frac{C_u}{C_d}$$

$$P = \frac{1}{DF} \times 100$$

$$E = \left(1 - \frac{1}{DF}\right) \times 100$$

where

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DF is the decontamination factor;

P is the penetration (in %);

E is the efficiency (in %);

C_u is the mass or concentration or number of particles, upstream;

C_d is the mass or concentration or number of particles, downstream (the unit shall be the same as upstream).

7 Evaluation and report

A report identifying the plant tested, test equipment used, all measurements and calculations shall be issued as required by the filtration plant manager. The report is subject to the verification and quality assurance checks as required by the testing organization.

It is up to the filtration plant owner to assess the results. As determined by the filtration plant owner's policy, filters where the measured DF is less than the required DF are considered via the plant operating procedures.

Trending of filter efficiencies may take place to highlight early signs of filter deterioration.

Persistently low DF readings after changing the filter may point towards problems with the filter element to housing seal or to damage of a single filter element, which requires diagnostic action (e.g. the housing to be changed, a leakage test to be performed, etc.).

Abnormally high test results, e.g., >50 000 DF, shall be submitted to a specific analysis that may include, but is not limited to, the following points:

— checking the flow rate compared to the filter design;

— sufficiency of the injection compared to the measurement accuracy;

— proper injection/sampling points locations.

It may be the filtration plant owner's policy to re-test if results of this magnitude are measured which indicate that there may have been a malfunction in the test.

The report shall mention the following:

— injected aerosol properties (type, mass median size, standard deviation);

— used normative method;

— upstream and downstream concentrations;

— flow rate of the air streams inside the ventilation duct;

— adequacy of the relative humidity range with regards to the test conditions;

— adequacy of temperature range with regards to the test conditions;

— filter pressure drop;

— type designations of each measurement instrument and apparatus used and its calibration status;

— final decontamination factor, penetration and/or efficiency;

— uncertainties on results;

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— any special condition or departures from this test method, or both, and any special procedures agreed on between the facility and its supplier.

The report should mention the airborne background concentration (for measurement performed in 6.9).

The uncertainties of the test results should, as far as possible, be within the global objective of less than 10 %.

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Annex A
(informative)

Aerosol candidates for *in situ* testing

The following are typical substances to generate test aerosols (liquid or solid test aerosols that are generated by spraying or atomizing them into the atmosphere):

— oil particulates;

— poly-alpha olefin (PAO) oil, with a specific kinematic viscosity of 4cSt at 100 °C;

— dioctyl sebacate (DOS);

— di-2-ethyl hexyl sebacate (DEHS);

— shell Ondina 917 oil or Finevestan A80B;

— soda fluoresceine (uranine).

The aerosol shall be chosen in agreement with national regulations (e.g. with the national safety authority), provided that the aerosol properties meet the requirements mentioned in 5.2.5.2.

Certain authorities have, for health reasons, prohibited the use of DOP as dioctyl (2-ethyl hexyl) phthalate for filter testing. In this International Standard, the direction is to use D.O.P. and not to use DOP. The acronym D.O.P. (dispersed oil particulates), is used to define substances which have similar aerosol properties that may be substitutes for dioctyl (2-ethyl hexyl) phthalate.

Any other aerosol (e.g. sodium produced in a flame) would be suitable if it meets the requirements given in this International Standard.

Adaptation of each method using these aerosols is mentioned in the relevant annex.

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Annex B
(normative)

Integrity testing — Typical methodology using dispersed oil test aerosols

B.1 Design philosophy

In situ testing is necessary in order to check that the filters have been installed correctly, and without damage, and to locate faults should they occur in service.

The test method involves the following basic steps:

— introduction of a test aerosol of sub-micron particles into the air flow upstream of the filtration system under test;

— measurement of the aerosol concentration in representative samples upstream of the filter to ensure challenge homogeneity and to provide an upstream challenge baseline;

— measurement of the aerosol concentration downstream of the filter;

— calculation of the efficiency/decontamination factor of the filtration system under test based on the measured upstream and downstream concentrations.

To test a filter *in situ*, a challenge aerosol is injected upstream of the filter. The aerosol mixes with the air in the duct and representative samples of this mixed air flow are taken upstream and downstream of the filter.

Whenever it is not possible to produce a test challenge aerosol which simulates the actual *in situ* challenge to a filter in real *in situ* conditions, it is common practice to use a dispersed oil particulate (D.O.P.) test. Thermally generated or "hot" dioctyl phthalate (DOP) gives challenge particles in the size range of 0,1 µm to 0,7 µm with an MMD of 0,5 µm. "Cold" D.O.P. generated by pneumatic atomisation usually gives particles in a somewhat larger size range.

A range broader than real MPPS range (typically 0,1 µm to 0,5 µm) can be accepted according to the conditions mentioned in 5.2.5.2.

Using oil particulate generator or heating Ondina E.L. oil in a smoke generator is adequate.

Representative samples are generally taken from the ventilation system by using installed sample probes. However, by scanning across the duct with a movable probe, the test methods can also be used to measure the variations in the concentration of aerosol particles across a duct section (for uniformity of mixing), and by extracting the sample close to the filter, to detect streaming through holes in the filter or filter seal.

The design shall be tested to confirm system performance. Since the test aerosol is submicron in diameter, aerosol separation by inertial effects is unlikely and, hence, isokinetic sampling is not necessary.

For nuclear installations, design provisions are given in ISO 17873 (for nuclear installations other than reactors) and in ISO 26802 (for nuclear reactors).

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B.2 Test procedure considerations

All internal upstream surfaces of the filter installation shall be subjected to an even, fully mixed (i.e. uniform) concentration of challenge aerosol. The extent to which this is achieved will determine the accuracy with which any aerosol leakage can be detected or measured. Extracted upstream aerosol samples shall be demonstrably representative of the aerosol particle concentration of the airflow. The extent to which this requirement shall be met depends on

— accuracy required to meet the safety requirement for the plant or facility, and

— inherent error in the measuring instruments, generation rate of the challenge, etc.

Under ideal conditions (good mixing of the test aerosol, relative deviation of 10 % to the mean value), the filter penetration measured by a single test should be within 40 %. Non-ideal geometry likely to be encountered in real situations can result in considerably large errors unless appropriate countermeasures are adopted.

A uniform concentration profile for the challenge aerosol is achieved by allowing an adequate mixing length between the injection point and the sample extraction point before the filter. This extraction point can be as close to the filter as plant design constraints and sample probe geometry allow.

The precise mixing length required depends on the particular system under consideration and especially on the flow regime (laminar or turbulent). Values deduced from an experimental rig (5 000 $m^3 \cdot h^{-1}$ to 10 000 $m^3 \cdot h^{-1}$, 600 mm square duct, 17 m,s^{-1} injection velocity) suggest that some 25 duct diameters are required for natural mixing of relative deviation of 10 % to the mean value from a central injection point (past research work suggests that using the previously recommended mixing length of 10 duct diameters might introduce a variation of three between maximum and minimum concentrations.) The duct length for mixing is also seen to be dependent on the velocity of the sample injection. For injection at values close to the duct velocity, which is the case for a leak on a filter or for an injection system which uses the depression in the duct to induce the sample, i.e. the hot D.O.P. generator, then natural mixing lengths (10 %) are greater than 30 diameters.

For plant arrangements other than those indicated in Table E.1, extra sampling points should be incorporated into the ductwork (see guidance in 5.2.8). The resulting information may then be used in assessing the accuracy of the efficiency/decontamination factor measurement.

Where there is not a complete run of straight ductwork for mixing, the above mixing lengths can be interpreted as follows:

— where the mixing length consists of two lengths of straight ductwork separated by one bend (with an angle up to and including a U bend), then the mixing length refers to the distance along the duct centreline including the bend;

— where the mixing length consists of several straight lengths of ductwork each of which is separated by a bend of any geometry, then the mixing length refers to the sum total of the several lengths of straight ductwork, i.e. excluding the lengths of the bends.

It should be noted that in the above context, the term duct diameter strictly means hydraulic diameter of the duct cross section. Hydraulic diameter is equal to four times the duct cross-sectional area divided by the perimeter of the duct cross section. For a circular duct, the hydraulic diameter is equal to the duct diameter while for a square duct, the hydraulic diameter is equal to the length of a side of the duct cross section.

It is important not to confuse the above mixing lengths with those quoted for stack sampling (see ISO 2889). In general, the requirements for filter testing are more demanding than those for stack sampling because:

— in filter testing, two separate samples are required from the duct (upstream and downstream of the filter) and errors can accumulate;

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— in filter testing, the concentration of test aerosol across the upstream filter face shall be very uniform (relative deviation of 10 % to the mean value);

— in stack sampling, a concentration profile with a relative deviation of 20 % to the mean value on the mean is considered acceptable (see ISO 2889).

The joining of branch ducts to the main duct within the mixing length (any branch ducts feeding air into the main duct) should be avoided because they can prejudice the foregoing assumptions, i.e. reduce the effectiveness of mixing.

NOTE 1 Mixing lengths can be reduced by using multipoint aerosol injection and by creating increased turbulence by the use of mixing devices. Changes in resistance to flow caused by such devices can upset the balance of airflows in other parts of the system.

The use of a multipoint injection array effectively reduces the duct section served by each injection hole and this produces a mixed flow in a shorter distance. However, experimental work has shown that the decrease in mixing length is not as great as might be expected from simple theory. Equal flow through each sampling nozzle is essential when a multi-point array is used. Flow through any of the arms of the array shall not be allowed to become restricted by deposition. Therefore, an array which can be inspected and cleaned is preferred.

Mixing devices can be very effective at shortening mixing distances, but with the disadvantage of having increased pressure drops. For proprietary devices, the manufacturer should be consulted concerning the pressure/flow characteristic of the selected mixing device. An option is to use devices such as the Stairmand Disc, or for greater efficiency a ring and doughnut, which can be mounted so that it can be rotated and hence feathered when not required for testing purposes. Experimental work reported in Table E.1 shows that mixing of 10 % with a central injection point is achieved in a minimum of 10 duct diameters using a 50 % area Stairmand Disc and forced (cold) injection. Using the hot DOP generator with the same Stairmand Disc increases the mixing length to 14 duct diameters for mixing with a relative deviation of 10 % to the mean value.

Experimental work has shown that by dividing the Stairmand Disc into three equal parts and using three points of injection (see Table E.1), the mixing length can be reduced to a value close to six duct diameters.

The mixing length required to ensure that a representative sample is extracted after a filter is greater than that required to mix the challenge aerosol before the filter since the emission (leak) point of the downstream aerosol may not be in the centre of the filter. For ideal theoretical conditions, the work quoted in Table E.1 suggests mixing lengths of greater than 30 duct diameters without a mixing device and 15 duct diameters with a 50 % Stairmand Disc for an ‘edge’ leak for mixing to within ±10 % variation on the mean.

Sampling extraction positions should be in a region of unobstructed straight ducting, which is free from static air or eddying. Since the test aerosol is submicron in diameter, aerosol separation by inertial effects is unlikely and hence isokinetic sampling is not necessary. Probe positions should be easily accessible to facilitate use.

The fan is an acceptable mixing device and it is recommended that the sample extraction point should be at least four duct diameters downstream of the fan to avoid the worst of the induced turbulence.

An alternative approach, which is of particular value for multi-filter banks, is the use of a multiple orifice sampling probe (MOSP) for downstream sample extraction. In this, the probe has a number of holes which are positioned in such a way that the sample drawn from the device represents the true mixed aerosol particle concentration, even though the probe itself is in an incompletely mixed flow. In order to ensure consistent sampling, each hole shall be run at ‘choked flow’ conditions. The MOSP is of no advantage for upstream measurements, since there is still the necessity to challenge the filter with a uniform concentration of test aerosol.

It is emphasized that the design of the MOSP is installation dependant and that testing is required to ensure that the sample extracted is adequately representative. With a well-designed and evaluated

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probe, sampling lengths can be reduced to about four duct diameters. MOSPs can also be used to identify a leaking filter in a bank of filters, if a separate MOSP is provided downstream of each filter.

Where a system is designed with filters in series, the filters should normally be separated by sufficient distance to allow aerosol injection and representative sampling upstream of the downstream filter, as well as mixing and sampling downstream of the upstream filter. This allows separate testing of each filter and hence the full worth of each unit can be claimed in the safety case.

Where filters in series cannot be individually tested adequately due to lack of separation, the limitation on the sensitivity of current measurement instruments, suitable for *in situ* testing, limits the accuracy of the DF which can be measured and hence claimed for the system of two filters in series. In such cases, the situation requires further diagnostic action. Individual filters/banks of filters can be tested during filter change operations, but this is not sufficient to prove the overall performance of a system when all filters are installed.

The adequacy of the design is supposed to be demonstrated during commissioning. It is the designers' responsibility to ensure that the design is testable and to provide the test schedule for the commissioning of the ventilation system. This schedule defines, among other things, the test method and apparatus for which the installed testing facilities were intended. The schedule should also describe the way of carrying out the tests and sufficient time shall be allowed to reach a full understanding of the filter system flow characteristics as they affect the measurement of filter efficiency. It is recommended that the test schedule should record the results of fingerprinting the filter system at the commissioning stage (see 5.2.2).

B.3 Principle of the method

The dispersed oil particulate (D.O.P.) test method is used for *in situ* system testing.

D.O.P. is produced by generating an aerosol with particles within a broad submicrometre mass median diameter size range. Using oil particulate generator or heating Ondina oil in a smoke generator is adequate.

Upstream and downstream measurements are made using an optical detector (optical particle counter, OPC, usually of the forward light scattering type) with an analogue or digital display. Consideration may be given to the use of a chart recorder or integrating circuitry to help resolve the continual variations due to eddying, etc., particularly at lower concentrations.

By using the appropriate generator, aerosol can be produced at a rate up to about 10 $g \cdot min^{-1}$, hence allowing filter DF determination of better than 10 000 at flow rates up to 10^5 $m^3 \cdot h^{-1}$ using a suitably sensitive detector and a fully experienced operator with an adequately designed system.

B.4 Test method

B.4.1 Evaluation of filtration system under test

Prior to testing, the filtration system shall be assessed and the existing testing provisions evaluated (ISO 14644-3 and ISO 2889). Key features shall be identified such as:

— injection point (type, geometry and location),

— upstream velocity measurement and sampling point(s) (type, geometry and location),

— downstream velocity measurement and sampling point(s) (type, geometry and location),

— duct sizes and geometry,

— filtration plant (housing type, number of housings, differential pressure measurement provisions, design parameters, etc.),

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— location of duct perturbations, grilles, dampers, flow straighteners, mixing devices, filter housings, fans, etc.,

— mixing length between the filter bank and the position of entry of any secondary duct teed into the main duct,

— mixing length from the main duct injection point to the filters and determination of the upstream sampling requirements,

— mixing length from the filter bank to the downstream sampling point(s) and determination of the sampling requirements.

From the information gathered, an assessment can be made of the adequacy of the installed testing provisions and the required sampling locations.

The duct geometry and the airflow within should be fully understood. For example, it is assumed that all of the nine preceding bullet points have been addressed and conclusions drawn as to the suitability of the position under question for installation either of an injection point or a sampling point. If the survey conclusion cannot be definite, then practical investigations will need to be carried out to establish suitability. This may involve trialling injections and sampling procedures to confirm or not the suitability of the proposed site. Sampling should be carried out using a technique showing concentration versus time as well as with variation of position within the immediate surrounding locality.

Typically, in proven well mixed airflow, successful sampling locations start from a range of 5 to 10 hydraulic diameters but, in such conditions, some publications (see Reference [11]) have shown that homogeneity uncertainties would be lower than 50 % (some other *in situ* experiments show the contrary, meaning that this parameter shall be well controlled). There are instances where greater distances are needed (see Annex E where distances of 30 diameters are proposed to reduce uncertainties). Particular attention should be given to the geometry of flow entry conditions. Any addition of a small secondary air stream close to the duct wall should be avoided.

Bends, fans, duct junctions and similar disturbances promote mixing, but may also produce distortions in velocity and contaminant concentration profile and angularity in the airflow in the first 2 to 3 hydraulic diameters downstream. Therefore, sampling locations too close to such disturbances should be avoided even at the cost of longer sampling lines.

In addition to the physics of obtaining a representative sample, there are other considerations in locating the probe and associated equipment. The location should be readily and safely accessible; it should not present a problem for sampler servicing and maintenance activities and it should be able to accommodate analysis or collection equipment that does not compromise the quality of the sample.

High radiation fields may present a problem with respect to worker safety at the sample extraction location. High ambient temperatures or humidity may also be a problem in some cases. Either of these situations may dictate longer transport lines than normally needed to accommodate installation of the sample collection and analysis equipment.

The values of the properties that signify a well-mixed location for sample extraction can be characterized by certain parameters that are stated as criteria in Annex B. The parameters of the selected sampling location shall be determined through the series of tests described in Annex B.

B.4.2 Preparation of test equipment

B.4.2.1 Aerosol generator

The generator used is either of the thermo-pneumatic type or purely pneumatic (atomiser) type. The generator shall generate dispersed oil particulates by heating Ondina E.L. oil (or equivalent) with an appropriate propellant gas to produce an aerosol of mass median diameter of a mainly submicrometre aerosol. By using the appropriate number of generators, the aerosol challenge shall be produced at a concentration suitable for checking concentrations as low as 0,01 % of the challenge concentration. The

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generator shall be used in accordance with the manufacturers' instructions and shall be serviced and checked for conformity at intervals no greater than two years, dependent upon usage and performance.

B.4.2.2 Aerosol detection device

Upstream and downstream measurements are made using an optical detector (usually of the forward light scattering type) with an analogue or digital display. Consideration may be given to the use of a chart recorder or integrating circuitry to help resolve the continual variations due to eddying, etc., particularly at lower concentrations. The sampling flow rate shall be in the range 25 $l \cdot min^{-1}$ to 50 $l \cdot min^{-1}$. The dynamic range shall be between 0,000 1 $\mu g \cdot l^{-1}$ to 600 $\mu g \cdot l^{-1}$. The aerosol photometer shall be operated in accordance with the manufacturers' instructions and shall be serviced and submitted for calibration at intervals no greater than 12 months, dependent upon usage and performance. Light scattering counting may also be used instead of a photometer.

B.4.2.3 Sampling probes and tubing

Moveable probes, where used, shall be made from stainless steel tubing. Probes up to 1,2 m are made from thin-wall tubing of a value close to 6 mm diameter. Probes over this length are made from 8 mm diameter thick walled (1,0 mm to 1,5 mm) tubing. All probes are used in an open-ended manner. During use, probes are graduated in accordance with the required sampling location determined in B.2.

Sample tubing is silicone rubber or non-electrostatic smooth walled flexible tubing. The bore of the sample tubing is at a value close to 6 mm to ensure a good seal with both the sampling probes and the aerosol photometer sampling ports. The tubing lengths are maintained as short as possible and equal on the upstream and downstream.

B.4.2.4 Flow meter

An air flow meter of the variable orifice type (e.g., rotameter) shall be used to measure the aerosol photometer sampling flow rate. The range of the instrument shall be commensurate with the sampling flow rate of the aerosol photometer with a resolution of 1 $l \cdot min^{-1}$.

B.4.2.5 Air velocity meter

An air velocity meter (e.g. hot wire anemometer or micro manometer with appropriate pitot) shall be available to measure duct air velocities. The instrument should have a range of 0,1 ms^{-1} to 30 ms^{-1} with a resolution of 0,1 ms^{-1}. The instrument shall be operated in accordance with the manufacturers' instructions and shall be submitted for calibration at intervals no greater than 12 months, dependent upon usage and performance.

B.4.2.6 Thermo-hygrometer

A thermo-hygrometer shall be available to measure duct air temperatures and humidities. The instrument shall have a temperature range of –10 °C to 60 °C with a resolution of 0,1 °C and a humidity range of 0 % RH to 95 % RH with a resolution of 0,1 % RH. The instrument shall be operated in accordance with the manufacturers' instructions and shall be submitted for calibration at intervals no greater than 12 months, dependent upon usage and performance.

B.4.2.7 Micro manometer

The micro manometer shall be available to measure duct pressures and filter differential pressures. The range of micro manometers, as well as their resolution, shall be adapted to the measurements to be performed. The instrument shall be operated in accordance with the manufacturers' instructions and shall be submitted for calibration at intervals no greater than 12 months, dependent upon usage and performance.

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B.4.3 Preparation of log sheets

Using the information obtained in B.2, appropriate test sheets shall be prepared specifying the system information, required measurements (climatic and upstream and downstream sampling special separation) and test equipment details.

B.4.4 Monitoring of climatic conditions

The required climatic conditions could be measured prior to commencement of testing. The data shall be recorded to the test sheet(s). Where possible, the system velocities shall be measured at the locations required for the upstream and downstream concentration measurements in 5.2.2 to allow for velocity profile corrections if needed (see B.2). The test equipment used shall satisfy the requirements of 5.2.5 to 5.2.8.

B.4.5 Aerosol generator setup

The aerosol generation equipment shall be placed adjacent to the identified injection point. The appropriate warm-up period shall be completed prior to commencing generation.

When generation commences, the output shall be adjusted to produce the required concentration of test aerosol (generally a concentration of at least 20 $\mu g \cdot l^{-1}$) at the upstream sampling point; however, the output shall be limited to prevent saturation of the detection equipment and to minimize challenge to the filters.

B.4.6 Photometer setup

The aerosol photometer shall be placed in such a way that the upstream and downstream test points can be reached with sample tubing of equal and minimum length. The appropriate warm-up period and manufacturers recommended pre-use checks shall be completed prior to commencing the test. The sampling flow rate shall be measured using a suitable flow meter. The upstream and downstream flows shall be within the manufacturers recommended range for the instrument and shall not differ by more than ±5 %.

The aerosol photometer shall be connected to the moveable test probes (if used) or MOSP via the sample tubing. The upstream probe (if used) shall be placed into the filtration system near the duct centre for the initial set up of aerosol generation levels.

B.4.7 Monitoring of upstream challenge

The aerosol generation shall be started and the concentration at the duct centre shall be measured. The aerosol generator output shall be adjusted so that the concentration is in the range 20 $\mu g \cdot l^{-1}$ to 40 $\mu g \cdot l^{-1}$.

The upstream challenge shall be measured at the locations determined in 5.2.2.

The aerosol concentration profile shall be assessed and the aerosol generation level adjusted in such a way that all measurement points fall into the 20 $\mu g \cdot l^{-1}$ to 40 $\mu g \cdot l^{-1}$ range; if necessary, the concentration profile shall be re- measured, the upper 40 $\mu g \cdot l^{-1}$ limit should be exceeded to ensure the lower 20 $\mu g \cdot l^{-1}$ is achieved.

The variation from the mean of all the concentration measurements shall be assessed. If the variation is ±10 %, no further adjustment is necessary, place the upstream test probe at a location where the concentration is as close to the average as possible (datum point).

If the variation is greater than ±10 %, further adjustments shall be made to the aerosol generation level and the variation re-assessed. If further adjustments offer no improvement, ensure that the ratio of minimum to maximum concentration does not exceed 2. Place the upstream test probe at a location where the concentration is as close 150 % of the minimum recorded concentration (datum point).

If the ratio of minimum to maximum concentration exceeds 2, the injection point requires re-design/re-location.

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The aerosol concentration shall be measured at the selected datum point and the aerosol photometer shall be adjusted so the reading is 100 %. The aerosol photometer zero shall be re-adjusted.

All data shall be recorded on the test log sheet.

B.4.8 Monitoring of downstream

The downstream concentrations shall be measured at the locations determined in 5.2.2 when using a moveable probe or from the downstream MOSP.

When taking penetration readings from multiple locations along a single measurement line, a trend rather than individual readings can be recorded, provided that:

— the reading is continuously monitored,

— the readings are <0,005 % or >0,02 %, the sampling probe is moved at a constant rate of <50 mm·s^{-1},

— the test log sheet is suitable annotated.

When taking a measurement from a downstream MOSP, the penetration shall be monitored for a period of at least 60 s.

The upstream datum and aerosol photometer zero shall be checked at the end of each sampling line or, when sampling from a MOSP, prior to terminating aerosol generation. Should the datum have drifted by >10 %, adjustment and re-measurement may be required. Small zero drifts have a large impact on apparent downstream concentrations which shall require re-measurement.

On completion of all sampling, the downstream probe shall be placed at the position of highest concentration and the aerosol generation terminated. The concentration at this point shall be monitored for residual background. Should the background be significant, the readings for all the sampling locations shall be recorded on the test log sheet.

B.4.9 Calculations

The average percentage penetration shall be calculated from all the individual readings obtained in B.4.7 and B.4.8. A percentage penetration obtained from a MOSP requires no further averaging.

If residual backgrounds were significant, these shall be subtracted from the individual readings obtained in B.4.7 and B.4.8 prior to calculating the average.

A velocity profile correction shall be performed if:

— the calculated average penetration is within the range of 50 % to 200 % of the acceptance criterion,

— the ratio of minimum to maximum downstream concentration is greater than 2,

— a velocity measurement was made from at least 75 % of the sampling locations.

The average velocity shall be calculated using the downstream sampling position velocities measured in B.4.7 and B.4.8.

A weighting factor for each sampling position shall be calculated by dividing the individual velocity by the average velocity. This factor is then multiplied by the corresponding penetration for that sampling position. The individual corrected penetrations shall be averaged to produce the corrected system penetration.

B.4.10 Identification of filter defects

The interpretation of test results and determination of the need for any remedial work will be undertaken by the facility management, according to agreement between management and the regulatory body.

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As determined by the filtration plant owner's policy, filters where the measured DF is less than the required DF should be replaced. Restriction on the use of the equipment served by the filtration system may need to be put in place until a new filter has been fitted and successfully tested, where, for safety or operational reasons, it would be impractical to allow the filter efficiency to fall below the claimed minimum efficiency a higher change efficiency then the safety case may be specified which allows the plant to still be operated and the filter changed in a longer time. Trending of filter efficiencies may take place to highlight early signs of filter deterioration.

A persistently low DF reading after filter changing may point towards problems with the filter element to housing seal, which may require the housing to be changed.

Abnormally high test results, e.g. >50 000 DF, shall be submitted to a specific analysis that may include, but is not limited to, the following:

— checking of the flow rate compared to the filter design;

— sufficiency of the injection compared to the measurement accuracy;

— proper injection/sampling points locations.

It may be the filtration plant owner's policy to re-test if results of this magnitude are measured which indicate there may have been a malfunction in the test.

To minimize the costs of remedial action to a filtration plant containing multiple filter elements that fail to satisfy the required acceptance criterion, it is usually necessary to identify which filter element(s) within a bank is defective.

Defective element identification in Unipak type housings requires either suitable test ports situated between adjacent housings, such as a moveable probe that may be inserted to identify high spots, or individual housing dampers that permit successive isolation of individual filter elements.

Defective element identification in ladder frame type installations requires the sequential sampling of installed MOSPs sited on the downstream face of individual filter elements. Due to eddy effects, visual examination of the downstream filter faces is often also required. Where no MOSPs are available, examination of the downstream penetration profile may identify areas of defect.

Defective element identification in circular type housings requires either suitable MOSPs sited in the outlet duct of individual filter housings or individual housing dampers that permit successive isolation of individual filter elements.

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Annex C
(normative)

Efficiency accountancy testing — Uranine test method

C.1 Object

Annex C defines a method for measuring filter efficiency using a Uranine aerosol.

It applies to filters, as well as filter banks. In this International Standard, the efficiency is expressed by a decontamination factor.

C.2 Principle

The test involves injecting solid particulates of Uranine upstream of the filter, collecting a sample of the aerosol upstream and downstream of the filter through sample filters, and extracting the Uranine from these filters by washing. Assay of these solutions is carried out by measuring their fluorescence.

C.3 Preparatory conditions

C.3.1 Aerosol generator

The aerosol generator, see Figure C.1, consists of the sprayer and the separator.

The sprayer

It consists of the following:

— a reservoir (1) containing the solution of Uranine;

— a spray head (2) comprising of eight ejectors (see Figure C.2); it is important that the concurrent 0,35 and 1,6 mm bores are precisely co-axial;

— a tube (3) air supply to the spray head;

— a suction tube for the Uranine solution (4);

— a coarse droplet baffle (5);

— output of liquid aerosol (6);

— a pressure gauge (7);

— a needle valve (8).

The separator

This has two stages. Each stage consists of the following:

— a vessel (9) whose walls are lined with absorbent material to fix the liquid deposits and prevent re-entrainment of the droplets by turbulence;

— a diaphragm (10) orifice diameter equal to 5 mm ± 0,05 mm for the first stage and 2 mm ± 0,05 mm for the second stage and a thickness of 2 mm ± 0,1 mm in both cases;

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— a nozzle (11) orifice diameter equal to that of the diaphragm member and separated from it by a distance of 3 mm ± 0,1 mm for the first stage and 1,6 mm ± 0,1 mm for the second stage.

The tip of the nozzle has a sharp edge and a profile of the polished outer surface of a 7 degree cone.

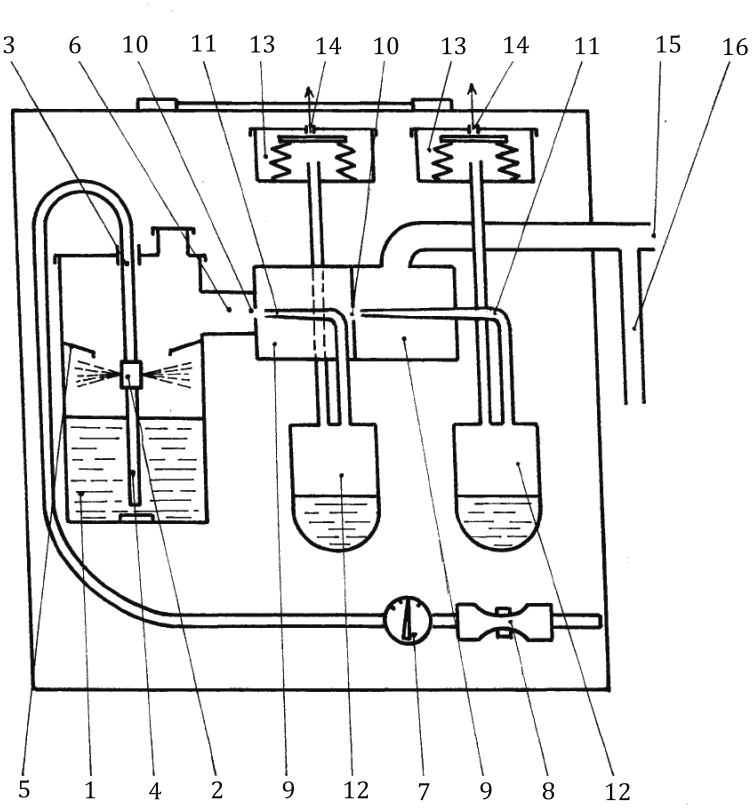
— a droplet catch-pot (12);

— a filter (13);

— a diaphragm (14) orifice diameter equal to 0,35 mm ± 0,02 mm and a thickness of 1 mm ± 0,05 mm.

The spray liquid from the sprayer passes through the high-speed orifice diaphragm (10). A small fraction of air is admitted into the nozzle (11), the majority then circumvents this nozzle. Because of their inertia, the larger particles do not follow the deflection of air streams, but are captured by the nozzle and collected in the catch-pot vessel (12). The air coming out of the catch-pot is filtered (13) and its flowrate is limited by the diaphragm (14). The liquid spray is released (15).

A dilution is made with dry air before injection into the circuit upstream ducting (16).



Key

1	reservoir	9	separator vessel
2	spray head	10	entry diaphragm
3	air supply tube	11	nozzle separation
4	solution suction tube	12	droplet catch-pot
5	coarse droplet baffle	13	filter
6	exit of liquid aerosol	14	diaphragm release
7	pressure gauge	15	aerosol output end
8	needle valve	16	dilution with dry air

Figure C.1 — Uranine aerosol generator

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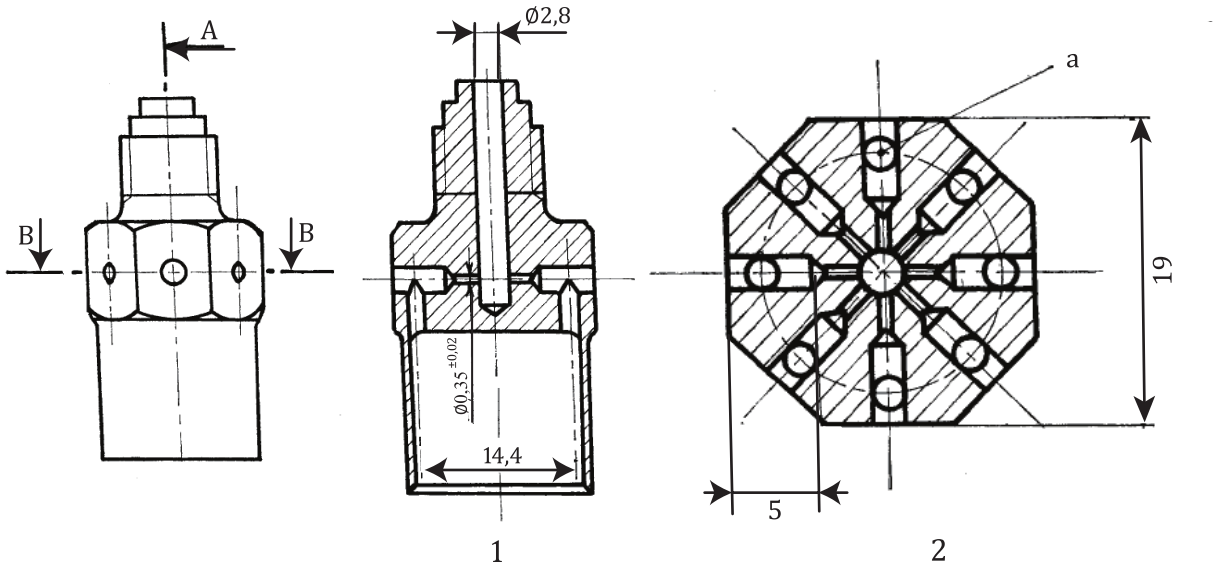
Dimensions in millimetres



Key

1 A-A cut

2 B-B cut

a 16 holes of 1,6 mm diameter

Figure C.2 — Spray head

The vertical holes (ø1,6) lead exactly in the axis of horizontal holes (ø1,6). Deburr should be performed carefully.

The characteristics of the aerosol produced by the generator shall be the following:

— the mass median diameter shall be within 0,12 µm and 0,18 µm (including measurement uncertainty);

— the geometric standard deviation shall be lower than 2;

— the spray nozzle flow rate shall be of 1,8 $m^3 \cdot h^{-1}$ (with 10 % uncertainties).

Furthermore, the generator should be such that its air leakage rate is less than 0,01 $mg \cdot h^{-1}$.

The criteria of conformity of the aerosol generator shall have been verified less than one year prior to the tests.

C.3.2 Test circuit and sampling device

The test circuit is presented in Figure C.3.

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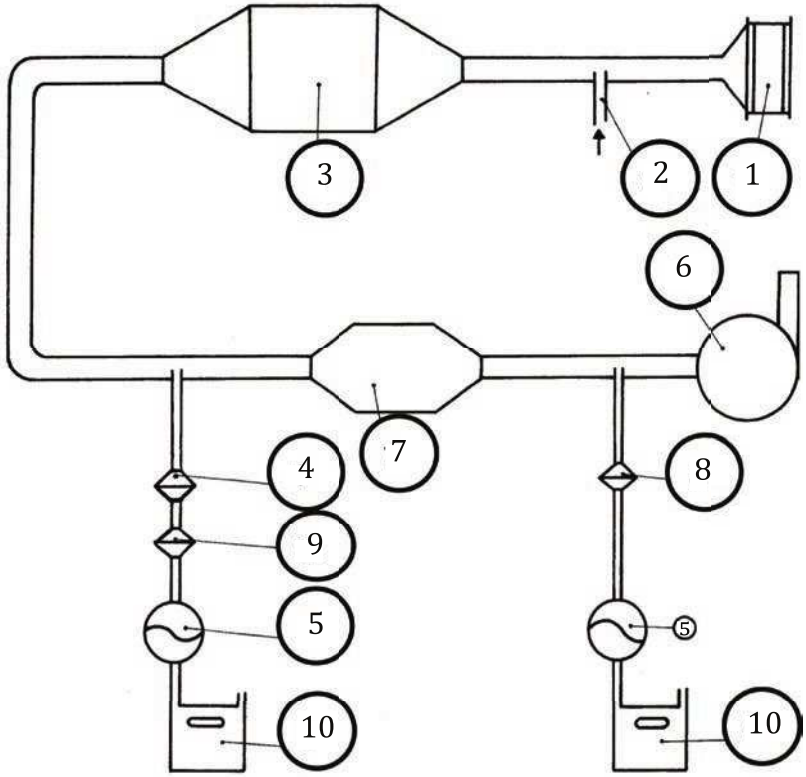

Key

1	input filter	6	fan
2	test aerosol injection point	7	filter element to test
3	mixing device, for homogenization	8	filter sampling downstream
4	filter sampling upstream	8a	optional filter control
5	pump	9	volumetric meter

Figure C.3 — Test circuit and sampling device

It is recommended to implement provisions for homogenization such as a mixing device (e.g., circular screen with a diameter equal to half the diameter of the duct) immediately downstream of the filter element.

The circuit includes a sampling probe upstream acting with a diameter of 15 mm connected to two filter holders in series, the first containing a sample filter input (4), the second filter control (8a) (option). A measurement of body volume (9) (e.g., gas meter) and device for air motion (5) (e.g., pump or ejector) complete the circuit. Given the fine aerosol, it is not necessary in this test to achieve isokinetic conditions.

The sample filter input is used for quality control of the aerosol test: its effectiveness, inferred from comparing the amount of Uranine collected in it and that the filter control received essentially depends on the size distribution of the test aerosol. Thus, a detection of faulty aerosol generation is possible.

The downstream sampling circuit includes a single filter called “sample filter downstream”.

Locating the upstream aerosol injection sampling line far away enough from the downstream sampling line and from the filter is important for achieving a representative/homogeneous sample. The sufficiency of

a) the distance between the upstream sampling and the filter, and

b) the distance between the downstream sampling and the filter

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shall be substantiated with regards to the objective of an adequate homogeneity at the sampling points.

The room temperature where the test circuit and sampling device are located shall be lower than 50 °C.

NOTE In a straight ductwork with a distance equal to 30 times the pipe diameter, the uncertainty is reduced to less than 10 % to 20 %.

C.3.3 Measuring apparatus: fluorometer

Use a photometer equipped with liquid fluorescence measurements. This gives a sensitivity of 10^{-11} g cm^{-3} selecting filters through appropriate optical wavelengths of radiation excitatory and fluorescence. The fluorescence is induced by the Uranine maximum excitation radiation having a wavelength close to 490 nm and the fluorescence spectrum shows a maximum intensity close to 520 nm.

A light source, such as an electric discharge lamp (e.g. xenon filled), shall be used. The radiation of 490 nm was selected through an interference filter primary. The fluorescence of solutions is measured through a secondary filter between the radiation wavelength of 520 nm. In practice, the difference between the radiation wavelengths selected by the primary and secondary filters is increased, owing to their bandwidth, in order to avoid an overlap of the transmission ranges of transmission that would result in an important “background noise”.

C.4 Operation method

C.4.1 General

The relative humidity of air should not exceed 80 % RH in all parts of the test circuit upstream of the filter control. The air temperature shall be lower than 50 °C.

The dilution air shall have a relative humidity less than or equal to 15 % moisture calculated the lowest temperature of the circuit upstream of the filter control.

C.4.2 Generation of test aerosol

An aqueous solution containing 1 % Uranine shall be prepared by dissolving 10 g of pure Uranine (fluorescein sodium $C_{20}H_{10}O_5Na_2$, purity 99,8 %) in one litre of distilled water. Fill the sprayer. The volume of solution required depends on the generation time scheduled. The solution shall be completely renewed after consumption of one third of its original volume.

NOTE For information, consumption of spray is about 50 cm^3/h less than the collected solution on the container walls and the barrier drops. However, because of evaporation, there is a concentration increase during operation. It is estimated that a 3 % increase in the diameter does not affect the filter efficiency in a sensitive way; this will allow an enrichment of the solution of 10 % to be admitted. It generally does not exceed such enrichment with a container of 90 cm^2 section made according to Figure C.1 for a consumption of 30 % to 35 % of the initial volume of the solution. So with 500 cm^3 of initial volume of solution, a generation suitable for three hours can be obtained, after which the solution shall be completely renewed.

Collection devices shall be prepared. These shall be washed thoroughly with distilled water probes as well as the filter holder without touching the inner surfaces to prevent organic traces. In case of doubt, these should also be cleaned with alcohol. The filters shall be entered with clean tweezers.

The various components of the sampling device shall be placed successively in the direction of movement of air in the order they are listed in Figure C.3. A pressure gauge shall be connected in addition to the level of the governing body volume measurement. The indication of this gauge allows calculation of the volume of air sampled. If a pump is used, its position should be reversed with the meter, according to Figure C.3. This avoids the pressure correction but it may be necessary to introduce a temperature correction if warm-up passage of the pump is important.

The aerosol shall be placed at the injection site. Dry air dilution shall be performed by connecting heating to the exit of the separator. The generation of aerosol shall be performed through admitting a

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compressed power sprayer at an effective pressure of around 2 bar abs and air dilution rate of at least 9 $m^3 \cdot h^{-1}$.

The circuit shall be put in operation during the sampling period t, calculated by Formula (C.1):

$$t = \frac{a \times Q \times E}{G \times p} \quad \text{(C.1)}$$

where

a is the Uranine mass needed in the sampling downstream (in g);

Q is the flow rate of the test filter (in $m^3 \cdot h^{-1}$);

E is the presumed decontamination factor of the filter to test (-);

G is the mass flow rate of the aerosol (in g), expected about 20 $mg \cdot h^{-1}$;

p is the sampling flow rate (in $m^3 \cdot h^{-1}$).

The Uranine mass (a) needed in the downstream sampling depends on the sensitivity of fluorescence measurement, which depends itself of the background noise of the sampling filter.

It is advisable to observe a ≥5× the measurement sensitivity of fluorescence.

EXAMPLE For an example of background noise of the sampling filter of $5{,}10^{-11}$ g/cm^3 of Uranine, the minimum measurable weight of Uranine can be defined as that which doubles this advisable value. If the sampling filter has a 50 mm diameter, they can be treated with 10 cm^3 of water only. The weight (a) is equal to $5 \cdot 10^{-10}$ g. In this case, assuming P = 3 $m^3 \cdot h^{-1}$, Q = 1 000 $m^3 \cdot h^{-1}$, E = 2 000, G = 20 $mg \cdot h^{-1}$, the sampling time would be 1 min.

C.4.3 Samples treatment

The sample filter and reference filter shall be treated by washing with distilled water containing 5 % ammonia decinormal. It is advisable to dilute the wash water solution from the upstream sample as it will contain relatively much larger quantity of Uranine.

By contrast, the control filter and the filter downstream sampling shall be washed with the minimum amount of water (e.g. 10 cm^3 for a filter of 50 mm in diameter). The washing solutions shall be titrated through the fluorometer.

C.5 Results

The results are expressed using a decontamination factor given in Formula (2):

$$DF = \frac{Cr \cdot Vr \cdot Qb}{Cb \cdot Vb \cdot Qa} \quad \text{(C.2)}$$

where

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Cr and Vr are the concentration (in g/L) and the volume (in L) of wash solution filter sampling upstream;

Ca and Va are the concentration (in g/L) and the volume (in L) of wash solution filter control;

Cb and Vb are the concentration (in g/L) and the volume (in L) of wash solution filter sampling downstream;

Qa is the volume of air sampled upstream (in m^3);

Qb is the volume of air sampled downstream volumes (in m^3) taken under the same conditions of temperature and pressure.

C.6 Data recording

The report of the test shall contain all the results expressed in C.4 and C.5, and also the results of the following tests:

— characteristics of the filter control;

— flow through the filter control;

— sampling time;

— characteristics of the fluorometer.

The test report should also indicate the operating details not provided in the standard and any incidents that might have influenced these results.

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Annex D
(informative)

Leakage test methods

Some additional tests may be needed in order to assess detection and measurement of aerosol leakage.

These tests may be performed to help verify

— that the filters have been correctly installed, and

— the absence of bypass leakage in the installation.

They may assist location of defects (small holes and other damages to the filter medium and the frame seal) and leaks (bypass leaks in the filter frame and gasket seal, leaks in the filter bank framework). These leak detection tests provide no data on the overall efficiency of the system.

The tests are performed by introducing an aerosol challenge upstream of the filters and scanning downstream of the filters and support frame, or sampling in a downstream duct. In the latter case, the aerosol challenge needs to contain at least a proportion of larger particles which would normally be removed completely by fully intact filters.

Reduced flow test: The sensitivity of the test in detecting leakages may be enhanced by reducing the airflow through the system to a fraction of normal flow. The proportion of flow through leakages may be more prominent under these conditions. In some cases, for operational reasons, it might not be possible to arrange this.

Oil thread test: In some circumstances, e.g., in plenum mounted installations, bypass leakages may be detected visually by adapting the technique used in the oil thread test.

The choice of the aerosols should also consider the limitation of sedimentation effects created by large particles. A challenge aerosol comprising particles smaller than 1 µm (as well as in some circumstances a proportion of particles up to 1 µm) is useful for leakage testing.

Relevant health and safety requirements shall be observed, in particular with regards to the potential toxic effects of the particles used for the tests.

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Annex E
(informative)

Guideline for representative sampling

Annex E gives guidelines for representative sampling.

Table E.1 gives a guideline for ideal theoretical homogeneous sampling (e.g. in laboratories), while the second part of Annex E gives indications on how to sample in industrial plants. ISO 2889 also provides detailed requirements for representative sampling.

Table E.1 — Guideline for theoretical downstream sampling (mixing lengths)

Downstream mixing length in duct diameters (D)	Number of sampling positions	Downstream sampling requirements
>30 D	1	One sample to be drawn from centre of duct
> 20 D ≤ 30 D	4	One sample to be drawn from the centre of four equal areas
> 15 D ≤ 20 D	9	One sample to be drawn from the centre of nine equal areas
> 10 D ≤ 15 D	16	One sample to be drawn from the centre of 16 equal areas
> 5 D ≤ 10 D	h × w 200 200	Samples to be taken every 200 mm in both directions, with edge samples 100 mm from duct walls
> 3 D ≤ 5 D	h × w 150 150	Samples to be taken every 150 mm in both directions, with edge samples 75 mm from duct walls
> 1 D ≤ 3 D	h × w 100 100	Samples to be taken every 100 mm in both directions, with edge samples 50 mm from duct walls
< 1 D	h × w 50 50	Samples to be taken every 50 mm in both directions, with edge samples 25 mm from duct walls
Multi orifice sampling probe (MOSP) installed in downstream duct	—	A single sample can be drawn from a MOSP provided that it is known to conform with the requirements tabulated above and that previous data have shown it to be operating correctly
Multi orifice sampling probe installed in a ladder frame	—	A sample drawn from such a MOSP should be used only to identify qualitatively a defective filter element
Multi orifice sampling probe installed in the circular duct D/S of a circular housing	—	A sample drawn from such a MOSP should be used only to identify qualitatively a defective filter element
Downstream of fan (D n/a)	1	One sample to be drawn from centre of duct at a sufficient distance from the fan to maximize flow linearity

The duration of the test shall be such that it minimizes the uncertainties, optimizes the cost, prevents saturation of the detection equipment and minimizes challenge to the filters.

For industrial plants requiring fine assessments of the sampling locations, in addition to ISO 2889 requirements, the following guidelines can be considered: the duct geometry and the airflow within should be fully understood (i.e. the homogeneous mixing should have been assessed).

Distances higher than 30 times generate a low uncertainty (less than 20 %) in proven well-mixed airflow in straight lines. Typically, in this proven well-mixed airflow (without perturbing elements upstream and downstream), sampling locations at 10 hydraulic diameters downstream of a flow

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disturbance generate homogeneity uncertainties (up to 50 % compared to the centre of the duct). Some singularities (elbows, dampers, T-junctions, heaters, coolers, etc.) can allow reduction of the adequate mixing distances in order to get the expected homogeneities, and would then lead to lower uncertainties. In general, and it has been shown with several examples of industrial layouts, a relative adequate homogeneity can be reached with distances of around 10 diameters thanks to perturbing elements such as dampers, elbows, T-junctions, etc.

The distance of three or more hydraulic diameters upstream of a flow disturbance is generally a location where uncertainties start to decrease. Particular attention should be given to the geometry of flow entry conditions. Any addition of a small secondary air stream close to the duct wall should be avoided. Bends, fans, duct junctions and similar disturbances promote mixing, but may also produce distortions in velocity and contaminant concentration profile and angularity in the airflow in the first two to three hydraulic diameters downstream. Therefore, sampling locations too close to such disturbances should be avoided even at the cost of longer sampling lines.

In addition to the physics of obtaining a representative sample, there are other considerations in locating the probe and associated equipment. The location should be readily and safely accessible, it should not present a problem for sampler servicing and maintenance activities and it should be able to accommodate analysis or collection of equipment that does not compromise the quality of the sample. High radiation fields under post-accident conditions may present a problem with respect to worker safety at the sample extraction location. High ambient temperatures or humidity may also be a problem in some cases. Either of these situations may dictate longer transport lines than normally needed to accommodate installation of the sample collection and analysis equipment.

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ICS 91.140.30

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