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# Testing HEPA/ULPA filters at the manufacturer's facility and in situ on the user's premises

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## 1. Introduction

**When the new standard EN 1822 "HEPA/ULPA Filters" came into force, this constituted an important step forward for cleanroom technology on a European level. EN 1822 is divided into five parts, defining salient characteristics for HEPA/ULPA filters, like classification, performance testing, leak-finding, and collection efficiency determination. Using the appropriate measuring instruments and test aerosols, it is possible in conformity with EN 1822 to achieve reproducible measurements for a HEPA/ULPA filter's most important parameters (pressure drop at nominal volume flow, collection efficiency at the efficiency minimum, plus freedom from leaks where necessary) under defined conditions. The standard thus makes a vital contribution to eliminating a confusing multiplicity of methods for specifying the collection efficiency of HEPA/ULPA filters.**

**For many users of HEPA/ULPA filters, moreover, it is of great importance to check the integrity and suitability of the HEPA/ULPA filters concerned in their installed condition. While in-situ testing of the HEPA/ULPA filters is performed in sectors like micro-electronics, food production, microsystems engineering, etc., in order to ensure the desired level of product quality, testing in the pharmaceutical industry is often even mandatory under statute law, so as to preclude any possibility of health hazards for humans. In many actual cases, it has emerged that filter users are insufficiently informed as to what filter characteristics can be meaningfully remeasured in situ, or in what cases recourse should be had to the values determined in conformity with EN 1822 by the filter's manufacturer.**

## 2. Testing HEPA/ULPA filters at the manufacturer's facility

A HEPA/ULPA filter's performance data are determined in a special test rig particularly suited for these measurements and specified in EN 1822. The salient measurements involved are

- pressure drop at nominal volume flow,
- overall collection efficiency (integral collection efficiency) for the particle size with the highest penetration (MPPS = **M**ost **P**enetrating **P**article **S**ize) at nominal volume flow,
- local collection efficiencies for the particle size with the highest penetration (MPPS) at nominal volume flow,
- freedom from leaks as from Filter Class H13

The results are used for allocation to a filter class from H10 to U17 (see Table 1). The new EN 1822 standard replaces under European law all national test standards for HEPA/ULPA filters, such as BS 3928, DIN 24184 or AFNOR NF X44-013. Major innovations introduced by EN 1822 include the use of modern particle-counting technology and determination of collection efficiency in the collection efficiency minimum.

All measurements are performed with the filter in its new condition, at a nominal volume flow which must always be specified. A typical filter test report to EN 1822 is depicted in Figure 2. The filter being tested is scanned by means of movable aerosol feeder nozzles and measuring probes, thus determining a large number of local collection efficiencies, which can be found in the graphics printed in the test report. Determining the collection efficiency minimum and the Most Penetrating Particle Size (MPPS) are particularly difficult operations in metrological terms. For Filter Classes H13 and H14, the standard alternatively permits what is called the oil thread test to be performed for leak-testing, i.e. the filter is not scanned.

As from Filter Class U15, the determination of local collection efficiencies (scan test) is mandatory. Often, a scan test of this nature is also agreed between user and filter manufacturer even for filters of Class H14. Defined framework conditions have to be complied with for the sophisticated measurements involved. These essentially comprise a constant test volume flow, a uniform velocity profile for the air

| Filter Class | Integral value | | Local value[1]) | |
|---|---|---|---|---|
| | Collection efficiency % | Penetration % | Collection efficiency % | Penetration % |
| H10 | 85 | 15 | — | — |
| H11 | 95 | 5 | — | — |
| H12 | 99.5 | 0.5 | — | — |
| H13 | 99.95 | 0.05 | 99.75[2]) | 0.25[2]) |
| H14 | 99.995 | 0.005 | 99.975[2]) | 0.025[2]) |
| U15 | 99.9995 | 0.0005 | 99.9975 | 0.0025 |
| U16 | 99.99995 | 0.00005 | 99.99975 | 0.00025 |
| U17 | 99.999995 | 0.000005 | 99.9999 | 0.0001 |

[1]) Lower local values may be agreed between supplier and purchaser than those specified in the table
[2]) Evaluation for freedom from leaks may also be possible using the oil thread test.

*Table 1 Filter classes and collection efficiencies to EN 1822*

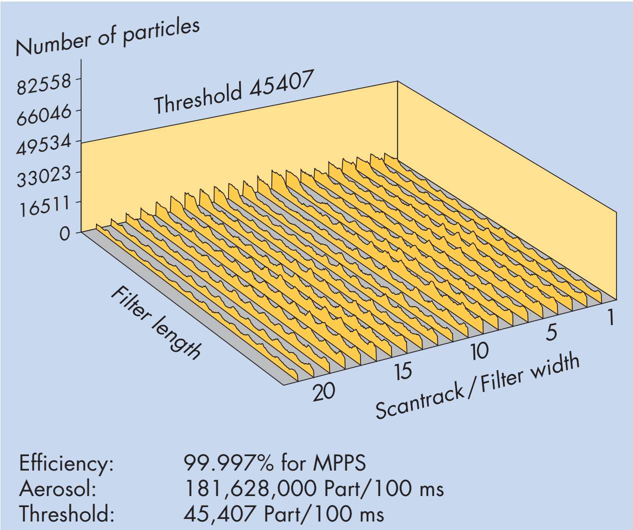


*Fig. 2 Multi-scan test report for a HEPA/ULPA filter Class H14 to EN 1822.*

over the filter's face area, and a temporally and positionally constant concentration of test particle size (MPPS). For statistical reasons, a sufficiently high clean-gas concentration must be assured, so as always to have enough counting events from the particle counters. This is directly linked to the raw-gas concentration, which has to be correspondingly high. A calibrated dilution stage must be provided for measuring the raw-gas concentration, so as to assure the metrological detectability of the raw-gas concentration by means of condensation nucleus counters or laser particle counters in the concentration range suitable for the measuring instrument involved.

## 3. In-situ filter testing

The manufacturer's measurements at the HEPA/ULPA filter, described here in abbreviated form, cannot be adopted in their entirety for a filter test routine carried out in situ, since most of the boundary parameters involved for measuring the overall collection efficiency (integral collection efficiency) as a mean value of local collection efficiencies cannot as a rule be set with sufficient precision at the filter's place of installation.
Users are accordingly recommended to have the manufacturer provide them as necessary with individual test reports for the HEPA/ULPA filters supplied. The filters and the associated test reports must be identified in a manner ensuring that the test reports can be unambiguously assigned to the right filter (e.g. by suitable numbering). The test report for a HEPA/ULPA filter has to provide all the relevant information on the filter concerned. The most important particulars are the specification values, the volume flow during measurement, the pressure drop at the test volume flow, the collection efficiency measured for MPPS, and the filter class derived from these.

Once achievement of the overall collection efficiency and the local collection efficiencies in conformity with the specification has been documented by the filter manufacturer with informative individual test reports, the task facing the user is to ensure that the filters installed have not been damaged during transport and installation, thus causing leaks at the filter itself or the filter seal. Correct installation and a tight fit in the filter mounting system must likewise be checked.

### 3.1 Aerosol generation and particle measuring technology

The modes of functioning and the performance limits of the instruments used for in-situ measurements will be dealt with first. It will usually be necessary to create an artificial aerosol, in order to set the raw-gas concentration before the filter and the clean-gas concentration behind the filter sufficiently high. Suitable basic substances are oily chemicals, atomized in a particular way. The best-known substances are DOP, DEHS (DOS) or Emery 3004. The oils are atomized into ultra-fine droplets by means of an aerosol generator, and inserted into the test air flow. One major advantage here is the achievement of high concentrations in a relatively narrow particle size range. The position of the size distribution's frequency maximum will depend on the atomizing technology involved. The widely used Laskin nozzle uses pressure to atomize the cold oil, thus achieving particle distributions with a frequency maximum of approx. 0.65 µm. A second method for generating aerosols is to evaporate the oil with heat, and then condense it. The condensed oil droplets exhibit a particle size distribution between 0.1 µm and 0.3 µm.

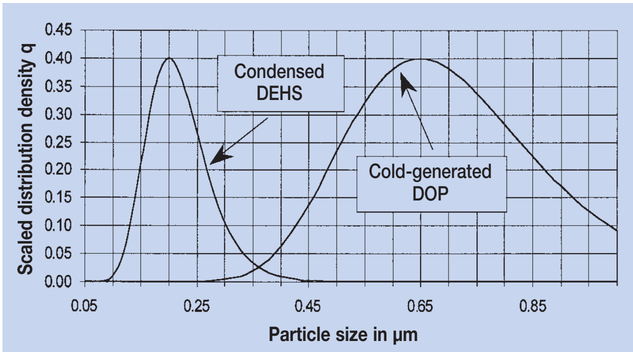


*Fig. 3 Distributive depiction of the relative frequency of particle size distributions for two test aerosols.*

Figure 3 shows a distributive depiction of the relative frequency of two particle size distributions, of the kind typically encountered with cold-atomized aerosols and from measurements with hot-generated DEHS. Since HEPA/ULPA filters mostly have their efficiency minimum in the particle size range between 0.1 µm and 0.3 µm, a filter's collection efficiency is poorer for hot-generated aerosols than for cold-generated aerosols. No value judgement on the two procedures for aerosol generation is intended here at present. The fundamental effect on the measurements, however, is notable, since the position of the frequency maximum and the width of the particle size distribution influence the collection efficiency being measured.
The particles are measured on the raw and clean-gas sides, either with an optical particle counter or with a photometer. Optical particle counters determine the number of particles in a sample volume per time interval, referenced to a particle size interval. For example, measurement results may be 1,625 particles per cubic foot in the size interval of 0.3 µm to 0.5 µm in the clean gas and 32,500,000 particles in the raw gas counted in 1 minute. Thus for the specified size interval of 0.3 µm to 0.5 µm, the filter's collection efficiency would be 99.995%. The ratio between clean and raw-gas concentrations for this size interval is referred to as the filter's penetration degree. The sum of penetration degree and collection efficiency always produces 100%. A collection efficiency curve determined in the laboratory for an H14 HEPA filter at nominal volume flow is depicted in Figure 4.

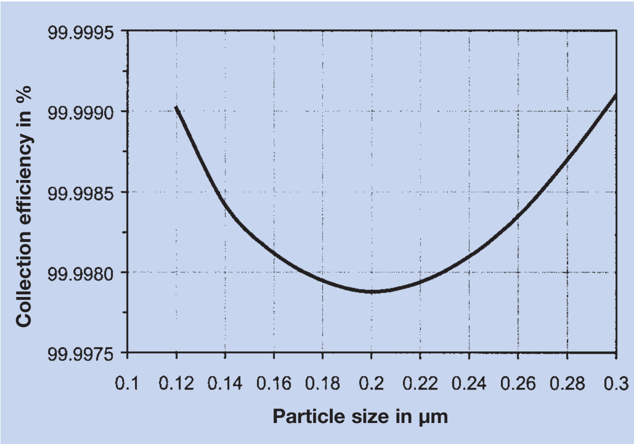


*Fig. 4 Collection efficiency curve for a Class H14 HEPA filter to EN 1822 at nominal volume flow.*

Photometers, by contrast, use a dispersion or extinction procedure to determine the mass concentration of the oil particles. The deflection of the pointer on the photometer is calibrated to 100% in the sufficiently high raw-gas concentration, and the pointer deflection in the clean gas measured in relation to it. This enables a percentage ratio to be stated between the mass concentrations in the raw and clean gases. The photometer thus does not permit statements to be made on particle number and size distribution. Photometers should be used only for leak tests on HEPA filters up to and including Class H13 to EN 1822, since the measuring procedure involved is too imprecise for very high-efficiency filters.

## 3.2 Standards and guidelines

The European standards and guidelines include several documents in which reference is made to in-situ testing of HEPA/ULPA filters. The American Institute of Environmental Science and Technology (IEST) has also published statements on these tests in its series of Recommended Practices (RP). Table 2 below provides an overview of the guidelines mentioned.
In all the documents mentioned, reference is made to the necessity for in-situ testing, in order to assure freedom from damage and correct, no-leaks installation of the HEPA/ULPA filters. No stipulations are provided for carrying out collection efficiency measurements on the installed HEPA/ULPA filters. Guideline 4/8 of the Eurovent Association even points out explicitly that the methodology described is suitable for leak detection at installed HEPA/ULPA filters, but not for determining the collection efficiency.

## 3.3 Actual examples for illustrating the performance limits of an in-situ measurement routine

Two examples have been selected to illustrate the performance of measurements on HEPA/ULPA filters in situ, and in particular the interpretation of the measurements obtained. Interpretation of the measurements is extremely important, as particle measurement cannot be more precise than the sampling method and the measuring instruments involved will permit.
The first example looks at measurements taken on duct HEPA filters. Duct HEPA filters are installed in the ducts of air-conditioning systems similarly to prefilters (e.g. pocket filters or cassette filters), and the clean air is fed to its destination via a duct system after being filtered. Most duct HEPA filters have to handle relatively large quantities of air per face area unit, so as to keep the filter housing within acceptable dimensions, and frequently conform to Filter Class H13 to EN 1822. For this filter class, EN 1822 specifies an individual leak test on the filter manufacturer's premises, so that the filter, the support system and the tight fit can usefully be checked again for leaks after the filter has been installed.
Figure 5 shows a typical measuring set-up for testing a duct HEPA filter. The measuring instrument used can be both a particle counter and a photometer. Before beginning the measurements, it is important to check whether the filter's raw and clean-gas sides are sufficiently accessible and whether the position of points for the sampling are conveniently located. When measuring the raw-gas concentration, it is essential to check (if using particle counters) that the maximum particle number concentration specified by the manufacturer of the counter is not being exceeded. If this maximum concentration is exceeded, there will be coincidence errors, i.e. many small particles will be measured as a few large particles. Since the particle concentration is considerably lower on the clean-air side of the filter being tested, the small particles there are correctly counted, and the measurements taken erroneously indicate a poorer collection performance of the filter concerned. For this reason, the raw-gas concentration usually has to be reduced using an interpolated calibrated dilution stage, and only then is the air fed to the particle counter.
For the measuring method described, the location of the sampling point in the duct must also be carefully chosen.

| Standard or Guideline | Title | Range of validity | Current version |
|---|---|---|---|
| VDI 2083, Part 3 | Cleanroom technology – metrology in cleanroom air | Germany | Draft, Feb. 1993 |
| Eurovent 4/8 | In-situ leakage test of high efficiency filters in clean spaces (D.O.P. aerosol test) | Europe | 1st edition, June 1985 |
| ISO 14644 – 3 | Cleanrooms and Associated Controlled Environments – Metrology and Test Methods | World | Draft, Sept. 2002 |
| IEST RP-CC034.1 | HEPA and ULPA Filter Leak Tests | North America | July 1999 |
| US Fed.Std. 209B | Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones | North America | 1973 (canceled Nov. 2001) |
| BS 5295 | Environmental cleanliness in enclosed spaces | Great Britain | 1989 |

*Table 2 Standards and guidelines with references to in-situ measurements of HEPA/ULPA filters.*

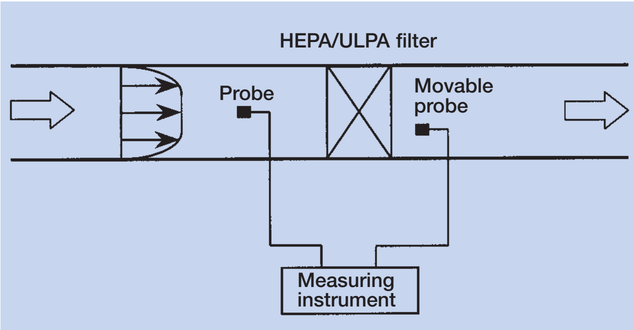


*Fig. 5 Typical measuring set-up for testing a duct HEPA/ULPA filter.*

While for determining the static pressure drop over an air filter it is sufficient to connect the pressure gauge directly to a hole in the duct's wall, for a particle counter or photometer measuring routine a measuring probe has to be inserted into the air flow. Care should be taken to avoid falsifying the results obtained by marginal effects such as laminar boundary layer flows in the wall area. To illustrate this, the velocity profile of the air in the duct flow is included in Figure 5.
On the clean-air side, the HEPA/ULPA filter's complete downstream area must be scanned with a movable probe. The traversing speed should not be more than 5 cm/s, so as to ensure a sufficient dwell time of the measuring probe above any possible leak. It should be pointed out here that HEPA/ULPA filters with pleat packs arranged in a V-shape cannot be scanned, since the measuring probe cannot be brought close enough to a possible leak in the pleated packs. Deep-pleated HEPA/ULPA filters with a pleat pack at right angles to the air flow are substantially more suited for scanning. The problems involved are illustrated in Figure 6.
For determining very small particles with a diameter of less than 0.5 µm, it is not absolutely essential to take the sample with isokinetic precision. Sampling should, however, not deviate too far from the isokinetic conditions concerned. Measuring errors resulting from non-isokinetic sampling become increasingly important with rising particle size.
Finally, the fundamental differences between particle counter and photometer measurements need mentioning again. Particle counters detect the numerical distribution of the particles, whereas photometers ascertain the mass distribution. The frequency maxima of the numerical and mass distributions will not usually be located at the same particle size. Large particles contribute a sizable proportion of the mass distribution, since the particle diameter enters into the particle mass to the power of three. For this reason, particle counters inevitably produce different results from photometers when determining collection efficiency. Both measuring methods are suitable for locating a leak at H13 duct filters, since all that is necessary is to detect a locally excessive clean-gas concentration in relation to the raw-gas concentration. Typical leaks at HEPA/ULPA filters usually cause a many times higher local penetration, thus ensuring that the leak is found.

As can be seen in Figure 7, the second example is designed to illustrate the measuring set-up for a terminal HEPA/ULPA filter, installed, for instance, in ceiling air outlets or in filter ceilings of laminar flow areas. Terminal HEPA/ULPA filters usually conform to Filter Classes H14, U15, U16 or U17 to EN 1822, or (less often) to Class H13 as well. By reason of the lesser measuring accuracy of photometers, it is advisable to use particle counters as measuring instruments from Class H14 upwards, and mandatory from Class U15. The example is intended to show the importance of a sufficiently high raw-gas concentration, the traversing speed of the measuring probe during clean-gas-side scanning of a HEPA/ULPA filter, the sampling volume flow of particle counters, and statistical evaluation of the measurements obtained. Attention to these parameters is gaining progressively in importance for measurements on HEPA/ULPA filters of the higher filter classes.

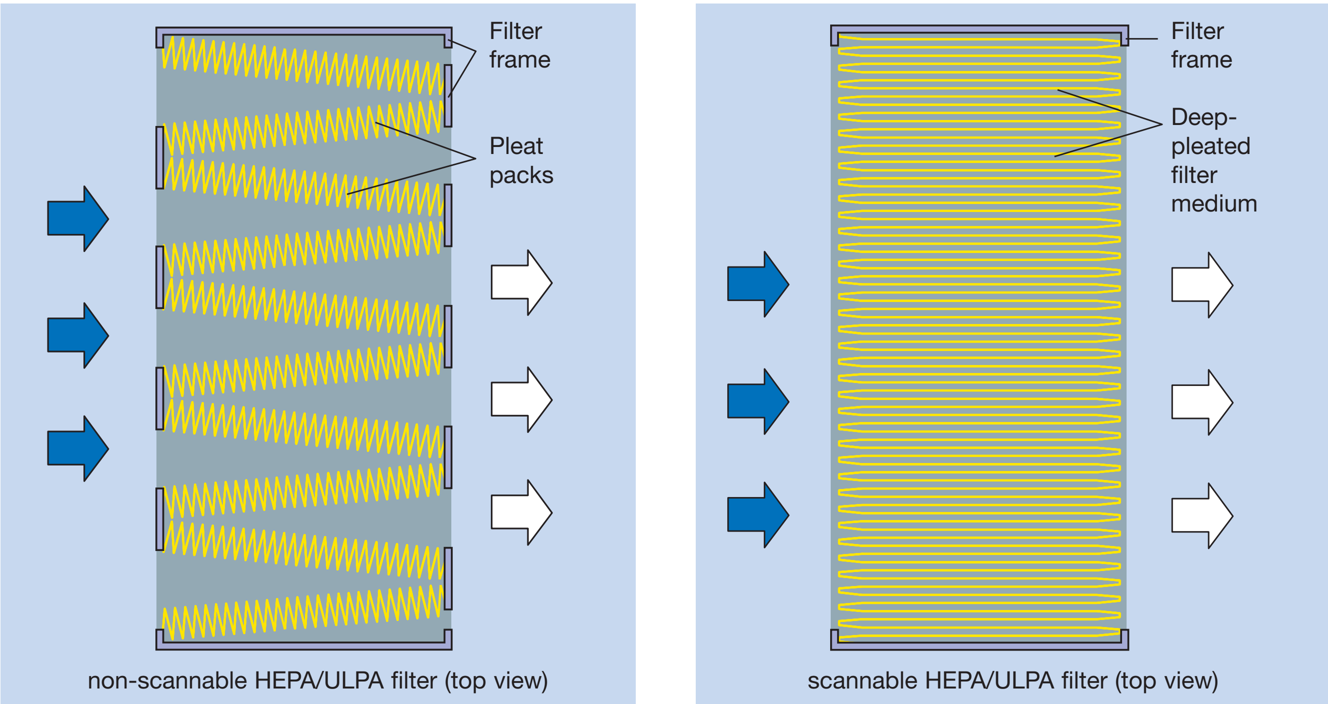


*Fig. 6 Schematic depiction of a HEPA/ULPA filter with V-shaped arrangement of the pleat packs (left) in comparison to a HEPA/ULPA filter with a deep-pleated filter medium (right).*

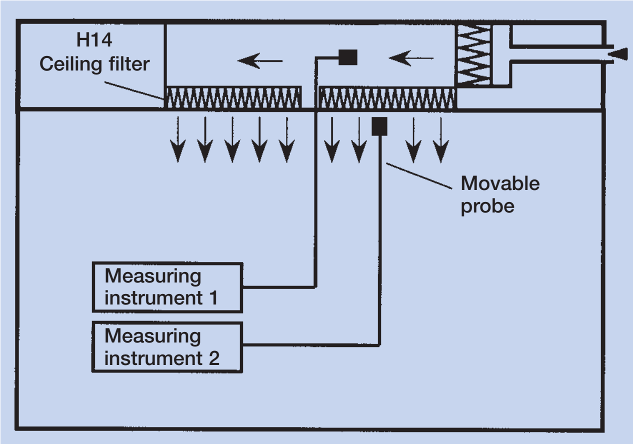


*Fig. 7 Measuring set-up for terminal HEPA/ULPA filters of Class H14 to EN 1822.*

The Class H14 HEPA filter shown in Figure 7 has a face area of 610 x 610 mm² and was being subjected to an air flow of 600 m³/h. On the raw-gas side, a concentration of 35,300,000 particles (e.g. DEHS particles) with 0.3 µm in size is to be set per cubic meter of air. The values for the raw-gas concentration, measured via an interpolated 1-to-10 dilution stage, fluctuate approximately around this target level. A second, constructionally identical particle counter (without the dilution stage) is used to measure the clean-gas concentration at the same time as the raw-gas concentration. Both particle counters possess a sample volume flow of 28.3 l/min. or 1 ft³/min. In conformity with the specifications laid down in the most important guidelines mentioned in Section 3.2, the probe's speed during scanning is required not to exceed 5 cm/s. The duration of the scanning function in this example was accordingly specified as 3 min., i.e. on both the raw and clean-gas sides 84.9 l (3 ft³) were taken as the sample volume. The measurements were repeated three times. The results of the three measuring routines for the particle size 0.3 µm are shown in Table 3 below.

From these measurement results, it can first of all be clearly concluded that the HEPA/ULPA filter tested has been tightly fitted during installation, and has no leaks. If there had been a leak, the penetration values would have been higher by at least one power of ten. No conclusions can be drawn from these measurements as to compliance with the integral minimum collection efficiency stated by the manufacturer of 99.995% for MPPS in order to comply with Class H14 to EN 1822. This, as shown in Figure 8, is to be explained using statistical analysis of the measurements concerned. The importance of a sufficiently high raw-gas concentration emerges clearly here, in order to achieve enough counter events on the clean-gas side. The measurements documented in Table 3, following calculation of mean value and standard deviation, produce the 95% confidence interval shown in Figure 8. With 95% certainty, the actual value of the collection efficiency lies within the bandwidth depicted, which in the example with three measurements (Fig. 8 left) ends below the collection efficiency of 99.995%. Thus it is not possible with this measuring method to arrive at an unambiguous statement as to whether Class H14 has been achieved or not. If, for example, the raw-gas concentration were to be lower by a factor of 10, then because of the smaller number of counter events on the clean-air side the size of the 95% confidence interval would increase substantially, rendering it much more difficult to draw conclusions on the actual collection efficiency. Increasing the raw-gas concentration (for technical reasons not easy to do in reality) or increasing the number of measurements would of course upgrade the accuracy of the measurements and the statistical certainty. This point is well illustrated in the right-hand diagram of Figure 8. Increasing the number of measurements causes the width of the confidence interval to decrease. Reducing the traversing speed of the clean-air-side measuring probe to below 5 cm/s would likewise increase the accuracy of the measurements at the cost of making the routine take longer. The use of particle counters with a smaller sample volume flow would require the measuring times to be significantly extended, since otherwise insufficient counter events would be available on the clean-air side.

One general principle applying to measurements is that the system-inherent measuring error (as is the case in the example from Table 3) should not lie within the same order of magnitude as the values determined. Table 4 gives an overview of the causes involved in system-inherent measuring errors during particle counter measurements on HEPA/ULPA filters already installed.

In the event of a leak in the filter, the situation for the measurements described is a more favourable one. Under EN 1822, a HEPA/ULPA filter of Class H14 has a leak when locally the collection efficiency is smaller than 99.975%. This value, as can be seen in Figure 8, lies significantly below the 95% confidence interval. Thus if locally a collection efficiency of less than 99.975% is measured, then the probability is high that there is a leak at this point of the filter. If the collection efficiency stated by the filter manufacturer deviates from the specified value by one power of ten, i.e. by one filter class, then if carried out meticulously the measuring procedure described is likewise suitable for evidencing this divergence from the specification.

Even though the example cites measurements from an H14 filter, the statements made apply analogously for mea-

| Results for particle size 0.3 µm | 1st measurement particle number in 84.9 l | 2nd measurement particle number in 84.9 l | 3rd measurement particle number in 84.9 l |
|---|---|---|---|
| Raw-gas-side measurement | 3296667 | 2547425 | 2847122 |
| Clean-gas-side measurement | 43 | 120 | 102 |
| Calculated penetration | 0.0013% | 0.0047% | 0.0036% |
| Calculated collection efficiency | 99.9987% | 99.9953% | 99.9964% |

*Table 3 Results from particle counter measurements for the particle size 0.3 µm on terminal HEPA filters of Class H14 to EN 1822.*

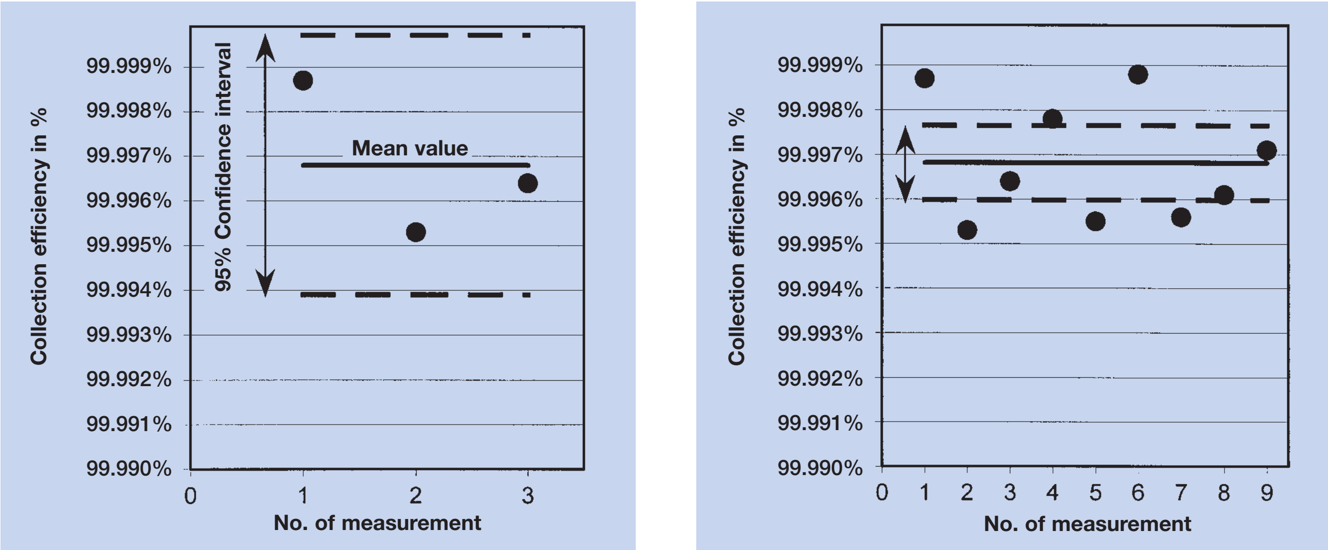


*Fig. 8 Graphical depiction of the measured values from Table 3 with mean value and 95% confidence interval (left) in comparison to a measurement with nine repetitions (right), where the first three values are identical to the values in Table 3.*

surements taken from ULPA filters in Classes U15, U16 and U17 to EN 1822. It is merely necessary to ensure a sufficiently high raw-gas concentration; i.e. determination of the collection efficiency becomes even more problematical, since the number of counter events on the clean-air side decreases as the filter class rises.

## 4. Summary

In cleanroom technology, collection efficiency and freedom from leaks are usually tested and documented at the manufacturer's facility for HEPA/ULPA filters as from Filter Class H13 by means of a standardized filter test in conformity with EN 1822. When the measurements at the installed filter (in situ) are meticulously carried out, the user has an option for evidencing freedom from leaks with a high degree of certainty. The customary metrological arrangements offer only limited options for checking the collection efficiency at a filter in situ, since the system-inherent measuring error often lies in the same order of magnitude as the measured value involved. In situ, therefore, only serious deviations from the filter's specified collection values can be evidenced with a reasonable metrological outlay.

## 5. Literature

Besides the standards/guidelines mentioned in Table 2, we recommend reading the following publications:

[1] *IEST-RP-CC006.2:* Testing cleanrooms, Institute of Environmental Science and Technology, April 1995.
[2] *EN 1822:* High efficiency particulate air filters (HEPA and ULPA), parts 1-5, Beuth Verlag GmbH, Berlin 1998/2001.
[3] *EUROVENT 4/10:* In situ determination of fractional efficiency of general ventilation filters, EUROVENT/CECOMAF, 1st edition, Paris 1996.
[4] *New HEPA/ULPA Filters for Clean Room Technology,* Schroth, Th., Filtration and Separation, Volume 33, Number 3/96, p. 245-250

| Causes of systematic measuring errors | Effects on the measurements |
|---|---|
| Uneven flow distribution over the filter's face area with locally higher media velocities | Locally higher particle concentration on the clean-air side |
| Raw-gas concentration fluctuates over place and time | Clean-gas concentration fluctuates over place and time |
| Simultaneously used particle counters for measuring raw and clean-gas concentrations are not measuring precisely the same | Measurements are imprecise by approx. +/-5 % |

*Table 4 Systematic measuring errors and their effects.*

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