Hessisches Landesamt
für Naturschutz,
Umwelt und Geologie

Hessian Agency
for Nature Conservation,
Environment and Geology

HESSEN

Annual Report 2025

Results of stack emission proficiency tests for substance ranges P, G, and O on the emission simulation apparatus in the year 2025

HLNUG Department I3 is accredited for performing
testing services according to DIN EN ISO/IEC 17043.
The accreditation is valid for the testing procedures listed in the certificate.

DAkkS
Deutsche
Akkreditierungsstelle
D-EP-14551-01-00

Contents

0. About this Report

This report is a translation of „*Jahresbericht 2025 – Ergebnisse der Emissionsringversuche der Stoffbereiche P, G und O an der Emissionssimulationsanlage im Jahr 2025*“ and was prepared with best care and attention. Nevertheless, the German version of this report shall be taken as authoritative. No guarantee can be given with respect to the English translation.

1. Summary

A total of 54 measuring institutes took part in HLNUG's dust stack emission proficiency tests (substance range P) in 2025, 41 of which were §29b measuring bodies and 13 were voluntary participants, 9 of which took part in the standard dust proficiency test and 4 in the short version. As in the past, the success rate in the standard dust proficiency test was significantly higher for the §29b measuring bodies (89%) than for the voluntary participants (56%).

A total of 53 measuring institutes took part in the gas stack emission proficiency tests (substance range G) in 2025, of which 46 were §29b measuring bodies and 7 were voluntary participants, 4 of which took part in the standard gas proficiency test and 3 in the short version. Unlike in previous years, the success rate for §29b measuring stations (64%) was significantly lower than for volunteers (100%) in the standard gas proficiency test.

A total of 15 measuring institutes took part in the odour stack emission proficiency tests (substance range O) in 2025, 9 of them on the basis of an authorisation in accordance with §29b BImSchG and 6 voluntarily. In both groups, 67% of the participants were successful.

2. Introduction

2.1 Legal Background

The stack emission proficiency tests offered at the Emission Simulation Apparatus (ESA) of Hessisches Landesamt für Naturschutz, Umwelt und Geologie (HLNUG, Hessian Agency for Nature Conservation, Environment and Geology) in Kassel were developed for the quality control of measuring bodies authorised to perform measurements in accordance with §29b Bundes-Immissionsschutzgesetz (BImSchG, Federal Immission Control Act (1)) in Germany. The proficiency tests presented in this annual report are accredited according to DIN EN ISO/IEC 17043 (2) and are recognised by all authorising authorities in Germany within the meaning of §16 Para. 4 No. 7a of the 41. Bundes-Immissionsschutzverordnung (41. BImSchV (3), 41st Federal Immission Control Ordinance). Regular successful participation in these stack emission proficiency tests is therefore a prerequisite for maintaining an authorisation in accordance with §29b BImSchG.

Consequently, about 80-90% of the participants are laboratories authorised to perform measurements in accordance with §29b BImSchG (Federal Immission Control Act), or applicants for authorisation in accordance with BImSchG. Nevertheless, other measuring institutes can also participate in the HLNUG stack emission proficiency tests, e.g. laboratories that do not perform measurements in the regulated sector in Germany but still want to check the quality of their emission measurements.

2.2 The Emission Simulation Apparatus

The prerequisite for carrying out stack emission proficiency tests is the ability to provide all participants at the same time with a stable and clearly defined simulated exhaust gas. For this purpose, HLNUG operates the Emission Simulation Apparatus (ESA, see Figure 1). It was designed as a model for an industrial flue gas chimney. It serves not only to carry out emission proficiency tests but also to carry out model investigations in the field of emission measurement technology.

The ESA has a total length of 110 m and extends over all seven floors of the HLNUG building in Kassel. The heart of this system is a vertical, 23 m high round stainless steel conduit with an inner diameter of 40 cm. This part of the ESA is the actual chimney substitute, equipped with sampling ports for taking samples for emission measurements.

The test atmosphere in the form of simulated exhaust gas is created by drawing in ambient air, pumping it through the system, heating it and adding precisely metered quantities of pollutants. The exhaust gas typically flows through the ESA at approx. 4 – 15 m/s, moving a volume of approx. 2000 – 6000 m^3/h through the system.

The air pollutants to be measured by the participants in the proficiency test are dispensed into the air flow in the dosing laboratory in the basement. For this purpose, the dosing laboratory is equipped with various Coriolis mass flow meters for dosing different gases, a dosing system for liquids, and a brush dosing unit for dosing dusts. The concentrations of air-polluting substances generated in the dosing laboratory are constantly monitored by continuous measurement.

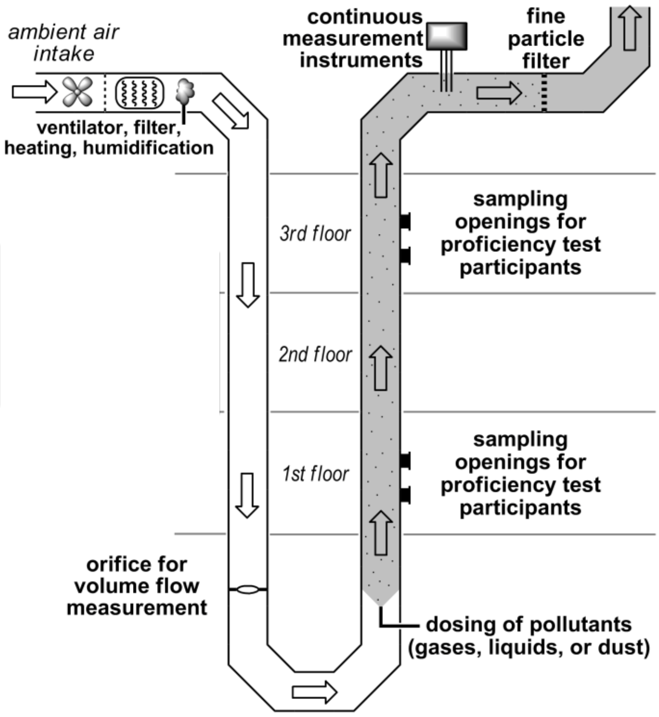


Figure 1: Scheme of HLNUG's emission simulation apparatus (simplified and not true to scale)

3. Organisational Information

In 2025, the following proficiency tests of the substance ranges P, G, and O were carried out:

Table 1: Proficiency Tests organised by HLNUG

Proficiency test	Type	Start	End	Participants
25P1	Dust	10.02.2025	11.02.2025	7
25G1	Gas	11.02.2025	13.02.2025	7
25P2	Dust	24.02.2025	25.02.2025	7
25G2	Gas	25.02.2025	27.02.2025	8
25P3	Dust	10.03.2025	11.03.2025	8
25G3	Gas	11.03.2025	13.03.2025	8
25P4	Dust	24.03.2025	25.03.2025	8
25G4	Gas	25.03.2025	27.03.2025	8
25P5	Dust	05.05.2025	06.05.2025	8
25G5	Gas	06.05.2025	08.05.2025	6
25O1	Odour	15.09.2025	16.09.2025	3
25O2	Odour	17.09.2025	18.09.2025	6
25O3	Odour	22.09.2025	23.09.2025	5
25O4	Odour	24.09.2025	24.09.2025	1
25P11	Dust short version	28.10.2025	28.10.2025	4
25G11	Gas short version	29.10.2025	30.10.2025	3
25P6	Dust	03.11.2025	04.11.2025	7
25G6	Gas	04.11.2025	06.11.2025	7
25P7	Dust	17.11.2025	18.11.2025	5
25G7	Gas	18.11.2025	20.11.2025	6

These proficiency tests were organised and carried out under the following conditions (see specifications for the respective substance ranges for details):

Table 2: Characteristics of HLNUG's stack emission proficiency tests

	dust (substance range P)	gas (substance range G)
duration of each sampling	30 min	
number of samplings	standard-version: for each component 9 (+ introductory measurement) short version: for each component 6 (+ introductory measurement)	
sampling	simultaneously for all participants (1st and 3rd floor)	
gas flow conditions	volume flow: 2000 … 6000 m^3/h (standard conditions, dry) mean flow velocity: 4 … 15 m/s (operating conditions, wet) temperature: 20 … 50 °C water vapour concentration: 0 … 50 g/m^3 (standard conditions, dry) static pressure: 0 … 10 hPa	

	dust (substance range P)	gas (substance range G)
concentrations	dust (total): 1 … 15 mg/m^3 heavy metals: 1 … 200 $\mu g/m^3$	NO_x as NO_2: 60 … 450 mg/m^3 CO: 10 … 100 mg/m^3 TOC: 4 … 100 mg/m^3 ethylbenzene: 1 … 40 mg/m^3 toluene: 1 … 40 mg/m^3 xylene (sum of isomers): 1 … 40 mg/m^3 SO_2: 20 … 150 mg/m^3 formaldehyde: 2 … 20 mg/m^3
result submission	within six weeks after the end of the proficiency test, in mg/m^3 for dust concentrations and $\mu g/m^3$ for heavy metal concentrations respectively, relating to standard conditions (dry) and with two digits after decimal point.	within four weeks after the end of the proficiency test, in mg/m^3, relating to standard conditions (dry) and with two digits after decimal point.
submission procedure	results are entered into an Excel-file provided by HLNUG and handed in via e-mail.	

	odour (substance range O)
duration of each sampling	10 min
number of samplings	3 per component
gas flow conditions	volume flow: 2000 … 6000 m^3/h (standard conditions, dry) mean flow velocity: 4 … 15 m/s (operating conditions, wet) temperature: 20 … 50 °C water vapour concentration: 0 … 50 g/m^3 (standard conditions, dry) static pressure: 0 … 10 hPa
concentrations	approx. 50 … 50000 ou_E/m^3
result submission	within one week after the proficiency test, in ou_E/m^3, rounded to integers
submission procedure	results are entered into an Excel-file provided by HLNUG and handed in via e-mail.

The proficiency tests were organised by:

Hessisches Landesamt für Naturschutz, Umwelt und Geologie
(*Hessian Agency for Nature Conservation, Environment and Geology*)

Dezernat I3 – Luftreinhaltung: Emissionen
(*Department I3 – Air Pollution Control: Emission*)

The location of the proficiency tests was:

Hessisches Landesamt für Naturschutz, Umwelt und Geologie
Ludwig-Mond-Str. 33
34121 Kassel
- GERMANY -

Tel.: +49 – 561 – 2000 137
Fax: +49 – 561 – 2000 225
E-Mail: pt@hlnug.hessen.de

Technically responsible for the execution of the proficiency tests are currently:

Dr Jens Cordes, Benno Stoffels and Prof Dr Dominik Wildanger.

4. Execution of the Proficiency Tests

4.1 Description of the Test Objects

In contrast to proficiency tests by other providers, HLNUG's stack emission proficiency tests take place at a stack simulator and include the sampling procedure. The test object in our proficiency tests is therefore the exhaust gas flow in the duct during the measurement period (see section 2.2). The test objects therefore only exist during the measurement, and the usual specifications for homogeneity and stability are therefore subject to interpretation for the stack emission proficiency tests at the ESA (4). Extensive investigations have shown that the standard deviations between the samples for the sampling points or measurement cross sections assigned to the participants reach the following maximum values:

Table 3: Maximum values of between samples standard deviations

variable	determined at	relative standard deviation between samples [%]
mass concentration of total dust and heavy metals	all available measurement planes (grid measurements)	1.58
mass concentrations of gases	lowest available measurement plane (point measurements)	0.15
mass concentrations of evaporated liquids	lowest available measurement plane (point measurements)	0.16

All determined between samples standard deviations are well below the criteria for the proficiency assessment of the participants. This ensures that all participants in the proficiency test will find comparable sampling conditions. The position of the sampling, i.e. the measurement plane assigned by the organizer, has no significant influence on the mass concentrations measured by the participant. An equivalent to the stability test in conventional proficiency tests does not exist at the ESA, as the test objects are not stored after the assigned values have been determined. Instead, the assigned values are determined individually for each test object during its generation, and thus during the simultaneous measurement by the participants.

4.2 Preparation of the Test Objects

The exhaust gas flow sampled by the participants in the ESA is generated by adding the test substances to be measured to the air flow generated by the system. Gases are added as pure substances, evaporated liquids either also as pure substances or as solutions in other evaporable liquids. Sometimes these liquids are also dosed as a homogeneous mixture of different pure substances (5).

In contrast to the pure substances in gas and odour proficiency tests, no reference materials are available on the market in sufficient quantities for particulate substances. Therefore, for proficiency tests of the substance range P, the certified reference materials produced by HLNUG according to DIN EN ISO 17034 (6) are used. The matrix here is an industrial dust, which is optimized by specific heavy metal doping, grinding, sieving and drying steps. Finally, a complete homogenization of the dust standard is achieved by intensive mixing of the batch.

The determination of the conventionally correct value ("assigned value") of the heavy metal concentration of a doped dust batch is based on the data from interlaboratory analyses carried out by laboratories of various German state institutes. The robust mean value from the individual values of the interlaboratory comparisons is regarded as the assigned heavy metal content value of the dust standard. The dust is subject to a homogeneity and stability test and verification, which is repeated at certain intervals. Homogeneity and stability of the test dusts are verified according to DIN ISO 13528 (7).

4.3 Metrological Traceability

The gaseous substances CO, NO and propane are dosed using Coriolis flow sensors. The mass flows are measured and gravimetrically traced via suitable test weights and balances. During dosing, liquids are taken from a container located on a balance. The mass flow is also recorded here by recording the weight values, and the balances used are metrologically traced via suitable test weights. The mass flows for SO_2 and dust are determined by differential weighing of the containers used. The assigned values of the heavy metal concentrations in the dust are determined by competent laboratories using various analytical instruments within the framework of interlaboratory comparisons. Within the scope of these interlaboratory comparisons, a total digestion of the dust is carried out in accordance with DIN EN 14385 (8), as well as an analysis using calibrated measuring equipment. This calibration is carried out by means of element solutions of known traceable composition. Consequently, the heavy metal concentrations in the test dusts used are metrologically traceable. The volume flow is determined by means of an orifice plate, which is regularly checked by means of metrologically traceable measuring instruments. By calculating from metrologically traceable mass flows and metrologically traceable volume flows, all mass concentrations indicated are also metrologically traceable. The maximum values of the relative standard uncertainty of the assigned values can be found in section 4.5.2 in Table 5 (dust), Table 6 (gas) and Table 7 (odour). Detailed information is given in the results communications of the individual proficiency tests.

4.4 Execution of the Measurements

Each participant determines the mass concentration of the emission components in accordance with (DIN) EN 15259 (9). In addition, the gas flow conditions must be recorded before the actual sampling begins. This includes exhaust gas velocity/flow rate, exhaust gas temperature and humidity as well as the air pressure in the system.

Table 4: Sequence of the stack emission proficiency tests of substance ranges P, G, and O

substance range	component	measurement method
P	dust	(DIN) EN 13284-1 (10)
	heavy metals	(DIN) EN 14385 (8)
G	NO_x as NO_2	(DIN) EN 14792 (11)
	CO	(DIN) EN 15058 (12)
	TOC	(DIN) EN 12619 (13)
	ETX	(DIN) CEN/TS 13649 (14)
	SO_2	(DIN) EN 14791 (15)
	formaldehyde	VDI 3862 part 2 (16), part 3 (17) or part 4 (18)
O	four odours	(DIN) EN 13725 (19)

4.5 Evaluation of the Proficiency Tests

4.5.1 Calculation of z-Scores

Dust and Gas Proficiency Test

The evaluation of the proficiency test is carried out in accordance with the respective specifications (for substance ranges P and G) on the basis of the z-score procedure. For the measurement value x_{ijk}, which is the result of measurement i of concentration level j of component k, a z-score value z_{ijk} is determined:

$$z_{ijk} = \frac{x_{ijk} - X_{ijk}}{\sigma_k \cdot X_{ijk}}$$

In this equation, X_{ijk} is the assigned value of the measurement, and σ_k is the precision criterion for component k. The assigned value is calculated from measurement data of the dosing devices and the volume flow.

Odour Proficiency Test

For odour emission proficiency tests, the evaluation is carried out on the basis of the z-score procedure, using logarithmised values:

$$z_{ik} = \frac{1}{\sigma_k} \cdot \log_{10}\left(\frac{x_{ik}}{X_{ik}}\right)$$

In this equation, X_{ik} is the assigned value of the measurement, and σ_k is the precision criterion for component k. The assigned value X_{ijk} is calculated from the mass concentration c_{ik} and the odour threshold $c_{0,k}$ of the component:

$$X_{ik} = \frac{c_{ik}}{c_{0,k}} \ \mathrm{ou_E/m^3}$$

The dosed mass concentration c_{ik} is determined for each measurement based on the measurement data of the dosing device and the volume flow. The odour threshold $c_{0,k}$ of n-butanol is $c_0 = 123\ \mu g/m^3$. The thresholds of all other components are deduced from results of proficiency test participants according to the following procedure:

a) A consensus value is calculated from the measurement results reported by at least 20 participants in at least two different proficiency tests previously run by HLNUG. Here, solely results of participants are taken into account, who achieved the result 'passed' for the component n-butanol in the respective proficiency test. The consensus value is obtained by the robust mean of the logarithmic values according the standard DIN ISO 13528 (7) and is updated on a regular basis by including new results. This calculation is restricted to measurements of the past five years as long as the above mentioned requirements are met.

b) If not enough measurement results of former proficiency tests are available to determine the consensus value of a component by means of the procedure described under a), an alternative method is used: Here, the consensus value of a component offered during a proficiency test is subsequently calculated from the participants' measurement results. Provided that the sampling was carried out within 14 days, results of several proficiency tests can be taken into account. Solely results of those participants are considered, who achieved the result 'passed' for the component *n*-butanol in the respective proficiency test. The consensus value is obtained by the robust mean of the logarithmic values according the standard DIN ISO 13528 (7). If less than nine measurement results for a particular component are available that fulfil the above mentioned criteria, neither a z-score-based evaluation nor a performance rating are possible.

In addition to *n*-butanol, the components ‚organic solvent mixture' (ETX), tetrahydrothiophene (THT) and artificial pigsty (PIG) were used in the odour stack emission proficiency tests in 2025. The odour threshold $c_{0,k}$ could be determined for these components with procedure a). For ETX, a consensus value of c_0 = 196 µg/m^3 was obtained from 192 measurements in the years 2020 to 2024. For the component THT, a consensus value of c_0 = 0.517 µg/m^3 was calculated from 192 individual measurements taken between 2020 and 2024. For the component PIG, a consensus value of c_0 = 214 µg/m^3 was obtained from 150 individual measurements taken between 2021 and 2024.

If the uncertainty of a true value u_k determined in compliance with DIN ISO 13528 (7) results for any component (except *n*-butanol) in a value for which with $\sigma_k = 0.16$ the following condition is not met:

$$\sigma_k \geq \frac{1}{0.3} \cdot \log_{10}(1 + u_k)$$

Then σ_k is adjusted in accordance with DIN ISO 13528 (7). In doing so, σ_k is recalculated precisely to two decimal places, so that the condition above is fulfilled. This was not necessary for any of the components in 2025.

4.5.2 Criteria for Proficiency Assessment

The criteria for the proficiency assessment of the participants (precision criteria) σ_k were defined as values from findings in accordance with section 8.2 of DIN ISO 13528 (7) by the German Federation/Federal States Working Group on Immission Control (LAI) and published within the framework of the specifications for stack emission proficiency tests. The values are for the individual components:

Table 5: Precision criteria dust proficiency test

No.	component	short designation	precision criterion σ_k in % of true value	max. standard uncertainty of assigned values [%]
P1	dust	St	7.0	1.55
P2	Cadmium	Cd	10.0	1.85
P3	Cobalt	Co	10.0	1.81
P4	Chromium	Cr	10.0	1.85
P5	Copper	Cu	10.0	1.98
P6	Manganese	Mn	10.0	1.96
P7	Nickel	Ni	10.0	1.85
P8	Lead	Pb	10.0	1.75
P9	Vanadium	V	10.0	1.96

Table 6: Precision criteria gas proficiency test

No.	component	short designation	precision criterion σ_k in % of true value	max. standard uncertainty of assigned values [%]
G1	NO_x as NO_2	Nk	3.1	1.03
G2	CO	Kk	3.6	1.08
G3	TOC	Ck	3.3	1.08
G4	ethylbenzene	Ed	4.1	1.01
G5	toluene	Td	4.1	1.01
G6	sum of *o*-, *m*-, *p*-xylene	Xd	4.1	1.01
G7	SO_2	Sd	3.4	1.11
G8	formaldehyde	Fd	3.6	1.17

Table 7: Precision criteria odour proficiency test

No.	component	short designation	precision criterion σ_k	max. standard uncertainty of assigned values [%]
O1	*n*-butanol	NBU	0.10	1.01
O2	solvent mixture	ETX	0.16	4.64
O3	tetrahydrothiophene	THT	0.16	3.71
O4	artificial pigsty odour	PIG	0.16	8.01

4.5.3 Assessment Scheme

Interpretation of the z-scores

The z-scores can be interpreted using the following scheme:

$$|z_{ijk}| \leq 2 \qquad \text{satisfactory}$$

$$2 < |z_{ijk}| < 3 \qquad \text{questionable}$$

$$|z_{ijk}| \geq 3 \qquad \text{unsatisfactory}$$

Generally, for each measurement resulting in a z-score of more than two, a causal research is advised.

The assessment of the individual component proceeds differently, depending on the substance range of the proficiency test.

Dust and Gas Proficiency Test

For the components in the dust and gas proficiency test, the mean value z_{jk} of the absolute values of the n z-scores of one concentration level (usually n = 3 for the standard version and n = 2 for the short version) is calculated:

$$z_{jk} = \sum_{i=1}^{n} \frac{|z_{ijk}|}{n}$$

Based on z_{jk}, to each concentration level a class number K_{jk} is assigned according to the following scheme:

$z_{jk} \leq 2$	results in $K_{jk} = 1$
$2 < z_{jk} < 3$	results in $K_{jk} = 2$
$z_{jk} \geq 3$	results in $K_{jk} = 3$

For each component at least 6 measurement results must be submitted, otherwise the respective component is automatically evaluated as „failed“.

A component was determined successfully, if the respective sum of class numbers does not exceed 6. If in justified single cases only values for two concentration levels were submitted, the component was determined successfully if the sum of class numbers does not exceed 4. Successful determinations are labelled “passed”, unsuccessful determinations are labelled “failed”. The overall result for the proficiency test is “passed”, if all components in the respective scheme (P1 to P9 for dust and G1 to G8 for gas) were rated “passed”. If one of these components was rated “failed”, the overall result is also “failed”. If a participant chose not to take part in the measurements for one or components, the overall result is “failed (incomplete participation)”, provided that all other components were assessed as “passed”.

For the proficiency tests in the pandemic version, no overall assessment took place.

Odour Proficiency Test

For the evaluation of odour measurements, the mean value z_k of the absolute values of the n z-scores (usually n = 3) of one component is calculated:

$$z_k = \sum_{i=1}^{n} \frac{|z_{ik}|}{n}$$

A component was determined successfully, if

$$z_k < 3$$

is fulfilled. In this case, the component is rated “passed“. If this criterion is not met or if no measurement result was submitted in due time, the component is rated “failed“. The overall result of the proficiency test is “passed”, if all components were determined successfully. If one or more components are rated “failed”, the overall result is “failed”.

Gas Flow Conditions

For the measurement of the gas flow conditions in the dust and gas proficiency tests, only two measurement values per copmonent are submitted and evaluated. The interpetration of the z-scores described above applies here as well. For the gas flow conditions, the mean value z_k of the absolute values of the n z-scores (usually n = 2) of one component is calculated:

$$z_k = \sum_{i=1}^{n} \frac{|z_{ik}|}{n}$$

The component volume flow was determined successfully, if

$$z_k < 3$$

is fulfilled. In this case, the component is rated “passed“. If this criterion is not met, the component is rated “failed”. If no measurement values were submitted, the component is rated “no participation”.

The proficiency test part Gas Flow Conditions is rated “passed”, if the component volume flow is rated “passed”. If this component was rated “failed”, the proficiency test part Gas Flow Conditions is also rated “failed”. If a participant did not participate in the component volume flow, the proficiency test part Gas Flow Conditions is noted as “not evaluated”.

4.5.4 Communication of the Assessment Result

Communication of the evaluation of the participants’ results by HLNUG is done within six weeks after the last day for submission of results for the respective proficiency test. This evaluation is given to the participants in form of a general survey, including tables and diagrams, and quoting their unique ID-code.

5. Results

5.1 z-Scores

A compact overview of the z-scores achieved by the participants can be found in the following box whisker plots. The rectangle indicates values between the 25th and 75th percentile (interquartile distance), the continuous line in the rectangle indicates the median of the values. The "antennas" reach from the upper edge of the rectangle to the highest and from the lower edge to the lowest value, which is still within 1.5 times the interquartile distance. Values outside this range are entered separately as points in the diagram.

In order to be able to assess the performance of individual participants across all components and to get an impression of the quality of measurements for individual components, the diagrams are available in two different sorts; on the one hand as an overview on one page, on the other hand sorted according to the respective median of the achieved z-scores.

A list of the individual measurements of all participants can be found in a separate document (appendix to the annual report).

5.1.1 Dust Proficiency Test (Substance Range P)

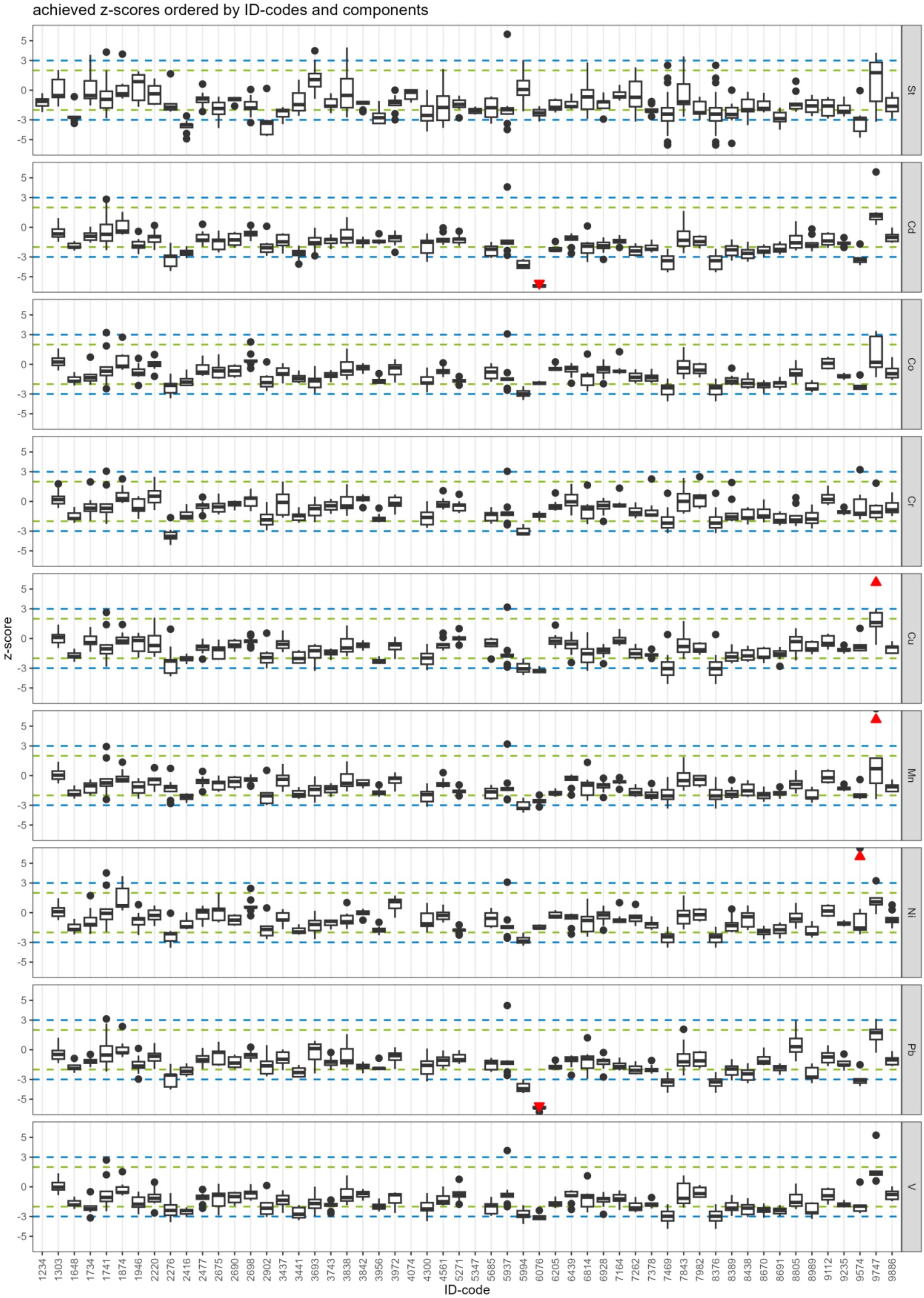
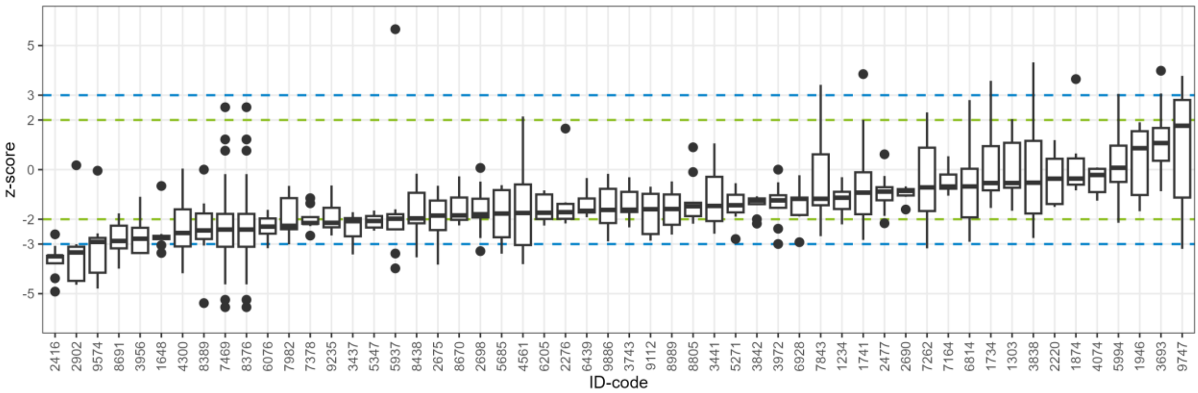
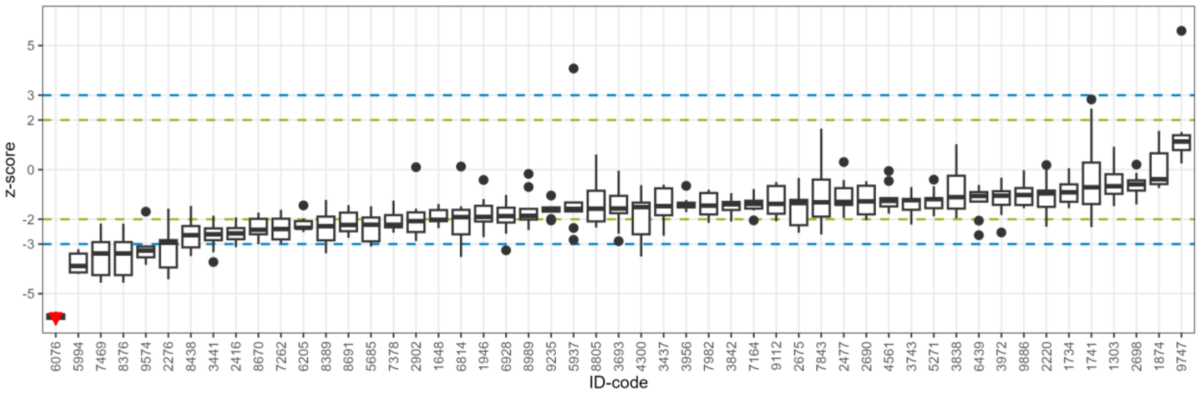


Figure 2: Achieved z-scores dust proficiency test

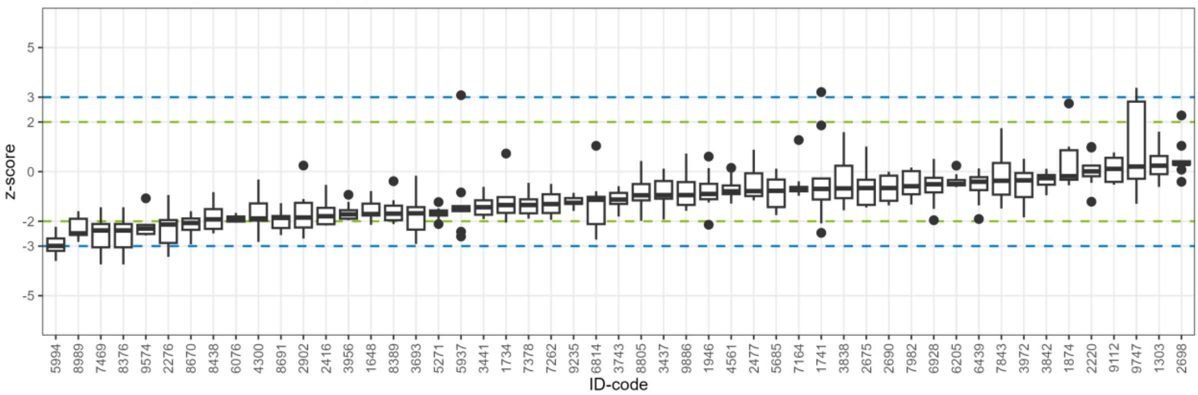
z-scores for component **dust concentration** (St)



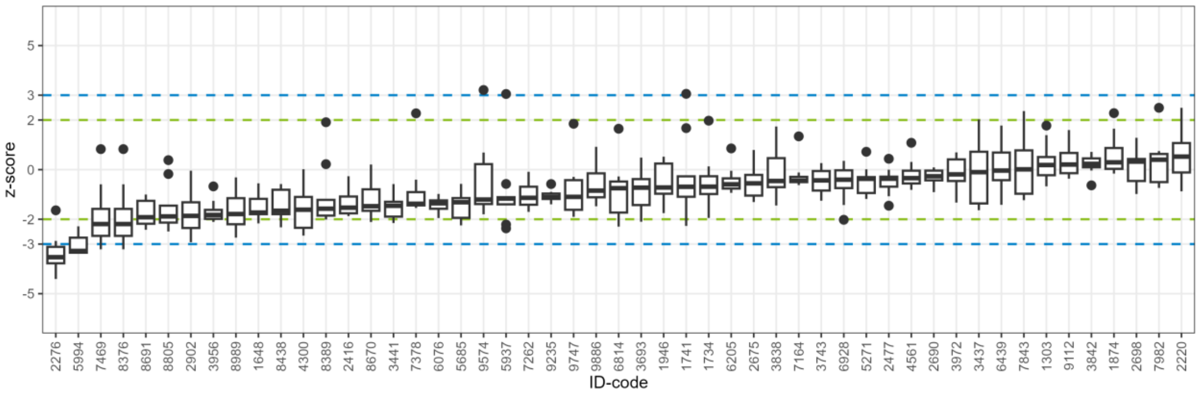
z-scores for component **Cadmium** (Cd)



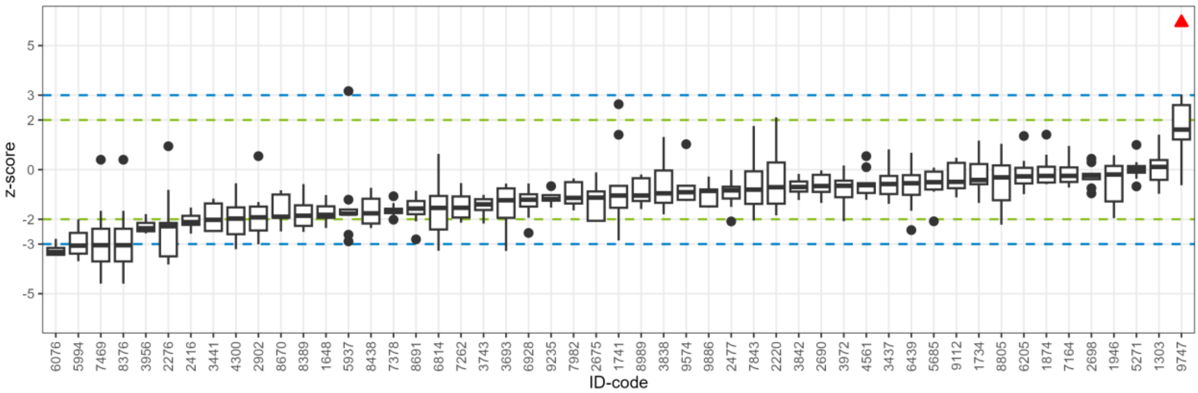
z-scores for component **Cobalt** (Co)



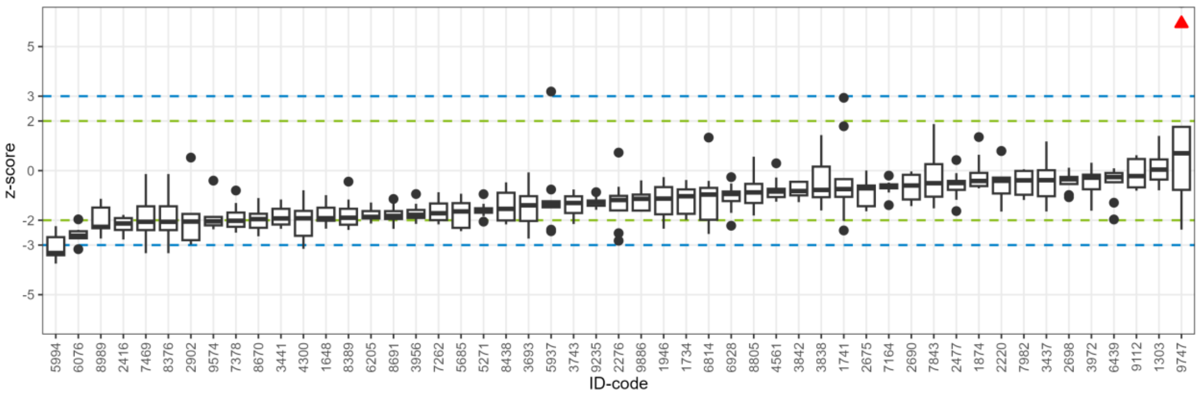
z-scores for component **Chromium** (Cr)



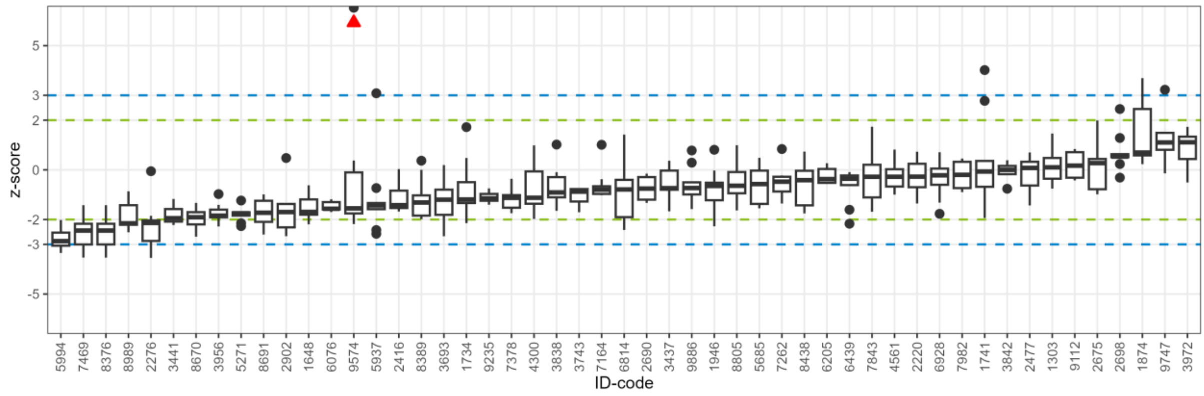
z-scores for component **Copper** (Cu)



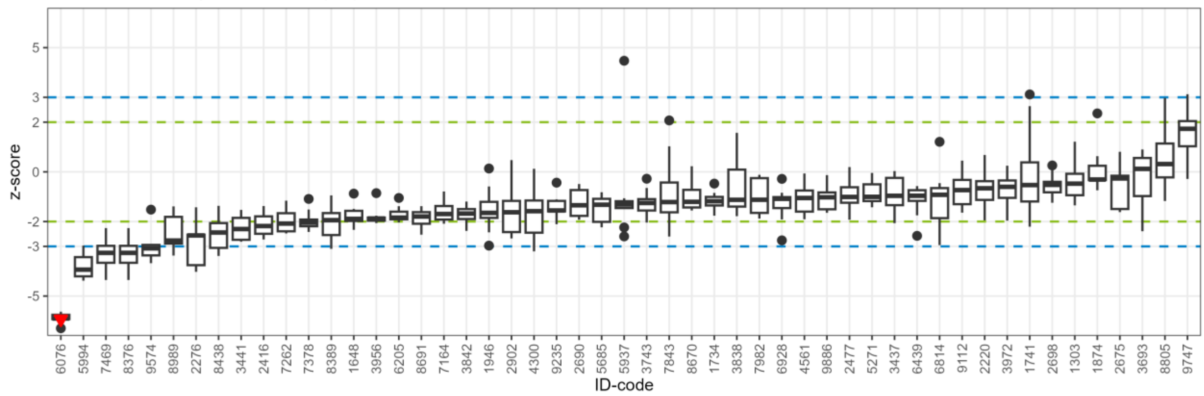
z-scores for component **Manganese** (Mn)



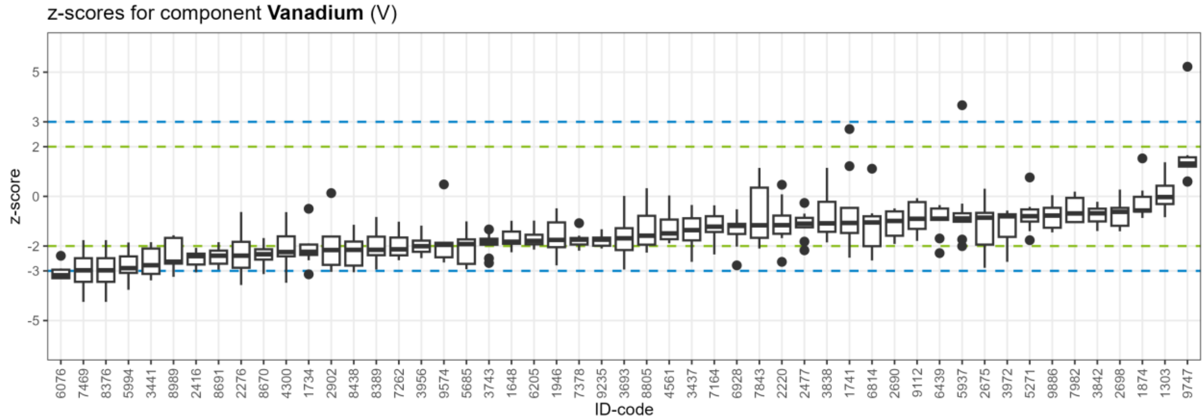
z-scores for component **Nickel** (Ni)



z-scores for component **Lead** (Pb)



z-scores for component **Vanadium** (V)



5.1.2 Gas Proficiency Test (Substance Range G)

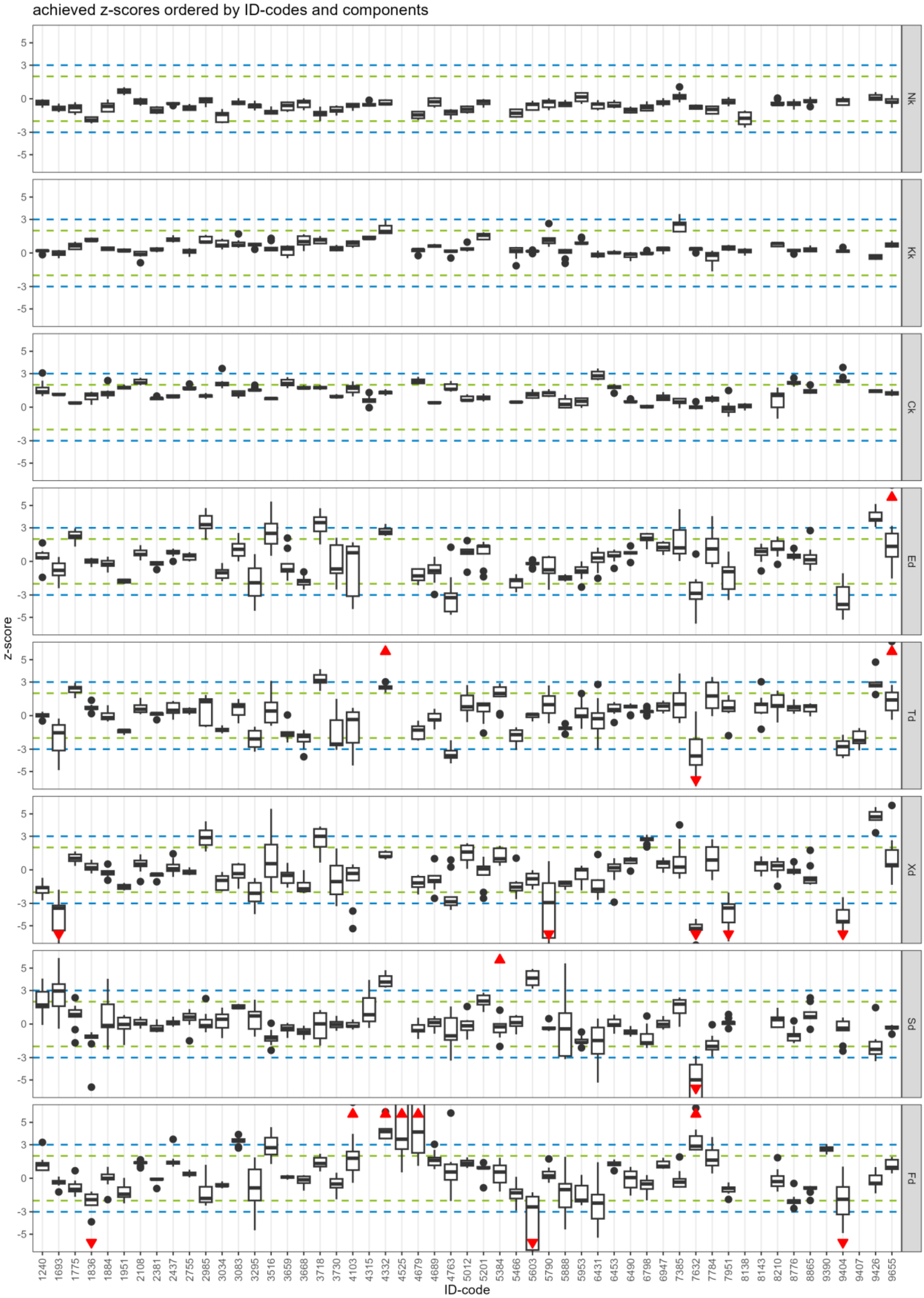
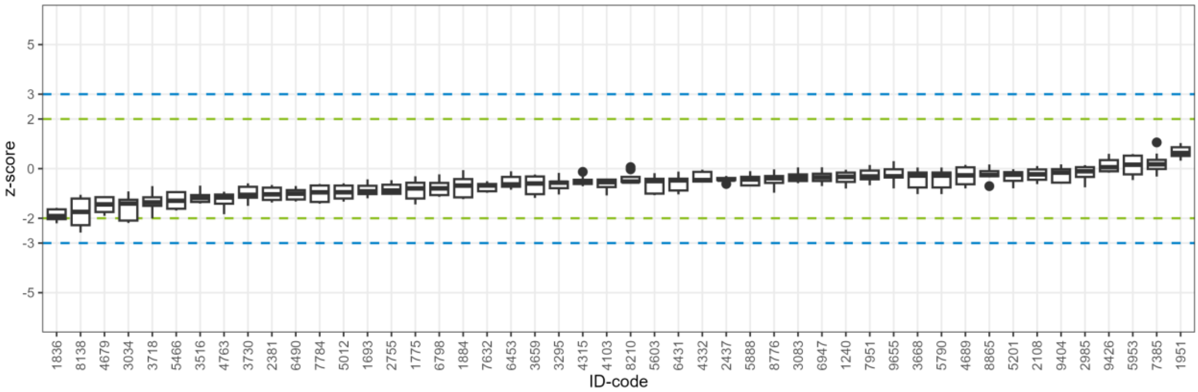
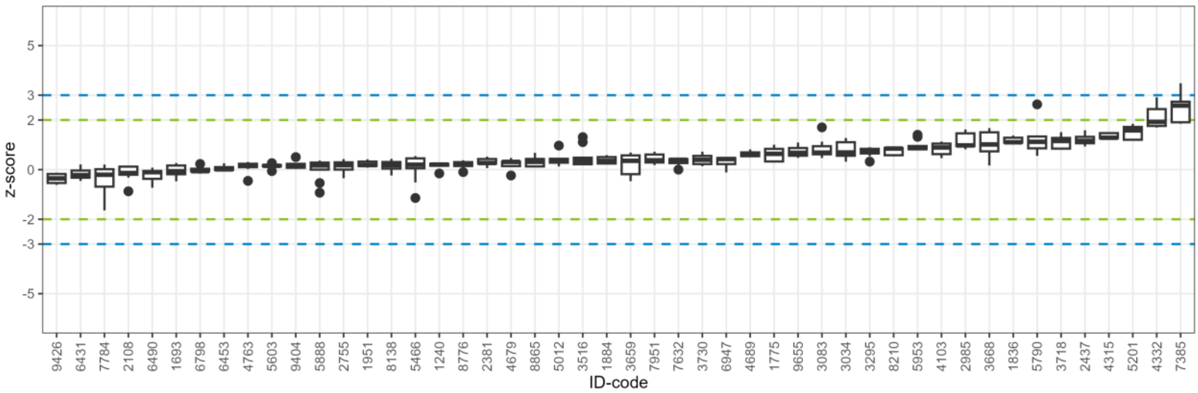


Figure 3: Achieved z-scores gas proficiency test

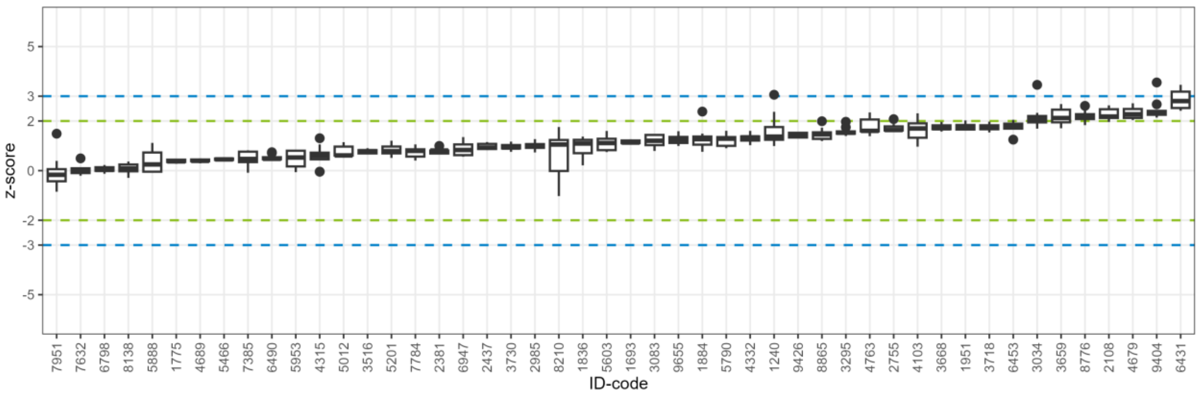
z-scores for component **NOx** (Nk)



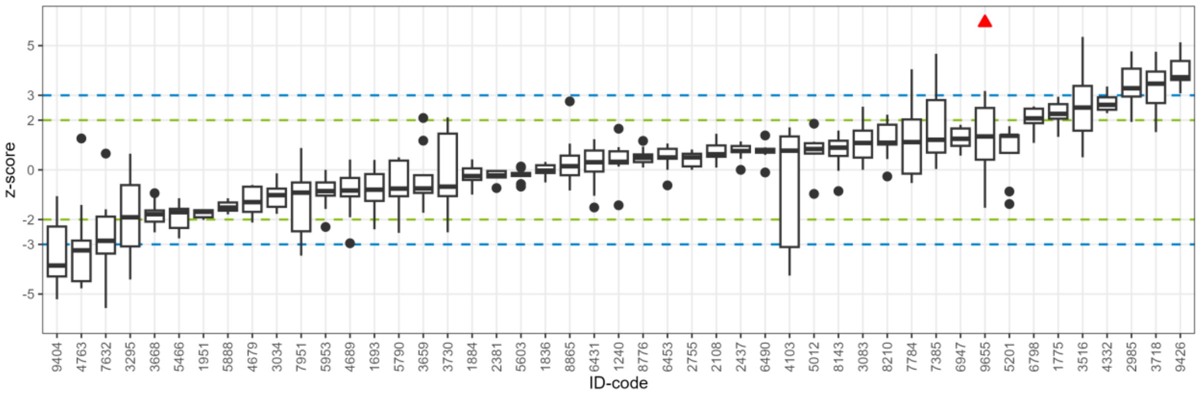
z-scores for component **carbon monoxide** (Kk)



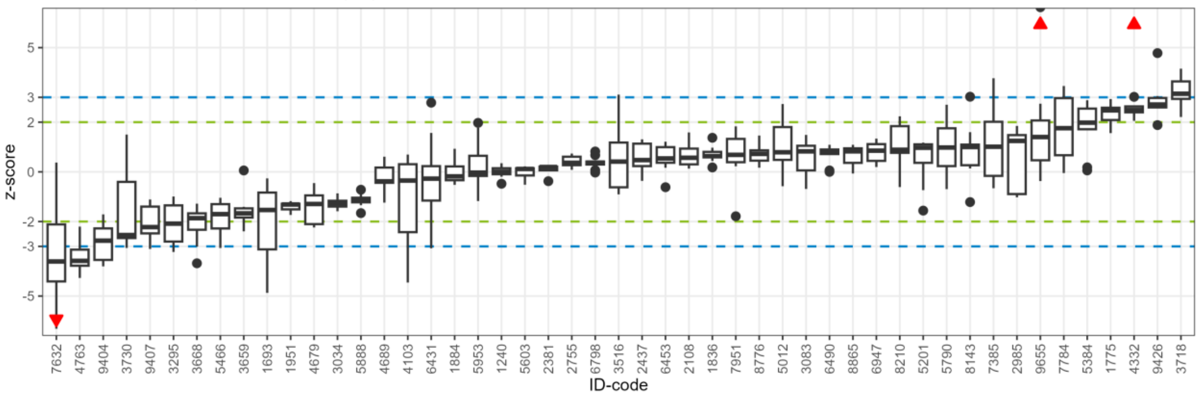
z-scores for component **TOC** (Ck)



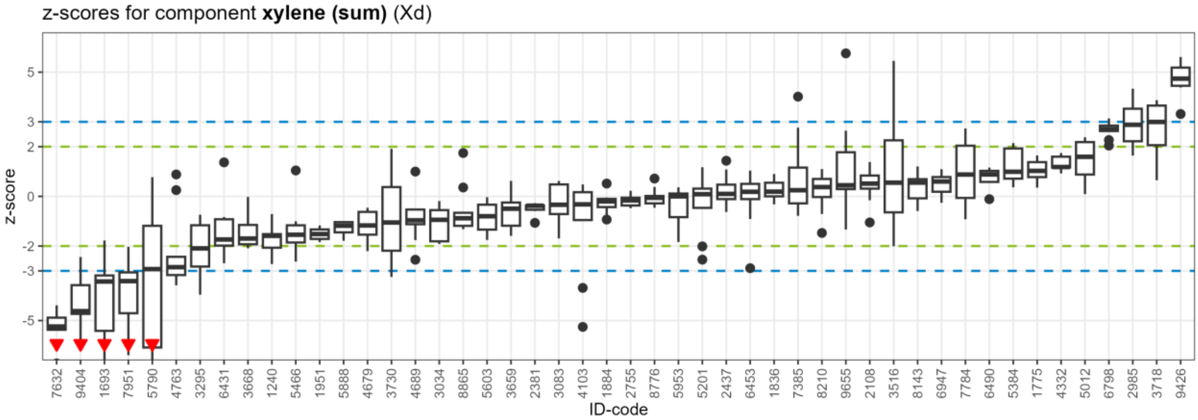
z-scores for component **ethylbenzene** (Ed)

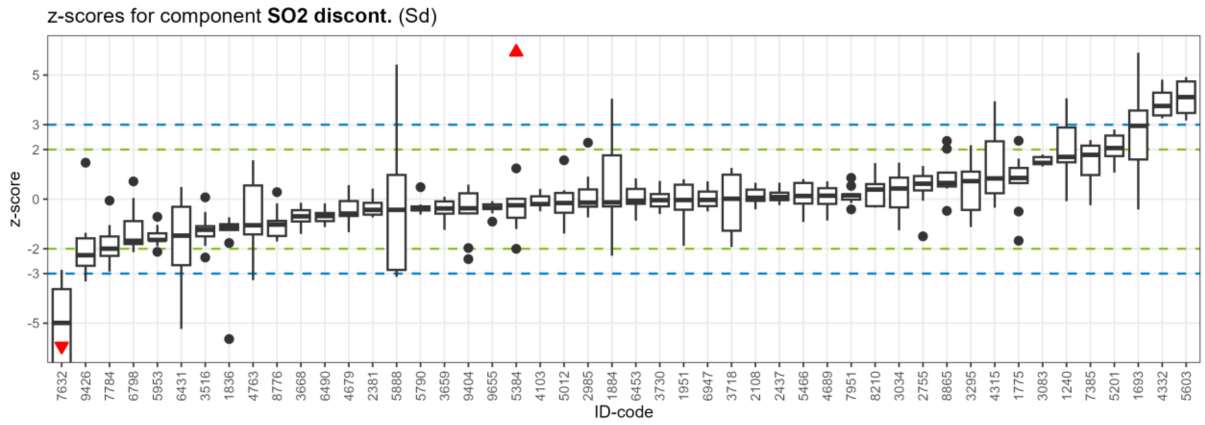


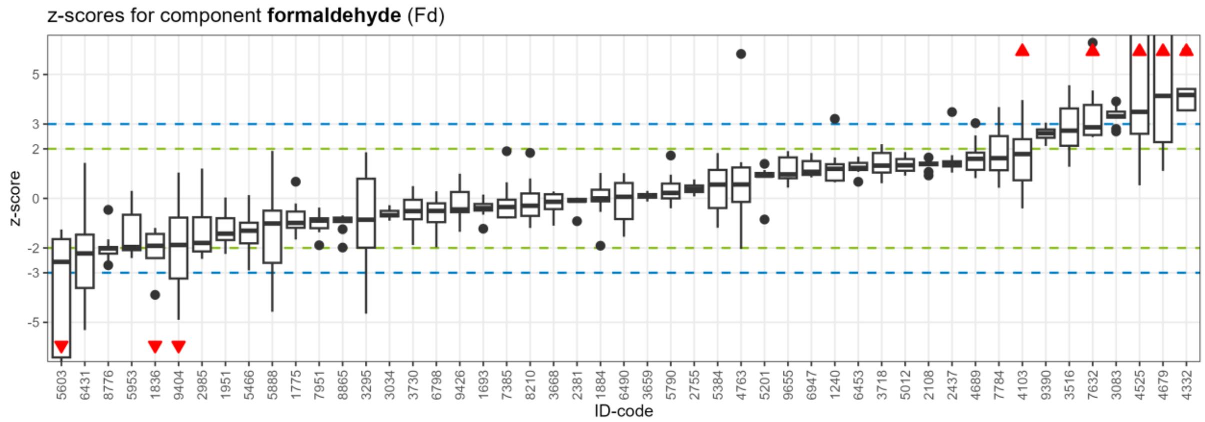
z-scores for component **toluene** (Td)



z-scores for component **xylene (sum)** (Xd)




z-scores for component **SO2 discont.** (Sd)
z-score
ID-code
5
3
2
0
-2
-3
-5
7632 9426 7784 6798 5953 6431 3516 1836 4763 8776 3668 6490 4679 2381 5888 5790 3659 9404 9655 5384 4103 5012 2985 1884 6453 3730 1951 6947 3718 2108 2437 5466 4689 7951 8210 3034 2755 8865 3295 4315 1775 3083 1240 7385 5201 1693 4332 5603


z-scores for component **formaldehyde** (Fd)
z-score
ID-code
5
3
2
0
-2
-3
-5
5603 6431 8776 5953 1836 9404 2985 1951 5466 5888 1775 7951 8865 3295 3034 3730 6798 9426 1693 7385 8210 3668 2381 1884 6490 3659 5790 2755 5384 4763 5201 9655 6947 1240 6453 3718 5012 2108 2437 4689 7784 4103 9390 3516 7632 3083 4525 4679 4332

5.1.3 Odour Proficiency Test (Substance Range O)

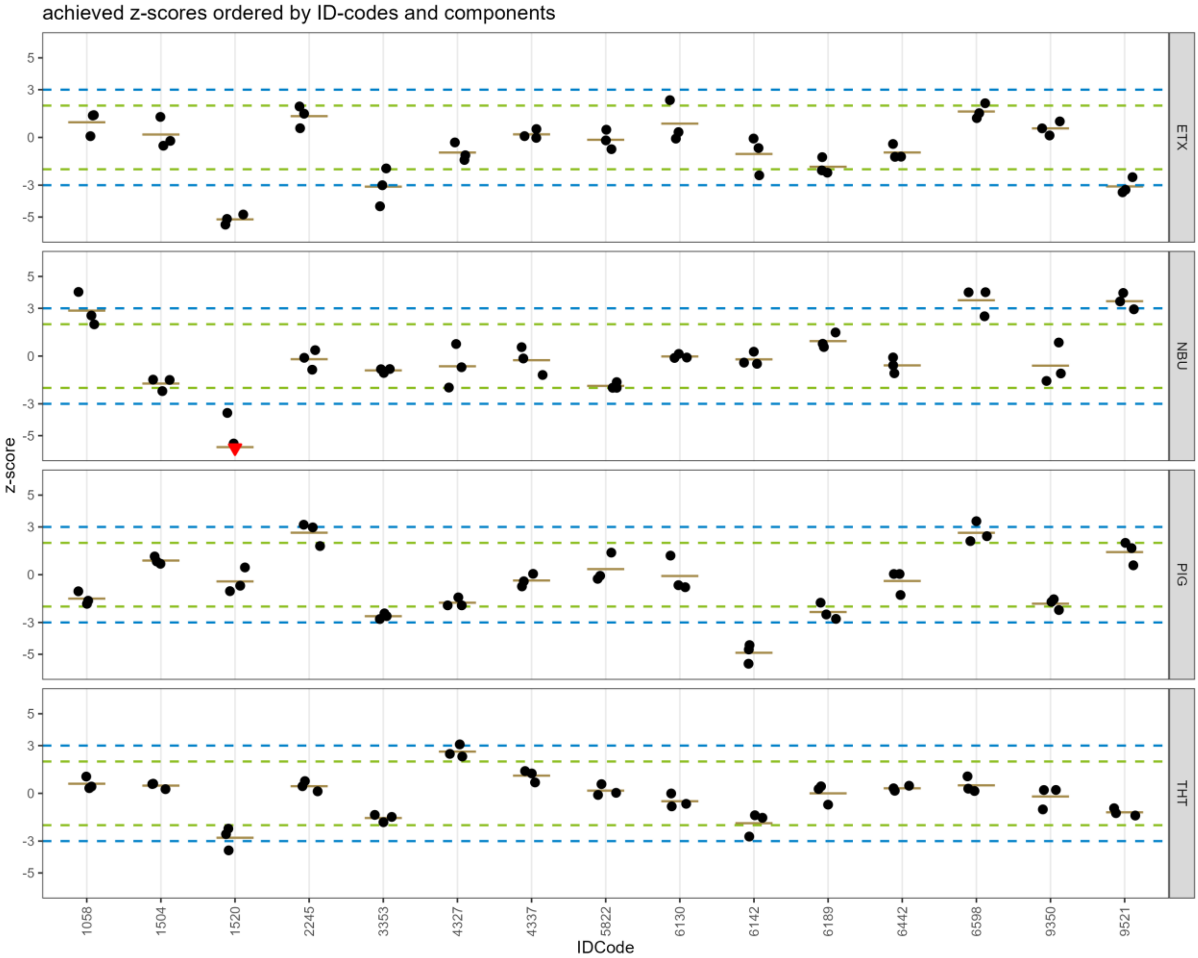
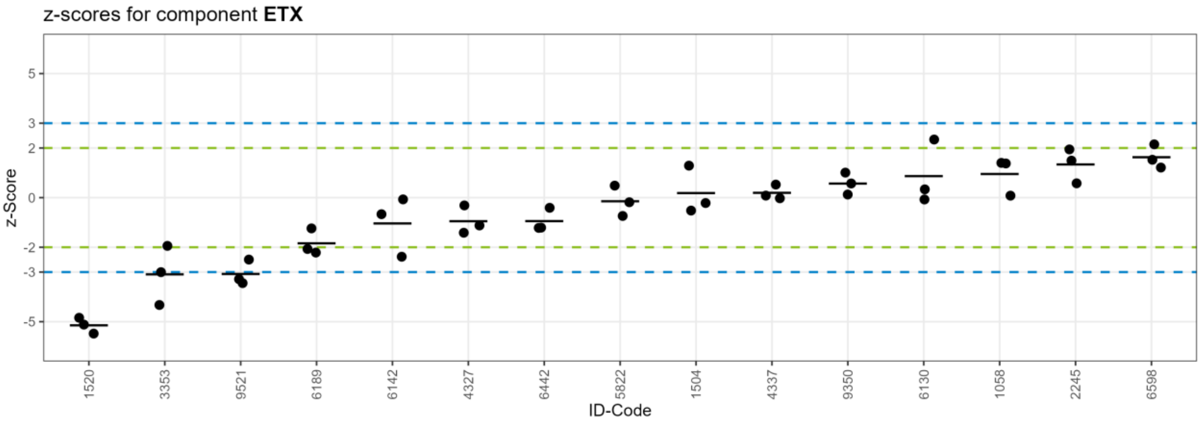
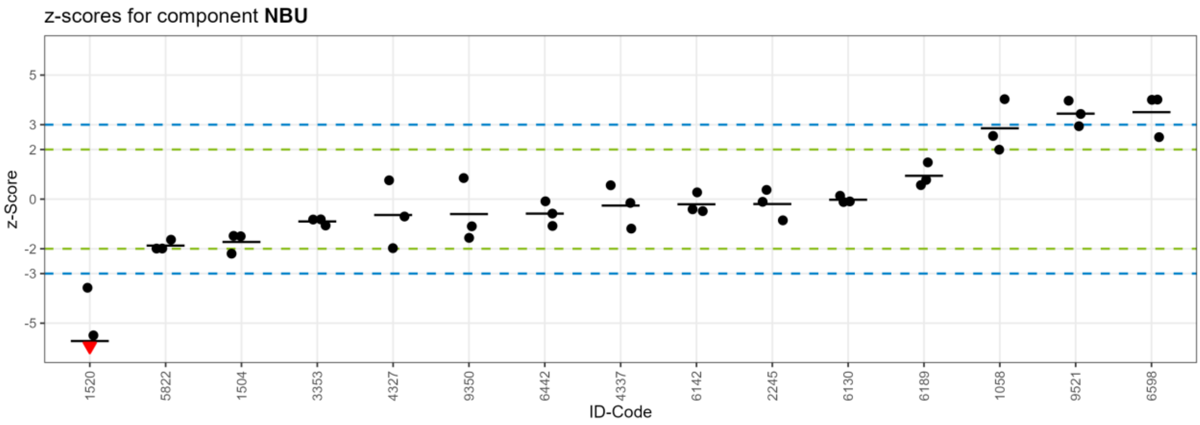
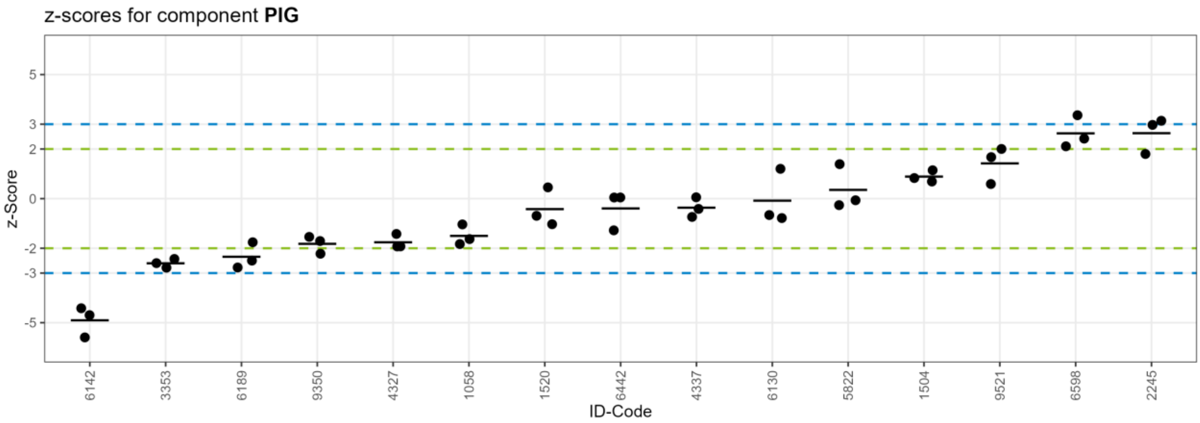
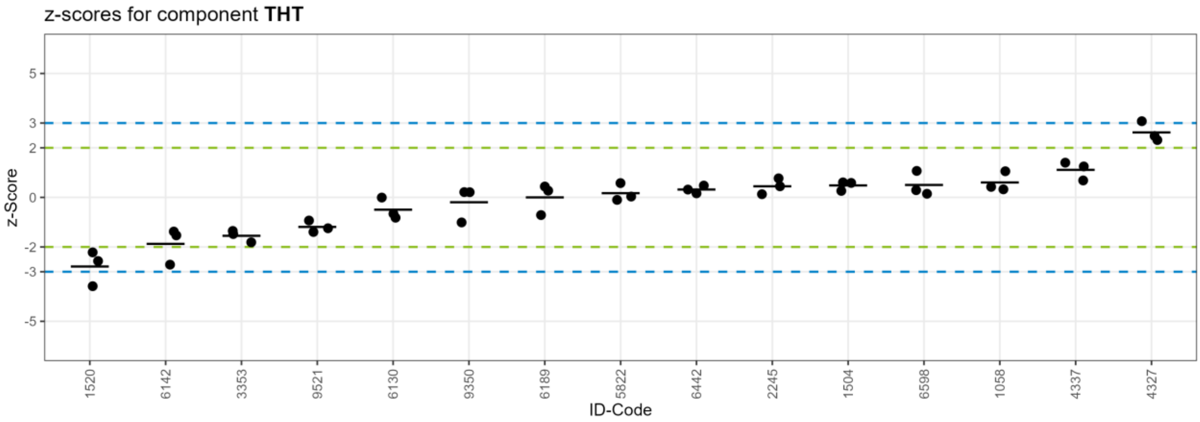


Figure 4: Achieved z-scores odour proficiency test




z-scores for component NBU
z-Score
5
3
2
0
-2
-3
-5
1520
5822
1504
3353
4327
9350
6442
4337
6142
2245
6130
6189
1058
9521
6598
ID-Code


z-scores for component PIG
z-Score
5
3
2
0
-2
-3
-5
6142
3353
6189
9350
4327
1058
1520
6442
4337
6130
5822
1504
9521
6598
2245
ID-Code


z-scores for component THT
z-Score
5
3
2
0
-2
-3
-5
1520
6142
3353
9521
6130
9350
6189
5822
6442
2245
1504
6598
1058
4337
4327
ID-Code

5.1.4 Gas flow conditions

The following diagrams show the results obtained by the participants for the measurement of the gas flow conditions. For each component, only one or two values are available per participant; these are shown as a point in each case. Mean values are indicated by a line.

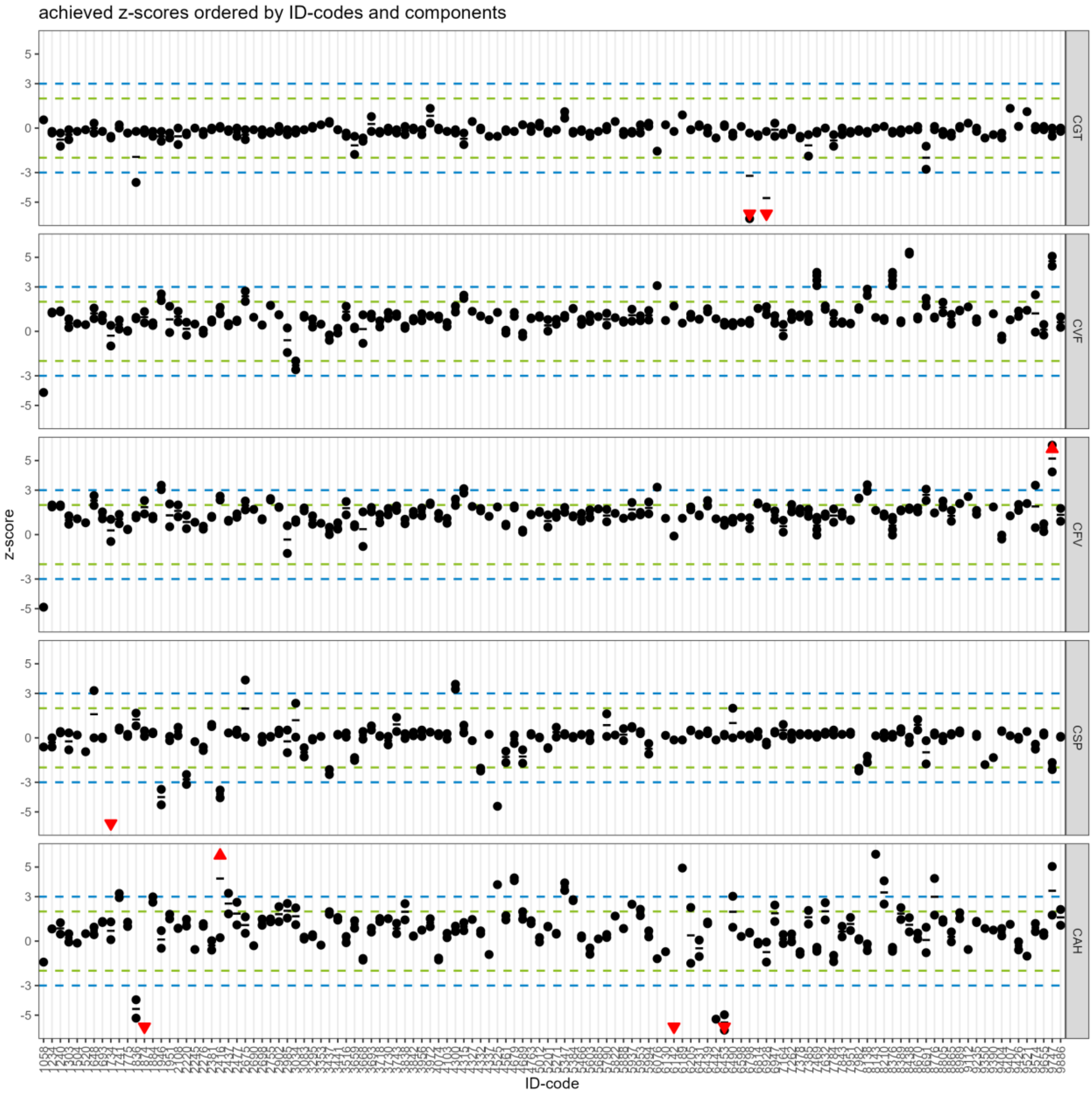
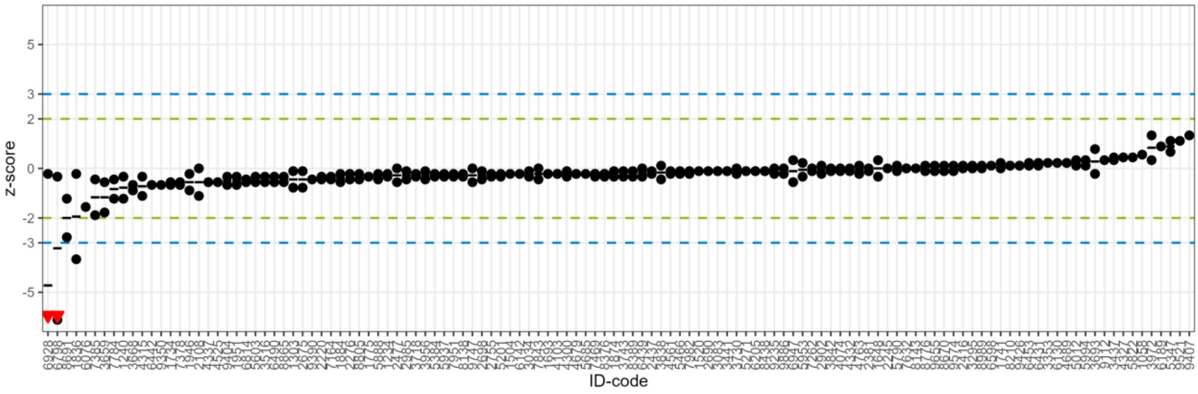
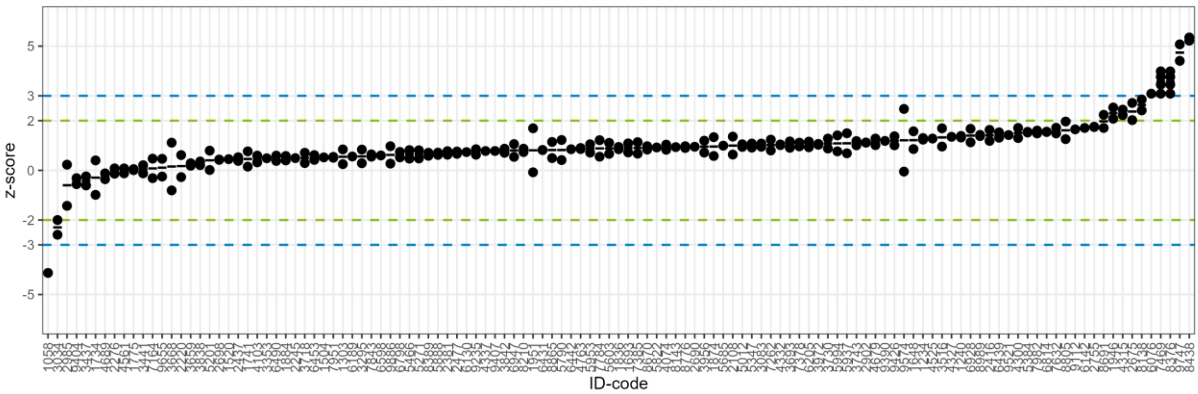


Figure 5: z-scores (or quotients from participant deviation and typical deviation) for gas flow conditions

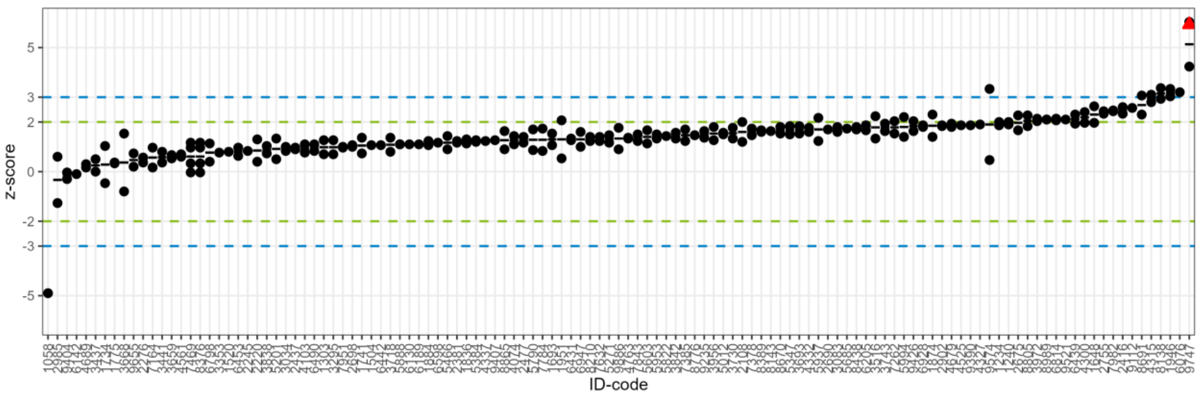
z-scores for component **temperature** (CGT)



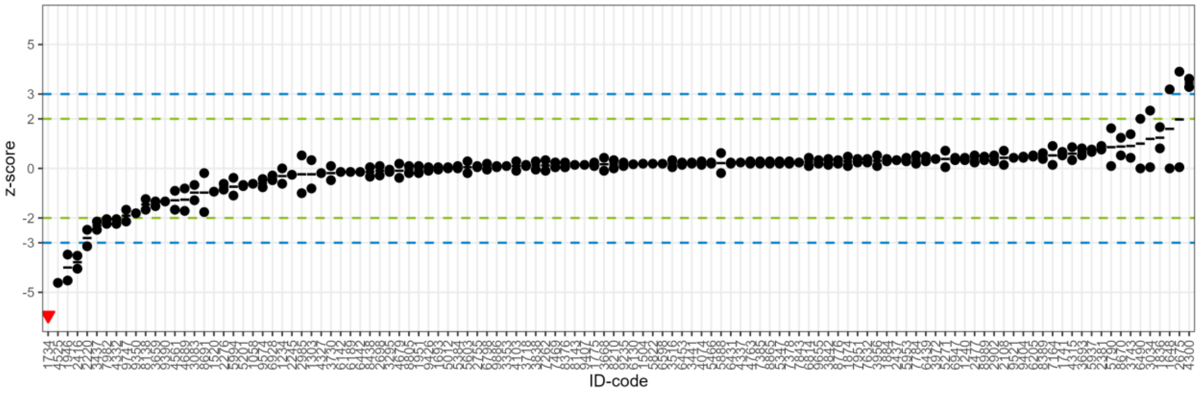
z-scores for component **total volume flow** (CVF)



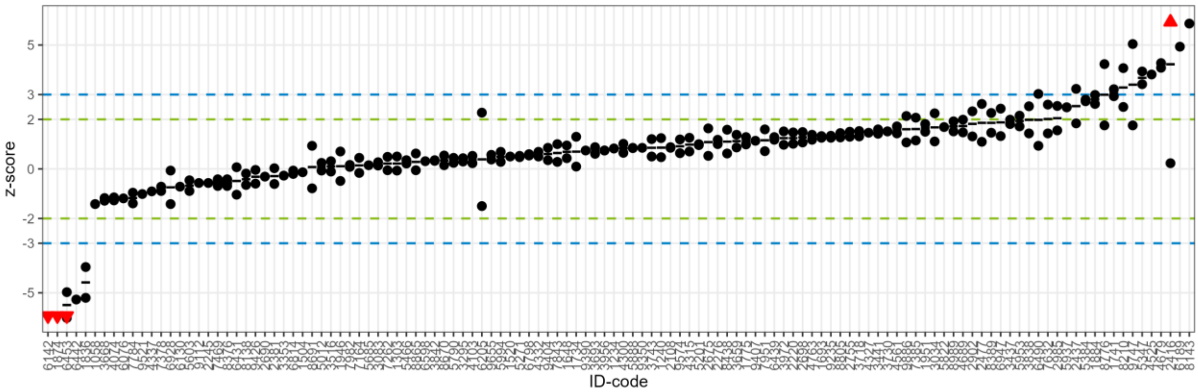
z-scores for component **flow velocity** (CFV)



z-scores for component **static pressure** (CSP)



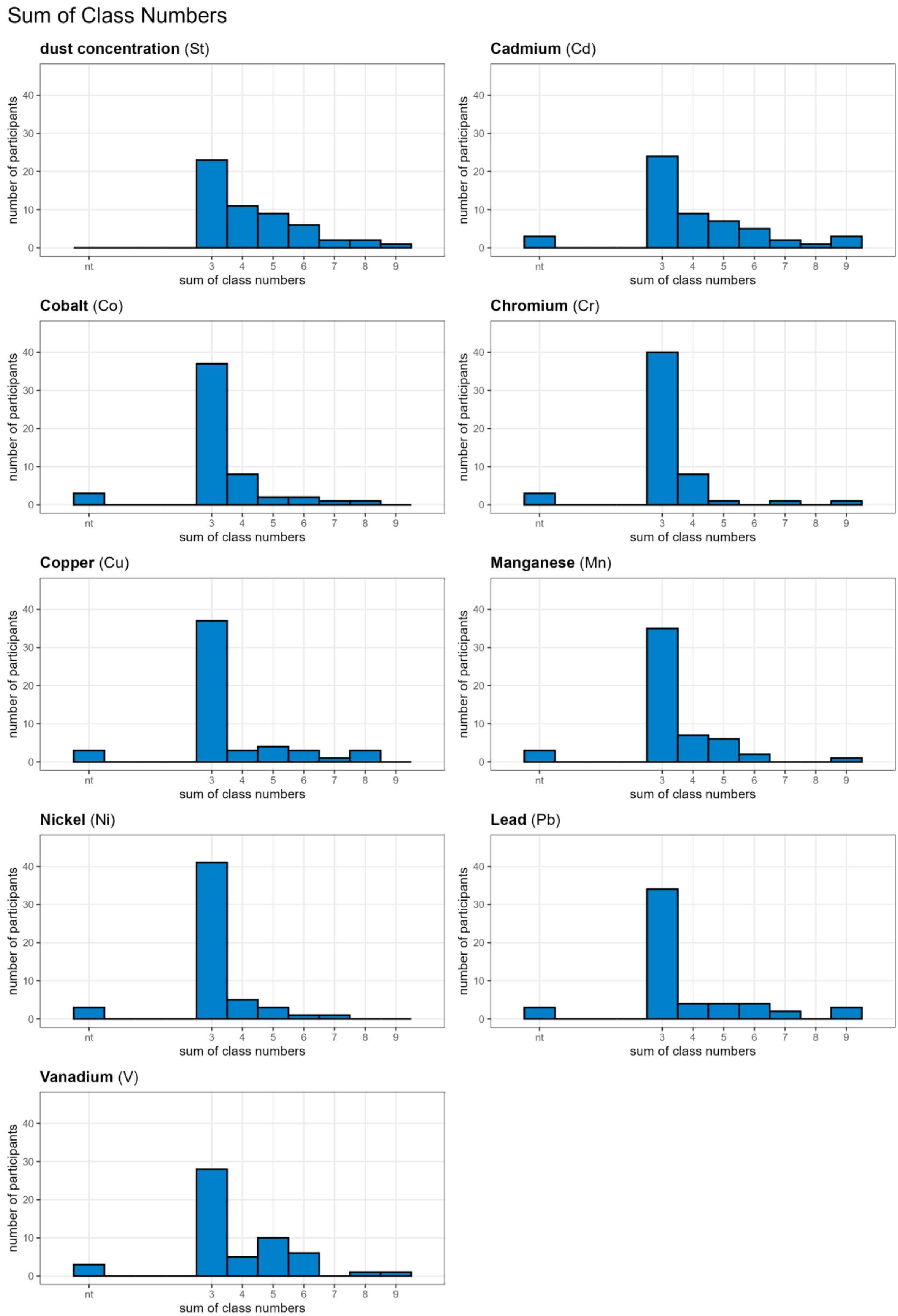
z-scores for component **water content flue gas** (CAH)



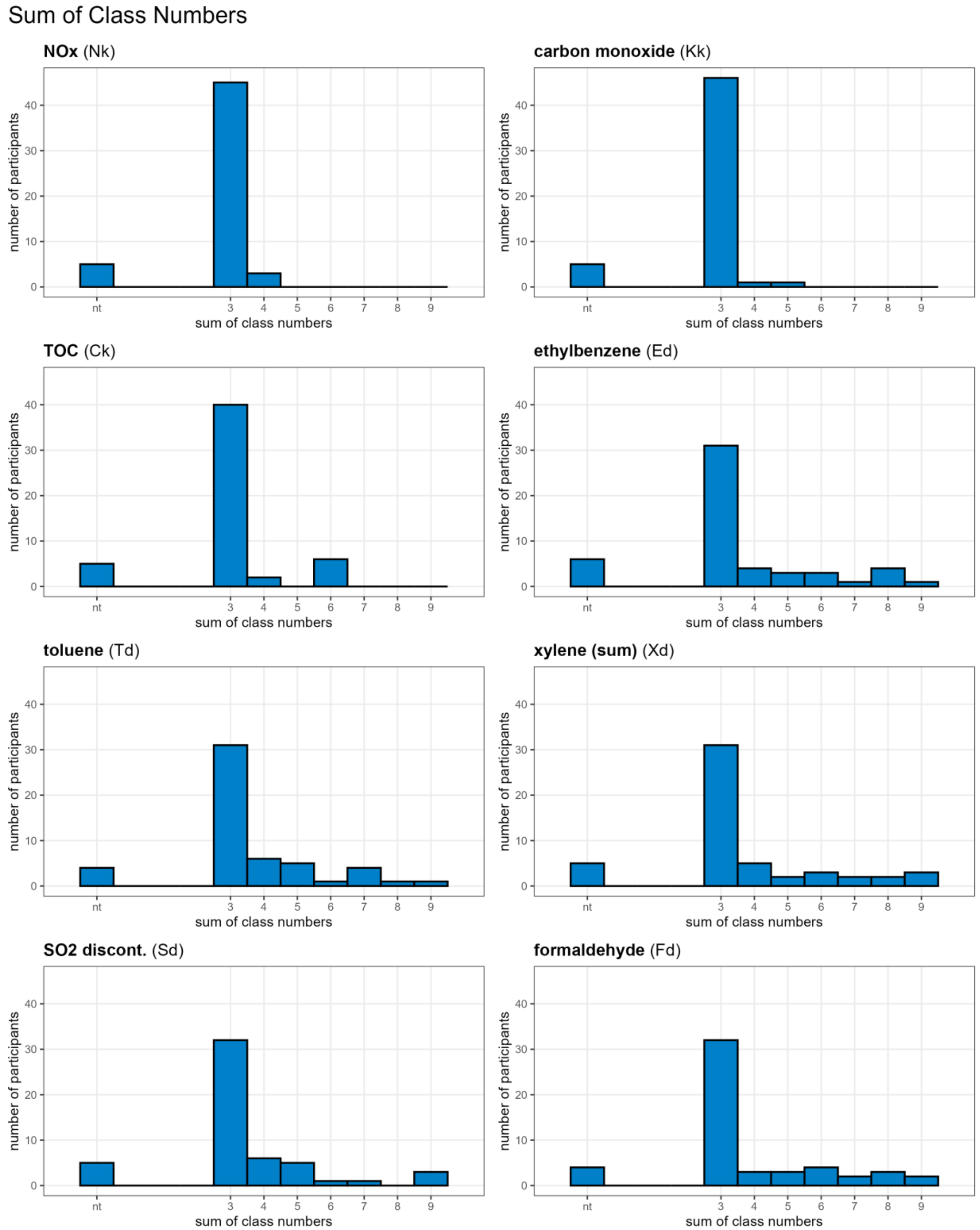
5.2 Sums of Class Numbers

The following schemes show the sum of class numbers that the participants achieved for the different components in form of histogram charts. For the interpretation of the sums of class numbers, please see section 4.5.3. Participants that did not hand in results for a component are listed as “nt”.

5.2.1 Dust Proficiency Test (Substance Range P)

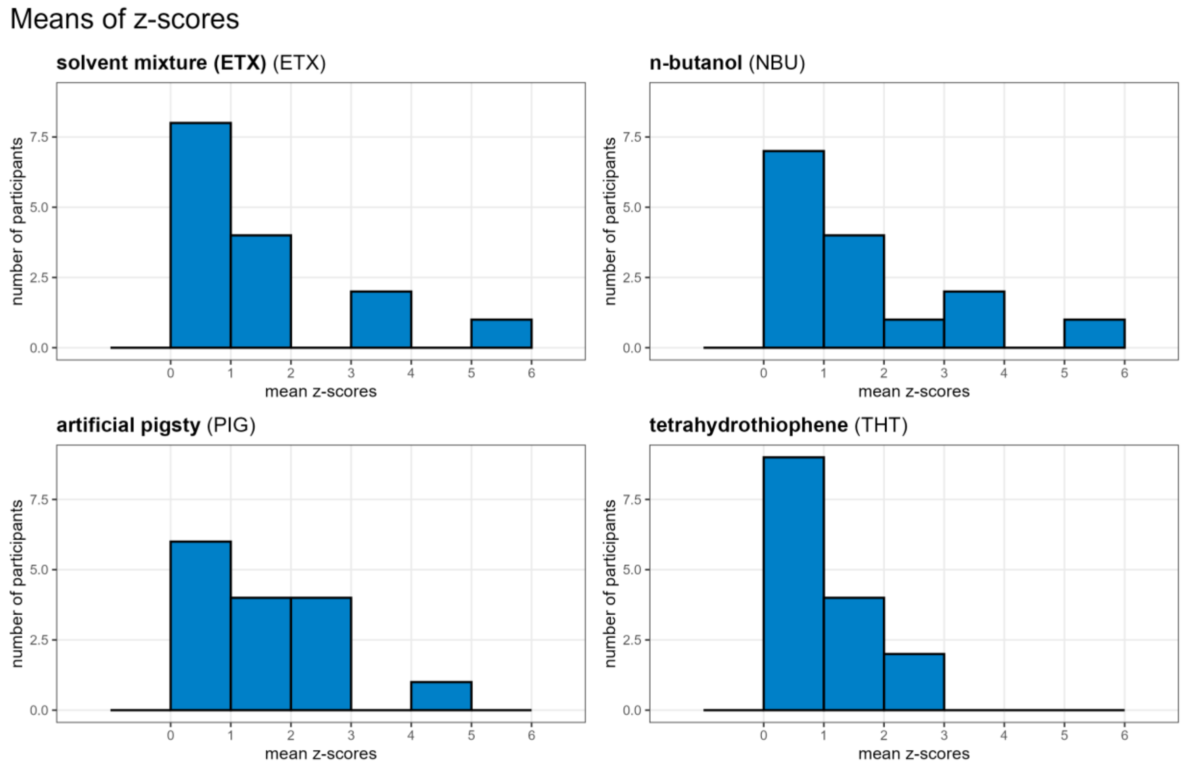


5.2.2 Gas Proficiency Test (Substance range G)



5.2.3 Odour Proficiency Test (Substance Range O)

In odour emission proficiency tests, instead of sums of class numbers a mean value of z-scores is calculated. The following figure shows these averaged z-scores in the form of histograms.



5.3 Theory Test

The 2019 specifications stipulate that a theory test be conducted for the dust and gas proficiency tests, which took the form of a 30-minute written test as part of the proficiency tests. One person per proficiency test participant was allowed to take part in this theory test. The content of the tests was the requirements of the standards and guidelines applied in the respective proficiency test for all participants. For the test, each participant was provided with a folder containing the standards as a reference work. Other aids, especially technical ones, were not permitted. The test consisted of a total of 15 questions, which were weighted with 1 to 3 points. The number of points depended on the difficulty of the question and its significance for the reliability of emission measurement values. A maximum of 33 points could be achieved in the test. There were four possible answers to each question, only one of which was correct. Participants received the full number of points allocated to the question for correct answers and no points for incorrect answers. The test was considered "passed" if at least half of the maximum possible points were achieved. If less than half of the maximum points were achieved, the test was considered "failed". The test was divided into three thematic sections, each of which was assessed separately. Each section contained five questions on a specific standard. The individual assessments of the thematic sections of the test had no impact on the overall result.

A total of 78% of all participants passed the theory test on the dust proficiency test in 2025, with a median score of 20.5 out of 33 points. The bottom quarter of participants scored 17 points or less, while the top quarter scored 24 points or more.

A total of 96% of all participants passed the theory test on the gas proficiency test, with a median score of 28 out of 33 points. The bottom quarter of participants scored 23 points or less in the theory test on the gas proficiency test, while the top quarter scored 31 points or more.

The new specifications for the odour proficiency test of 2024 also provide for a theory test, which has been organised in the same way as the already established tests for dust and gas. 78% of all participants passed this new odour theory test. The median score here was 27 out of 33 points. The bottom quarter of participants scored 19 points or less, while the top quarter scored 28 points or more.

6. Interpretation of Results

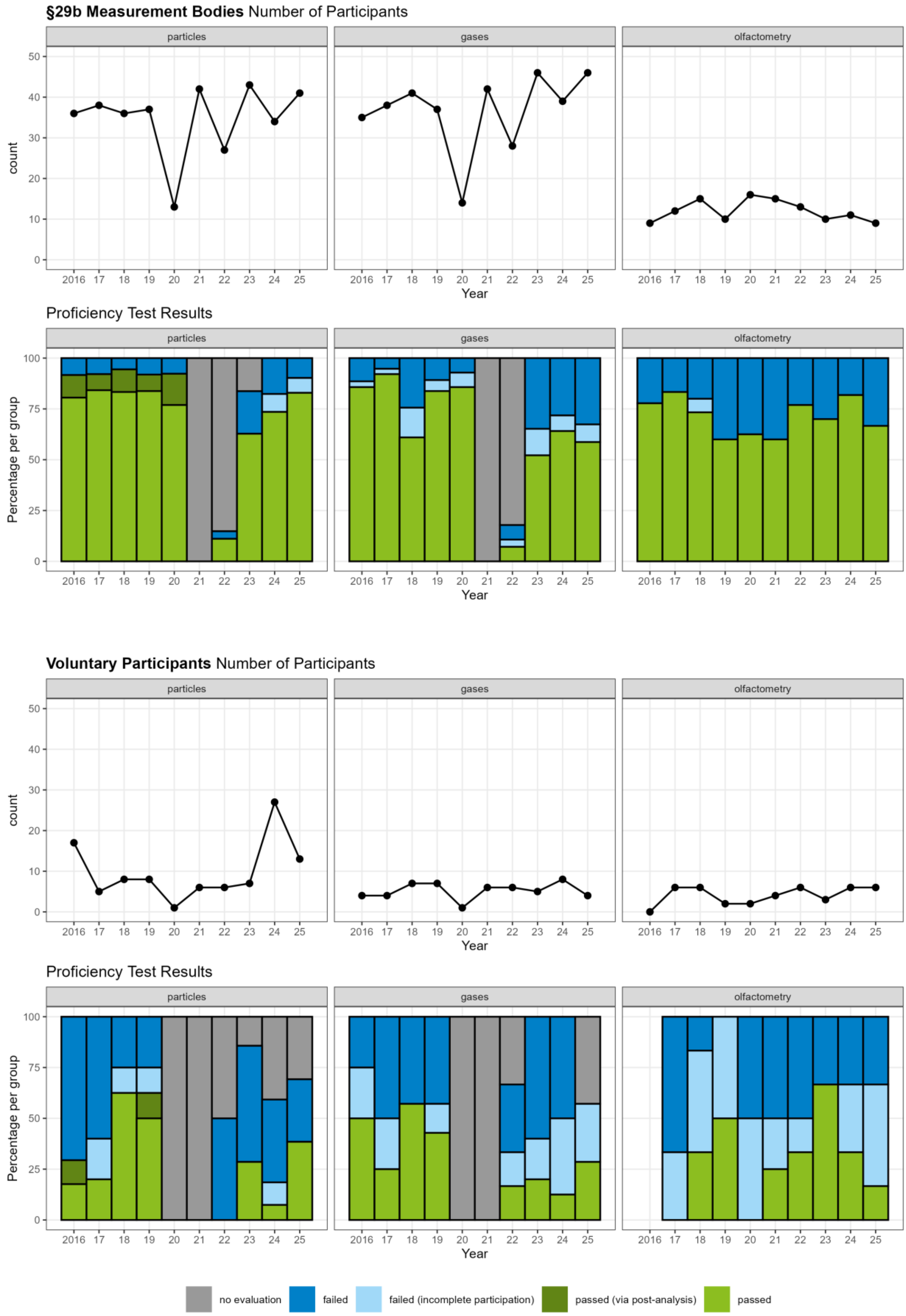


Figure 6: Number of participants and distribution of results, broken down by participant type.

Table 8: Overview of results since 2021 (§29b-bodies)

year	proficiency test	passed	failed	failed (incomplete participation)	not evaluated
2021	dust (pandemic version)	-	-	-	42
	gas (pandemic version)	-	-	-	42
	odour	9	6	-	-
2022	dust	3	1	-	-
	dust (pandemic version)	-	-	-	23
	gas	2	2	1	-
	gas (pandemic version)	-	-	-	23
	odour	10	3	-	-
2023	dust	27	9	-	7
	gas	24	16	6	-
	odour	7	3	-	-
2024	dust	25	6	3	-
	gas	25	11	3	-
	odour	9	2	-	-
2025	dust	34	4	3	-
	gas	27	15	4	-
	odour	6	3	-	-

Table 9: Overview of results since 2021 (voluntary participants)

year	proficiency test	passed	failed	failed (incomplete participation)	not evaluated
2021	dust (pandemic version)	-	-	-	6
	gas (pandemic version)	-	-	-	6
	odour	1	2	1	-
2022	dust	-	3	-	-
	dust (pandemic version)	-	-	-	3
	gas	1	2	1	-
	gas (pandemic version)	-	-	-	2
	odour	2	3	1	-
2023	dust	2	4	-	1
	gas	1	3	1	-
	odour	2	1	-	-
2024	dust	2	11	3	-
	dust (short version)	-	-	-	11
	gas	1	4	3	-
	odour	2	2	2	-
2025	dust	5	4	-	-
	dust (short version)	-	-	-	4
	gas	2	-	2	-
	gas (short version)	-	-	-	3
	odour	1	2	3	-

6.1 §29b Measuring Bodies

A total of 34 out of 41 (83%) of the §29b-authorised measuring bodies passed the dust proficiency test. Four (10%) of the authorised measuring bodies failed. Three others (7%) submitted only some of the measurement results when they repeated the test after failing the proficiency test, but all of these results passed. If these participants, who are counted as having failed the proficiency test for formal reasons, are disregarded, 89% of the authorised measuring bodies passed the proficiency test. The pass rate was thus higher than in 2024 (81%) and clearly exceeded the average of approximately 82% from 2016 to 2020 (before the SARS-CoV2 pandemic).

The gas proficiency test was passed by 27 of 46 (59%) of the authorised measuring bodies, while 15 (33%) authorised measuring bodies failed. Four others (9%) participated only in selected components as part of a repeat participation after failing a proficiency test, and passed these. If these participants, who for formal reasons are counted as having "failed" the proficiency test, are disregarded, 64% of the authorised measuring bodies passed the proficiency test. The pass rate was thus below the previous year's figure (69%) and again significantly below the average for the years 2016 to 2020 before the SARS-CoV-2 pandemic (approx. 87%).

A comparison with the results from 2016 to 2020 shows that the relative deviations of the measured values from the target values for many dust and gas components were also greater on average in 2025 than in the years before the pandemic. A graphical representation of the distribution of the measured values in the proficiency tests of previous years can be seen in Figure 7 and Figure 8. Here, for each component and for each year since 2016, the distribution of the measured values according to their deviation from the respective target value is shown in the form of a "violin plot", a combination of a "box plot" and a "kernel density plot". The wider the shape shown, the more measurement results lie in the relevant range.

Investigations by the HLNUG into dust sampling in accordance with EN 13284-1 revealed that two factors are primarily responsible for the lower-than-expected results observed in our interlaboratory tests: deviations from isokinetics and the use of non-sharp-edged probes (20). The condition of the probe tips used in the dust proficiency test is now documented photographically. These photographs confirm that the use of clearly non-sharp probe tips, e.g. those with dents or notches or those with an above-average thick edge, leads to significantly below-average measurement results. According to theory, thick edges cause turbulence at the probe tip, which manifests itself in reduced recovery rates, an effect that the HLNUG was able to confirm through its own measurements. Damaged nozzle rims (dents and notches) are likely to cause a similar, probably even more pronounced effect. In fact, among the unsuccessful participants in the proficiency test, there were a striking number who used probes with thick edges or even damaged probes.

The results of the gas proficiency test in recent years have shown a similar trend to that of the dust proficiency test, although in this case it is limited to the discontinuous components, in particular the organic substances ethylbenzene, toluene, and xylene. While the results for the continuous components NO_x, CO and TOC remained consistently very good, the measurement results for the individual organic substances, similar to those for dust, deviated in the years 2021 to 2024 significantly from the values for 2016-2020 (see Figure 8).

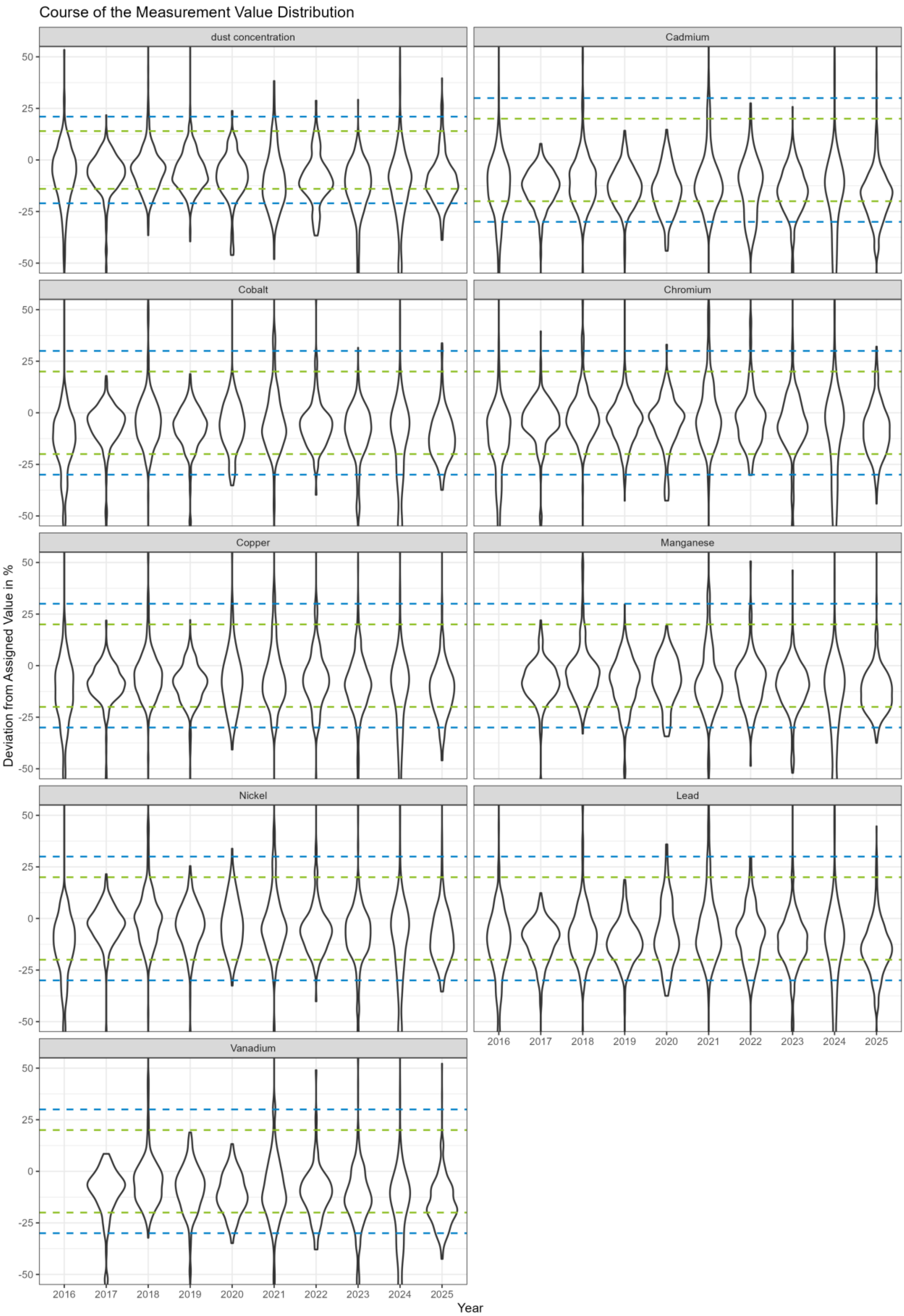


Figure 7: Course of the measurement value distribution in the dust proficiency tests 2016-2025 (all participants)

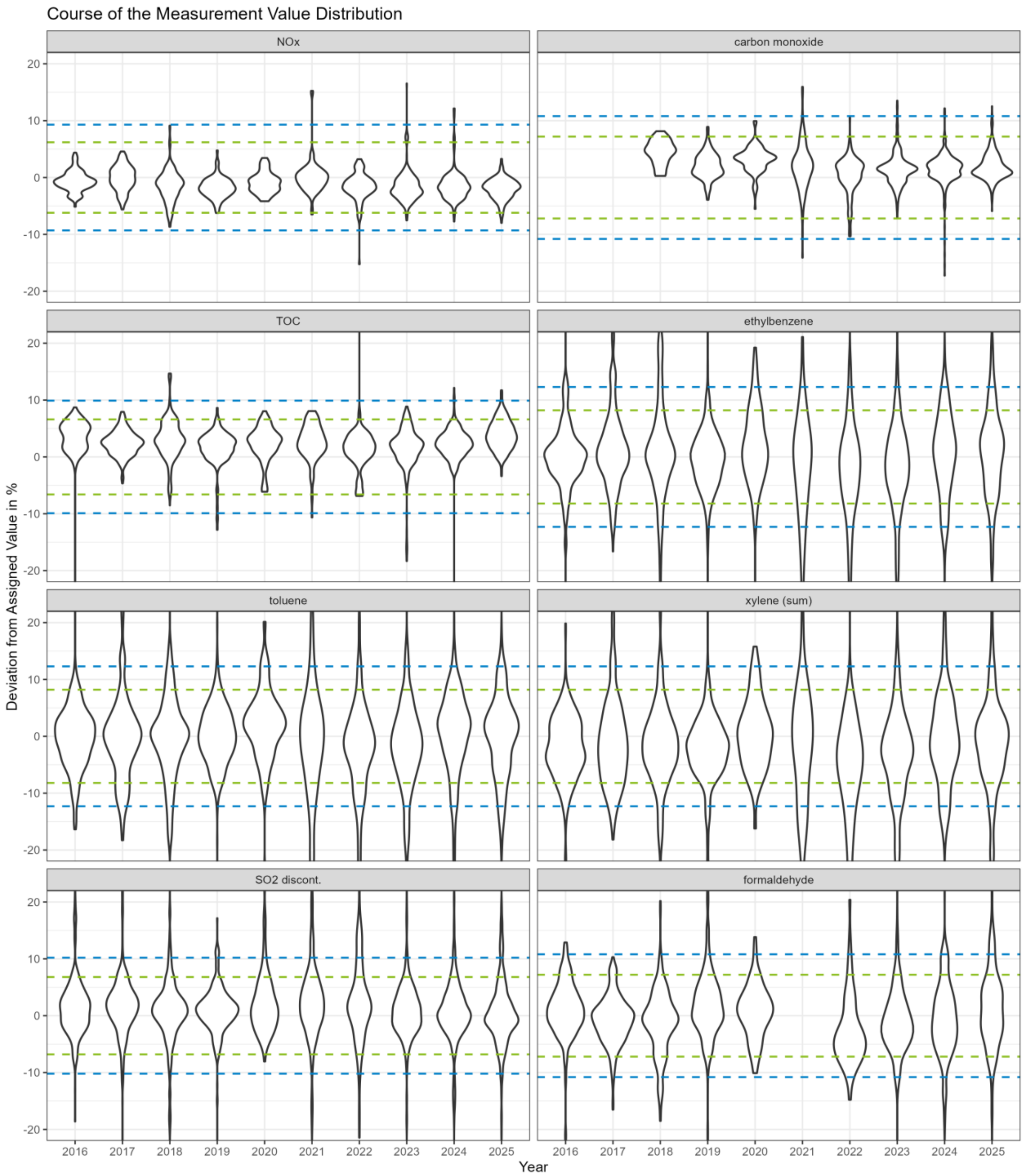


Figure 8: Course of the measurement value distribution in the gas proficiency tests 2016-2025 (all participants)

Broken down by year, the data for the determination of individual organic substances (ethylbenzene, toluene, and xylene) in particular paint a surprisingly inconsistent picture. While most measured values were close to the target value on average from 2016 to 2019, there is a significantly higher dispersion in the results from 2021 onwards, with a tendency towards underestimates (see Figure 9). It should be noted in this figure that only 14 participations were evaluated in 2020, compared to 31 to 47 in the other years (on average approximately 42 participations).

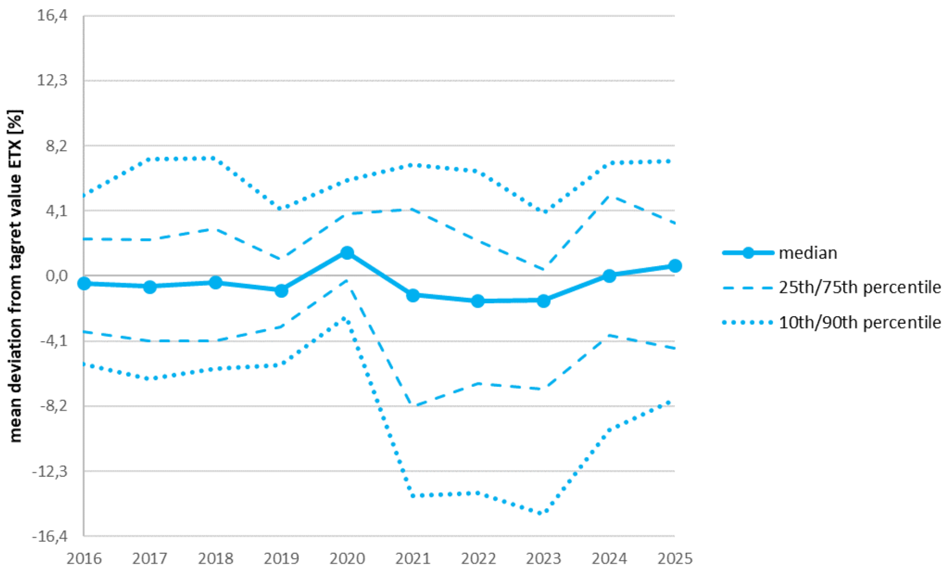


Figure 9: Average deviation of the measurement results from the target value for the components ethylbenzene, toluene, and xylene in the years 2016-2025 (all participants)

There is no known specific reason for the significantly increased variation in participant results after 2020. The dosing procedure has remained unchanged for many years. The only change has been in the distribution of concentrations. Until 2020, the nine measurements in the gas proficiency test consisted of only three different concentrations, each of which was measured three times in succession. From 2021 to mid-2022, the proficiency tests were carried out exclusively in the pandemic version, in which there were only 3 measurements with different concentrations. Since the end of 2022, 9 measurements have again been carried out in the standard gas proficiency test, but now with 9 different concentrations in random order. These different concentration distributions should not actually have any influence on the average deviation of the measurement results from the target value, as the samples do not influence each other during analysis, at least if the sampling is carried out in accordance with the standard. Carryover of analytes between samples is not usually observed for this type of measurement. The majority of participants had no problem performing measurements for individual organic substances even after 2020. Since 2024, even those measuring bodies that had difficulties with these measurements from 2021 onwards seem to be gradually reducing their deficits.

In 2025, a total of 6 out of 9 authorised measuring bodies (67%) passed the odour proficiency test. The results of the odour proficiency test were thus slightly worse than the average for the years 2016-2024 (approx. 72% of participants passed), even though the evaluation criteria for all components except *n*-butanol have become significantly more generous with the new specifications of 2024. For these components, the average deviation from the target value may now be up to a factor of 3 (instead of 2 previously). However, due to the comparatively small number of participants, the results of individual participants alone can cause significant fluctuations in the pass rate for the odour proficiency test. One of the three measuring bodies that failed did not pass the *n*-butanol component, another measuring body did not pass the solvent mixture (ETX) component, and the third unsuccessful participant failed both *n*-butanol and ETX. In the case of these three participants, classic errors in the performance of odour measurements can be traced back to the olfactometry protocols.

One participant who achieved significantly low measurement results for the solvent mixture (ETX) component showed a noticeable trend: the measured values for the three consecutive samples ETX fell continuously, so that the measured value for the third sample was only 42% of the measured value for the first sample. Although such fluctuations are by no means unusual in odour measurements on real plants, these measured values in a proficiency test in which all three samples contained identical concentrations would probably have warranted a follow-up examination after a longer break for the assessors in order to rule out assessor fatigue. The use of more than four assessors would probably also have led to smaller deviations, as the probability of coincidental identical trends in assessor behaviour decreases rapidly with increasing numbers of assessors.

Another participant measured significantly excessive odour concentrations for *n*-butanol. It was noticeable here that 3 of the 4 assessors used made multiple zero sample errors or omitted steps, in some cases both in the same run. It is obvious here that the assessors repeatedly reported an odour before this perception was really clear, so it was more a matter of guessing than measuring. Even if the error rates that occurred do not exceed the tolerance limits of the standard, meaning that the measurement was carried out in accordance with the standard despite zero sample and reference air errors, such anomalies should trigger a critical review of the measurement.

The third unsuccessful §29b measuring body determined concentrations that were too high for *n*-butanol and too low for the solvent mixture (ETX). Here, three out of four assessors also made reference air and/or zero sample errors in the *n*-butanol samples. One of these assessors also made these errors in the *n*-butanol test gas sample for the suitability test of the assessors before the measurements on the actual proficiency test samples began. The concentrations determined for the solvent mixture (ETX) were too low. It is noteworthy here that the olfactometry was started in all rounds with a dilution level of approx. 2000, while the samples had a target concentration of approx. 1400 ou_E/m^3. The first dilution level was thus only 1.4 times higher than the expected measurement result and therefore within a range in which many assessors can already perceive the odour. It had already been shown in the past that a starting level that is too low usually leads to underestimates in olfactometry. The measurement results for this participant averaged approximately 470 ou_E/m^3, which corresponds fairly accurately to the empirical value for a starting level that is too low: the measurement result is then usually approximately ¼ of the starting level. To determine the starting level, this participant stated: "At the beginning, the olfactometer operator smelled the respective substance directly from the sample." This method of determination is obviously highly prone to error. If the odour concentration could really be reliably determined by smelling the undiluted sample, the olfactometer would actually be superfluous. This method of determining the starting level is therefore not recommended.

In summary, a number of typical errors can be identified among the unsuccessful participants, which should be avoided as far as possible when measuring odours:

- Zero sample errors, reference air errors and skipped levels are indications that assessors are reporting odours before they are clearly perceived. These errors should not be ignored, as they lead to overestimations.
- A continuous significant decline in measurement results may indicate fatigue on the part of the assessors, causing them to report odour perception for the same concentration later and later. This can lead to underestimations.
- Experience has shown that selecting a starting level that is too low leads to underestimations. The starting level should not be determined by simply smelling the undiluted sample.

Since all unsuccessful participants clearly made mistakes in performing the olfactometry, the new evaluation criteria can be considered appropriate. In this context, it is important to note that only the first point, namely the occurrence of zero sample errors, reference air errors and skipped dilution steps, would be noticeable in routine measurements. When measuring real emission sources, it would not be expected that all samples would have the same concentration, and a starting level that is too low could also go unnoticed due to the lack of a reliable target value.

6.2 Voluntary Participants

The number of voluntary participants in our proficiency tests varies from year to year. As a rule, there are approximately 8 participants in the dust proficiency test, approximately 6 participants in the gas proficiency test and approximately 5 participants in the odour proficiency test. In 2025, there was an above-average number of participants in the dust proficiency test, with 13 volunteers, 4 of whom took part in the new short version of the dust proficiency test. There were 7 volunteers in the gas proficiency test, 3 of whom took part in the new short version of the gas proficiency test, and 6 volunteers in the odour proficiency test. Due to the usually low number of voluntary participants in many years, the collected results for a given year are extremely influenced by the performance of individual laboratories, which means that a long-term comparison is only of limited value.

In the dust proficiency test, a total of 5 of the 9 voluntary participants (56%) in the standard dust proficiency proficiency were successful in 2025, while 4 (44%) voluntary participants failed this proficiency test. The 4 participants in the short version were not assessed in terms of pass/fail.

In the gas proficiency test, 2 out of 4 (50%) of the voluntary participants passed the standard proficiency test. The other 2 participants (50%) only passed selected components, while they did not participate in the remaining components. Formally, these participations are counted as "failed (incomplete participation)". If only the voluntary participants who took part in the standard gas proficiency test in its entirety are considered, the pass rate was 100%. The 3 participants in the short version of the gas proficiency test were not assessed in terms of pass/fail.

In the odour proficiency tests, one of six voluntary participants (17%) passed, while two voluntary participants (33%) failed the proficiency test. The remaining three participants (50%) achieved sufficiently good measurement results, but did not complete their olfactometry within six hours of sampling and were therefore counted as "failed (incomplete participation)". Without these two participants, the pass rate was 33%; if they are considered "passed", the pass rate was 67%.

One of the voluntary participants failed the artificial pigsty (PIG) component. In this case, the olfactometry was not started until 26-28 hours after sampling, and the low results obtained (approx. 1/6 of the target value) indicate that the samples had deteriorated during the long storage period. Another volunteer participant failed the *n*-butanol and solvent mixture (ETX) components. For *n*-butanol, the concentration of the samples was approximately 500 ou_E/m^3 in each case. Olfactometry was performed for the three samples with a starting dilution of approximately 450, 120 and 230, and thus below the sample concentration in all three cases. The measurement results here were approximately 220, 80 and 140 ou_E/m^3, clearly following the starting dilution levels. Unfortunately, no specific details on the olfactometry procedure are available for this participant, and the selection of the starting dilution levels is also not traceable here. In the case of the solvent mixture (ETX), the cause of the error is less clear. Here, the concentration of the samples was approx. 260 ou_E/m^3, and the olfactometry was started for the three samples with dilution levels of approx. 1000, 450 and 120. Regardless of the starting dilution level, the measurement result was always approx. 40 ou_E/m^3, which is approx. 15% of the target value. It is possible that instead of the odour detection threshold, the recognition threshold was determined here, at which not only is a non-specific odour perceived, but the odour can also be clearly recognised and identified. No specific data is available on the odour recognition thresholds of the solvents used in the ETX mixture. However, the values are presumably significantly above the odour detection threshold, which should therefore also apply to the mixture.

6.3 Gas Flow Conditions

In each proficiency test, the participants must also determine and specify the gas flow conditions. The values recorded in 2025 (see section 5.1.4) essentially correspond to the observations of previous years: The measured values for temperature (CGT), static pressure (CSP), volume flow (CVF), and flow velocity (CFV) show minimal deviations from the assigned values for most participants. Participants generally tend to report higher measurement results (approx. +0.5 m/s) for the average flow velocity. One possible explanation for this is insufficient sealing of the sampling port during data collection, which leads to an increased volume flow compared to the total period. However, the fact that the volume flow is usually only measured at four points with identical radii in the duct cross-section is also likely to play a role. Although this method complies with standards, it does not necessarily lead to correct values if the flow velocity at the selected radius does not exactly correspond to the average flow velocity across the entire duct cross-section. The tendency towards increased measurement results for the volume flow is a direct consequence of the deviations in flow velocity, as the latter variable is calculated from the former. In both cases, however, the deviations observed are usually minor. In comparison, the measurement results for exhaust gas humidity (CAH) vary much more widely, with larger deviations from the assigned values and individual "outliers".

7. Optional Information from Participants

All participants were asked to provide additional information about their measurements on a voluntary basis, together with the measurement results. Again, the information provided is not listed here in detail; instead, the data obtained is summarised in tables and presented graphically below. Unless otherwise stated, the data is based on feedback from participants from 2016 to 2025.

For some components, participants have a certain degree of freedom in choosing different process parameters. Based on the voluntary information provided by the participants, an attempt was made to determine correlations between the methods, devices, etc. used and the results achieved. Since 6-9 measurements are usually carried out for each component at different concentrations, it is difficult to make a clear statement about the quality of a process. For the sake of simplicity and clarity, correlations were therefore established with the average deviations of the participants' results from the target value, with negative values also being included in the average. Furthermore, similar components, such as heavy metals or organic solvents, were combined into a common average value where appropriate. This type of evaluation certainly simplifies the problem and cannot reflect all the details. For example, different influences at different concentration ranges or high fluctuations between the individual results of a participant are completely ignored in this evaluation. However, limiting the evaluation to the mean values of the participants' z-scores allows for a simple estimation of the effects of different methods on the mean deviation of the measured values from the assigned value.

For most evaluations, a certain stabilisation of the values can be observed. This is ultimately due to the fact that the data basis for the annual report 2025 has only increased slightly, while the values for most evaluations hardly differ from those of previous years. As a result, most findings become increasingly reliable and meaningful over time.

For all correlations presented in this report, it should be noted that a correlation is merely an indication of a connection, but in no way proves causality. For example, it is entirely conceivable that participants who use a particular device or method may coincidentally have other similarities that actually affect the measurement results, while the identified similarity may not play a role at all.

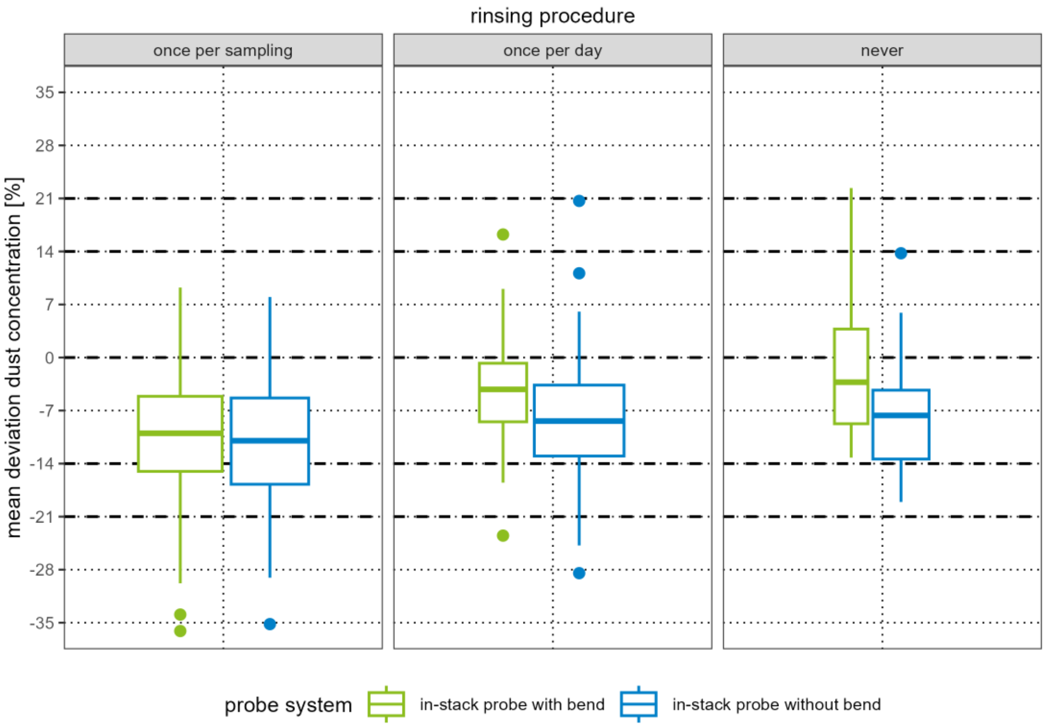
Another aspect that should be taken into account with this data is that although the figures are representative of the proficiency test participantions, they are not necessarily representative of the respective measurement method. Authorised measuring bodies that fail the proficiency test due to high deviations from the assigned values are promptly requested to participate again. As a result of these repeated participations, the measurement results of the less reliable measuring institutes are disproportionately represented in the data, while the measurement results of very reliable laboratories are underrepresented.

7.1 Probes and Rinsing Procedures in Dust Sampling

When correlating probe systems and rinsing procedures, the participants in the dust proficiency test are divided into six groups, depending on whether an in-stack probe with or without a bend (e.g., gooseneck or elbow) is used and whether this probe is rinsed after each sampling, every working day, or never. A total of eight participants who stated that they rinse once at the end of the proficiency test were included in the daily rinsing group.

The database in this report covers the results between autumn 2018 and the end of 2025. In summer 2018, the query regarding the frequency of the rinsing procedure was specified in more detail, and a total of 270 participants have since provided relevant information about their rinsing procedure. In previous years, only the basic question of whether rinsing was carried out (yes/no) was asked, so unfortunately the older data is not comparable.

Due to the relatively small number of cases, some of the results presented are significantly influenced by individual results from few laboratories. The above-average results for combination 3 (probe with bend that is not rinsed: right-hand figures, green) are probably not representative of this type of sampling. Combination 3 is explicitly non-compliant with the standard, as this probe geometry is likely to result in dust adhering to the inner surface of the probe, which can lead to significant underestimations if rinsing is not performed at all.



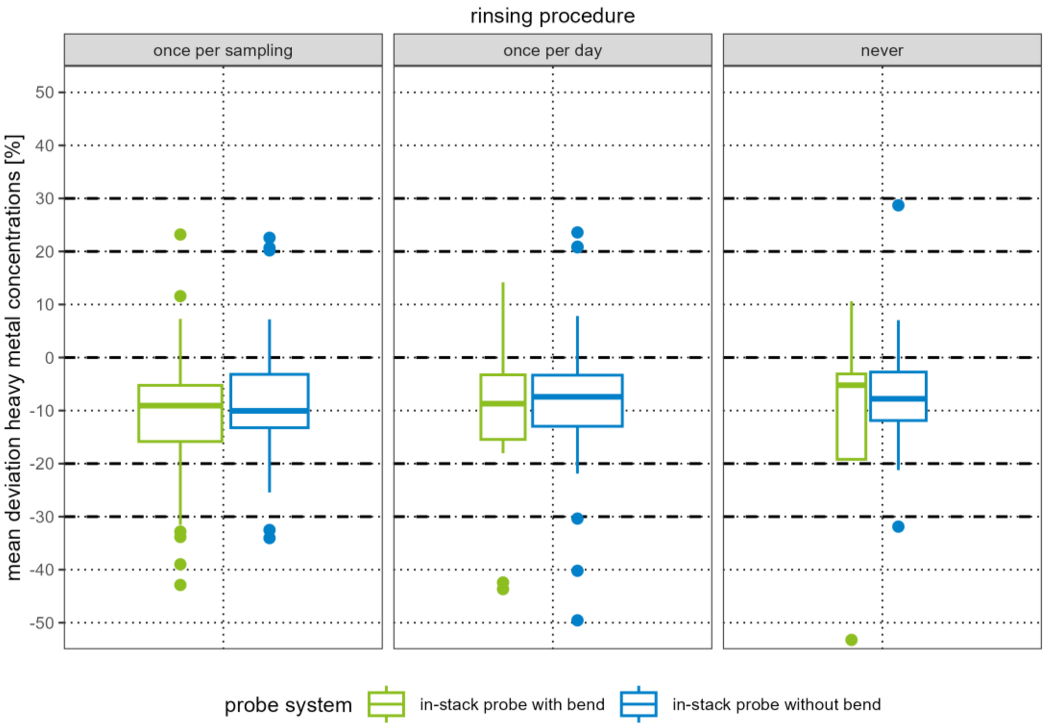


Figure 10: Deviations for dust and heavy metals, broken down by probe type and rinsing method (2018-2025).

Table 10: Correlation of dust measurement results with probe systems and rinsing procedures (2018-2025)

combi-nation	probe system	rinsing procedure	median of mean devia-tions total dust results	number of participants	median of mean devia-tions heavy metal results	number of participants
1 **(left)**	in-stack probe **with** bend(s)	after each sampling	−10.0%	69	−9.1%	67
2 **(centre)**		once per day	−4.2%	22	−8.7%	19
3 **(right)**		no rinsing	*−3.3%**	*11*	*−5.2%**	*8*
4 **(left)**	in-stack probe **without** bend	after each sampling	−11.0%	59	−10.1%	58
5 **(centre)**		once per day	−8.4%	78	−7.4%	77
6 **(right)**		no rinsing	−7.6%	31	−7.8%	30

*This combination was only indicated by approximately 3-4% of the participants. The median is clearly less meaningful here than for the other combinations.

It is striking that participants with a probe without a bend achieve better measurement results for dust concentration if rinsing is not carried out after each measurement (combinations 4, 5 and 6). The measurement results for heavy metals with this type of probe are very close to the average result for total dust in all cases.

When rinsed after each measurement, probes with bend (combination 1) achieve similar average results to probes without bend (combination 4) for both dust and heavy metals. The best results in the comparison were achieved with an in-stack probe with bend and daily rinsing (combination 2), although the average recovery of 95.8% of the dust mass concentration is based on comparatively few participations (22, approx. 8% of all measurement results). At the same time, this is the only combination in which the deviation for heavy metals is on average more than twice as high as the deviation for total dust.

On average, the results of the dust measurements in the 2025 proficiency tests again show general underreporting, as was already the case in previous years. A detailed investigation of this phenomenon and its probable cause was published by the HLNUG in a scientific journal in 2021 (20).

7.2 Diameter of the Nozzle Opening in Dust Samplings

Based on the data collected since 2016 on the measurement results submitted and the diameters of the nozzle openings used (approx. 410 participations), a trend can now be identified. The majority of participants (approx. two-thirds) use nozzle openings with a diameter of 10.0 mm. Most of the remaining participants can be divided into three groups: Approximately a quarter of participants use probes with a diameter between 8.0 and 9.9 mm. Some participants (less than 5%) use probes with diameters between 10.1 and 12.0 mm. Most of the remaining participants (less than 10%) use a probe diameter of less than 8.0 mm, despite the standard specification to the contrary. A direct comparison shows that participants using 10 mm probes achieved the best results on average. Slightly lower recovery rates were achieved with probe diameters between 8 and 10 mm. The results obtained using probe diameters of less than 8 mm are significantly lower and show greater variation.

Probe diameters < 6 mm or > 10 mm were used by fewer than 21 participants (or 5% of all participants) and are not explicitly listed here.

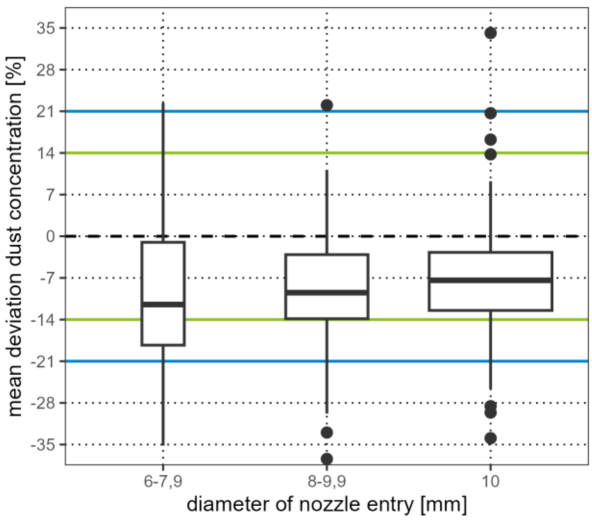


Figure 11: Average deviation of dust concentration from target value, broken down by nozzle diameter (2016–2025).

Table 11: Correlation of dust measurement results with nozzle opening diameters (2016–2025)

Diameter of the nozzle opening	6 to 7.9 mm	8 to 9.9 mm	10 mm
75th percentile	–1.0%	–3.1%	–2.7%
Median	–11.5%	–9.5%	–7.4%
25th percentile	–18.3%	–13.9%	–12.5%
Number of values	30	113	252

The observation that larger nozzle opening diameters lead to better measurement results is not surprising from a physical point of view. As the diameter of the nozzle opening increases, several parameters that are relevant to the quality of the measured values change. Turbulence at the edge of the nozzle opening becomes less relevant to the exhaust gas flow into the probe as the diameter increases. The error in determining the opening area becomes smaller, which leads to a smaller error in isokinetics, as the sample volume flow is calculated on the basis of this area. The extracted volume per sample and the dust mass collected on the filter increase. The higher dust mass reduces the relative influence of weighing errors, while wall effects and losses play an increasingly minor role. This can be easily understood using the following numerical examples.

Table 12: Example effects of different nozzle opening diameters on various parameters of a dust measurement

Parameter	Diameter of the nozzle opening		
	6 mm	8 mm	10 mm
Sample volume at a flow velocity of 11 m/s, 30 °C, 1013 mbar and 2 vol.-% water vapour	0.49 m^3 (sc, dry)	0.88 m^3 (sc, dry)	1.37 m^3 (sc, dry)
Relative error if the sample volume was calculated to be 0.03 m^3 (sc, dry) too large	–5.7%	–3.3%	–2.1%
Dust mass in the sample at an exhaust gas concentration of 5 mg/m^3 (sc, dry)	2.5	4.4	6.9
Relative error at this concentration and a dust loss of 0.3 mg from the sample	–12.1%	–6.8%	–4.4%
Error in isokinetics if the diameter of the nozzle is 0.2 mm smaller than assumed	+7.0%	+5.2%	+4.1%
Maximum underestimation due to this isokinetic error with coarse-grained dust	–6.6%	–4.9%	–4.0%
Ratio of nozzle opening area (in mm^2) to nozzle opening circumference (in mm)	1.5	2.0	2.5

It should also be noted in this context that the condition of the nozzle opening has a significant influence on the measurement results. To ensure reliable measurement results, it is essential to use a sharp-edged and undamaged probe. Since the beginning of 2023, the condition of the participants' nozzle openings has been documented photographically in the dust proficiency test. During this period, 15 participants have used probes with a diameter of 10 mm or more that can be considered "sharp-edged" and undamaged. The median of the mean deviation of these participants from the target value was –2.8%, with the 75^{th} and 25^{th} percentiles at +0.5% and –8.9%. During the same period, 55 participants used probes with an opening diameter of 10 mm or more that cannot be considered "thin-walled" and/or had clearly visible damage such as dents or notches. For these participants, the median of mean deviations from the target value was –11.5%, with the 75^{th} and 25^{th} percentiles at –7.1% and –15.6%. These figures should be used with caution, as there is no clear definition of "sharp-edged" and, accordingly, no clear boundary between suitable and unsuitable probes. The classification of the measurement results into the above-mentioned groups is therefore not entirely clear in this particular case. However, the general trend is consistent with our own investigations (20).

7.3 Analytical Instruments for Heavy Metals

The information provided by participants on the analysis device used for heavy metal analysis reveals hardly any differences between AAS and ICP users. A total of 43 participants stated that they performed heavy metal analysis using AAS devices, while 338 participants stated that they used an ICP device. All participants achieved comparable z-scores for heavy metals on average, regardless of the analysis device used. However, the measured values of ICP users vary more widely than those of AAS users.

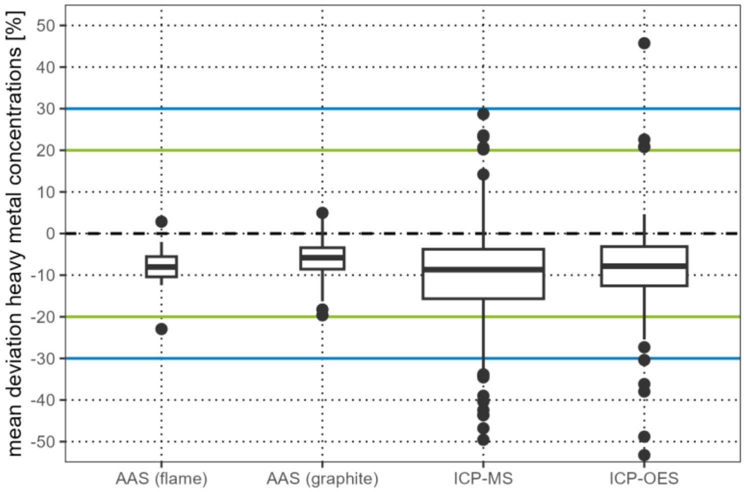


Figure 12: Average deviation of heavy metal concentrations from the target value, broken down by the analysis devices used (2016-2025).

Table 13: Correlation of the mean deviation from the assigned value for heavy metal results and the used analysis devices (2016-2025)

analysis device	flame-AAS	graphite furnace AAS	ICP-MS	ICP-OES
75th percentile	−5.5%	−3.4%	−3.8%	−3.1%
median	−8.0%	−5.8%	−8.7%	−7.8%
25th percentile	−10.4%	−8.6%	−15.7%	−12.6%
number of values	14	29	225	113

If the mean recovery of the heavy metal measurements is corrected by the mean recovery of the total dust measurements, the picture is essentially the same. However, the median values of the deviations in this calculation are around zero, which indicates that the underestimation of total dust is the determining error in the heavy metal concentrations. This observation is not surprising, as the missing dust mass in the samples must naturally lead to proportional underestimates of heavy metals. The key finding here is that other sources of error probably do not play a major role.

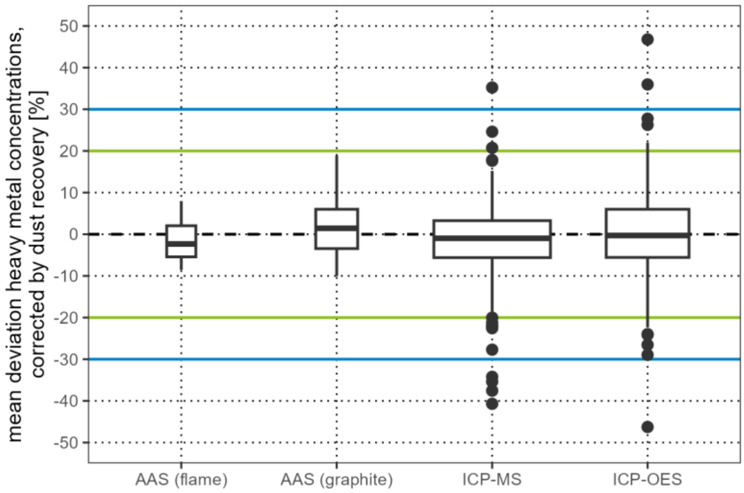


Figure 13: Average deviation of heavy metal concentrations from the target value, broken down by the analysis devices used, corrected for the mean deviation of the total dust concentration (2016-2025).

Table 14: Correlation of the average deviation of heavy metal concentrations from the target value with the analytical instruments used, corrected for the average deviation of the total dust concentration (2016-2025)

Measuring device	**Flame AAS**	**Graphite furnace AAS**	**ICP-MS**	**ICP-OES**
75th percentile	+2.0%	+6.0%	+3.3%	+6.0%
Median	–2.3%	+1.4%	–1.0%	–0.3%
25th percentile	–5.4%	–3.4%	–5.6%	–5.6%
Number of values	14	29	224	113

7.4 Chemicals in the digestion solution

The standard method specifies minimum requirements for the composition of the digestion solution for heavy metal analysis, but there is relatively large leeway in the composition of the digestion solution. Since 2024, participants have therefore been asked to provide information on the combination of chemicals they use. The vast majority of participants use the combination of hydrofluoric acid (HF) and nitric acid (HNO_3) specified as the minimum requirement in the standard procedure, with approximately half of them also adding hydrogen peroxide (H_2O_2), while a few laboratories add hydrochloric acid (HCl) instead. The measurement results of these participants are generally similar, but the addition of hydrogen peroxide and hydrochloric acid seems to lead to a greater variation in the results.

A total of eight participants have so far stated that instead of hydrofluoric acid they use a combination of tetrafluoroboric acid (HBF_4) and nitric acid. Half of these participants have also added hydrochloric acid (HCl). The measurement results of this group show comparatively large deviations, but only limited data is available, so the findings do not yet allow a general statement to be made about the method.

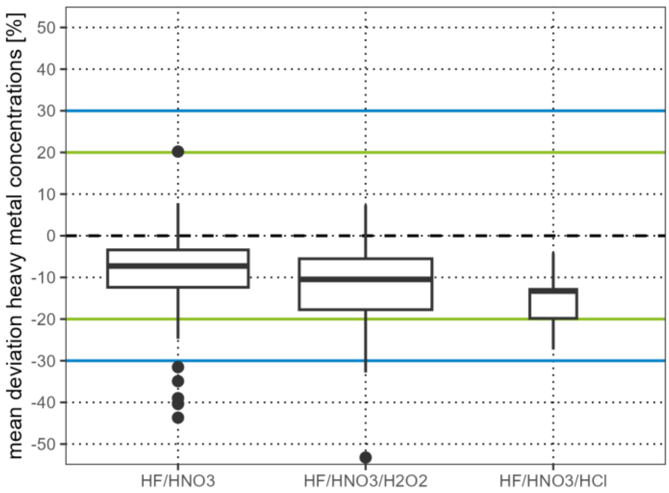


Figure 14: Average deviation of heavy metal concentrations from the target value, broken down by the chemicals used in the digestion solution (2024-2025).

Table 15: Correlation of the average deviation of heavy metal concentrations from the target value with the chemicals used in the digestion solution (2024-2025)

Chemicals	HF and HNO_3	HF, HNO_3 and H_2O_2	HF, HNO_3 and HCl
75th percentile	−3.4%	−5.5%	−12.9%
Median	−7.3%	−10.5%	−13.3%
25th percentile	−12.4%	−17.8%	−19.8%
Number of values	45	40	5

For the digestion composition, the measurement results were also evaluated with corrections for deviations in the respective total dust concentration. Similar to the analysis of the analytical instruments, it can be seen that the observed underestimations of heavy metals can essentially be attributed to errors in dust recovery. The participants who add hydrochloric acid to their digestion are an exception here. In these participants, the lower recovery rates for heavy metals cannot be explained solely by insufficient dust quantities in the sample.

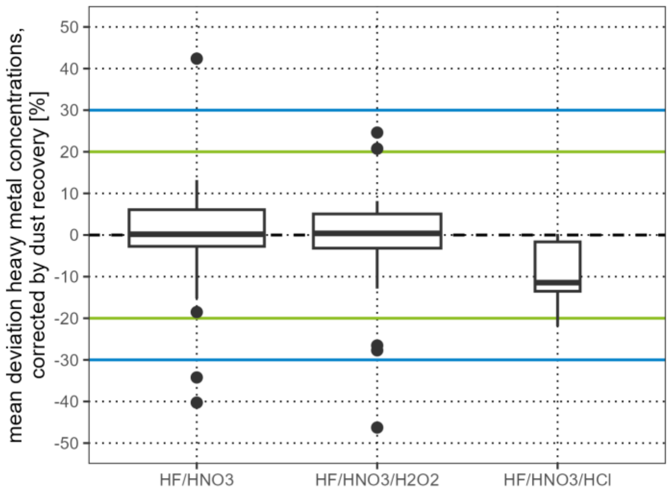


Figure 15: Average deviation of heavy metal concentrations from the target value, broken down by the chemicals used in the digestion solution, corrected in each case by the average deviation of the total dust concentration (2024-2025).

Table 16: Correlation of the mean deviation of heavy metal concentrations from the target value with the chemicals used in the digestion solution, corrected for the mean deviation of the total dust concentration (2024-2025)

Chemicals	HF and HNO_3	HF, HNO_3 and H_2O_2	HF, HNO_3 and HCl
75th percentile	+6.1%	+5.1%	–1.6%
Median	+0.2%	+0.4%	–11.4%
25th percentile	–2.7%	–3.2%	–13.5%
Number of values	45	40	5

For the four participants who carried out the digestion with HBF_4/HNO_3, the average underestimation is only approx. –2% when the underestimations in the total dust mass are taken into account in the calculations. However, for the four participants who used a combination of tetrafluoroboric acid (HBF_4), nitric acid (HNO_3) and hydrochloric acid (HCl) for digestion, there is still an average underestimation of –14% even when corrected for the recovery of the total dust concentrations.

7.5 Solvents for Desorption of ETX

For the desorption of the solvents ethylbenzene, toluene, and xylene (ETX) from the activated carbon in the sampling tubes, the participants have a choice of other solvents or solvent mixtures in addition to the usual solvent carbon disulfide (CS_2). The majority of participants stated that they had worked with CS_2. The results of all participants are close to the target value on average.

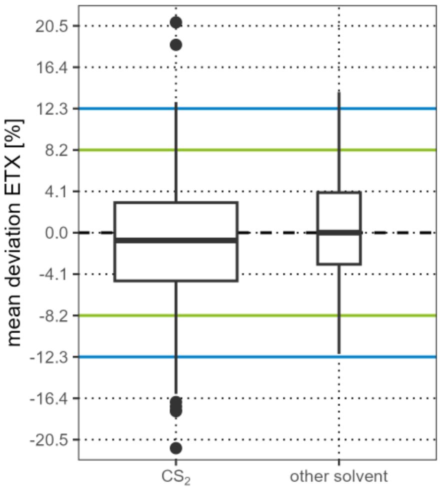


Figure 16: Average deviation of ETX measurement results from the target value, broken down by the desorption solvent used (2016-2025).

Table 17: Correlation of ETX measurement results with the desorption solvent (2016-2025)

solvent used in desorption	CS_2	other solvent
75th percentile	+3.0%	+4.0%
median	−0.7%	+0.0%
25th percentile	−4.7%	−3.1%
number of values	323	39

7.6 Gas Chromatography Detectors

Gas chromatographs with either an FID detector or a mass spectrometer (MS) are generally used to analyse ETX samples. The information provided by the participants reveals the following picture.

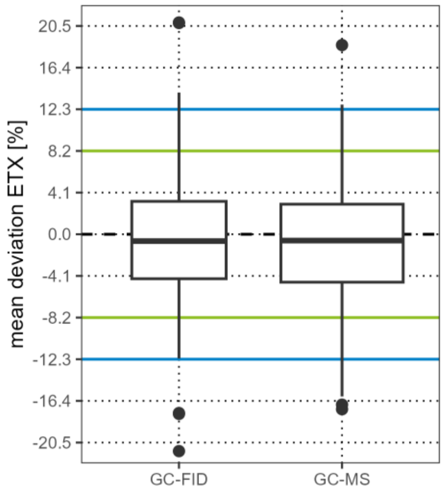


Figure 17: Average deviation of ETX measurement results from the target value, broken down by analysis devices used (2016-2025).

Table 18: Correlation of ETX measurement results with analytical instruments (2016-2025)

analytical instrument	GC-FID	GC-MS
75th percentile	+3.2%	+3.0%
median	−0.7%	−0.6%
25th percentile	−4.4%	−4.7%
number of values	135	227

For the entire sampling and analysis process, the participants achieved comparable results close to the target value on average with both detector variants.

7.7 Sulfur Dioxide

For the discontinuous determination of sulfur dioxide concentrations, participants can choose between analysis of the samples using ion chromatography or the Thorin method as part of the standard reference method. The following picture emerges from the information provided by the participants:

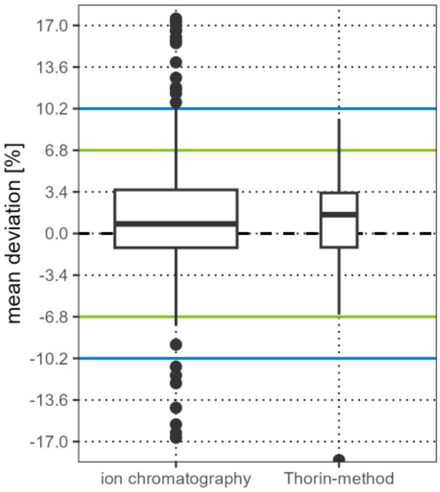


Figure 18: Average deviation of sulfur dioxide measurement results from the target value, broken down by analysis method used (2016-2025).

Table 19: Correlation of sulfur dioxide measurement results with the analytical method used (2016-2025)

method	ion chromatography	Thorin-method
75th percentile	+3.6%	+3.3%
median	+0.7%	+1.5%
25th percentile	–1.2%	–1.6%
number of values	343	31

The results presented here show a slightly lower average deviation for the ion chromatography method, but the number of participants using the Thorin method is comparatively small.

7.8 Formaldehyde

For the measurement of formaldehyde concentrations, participants can choose from the guidelines VDI 3862 Parts 2 (16), 3 (17), and 4 (18). Only the procedures according to Part 2 and Part 4 were used by more than 5% of the participants and are therefore shown in the following diagram. The following picture emerges from the information provided by the participants:

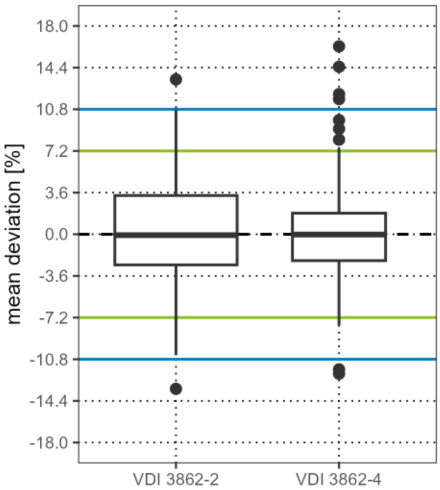


Figure 19: Average deviation of formaldehyde measurement results from the target value, broken down by the guideline used (2016-2025).

Table 20: Correlation of formaldehyde measurement results with the guidelines used (2016-2025)

guideline (method)	**VDI 3862 Part 2 (DNPH wash bottles)**	**VDI 3862 Part 4 (AHMT-procedure)**
75th percentile	+3.3%	+1.8%
median	−0.1%	−0.0%
25th percentile	−2.6%	−2.3%
number of values	163	95

The DNPH wash bottle method appears to deliver values that are comparable on average to those obtained using the AHMT method. However, the dispersion of results appears to be somewhat lower with the AHMT method.

7.9 Feedback from Participants

Since 2019 HLNUG provides an online feedback questionnaire for its proficiency test participants. The possible ratings for the questions range from 1 (very good), over 2 (rather good) and 3 (rather bad) to 4 (very bad). The mean value for the answers to the respective question is shown in the following figure.

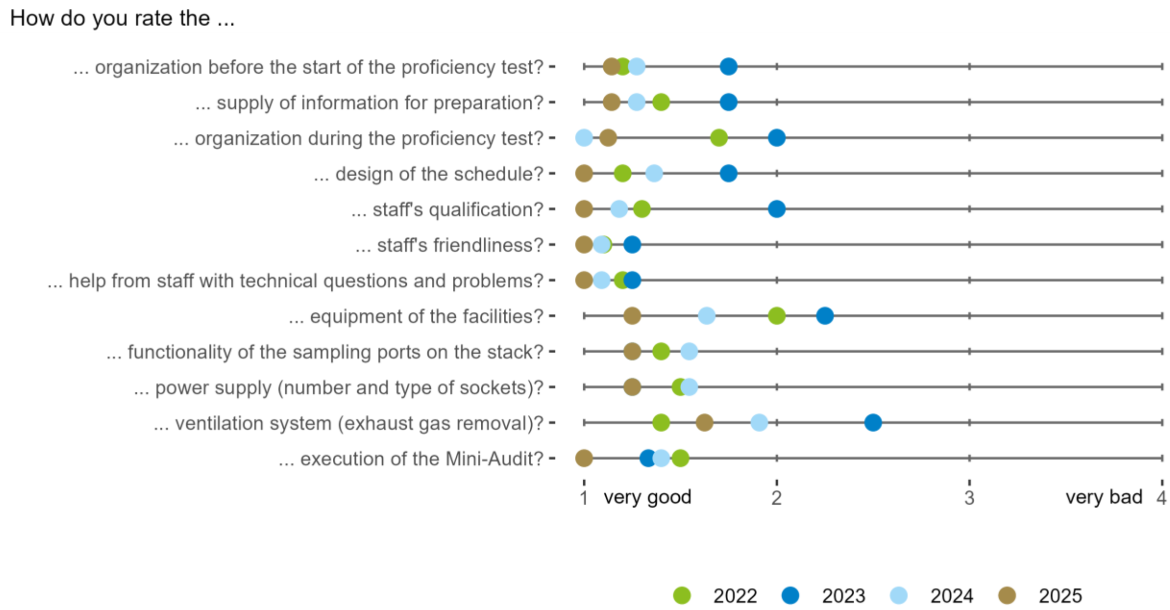


Figure 20: Feedback from participants on the interlaboratory tests (2022-2025).

A total of 8 responses were received last year (approx. 7% of all participants). The feedback received showed that participants were again highly satisfied with the implementation of the proficiency tests in 2025. Participants were particularly satisfied with the schedule, the qualifications and friendliness of the staff, and the assistance provided by the staff with technical questions and problems (average score: 1.0 in each case). As in the previous year, the worst ratings were given to the ventilation system (average score: 1.6). In particular, the lack of options for extracting exhaust air from the sampling systems was criticised.

One participant criticised what he considered to be an insufficient number of 3" sampling ports, particularly in the gas proficiency test. However, it is not possible to simply install additional sampling ports on the stack simulator. The only realistic way to increase the number of sampling ports available per participant would therefore be to reduce the number of participants. In order to increase the number of sampling ports per participant by a third, the number of participants could, for example, be reduced to a maximum of 6 per proficiency test. This is also in line with the suggestion of another participant who would like to reduce the number of measuring institutes per proficiency test in general. However, this would also require an increase in the participation fees by approximately € 1000 per participant and proficiency test. It is questionable whether this measure would really be in the interests of the participants.

Another criticism was that there was too little time to set up the measuring equipment. From the HLNUG's point of view, however, this is a problem that affects only a few participants. Most measuring institutes use idle times during the measurements and before the start of sampling in the morning to set up their measuring equipment, so that after the end of sampling in the afternoon there is only a little work left to do. Solely those institutes that only begin to prepare the sampling systems for the following day after the measurements have ended are actually pressed for time. A change to the schedule is therefore not currently indicated.

It was also suggested that the invitations to the proficiency test should be sent out much earlier. This criticism is not entirely understandable, as the invitations for most of the proficiency tests in 2025 were already sent out at the end of July 2024, i.e. more than six months in advance for most participants. In principle, however, the planning of the proficiency test dates can be brought forward even further, so that the invitations are sent out approximately one year before the participation date. Irrespective of this, the laboratories can of course also take action themselves and, in the event of foreseeable scheduling difficulties, suggest possible periods for participation in the proficiency test. Thanks to regularly updated long-term planning on the part of the HLNUG, the §29b-authorised measuring bodies know at least three years in advance which branch will be invited to participate in the proficiency test in which year.

Another participant criticised the fact that the theory test had too little to do with the practical work of the measuring institutes. Open questions about the technical regulations would be clarified in practice by computer-assisted searches in electronic documents, rather than by leafing through paper files. Some questions in the test also seemed more like harassment than a test of the institutes' specialist knowledge. To answer this, it should be noted that the theory test is not intended to replicate the practical activities carried out at the measuring insititute. Rather, the aim here is to obtain a picture of the participants' specialist knowledge regarding the content of the technical regulations by means of a uniform, independent and non-manipulable test. One of the prerequisites for this is that the questions relate solely to the content of the standards and guidelines, as "good practice" is ultimately often a matter of opinion and does not usually allow for clearly right or wrong answers. The restriction to questions that can be answered clearly on the basis of the standard, in conjunction with the test design (always exactly four possible answers, only one of which is correct), leads in some cases to relatively challenging tasks, while some other questions relate to aspects that are of little relevance to the accuracy of the measurement results. However, both cases are compensated for by assigning different scores (from 1 to 3 points) to the questions. The assessment scheme also aims to ensure that not every single question has to be answered correctly. The target is simply to achieve more than half of the maximum score. In case of doubt, only 6 out of 15 questions need to be answered correctly. In our view, the use of paper files is the only way to conduct the test without the need to memorise all the standards, but at the same time without the possibility of manipulation. An alternative would be to provide computers or tablets without internet access. However, this would be disproportionate to the objective of the theory test. The test was deliberately designed to be low-threshold, without any specific obligations or consequences for participants. Our observation in the various proficiency tests so far is that the test results correlate well with the participants' specialist knowledge. People who are confident in the technical regulations usually have no problem passing the test. So far, those who have been unsuccessful are mainly people who, in their everyday work, limit themselves to implementing the most important points of their measuring institute's work instructions without actively engaging with the underlying standards and guidelines.

Ammonia (NH_3) and nitrous oxide (N_2O) were suggested by one participant as additional components. If this request is made more frequently in future, an implementation in our proficiency tests can be considered.

8. Concluding Remark

The measurement results in the stack emission proficiency tests in 2025 have changed only slightly compared to 2024. For many components, the measurement results in the dust and gas proficiency tests are still worse than in the years before the SARS-CoV-2 pandemic. This applies in particular to discontinuous components such as total dust and individual organic substances (ethylbenzene, toluene, and xylene). In the case of total dust, a correlation between the measurement results and the probes used is apparent. Participants who used sharp-edged probes with a diameter of at least 10 mm achieved significantly better measurement results on average than participants who used thick-edged and/or damaged nozzles with smaller diameters. For most participants, underestimations for heavy metals are a direct consequence of under-estimations for total dust. The addition of hydrochloric acid (HCl) to the digestion solution may have a negative effect on the recovery of heavy metals, but this observation is based on only a few measurement results so far and could therefore also be a false conclusion. In the case of the organic components ethylbenzene, toluene, and xylene, the causes of the increasingly frequent underestimates in recent years are unclear, but the participants seem to be gradually identifying and eliminating sources of error. In any case, the underestimates observed there recently are declining.

In the odour proficiency test, the participants achieved slightly below-average results overall in 2025, but the small number of participants (usually 15-20) in this proficiency test leads to enormous fluctuations in the statistics. This year, some participants were again unsuccessful due to typical errors in olfactometry. These included zero sample errors and dilution step omissions by the assessors, from which the correct conclusions were not drawn, as well as errors in determining an adequate starting dilution.

Since 2024, we have also been offering a short version of the dust and gas proficiency test. This version of the proficiency test, which is reduced to 6 evaluated measurements, is specifically aimed at those participants who do not wish to be authorised in accordance with §29b BImSchG (Federal Immission Control Act) and the 41. BImSchV (41st Federal Immission Control Ordinance). The short version is planned with measurements only from Tuesday to Thursday, leaving Monday and Friday completely free for arrival and departure. As the short version does not meet the requirements of the LAI specifications and is therefore not suitable for an authorisation in accordance with 41. BImSchV, this new programme is unfortunately of no use to the majority of our participants, the authorised measuring bodies in Germany. However, around 15-20% of our participants now come from abroad. These measurement institutes do not generally seek §29b-authorisation in Germany and are showing increasing interest in the short version of our dust and gas proficiency test.

Kassel, 16th February 2026

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