National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Inter-laboratory comparison filter weighing 2011

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GGD Amsterdam

Colophon

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This study has been conducted at the own initiative of the participants in this comparison with the aim of checking the quality of reference measurements of particulate matter.

Abstract

Inter-laboratory comparison filter weighings 2011

Reference measurements of particulate matter (PM) in ambient air are performed by sampling a known volume of air through a filter for 24 hours. By measuring the mass difference of the filter before and after sampling the concentration of particulate matter may be determined. For this purpose filters are weighed at least twice under strict conditions of temperature and relative humidity, as prescribed in European Standards EN 12341 and EN 14907.

In order to investigate whether application of this procedure – when applied by different laboratories – leads to comparable results, an inter-laboratory comparison has been conducted. For this purpose one pilot laboratory has sent sets of 12 filters typically used for low-volume sampling (8 loaded, 4 blanks) to other participating laboratories. After having been weighed by participants the filters have been reweighed by the pilot laboratory.
In addition, the weighing conditions in participants' weighing rooms have been monitored using portable temperature/humidity meters. The monitoring results indicate that none of the laboratories has problems in meeting the requirements for weighing conditions given in EN 12341 and EN 14907.

Evaluation of the results of the comparison shows that – when average results of the pilot laboratory are used as reference values and En scores are calculated using estimated weighing uncertainties – all results but one correspond with the reference values.

From the results the inter-laboratory (reproducibility) uncertainty of the weighing results has been calculated and has been found to be 0,078 mg for a confidence level of 95 % for all filters. This corresponds to a relative uncertainty of 2,8% at the level of daily limit value for PM_{10}.

Keywords:
particulate matter, PM, reference measurements, filter weighing, comparability

Rapport in het kort

Inter-laboratorium vergelijking filterwegingen 2011

Referentie-metingen van fijnstof (PM) in buitenlucht vinden plaats door gedurende 24 uur een bekend volume lucht door een filter te zuigen. Door bepaling van het verschil in de massa van het filter voor en na dit proces kan de concentratie fijnstof worden berekend. Het filter wordt hiertoe minimaal tweemaal gewogen onder nauwkeurig bepaalde omgevingscondities (temperatuur, relatieve luchtvochtigheid). Een en ander is vastgelegd in de Europese normen EN 12341 en EN 14907.

Om te onderzoeken in hoeverre deze procedure bij verschillende meetinstanties tot vergelijkbare resultaten leidt, is een vergelijkend onderzoek verricht. Hierbij zijn door één laboratorium 12 verschillende filters zoals gebruikt bij "low-volume sampling" (8 beladen, 4 blancos) toegezonden aan andere deelnemers aan het onderzoek. Na weging door deelnemers zijn de filters door het eerste laboratorium opnieuw gewogen. Tevens zijn gedurende de wegingen de omgevingscondities in de weegruimtes gevolgd m.b.v. draagbare temperatuur/vochtigheidsmeters. Hieruit blijkt dat geen van de laboratoria problemen heeft om de eisen voor weegcondities gegeven in EN 12341 en EN 14907 te halen.

Evaluatie van de resultaten van het onderzoek toont aan dat - wanneer de gemiddelde weegresultaten van eerste meetinstantie als referentiewaarden worden genomen, en En-scores worden berekend aan de hand van geschatte meetonzekerheden – op één na alle resultaten overeenkomen met de referentiewaarden bij een betrouwbaarheid van 95 %.

Uit de resultaten kan tevens de inter-laboratorium onzekerheid voor filterwegingen worden bepaald. Deze bedraagt 0,078 mg bij een betrouwbaarheid van 95 %. Dit komt overeen met een relatieve onzekerheid van 2,8% bij een massa overeenkomend met de daggemiddelde grenswaarde voor PM_{10}.

Trefwoorden:
fijnstof, PM, referentie-metingen, filterweging, vergelijkbaarheid

Contents

Summary

This report describes the methods used, results and evaluation of an inter-laboratory comparison for the weighing of filters used for sampling particulate matter in ambient air, held in April 2011.
Determination of masses of filters is an essential part of the application of the European reference methods for the measurement of concentrations of PM_{10} and $PM_{2.5}$ in ambient air. The procedures for filter weighing are described in European Standards 12341 [1] and EN 14907 [2]. They comprise subsequent weighings under strict conditions of temperature and relative humidity of the weighing facilities.

This comparison is one of the activities organized by air monitoring networks in Belgium and the Netherlands for harmonization of monitoring methods. Participants in the comparison are LANUV (DE), ISSeP (BE), VMM (BE), Demokritos (GR), DCMR (NL), Province of Limburg (NL), RIVM (NL) and GGD Amsterdam (NL, pilot laboratory).

The results of the comparison show that:

- On average, filter masses decrease during the sequence "weighing by pilot – weighing by participant – reweighing by pilot". The average decrease is 0,027 mg. For some filters the decrease is > 0,1 mg. By taking these changes into account in the uncertainty budget adverse effects on participants' performances is avoided.
- One participant has experienced some difficulties in keeping results of duplicate weighings within the requirements of [1] and [2].
- Difference in results of participants and pilot laboratory tend to be slightly negative, with an average difference of -0,014 mg
- None of the participant has problems in keeping its weighing room conditions within the required ranges given in EN 12341 and EN 14907 (20 ± 1 °C; 50 ± 5 %rh).

Evaluation of the results based on En scores calculated relative to the results of the pilot laboratory reveals excellent performance of the laboratories on average, with only one result not meeting the $En \leq 1$ criterion.

When normalized results are used to evaluate the method performance using ISO 5725 part2 statistics, the expanded uncertainty for reproducibility for all results is found to be 0,078 mg. This corresponds to a relative uncertainty of 2,8% at the level of daily limit value for PM_{10}.

1 Introduction

Determination of masses of filters is an essential part of the application of the European reference methods for the measurement of concentrations of PM_{10} and $PM_{2.5}$ in ambient air. The procedures for filter weighing are described in European Standards 12341 [1] and EN 14907 [2][1]. They comprise subsequent weighings under strict conditions of temperature and relative humidity of the weighing facilities.
Such conditions are essential in order to avoid significant changes in filter masses due to (de)sorption of water vapour – both by filter materials and particulate matter – and evaporation of semi-volatile constituents of particulate matter [3].

In order to investigate the comparability of the mass determination of filters – both loaded and blank filters – an inter-laboratory comparison has been conducted in March 2011. Participating laboratories are LANUV (Essen, Germany), Demokritos (Athens, Greece), VMM (Antwerp, Belgium), ISSeP (Liège, Belgium), RIVM (Bilthoven, Netherlands), DCMR (Schiedam, Netherlands), Province of Limburg (Maastricht, Netherlands) and GGD Amsterdam (Amsterdam, Netherlands).

This report describes the methods used, results and findings of this comparison.

[1] EN 12341 and 14907 are currently revised and merged into a new EN 12341. Some of the changes resulting from this revision have already been used in the evaluation of the results of this study.

2 Methods

The comparison is based on the weighing of filters typically used for low-volume sampling in accordance with [1] and [2], with a diameter of 47 mm.
Fifty-six loaded filters and 28 blank filters have been collected by the pilot laboratory (GGD Amsterdam) from the following sources:

- 14 Whatman QMA quartz-fibre filters from two urban monitoring sites (RIVM)
- 14 Whatman QMA quartz-fibre filters from a rural seaside monitoring site (RIVM)
- 14 Whatman QMA quartz-fibre filters from various urban monitoring sites (GGD)
- 14 blank Whatman QMA quartz-fibre filters (GGD)
- 14 Pall Tissuquartz-UP quartz-fibre filters from two monitoring sites (VMM)
- 14 blank Pall Tissuquartz-UP quartz-fibre filters (VMM).

All filters have been conditioned in the pilot laboratory's weighing facilities for a minimum of 48 hours at 20 °C and 50% relative humidity (%rh). After the conditioning the filters have been subjected to three consecutive weighings, with a minimum interval of 24 hours between weighings (from April 6 to 8). When the results of the first and third weighing differ by less than 0,040 mg, the mean results for all filters are used as the "mass before despatch". For the filters for which the difference was more than 0,040 mg, the mean of the second and third weighings is used (filters B14, C17, C27).

Subsequently, the set of filters has been divided into seven subsets of twelve, each containing two filters of the sources mentioned above, and despatched to the other participants.
In addition, all participants except Demokritos have been supplied with portable temperature/relative humidity sensors set to log readings every 10 minutes. Filters and sensors have been transported to the participants in cool boxes.
The sensors have been used to record temperatures and relative humidities in the participants' weighing facilities over a period enclosing the actual periods during which weighings have been performed.

All participants have stored, conditioned and weighed the filters in their own facilities according to the procedure described in [1] and [2]: conditioning for a minimum of 48 hours followed by a first weighing, conditioning again for a minimum of 24 hours followed by a second weighing.
The sensors have been placed next to the filters during the whole procedure.

After their return filters and sensors have been placed in the pilot laboratory's weighing room. Filters have been reconditioned and reweighed three times following the prescribed conditions (from April 26 to 29). The mean of the weighing results has been as described above and is used as the "mass after return".
The sensors have been re-calibrated in the weighing room by comparison of their readings with those of a calibrated dew point meter. Results of the calibrations have been used to correct the readings.

In Annex 1 the codes and sources of the filters provided to the participants are given anonymously.

3 Results and evaluations

3.1 Results

3.1.1 General

The results of the weighings are presented anonymized in Annex 2 as follows:

- filter codes are given in the left hand column;
- the second and third columns give the weighing results of the pilot laboratory before and after despatch to participants;
- the fourth column gives the mean result that is used as the reference value;
- the fifth and sixth columns give the two weighing results of each participant;
- the seventh column gives the mean participant results
- the eighth column shows the difference between participants' mean and reference values.

3.1.2 Results of the pilot laboratory

From the results of the weighings performed by the pilot laboratory before and after despatch it is observed that, on average, the mass "after return" is lower than that "before despatch", the mean difference being 0,027 mg. The results for filter A23 have been excluded from the calculations, since the decrease of 0,62 mg is outside the range of plausible mass losses. When considering different filter types and distinguishing between loaded and blank filters, the following is observed:

- loaded code A filters show an average decrease of 0,049 mg in mass, while blank code A filters do not gain or lose mass;
- loaded code C filters (of the same type as code A) have an average decrease of 0,043 mg;
- loaded code B filters decrease in mass by 0,051 mg on average, while the code B blanks increase in mass by 0,020 mg on average;
- for some filters the mass decrease exceeds 0,1 mg.

The mass changes of the loaded filters are plotted in Figure 1 below against the masses of PM originally determined on the filters. The relation observed between the mass change and the filter loading suggests a proportionality between the mass loss and the mass of PM on the filter. This may be an indication for losses of (semi-)volatile constituents of the PM.
It is noted that no difference is observed in behaviour between Whatman QMA and Pall Tissuquartz filter types for the loaded filters whereas Pall Tissuquartz blank filters show a slight increase in mass upon return to the pilot laboratory. This may be a consequence of the fact that the Whatman QMA filters have been preconditioned before use by exposure to high relative humidities at 20 °C for 3 weeks.

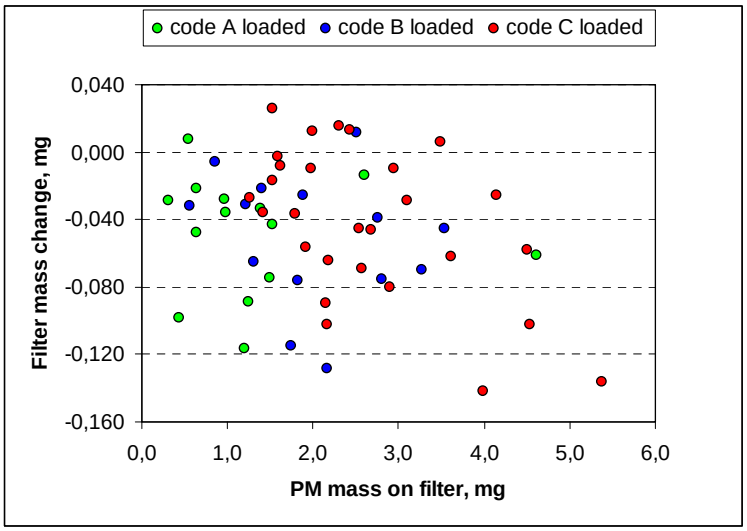


Figure 1. Mass changes of loaded filters after return to the pilot laboratory.

3.1.3 Results of the other participants

Differences between mean participants' results and reference values range from -0,076 mg to +0,063 mg (when excluding the results for filter A23), with an average of -0,014 mg. All differences for blank filters but for one (+0,001 mg) are slightly negative with an average of -0,017 mg.

Results marked in orange indicate a difference between consecutive weighings in excess of the requirements of EN 14907 (0,040 mg for blank filters, 0,060 mg for loaded filters). These show that Lab 4 has had some problems in keeping differences between duplicate weighings within required ranges.

Corrected results of measurements of temperatures and relative humidities in weighing facilities of participants (one-hour average values) are presented graphically in Annex 3.

The diagrams show that all laboratories have facilities capable of meeting the requirements of EN 12341 and EN 14907 for control of temperature and relative humidity. A closer study of the relative humidity fluctuations shows that all laboratories will be capable of meeting stricter requirements of control of relative humidity as proposed in the draft revision of EN 12341 (a maximum variation of relative humidity of ±2,5 %rh).

3.2 Evaluation

3.2.1 Laboratory performance

For the evaluation of the results of the comparison the *En*-score model has been applied. The parameter *En* is calculated as follows [4]:

$$En = \frac{\left|x_p - x_{ref}\right|}{2 \cdot \sqrt{u_p^2 + u_{ref}^2}}$$

where

x_p = participant's result
x_{ref} = reference value
u_p = measurement uncertainty of the participant's result
u_{ref} = measurement uncertainty of the reference value.

An En-score ≤ 1 is an indication of comparability of the participant's result and the reference value at a level of confidence of 95 %.

The mean results of the two weighings of each filter performed by the participants have been taken as values of x; the mean results of the weighings before and after performed by the pilot laboratory have been taken as reference values.

The measurement uncertainty of the values of x has been estimated based on the approach described in the latest draft revision of EN 12341 as follows:

$$u_{x,p}^2 = u_{cal}^2 + u_{zd}^2 + u_{buoy}^2 + u_{\Delta x,p}^2$$

where

u_{cal} = uncertainty in the calibration of the balance used for the weighings
u_{zd} = uncertainty due to zero drift of the balance
u_{buoy} = uncertainty due to differences in buoyancy;
$u_{\Delta x,p}$ = uncertainty due to the difference between the two weighing results of the participants.

The first three uncertainty contributions have been calculated from the maximum criteria and default values given in the latest draft revision of EN 12341, resulting in a value of 0,0156 mg. The fourth contribution is calculated as:

$$u_{\Delta x,p}^2 = \frac{\left(x_{p,2} - x_{p,1}\right)^2}{12}$$

where $x_{p,1}$ and $x_{p,2}$ are the two participant's weighing results.

The uncertainty of the reference values is estimated similarly as

$$u_{x,ref}^2 = u_{cal}^2 + u_{zd}^2 + u_{buoy}^2 + u_{\Delta x,ref}^2$$

where $u_{\Delta x,ref}$ is the uncertainty due to the difference between the results of the pilot laboratory before and after despatch of the filters.

The uncertainty due to the difference between the two weighing results of the pilot laboratory has been calculated by assuming a uniform distribution as:

$$u^2_{\Delta x,ref} = \frac{\left(x_{ref,2} - x_{ref,1}\right)^2}{12}$$

where $x_{ref,1}$ and $x_{ref,2}$ are the weighing result before despatch and after return of the filters.

Because of potential differences in weighing room relative humidities between participants and pilot laboratory an additional (default) uncertainty contribution has been added based on the maximum criteria for blank and loaded filter masses given in the latest draft revision of EN 12341:

- 0,060/√3 µg for loaded filters;
- 0,040/√3 µg for blank filters.

The results of all calculations are given in Annex 4. These show that for all samples except one for Lab 4, En scores are ≤ 1, indicating correspondence with the reference values at 95% probability.

In order to evaluate the mutual comparability of the results of all participants their results have been normalized to the reference values as follows:

$$x_n = \frac{x}{x_{ref}}$$

3.2.2 Method performance

Uncertainty from differences

The uncertainty of the weighing method may be estimated from the differences of the results of participants and the pilot laboratory as follows:

$$u^2 = \frac{\sum_1^n \left(x_{i,p} - x_{i,ref}\right)^2}{2n}$$

where

$x_{i,p}$ = participant's result for sample *i*
$x_{i,ref}$ = reference value for sample *i*
n = number of samples (83).

The resulting uncertainty is 0,020 mg.

When using results for loaded filters only, the uncertainty is 0,022 mg and the expanded uncertainty (95% confidence) is 0,044 mg.

ISO 5725 approach

The availability of normalized measurement results permits the evaluation of the method performance by application of the statistics of ISO 5725 part 2 [5] by treating normalized results for one laboratory as replicate results. Normalized results are calculated as follows:

$$x_{i,n} = \frac{x_{i,p}}{x_{i,ref}}$$

where

$x_{i,p}$ = participant's result for sample *i*
$x_{i,ref}$ = reference value for sample *i*

Calculation of ISO 5725 statistical parameters for results of all filters yields the following results.

Repeatability RSD*	0,00016
Between-laboratory RSD	0,00015
Reproducibility RSD	0,00022

** RSD = relative standard deviation*

These results show that the weighing method used is quite robust: the ratio of reproducibility and repeatability standard deviations is < 2.

Using the mean mass of all filters the absolute statistics may be estimated.

Repeatability SD** (mg)	0,021
Between-laboratory SD (mg)	0,020
Reproducibility SD (mg)	0,029

*** SD = standard deviation*

When differentiating between results for loaded filters and blank filters (although the number of blank filters per participant is relatively small), the following values are obtained.

	Loaded filters	*Blank filters*
Repeatability RSD	0,00015	0,00015
Between-laboratory RSD	0,00018	0,00006
Reproducibility RSD	0,00024	0,00017
Repeatability SD (mg)	0,021	0,019
Between-laboratory SD (mg)	0,025	0,008
Reproducibility SD (mg)	0,033	0,021

When using reproducibility standard deviations as measures of the uncertainties of weighing results of loaded and blank filters, the method uncertainty may be calculated by combining both results in quadrature:

$$u_m^2 = s_{R,l}^2 + s_{R,b}^2$$

where $s_{R,l}$ and $s_{R,b}$ are the reproducibility standard deviations for loaded and blank filter weighings, respectively.
The combination results in an uncertainty value of 0,039 mg and an expanded uncertainty (95% confidence) of 0,078 mg.
This value is considerably higher than the value obtained from differences in results between participants and pilot laboratory.

4 Conclusions

Methods

The comparison involves the transport of filters to and from participating laboratories with filter weighings performed by the pilot laboratory before and after both transportations. It is observed that during this process the mass of loaded filters on average decreases, potentially due to losses of (semi)volatile constituents of particulate matter. No differences are observed between the two different filter types involved- Whatman QMA and Pall Tissuquartz - although the Whatman QMA filters have been preconditioned at high relative humidities, which may make losses of water an obvious cause of mass decrease.

The mass decreases are incorporated into the uncertainty budget used for the evaluation of laboratory performances.

Laboratory performance

Overall, the results of the laboratory performance evaluation are satisfactory. Only one laboratory has problems for two filters in meeting requirements for duplicate filter weighings given in EN 12341 and EN 14907.
Evaluation by En-scores shows that only one result (of the same laboratory as above) slightly exceeds the performance requirement of En ≤ 1.

A study of the control of temperatures and relative humidities in the weighing facilities of participants shows that these laboratories will all be capable of meeting stricter requirements of relative humidity control (within ± 2,5% expressed as hourly averages) as proposed in the draft revision of EN 12341.

Method performance

The method performance, expressed as the reproducibility standard deviation of weighing results calculated according to ISO 5725 part 2 is 0,029 mg. When results of loaded filters only are used the reproducibility standard deviation increases slightly to 0,033 mg.

By combining uncertainties for the weighing of loaded and blank filters expressed as reproducibility standard deviations, an uncertainty of 0,039 mg results, leading to an expanded method uncertainty of 0,078 mg.
When using this value to calculate the relative uncertainty contribution of the weighing process to the overall uncertainty of the measurement of PM, expressed at the limit values of PM_{10} and $PM_{2.5}$, the following values are obtained:

- PM_{10} at 50 µg/m3 (daily limit value): 2,8%
- $PM_{2.5}$ at 30 µg/m3 (pseudo-daily limit value [6]): 4,6%.

These values suggest that the uncertainty contributions of the filter conditioning and weighing process as obtained in this study are relatively small considering that the maximum allowed uncertainty is 25%.

References

[1] EN 12341: 1998. Air quality – Determination of the PM_{10} fraction of suspended particulate matter – reference method and field test procedure to demonstrate reference equivalence of measurement methods.

[2] EN 14907: 2005. Ambient air quality- Reference gravimetric measurement method for the demonstration of the $PM_{2,5}$ mass fraction of suspended particulate matter.

[3] CEN/TC 264 WG 15. Unpublished results.

[4] ISO 17043: 2010. Conformity assessment – general requirements for proficiency testing.

[5] ISO 5725:1994 part 2. Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.

[6] Guidance to the Demonstration of Equivalence of Ambient Air Monitoring Methods, ed. January 2010. Available at http://ec.europa.eu/environment/air/quality/legislation/assessment.htm.

Annex 1 – Filters supplied

Laboratory 1 - VMM

Filter Code	*Source*	*PM mass (mg)*
A9	GGD	0,438
A10	GGD	0,636
B9	VMM	1,818
B10	VMM	2,160
C9	RIVM	2,154
C10	RIVM	2,900
C23	RIVM	4,536
C24	RIVM	1,921
A23	Whatman QMA blank	
A24	Whatman QMA blank	
B23	Pall Tissuquartz blank	
B24	Pall Tissuquartz blank	

Laboratory 2 - LANUV

Filter Code	*Source*	*PM mass (mg)*
B3	VMM	1,404
A18	Whatman QMA blank	
A17	Whatman QMA blank	
A4	GGD	1,492
A3	GGD	0,977
C18	RIVM	2,182
C17	RIVM	2,173
C4	RIVM	1,414
C3	RIVM	4,511
B18	Pall Tissuquartz blank	
B17	Pall Tissuquartz blank	
B4	VMM	1,306

Laboratory 3 - ISSeP

Filter Code	*Source*	*PM mass (mg)*
A7	GGD	1,197
A8	GGD	1,242
A21	Whatman QMA blank	
A22	Whatman QMA blank	
B7	VMM	1,752
B8	VMM	2,810
B21	Pall Tissuquartz blank	
B22	Pall Tissuquartz blank	
C7	RIVM	3,614
C8	RIVM	1,615
C21	RIVM	5,375
C22	RIVM	3,996

Laboratory 4 - Demokritos

Filter Code	*Source*	*PM mass (mg)*
A13	GGD	1,529
A14	GGD	1,390
A27	Whatman QMA blank	
A28	Whatman QMA blank	
B13	VMM urban	0,562
B14	VMM urban	3,543
B27	Pall Tissuquartz blank	
B28	Pall Tissuquartz blank	
C13	RIVM	1,267
C14	RIVM	2,680
C27	RIVM	2,304
C28	RIVM	1,522

Laboratory 5 - DCMR

Filter Code	*Source*	*PM mass (mg)*
A12	GGD	4,616
A26	Whatman QMA blank	
B25	Pall Tissuquartz blank	
B26	Pall Tissuquartz blank	
C12	RIVM	1,584
B12	VMM	1,223
B11	VMM	1,890
A11	GGD	2,605
A25	Whatman QMA blank	
C25	RIVM	2,430
C11	RIVM	3,103
C26	RIVM	1,528

Laboratory 6 – Prv Lmb

Filter Code	*Source*	*PM mass (mg)*
A5	GGD	0,553
B5	VMM	2,502
C5	RIVM	2,941
A6	GGD	0,961
B6	VMM	3,278
C6	RIVM	4,141
A19	Whatman QMA blank	
B19	Pall Tissuquartz blank	
C19	RIVM	1,976
A20	Whatman QMA blank	
B20	Pall Tissuquartz blank	
C20	RIVM	1,797

Laboratory 7 - RIVM

Filter Code	*Source*	*PM mass (mg)*
B15	Pall Tissuquartz blank	
B16	Pall Tissuquartz blank	
C1	RIVM	3,496
C2	RIVM	2,572
C15	RIVM	2,537
C16	RIVM	1,991
A2	GGD	0,308
A1	GGD	0,634
A16	Whatman QMA blank	
A15	Whatman QMA blank	
B1	VMM	2,755
B2	VMM	0,860

Annex 2 – Results of weighings

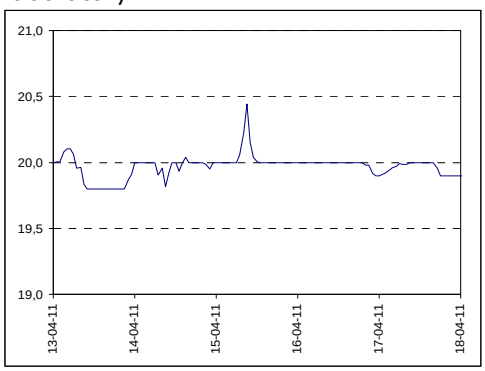
Results of weighings, all in mg.

Filter code	Pilot			Participant			Difference part - pilot
	Before	After	Mean	Result 1	Result 2	Mean	
A9	151,844	151,746	151,795	151,823	151,797	151,810	0,015
A10	148,340	148,292	148,316	148,332	148,331	148,332	0,015
B9	127,376	127,300	127,338	127,349	127,336	127,343	0,005
B10	97,290	97,162	97,226	97,268	97,236	97,252	0,026
C9	150,088	149,998	150,043	150,058	150,040	150,049	0,006
C10	151,226	151,145	151,186	151,201	151,178	151,190	0,004
C23	146,546	146,434	146,490	146,529	146,492	146,511	0,021
C24	144,661	144,604	144,633	144,650	144,641	144,646	0,013
A23	**147,803**	**147,182**	**147,492**	147,795	147,795	147,795	**0,303**
A24	145,155	145,129	145,142	145,131	145,135	145,133	-0,009
B23	100,629	100,640	100,635	100,625	100,642	100,634	-0,001
B24	104,553	104,566	104,559	104,554	104,557	104,556	-0,004
B3	132,719	132,698	132,709	132,657	132,647	132,652	-0,057
A18	146,051	146,054	146,053	146,049	146,048	146,049	-0,004
A17	147,249	147,249	147,249	147,241	147,244	147,243	-0,006
A4	156,371	156,296	156,334	156,313	156,309	156,311	-0,023
A3	147,539	147,503	147,521	147,523	147,500	147,512	-0,010
C18	145,348	145,284	145,316	145,292	145,264	145,278	-0,038
C17	146,026	145,905	145,965	145,946	145,951	145,949	-0,017
C4	140,083	140,047	140,065	140,029	140,032	140,031	-0,035
C3	142,125	142,067	142,096	142,073	142,063	142,068	-0,028
B18	104,683	104,711	104,697	104,659	104,655	104,657	-0,040
B17	109,632	109,655	109,644	109,603	109,604	109,604	-0,040
B4	101,421	101,356	101,389	101,359	101,350	101,355	-0,034
A7	148,672	148,555	148,614	148,575	148,565	148,570	-0,043
A8	155,690	155,601	155,646	155,609	155,606	155,608	-0,038
A21	146,256	146,302	146,279	146,261	146,263	146,262	-0,017
A22	146,191	146,199	146,195	146,192	146,192	146,192	-0,003
B7	102,685	102,569	102,627	102,555	102,547	102,551	-0,076
B8	100,666	100,590	100,628	100,557	100,570	100,564	-0,065
B21	100,826	100,858	100,842	100,813	100,812	100,813	-0,029
B22	99,980	100,018	99,999	99,965	99,966	99,966	-0,034
C7	141,661	141,598	141,630	141,571	141,575	141,573	-0,057
C8	148,082	148,074	148,078	148,072	148,069	148,071	-0,008
C21	148,312	148,176	148,244	148,175	148,167	148,171	-0,073
C22	145,632	145,490	145,561	145,510	145,500	145,505	-0,056

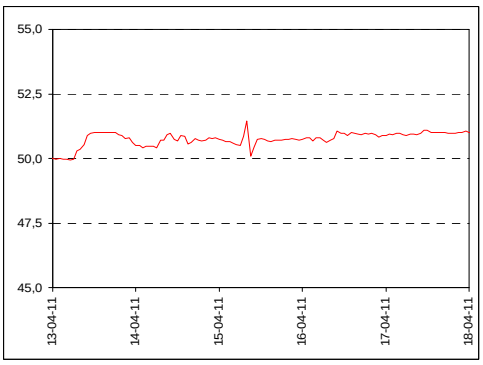
Filter code	Pilot			Participant			Difference part - pilot
	Before	After	Mean	Result 1	Result 2	Mean	
A13	155,144	155,101	155,122	155,125	155,135	155,130	0,008
A14	149,259	149,226	149,242	149,185	149,240	149,213	-0,030
A27	146,453	146,440	146,447	146,420	146,445	146,433	-0,014
A28	145,505	145,479	145,492	145,475	145,480	145,478	-0,014
B13	94,330	94,298	94,314	94,305	94,295	94,300	-0,014
B14	102,154	102,101	102,127	102,080	102,055	102,068	-0,060
B27	108,926	108,927	108,927	108,840	108,880	108,860	-0,067
B28	104,196	104,200	104,198	104,130	104,165	104,148	-0,051
C13	150,740	150,713	150,727	150,695	150,745	150,720	-0,007
C14	150,513	150,467	150,490	150,445	150,480	150,463	-0,027
C27	144,848	144,849	144,849	144,780	144,800	144,790	-0,059
C28	144,518	144,502	144,510	144,490	144,475	144,483	-0,027
A12	149,331	149,270	149,301	149,326	149,331	149,329	0,028
A26	149,369	149,391	149,380	149,369	149,381	149,375	-0,005
B25	104,226	104,265	104,246	104,228	104,238	104,233	-0,012
B26	100,663	100,707	100,685	100,657	100,665	100,661	-0,024
C12	149,908	149,905	149,906	149,910	149,908	149,909	0,003
B12	103,066	103,035	103,051	103,049	103,054	103,052	0,001
B11	117,965	117,939	117,952	117,944	117,955	117,950	-0,003
A11	154,230	154,216	154,223	154,243	154,238	154,241	0,017
A25	147,773	147,791	147,782	147,778	147,788	147,783	0,001
C25	143,797	143,794	143,796	143,774	143,786	143,780	-0,016
C11	150,665	150,636	150,651	150,653	150,632	150,643	-0,008
C26	142,144	142,157	142,151	142,220	142,194	142,207	0,056
A5	154,707	154,714	154,710	154,715	154,716	154,716	0,005
B5	102,409	102,421	102,415	102,397	102,388	102,393	-0,023
C5	141,423	141,414	141,419	141,422	141,418	141,420	0,002
A6	155,377	155,349	155,363	155,382	155,381	155,382	0,019
B6	99,454	99,385	99,420	99,436	99,434	99,435	0,016
C6	144,105	144,079	144,092	144,096	144,101	144,099	0,007
A19	146,408	146,424	146,416	146,409	146,414	146,412	-0,005
B19	96,559	96,601	96,580	96,568	96,573	96,571	-0,010
C19	145,453	145,430	145,441	145,451	145,453	145,452	0,011
A20	147,115	147,131	147,123	147,116	147,120	147,118	-0,005
B20	99,212	99,216	99,214	99,210	99,210	99,210	-0,004
C20	147,439	147,402	147,420	147,428	147,435	147,431	0,011
B15	103,028	103,038	103,033	103,006	103,001	103,004	-0,030
B16	106,506	106,501	106,504	106,491	106,473	106,482	-0,022
C1	142,078	142,084	142,081	142,062	142,084	142,073	-0,008
C2	152,160	152,091	152,125	152,135	152,136	152,136	0,010
C15	144,354	144,308	144,331	144,319	144,301	144,310	-0,021
C16	145,679	145,691	145,685	145,636	145,648	145,642	-0,043
A2	155,215	155,186	155,200	155,190	155,198	155,194	-0,006
A1	152,286	152,264	152,275	152,260	152,265	152,263	-0,012
A16	148,951	148,933	148,942	148,933	148,931	148,932	-0,010
A15	148,320	148,293	148,307	148,303	148,298	148,301	-0,006
B1	114,928	114,889	114,909	114,902	114,877	114,890	-0,019
B2	132,122	132,116	132,119	132,095	132,074	132,085	-0,035

Annex 3 – Weighing room conditions

Laboratory 1

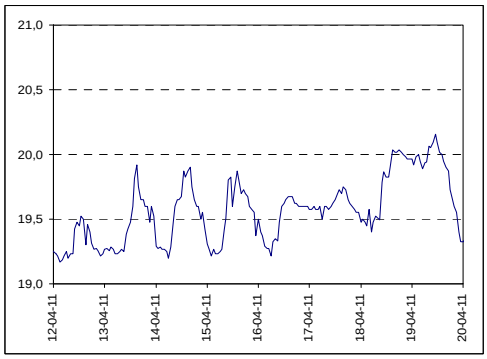


Weighing room temperature (°C)

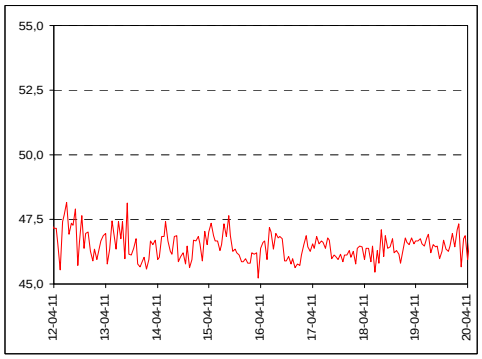


Weighing room relative humidity (%rh)

Laboratory 2

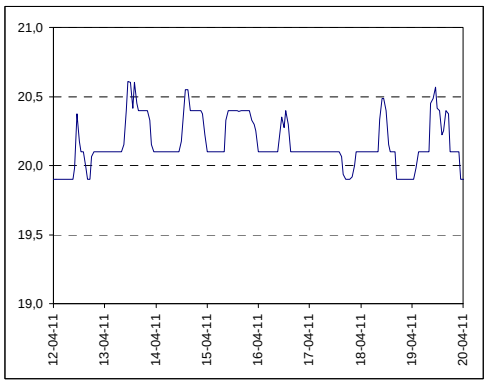


Weighing room temperature (°C)

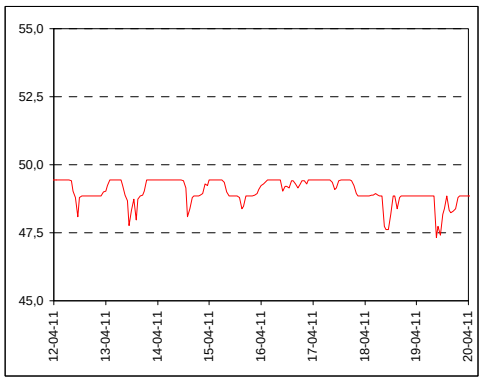


Weighing room relative humidity (%rh)

Laboratory 3

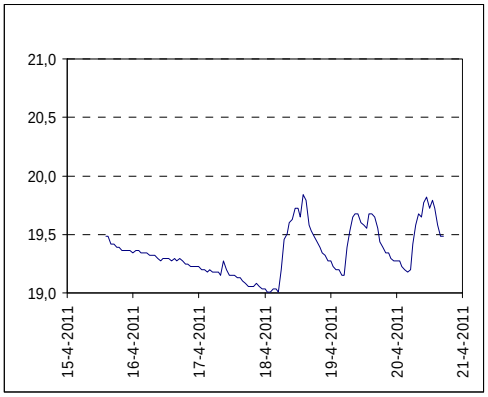


Weighing room temperature (°C)

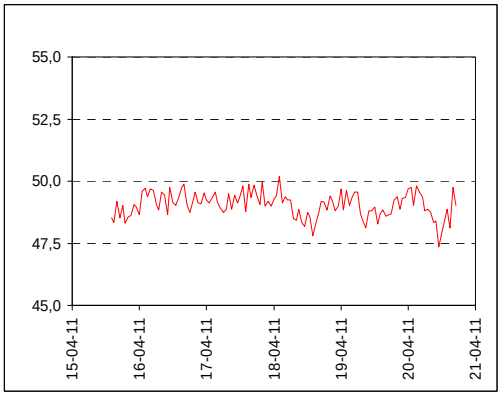


Weighing room relative humidity (%rh)

Laboratory 4

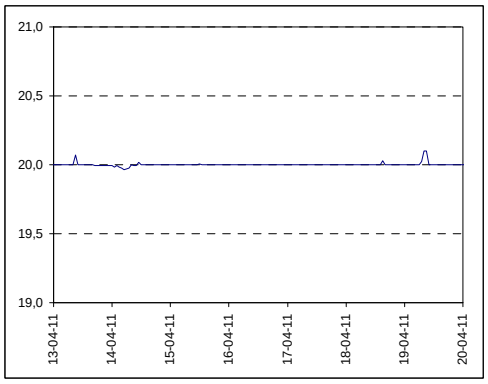


Weighing room temperature (°C)

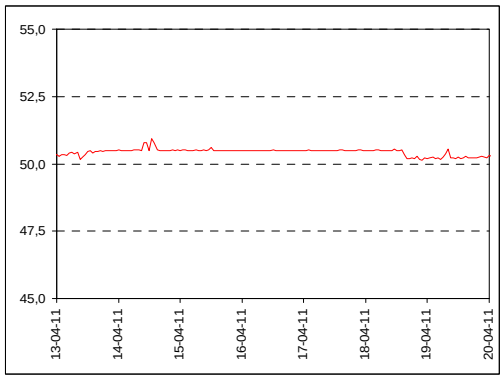


Weighing room relative humidity (%rh)

Laboratory 5

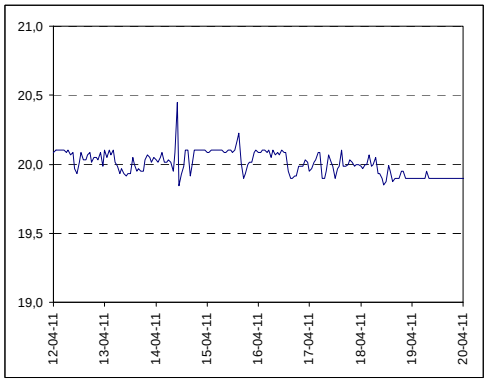


Weighing room temperature (°C)

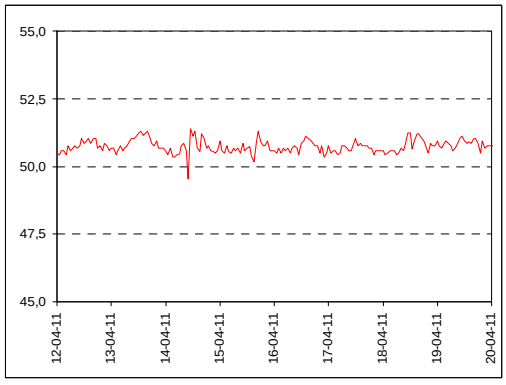


Weighing room relative humidity (%rh)

Laboratory 6

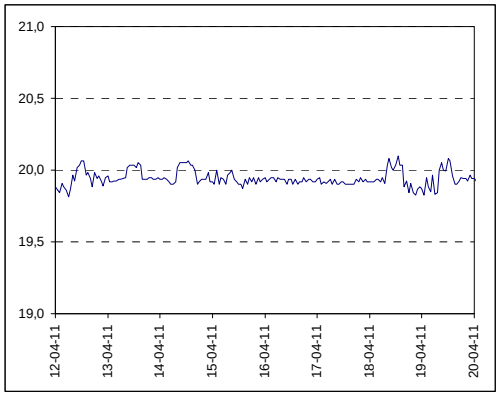


Weighing room temperature (°C)

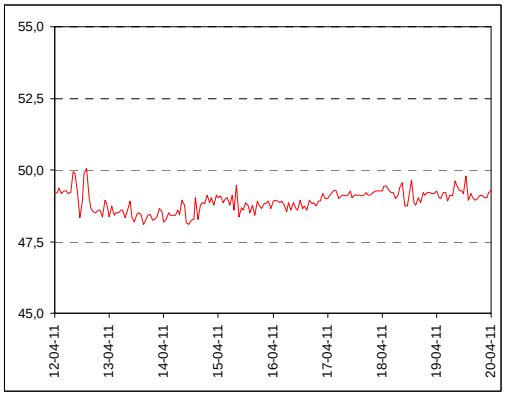


Weighing room relative humidity (%rh)

Laboratory 7



Weighing room temperature (°C)



Weighing room relative humidity (%rh)

Annex 4 – Evaluation

Weighing results, uncertainties (in mg) and En scores.

Filter code	Pilot		Participant		En score
	Reference	Uncertainty	Mean	Uncertainty	
A9	151,795	0,0323	151,810	0,0156	0,15
A10	148,316	0,0209	148,332	0,0156	0,17
B9	127,338	0,0269	127,343	0,0156	0,05
B10	97,226	0,0401	97,252	0,0156	0,23
C9	150,043	0,0301	150,049	0,0156	0,06
C10	151,186	0,0279	151,190	0,0156	0,04
C23	146,485	0,0334	146,511	0,0156	0,25
C24	144,633	0,0226	144,646	0,0156	0,15
A23	**147,492**	**0,1800**	147,795	0,0156	
A24	145,142	0,0174	145,133	0,0156	0,13
B23	100,635	0,0159	100,634	0,0156	0,02
B24	104,559	0,0161	104,556	0,0156	0,06
B3	132,709	0,0168	132,652	0,0156	0,68
A18	146,053	0,0156	146,049	0,0156	0,06
A17	147,249	0,0156	147,243	0,0156	0,10
A4	156,334	0,0265	156,311	0,0156	0,24
A3	147,521	0,0187	147,512	0,0156	0,11
C18	145,316	0,0243	145,278	0,0156	0,42
C17	145,956	0,0334	145,949	0,0156	0,07
C4	140,065	0,0187	140,031	0,0156	0,41
C3	142,096	0,0228	142,068	0,0156	0,31
B18	104,697	0,0176	104,657	0,0156	0,61
B17	109,644	0,0170	109,604	0,0156	0,62
B4	101,389	0,0244	101,355	0,0156	0,38
A7	148,614	0,0370	148,570	0,0156	0,41
A8	155,646	0,0301	155,608	0,0156	0,40
A21	146,279	0,0205	146,262	0,0156	0,25
A22	146,195	0,0158	146,192	0,0156	0,04
B7	102,627	0,0368	102,551	0,0156	0,72
B8	100,628	0,0268	100,564	0,0156	0,70
B21	100,842	0,0182	100,813	0,0156	0,44
B22	99,999	0,0192	99,966	0,0156	0,50
C7	141,630	0,0238	141,573	0,0156	0,63
C8	148,078	0,0158	148,071	0,0156	0,10
C21	148,244	0,0422	148,171	0,0156	0,65
C22	145,561	0,0438	145,505	0,0156	0,48

Filter code	Pilot		Participant		En score
	Reference	Uncertainty	Mean	Uncertainty	
A13	155,122	0,0200	155,130	0,0156	0,09
A14	149,242	0,0183	149,213	0,0156	0,35
A27	146,447	0,0161	146,433	0,0156	0,22
A28	145,492	0,0173	145,478	0,0156	0,22
B13	94,314	0,0181	94,300	0,0156	0,16
B14	102,124	0,0203	102,068	0,0156	0,65
B27	108,927	0,0156	108,860	0,0156	1,04
B28	104,198	0,0156	104,148	0,0156	0,80
C13	150,727	0,0174	150,720	0,0156	0,08
C14	150,490	0,0205	150,463	0,0156	0,31
C27	144,842	0,0162	144,790	0,0156	0,63
C28	144,510	0,0163	144,483	0,0156	0,33
A12	149,301	0,0235	149,329	0,0156	0,31
A26	149,380	0,0168	149,375	0,0156	0,07
B25	104,246	0,0192	104,233	0,0156	0,18
B26	100,685	0,0201	100,661	0,0156	0,35
C12	149,906	0,0156	149,909	0,0156	0,03
B12	103,051	0,0180	103,052	0,0156	0,01
B11	117,952	0,0173	117,950	0,0156	0,03
A11	154,223	0,0161	154,241	0,0156	0,21
A25	147,782	0,0165	147,783	0,0156	0,02
C25	143,787	0,0161	143,780	0,0156	0,09
C11	150,651	0,0177	150,643	0,0156	0,10
C26	142,144	0,0172	142,207	0,0156	0,75
A5	154,710	0,0157	154,716	0,0156	0,06
B5	102,415	0,0160	102,393	0,0156	0,28
C5	141,419	0,0158	141,420	0,0156	0,02
A6	155,363	0,0175	155,382	0,0156	0,22
B6	99,420	0,0255	99,435	0,0156	0,17
C6	144,092	0,0172	144,099	0,0156	0,08
A19	146,416	0,0163	146,412	0,0156	0,07
B19	96,580	0,0196	96,571	0,0156	0,14
C19	145,435	0,0159	145,452	0,0156	0,21
A20	147,123	0,0163	147,118	0,0156	0,08
B20	99,214	0,0156	99,210	0,0156	0,06
C20	147,420	0,0189	147,431	0,0156	0,13
B15	103,033	0,0159	103,004	0,0156	0,47
B16	106,504	0,0157	106,482	0,0156	0,34
C1	142,081	0,0157	142,073	0,0156	0,10
C2	152,125	0,0254	152,136	0,0156	0,11
C15	144,331	0,0204	144,310	0,0156	0,24
C16	145,685	0,0160	145,642	0,0156	0,52
A2	155,200	0,0177	155,194	0,0156	0,08
A1	152,275	0,0168	152,263	0,0156	0,15
A16	148,942	0,0164	148,932	0,0156	0,15
A15	148,307	0,0175	148,301	0,0156	0,09
B1	114,909	0,0192	114,890	0,0156	0,23
B2	132,119	0,0157	132,085	0,0156	0,42

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