TÜV RHEINLAND IMMISSIONSSCHUTZ UND ENERGIESYSTEME GMBH

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DAP-PL-3856.99

Report on the suitability test of the ambient air quality measuring system BAM-1020 with $PM_{2.5}$ pre-separator of the company Met One Instruments, Inc. for the component $PM_{2.5}$

TÜV Report No.: 936/21209919/A
Koeln, March 26, 2010

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TÜV Rheinland Immissionsschutz und Energiesysteme GmbH
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- Determination of emissions and immissions of air pollution and odor substances;
- Inspection of correct installation, function and calibration of continuously running emission measuring devices including systems for data evaluation and remote monitoring of emissions;
- Suitability testing of measuring systems for continuous monitoring of emissions and immissions, and of electronic systems for data evaluation and remote monitoring of emissions

according to EN ISO/IEC 17025.

The accreditation is valid up to 31-01-2013. DAR-register number: DAP-PL-3856.99.

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DAR
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Report on the suitability test of the ambient air quality measuring system BAM-1020 with PM2.5 pre-separator of the company Met One Instruments, Inc. for the component PM2.5

Device tested:	BAM-1020 with PM2.5 pre-separator
Manufacturer:	Met One Instruments, Inc. 1600 NW Washington Blvd. Grants Pass, Oregon 97526 USA
Test period:	Start: July 2008 End: March 2010
Date of report:	March 26, 2010
Report number:	936/21209919/A
Editor:	Dipl.-Ing. Karsten Pletscher T.: +49 221 806-2592 karsten.pletscher@de.tuv.com

Scope of report:

Report		147	Pages
Annex	Page	148	ff.
Manual	Page	190	ff.
Manual	of	96	Pages
Total		285	Pages

Content

1 Summary and proposal for declaration of suitability

1.1 Summary

According to Directive 2008/50/EG of 21 May 2008 on “Air quality and cleaner air for Europe” (replaces Council Directive of 27 September 1996 on ambient air quality assessment and management including its daughter directives 1999/30/EC, 2000/69/EC, 2002/3/EC and the Council Decision 97/101/EC), the methods described in Standard EN12341 „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“ and Standard EN14907 „Ambient air quality - Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter“ serve as reference methods for suspended particle measurement of the respective mass fraction. However, EC member states are free to use any other method in the case of particulate matter for which the Member State concerned can demonstrate displays a consistent relationship to the reference method. In that event the results achieved by that method must be corrected to produce results equivalent to those that would have been achieved by using the reference method.“ (2008/50/EC, Annex VI, B1).

The Guidance “Demonstration of Equivalence of Ambient Air Monitoring Methods” [4] (which was developed by an ad hoc EC task group (Source: http://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf, Version July 2009) describes an equivalence check method for non-standard measurement methods. Although this is not a normative Guide, it is tentatively recommended for application by the CAFE (Clean Air For Europe) committee.

The following limits were applied during suitability testing:

	$PM_{2.5}$
Annual limit value (1 a)	25 µg/m³

as well as for the calculations according to the Guide [4]

	$PM_{2.5}$
Limit value	30 µg/m³

Standard VDI 4202, sheet 1 of June 2002 describes all „Minimum requirements for suitability tests of automatic ambient air measuring systems". General parameters for the related tests are given in Standard VDI 4203, sheet 1 „Testing of automatic measuring systems - General concepts" of October 2001 and furthermore specified in VDI 4203, sheet 3 „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants" of August 2004. The fulfilment of the requirements from VDI standards is mandatory in Germany.

Since all reference values given in these standards are adapted for PM_{10} we recommend applying the following reference values for $PM_{2.5}$ measurement:

	$PM_{2.5}$
B_0	2 µg/m³
B_1	25 µg/m³
B_2	200 µg/m³

Only for B_1 an adaption has been done on the level of the limit value for the annual mean.

Met One Instruments, Inc. has commissioned TÜV Rheinland Immissionsschutz und Energiesysteme GmbH (in Germany), Bureau Veritas,and the National Physical Laboratory (both in the UK) with the performance of a suitability testing of BAM-1020 measuring system for the components PM2.5.

The measuring system BAM-1020 with a PM_{10} pre-separator is already suitability-tested and published in the German Bundesanzeiger.

Declaration of suitability: BAnz.: 12.04.2007 No. 75, page 4139, based on
TÜV-report no. 936/21205333/A of 06.12.2006

The suitability testing of the measuring system was carried out applying the following standards and requirements:

- Standard VDI 4202 sheet 1, „Minimum requirements for suitability tests of automatic ambient air measuring systems – Point-related measurement methods of gaseous and particulate pollutants", June 2002

- Standard VDI 4203 sheet 3, „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants“, August 2004
- Standard EN 14907, „Ambient air quality - Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter“, German version EN 14907: 2005
- Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of July 2009

The measuring system BAM-1020 determines the particulate concentration by a radiometer measuring principle. With the aid of a pump, ambient air is sucked at 16.7 LPM *via* a $PM_{2.5}$ pre-separator (consisting of a PM_{10} sampling inlet and a $PM_{2.5}$ Sharp Cut Cyclone). The dust-laden air is then sucked on a filter tape. The determination of the separated mass of dust on the filter tape is performed after the respective sampling by the radiometric measuring principle of beta-attenuation.

The tests took place in the laboratory and for several months in the field. The following sites were chosen for the field test:

Table 1: Description of the test sites

	Teddington (UK), Summer	Cologne, parking lot (Germany), Winter	Bornheim, Motorway, parking lot (Germany), Summer	Teddington (UK), Winter
Time period	07/2008 – 11/2008	12/2008 – 04/2009	08/2009 – 10/2009	12/2009 – 02/2010
No. of paired values: Candidates	83	77	60	46
Characteristics	Urban background	Urban background	Rural + Motorway	Urban background
Classification of ambient air load	low to average	average to high	low to average	average

The complete test was performed within the scope of the test program „Combined MCERTS and TÜV PM Equivalence Testing Programme". In the context of European harmonization, the test program was developed by British and German test institutes (Bureau Veritas UK Limited, National Physical Laboratory (NPL) and TÜV Rheinland) and comprises the testing of the latest series of suspended particle measuring systems by different manufacturers in the laboratory and at field test sites in the UK and in Germany.

The minimum requirements were fulfilled during suitability testing.

TÜV Rheinland Immissionsschutz und Energiesysteme GmbH therefore suggests publication of BAM-1020 as a suitability-tested measuring system for continuous monitoring of suspended particulate matter $PM_{2.5}$ in ambient air.

1.2 Notification proposal:

On the basis of the positive results that have been achieved, the following recommendation is made for the notification as a suitability-tested measuring system:

Measuring system:
BAM-1020 with PM2.5 pre-separator for PM2.5

Manufacturer:
Met One Instruments, Inc., Grants Pass, USA

Suitability:
For permanent monitoring of suspended particulate matter $PM_{2.5}$ in ambient air(stationary operation).

Measuring ranges during the suitability test:

Component	Certification range	Supplementary range	Unit
$PM_{2.5}$	**0 – 1,000**	-	µg/m³

Software version:
Version 3236-07 5.0.10

Restrictions:
During the check of the tightness of the sampling system within the scope of the suitability test, values of 1.8 % and 2.4 % have been determined. According to the minimum requirement, the leak rate shall not be greater than 1 % of the sample flow rate.

Notices:

1. The requirements according to guide “Demonstration of Equivalence of Ambient Air Monitoring Methods” are fulfilled for the measured component $PM_{2.5}$.
2. For the recordation of $PM_{2.5}$, the system has to be equipped with the following options: Sample heater (BX-830), PM_{10}-sampling inlet (BX-802), $PM_{2.5}$ Sharp Cut Cyclone SCC (BX-807), combined pressure and temperature sensor (BX-596) respectively as an alternative ambient temperature sensor (BX-592).
3. The cycle time duringthe suitability test was 1 h, i.e. an automatic filter change has been performed every hour. Each filter spot has been used one time.
4. The sampling time within the cycle time is 42 min.
5. The measuring system has to be operated in a lockable measuring cabinet.
6. The measuring system is to be calibrated on site in regular intervals by application of the gravimetric $PM_{2.5}$ reference method according to EN 14907.
7. The identical measuring system is also distributed by the company Horiba Europe GmbH, 61440 Oberursel, Germany under the name APDA-371 with $PM_{2.5}$ pre-separator.

Test report:

TÜV Rheinland Immissionsschutz und Energiesysteme GmbH, Cologne, Germany
Report-No.: 936/21209919/A of March 26, 2010

1.3 Summary of test results

Minimum requirement	Specification	Test result	Fulfilled	Page
4 Requirements on instrument design				
4.1 General requirements				
4.1.1 Display for measured values	Shall be available.	The measuring device comprises a display for measured values.	yes	54
4.1.2 Easy maintenance	Maintenance works should be feasible from outside without taking much time and effort.	Maintenance works can be carried out with commonly available tools taking reasonable time and effort.	yes	55
4.1.3 Function test	Particular instruments for function tests shall be considered as part of the device and thus shall be evaluated in the corresponding sub-tests. Test gas units shall indicate readiness by status signals and shall allow direct or remote access to control functions via the measuring system. The measurement uncertainty of the test gas unit shall not exceed 1 % of B_2 within three months.	All system functions listed in the manual are available, activatable and functioning. The current system status is continuously monitored and displayed by a set of different status messages (operation, warning and error messages).	yes	58
4.1.4 Setup- and warm-up times	Shall be specified in the manual.	The setup- and warm-up times were determined.	yes	60
4.1.5 Instrument design	Shall be specified in the manual.	The instrument design specifications listed in the operating manual are complete and correct.	yes	61
4.1.6 Security	Shall contain a protection mechanism against unauthorized adjustment.	The AMS is protected against unauthorized and unintended adjustment. In addition, the AMS shall be locked in a measuring cabinet.	yes	62
4.1.7 Data output	Analogue and / or digital outputs shall be available.	Measured signals are offered analogue (0-1 resp. 10 V resp. 0–16 mA / 4-20 mA) and digital (via RS 232).	yes	63
4.2 Requirements for mobile measuring systems	Permanent availability shall be ensured. The requirements of stationary operation shall also be fulfilled during mobile operation.	In the context of the field test, the measuring system was operated at several different sites, but cannot be operated in moving vehicles.	no	65

Minimum requirement		Specification	Test result	Fulfilled	Page
5.	Performance requirements				
5.1	General	The manufacturer's specifications given in the manual shall not contradict the results of the suitability test.	Differences between the instrument design and the descriptions given in the manual could not be detected.	yes	66
5.2	General requirements				
5.2.1	Measuring range	The upper limit of the measuring range shall exceed B_2.	A measuring range of 0 to 1,000 µg/m³ is set by default. Other measuring ranges in the range between at minimum 0-100 µg/m³ and at maximum 0-10,000 µg/m³ are possible.	yes	67
5.2.2	Negative output signals	Shall not be suppressed (living zero point).	Negative measuring signals are displayed directly and are output correctly via the respective measured value outputs by the measuring system.	yes	68
5.2.3	Analytical function	The relation between output signals and measured quantity shall be determined by regression calculation and represented by the analysis function.	A statistically firm correlation could be proven between the reference method and the instrument reading.	yes	69
5.2.4	Linearity	The deviation of the group averages of the measured values for calibration function shall not exceed 5% of B_1 within the range of zero to B_1. Within the range of zero to B_2 the deviation shall not exceed 1% of B_2.	The test should be carried out according to minimum requirement 5.3.1 „Equivalency of the sampling system" for particle measuring devices.	yes	71
5.2.5	Detection limit	B_0 or less.	The detection limit has been determined from the investigations to 1.33 µg/m³ for device 1 (SN 17010) and to 1.09 µg/m³ for device 2 (SN 17011).	yes	71
5.2.6	Response time	Not more than 5% of the averaging time (equal to 180 s).	Not applicable.	-	74
5.2.7	Ambient temperature dependency of zero point	The measured value at zero point shall not exceed B_0 at ΔT_u by more than 15 K between +5°C and +20°C. Between +20°C and +40°C it shall not exceed B_0 at ΔT_u by more than 20 K.	A maximum influence of the ambient temperature on the zero point of -1.6 µg/m³ was calculated.	yes	75

Minimum requirement	Specification	Test result	Fulfilled	Page
5.2.8 Ambient temperature dependency of the measured value	The measured value in the range of B_1 shall not exceed 5% at ΔT_u by more than 15 K between +5°C and +20°C. Between +20°C and +40°C it shall not exceed 5% at ΔT_u by more than 20 K.	No deviations greater than -0.2 % were determined for device 1 (SN 17010). For device 2 (SN 17011) deviations did not exceed 0.3 % of the initial value at 20 °C.	yes	77
5.2.9 Zero drift	Shall not exceed B_0 within 24h or during the maintenance interval.	The detected values are all within the allowed limits of B0 = 2 µg/m³ during the maintenance interval.	yes	79
5.2.10 Drift of the measured value	Shall not exceed 5% of B_1 within 24h or during the maintenance interval.	The measuring system carries out a regular device-internal check of the sensitivity of the radiometric measurement during each measurement cycle. This test leads to no interruption of the ongoing measuring operation. The values for the drift of the sensitivity, determined within the scope of the test, were at maximum 0.5 % (SN 17010) and -0.5 % (SN 17011) in the maintenance interval.	yes	84
5.2.11 Cross sensitivity	Shall not exceed B_0 in the range of zero point and 3% of B_2 within the range of B_2.	Not applicable.	-	88
5.2.12 Reproducibility RD R_D	$R_D \geq 10$ related to B_1.	Reproducibility RD in the field was 10 for the complete data set.	yes	89
5.2.13 Hourly mean values	Formation shall be possible.	The formation of hourly averages for the component PM2.5 is not necessary for the monitoring of the relevant limit values, but possible..	-	91
5.2.14 Mains voltage and frequency	Change of the measured value in the voltage interval (230 + 15/-20 V) does not exceed B_0 at B_1. For mobile use, the change of the measured value does not exceed B_0 for the frequency interval (50 ± 2) Hz.	No deviations > 0.1 % for device 1 (SN 17010) and > -0.1 % for device 2 (SN 17011) caused by mains voltage changes could be detected.	yes	93
5.2.15 Power outage	Uncontrolled emission of operating gas or reference gas for calibration shall be prevented. Device parameters shall be buffered against loss. Operating mode shall be secured on return of the mains voltage and the measurement shall be resumed.	All instrument parameters are protected against loss by buffering. The measuring system is in the normal operating condition after the restoration of the power supply and continues independently taking measurements upon reaching the next hour.	yes	95

Minimum requirement	Specification	Test result	Fulfilled	Page
5.2.16 Operating states	The AMS shall allow monitoring of system functions by telemetrically transmitted status signals.	The measuring systems can be controlled and monitored extensively from an external PC via *a* modem.	yes	96
5.2.17 Switchover	The AMS shall allow manual and telemetric activation of measurement, function test and/or calibration.	Generally all necessary operations for functional check and calibration can be monitored directly at the device or *via* telemetric remote control.	yes	97
5.2.18 Availability	At least 90 %.	The availability amounts to 97.9 % for device SN 17010 and 99.0 % for device SN 17011 without test-related outage times. Those included, the availability amounts to 94.6 % for device SN 17010 and 95.7 % for device SN 17011.	yes	99
5.2.19 Converter efficiency	At least 95 %.	Not applicable.	-	100
5.2.20 Maintenance interval	Preferably 28 days, at least 14 days.	The maintenance interval is defined by necessary maintenance proceedures and is 1 month.	yes	101
5.2.21 Total uncertainty	Compliance with the requirements on data quality [G10 to G12].	The determined total uncertainties were 14.64 % respectively 15.29 % for U(c) and 10.05 % respectively 12.35 % for $U(\bar{c})$.	yes	102
5.3 Requirements on measuring systems for particulate air pollution				
5.3.1 Equivalency of the sampling system	Shall be confirmed in comparison with the reference method according to EN 12341 [T2].	Not applicable for PM2.5 sampling systems. Please refer to chapter 7 of this report.	-	105

Minimum requirement		Specification	Test result	Fulfilled	Page
5.3.2	Reproducibility of the sampling system	Shall be confirmed in the field for two identical sampling systems according to EN 12341 [T2].	Not applicable for PM2.5 sampling systems. Please refer to chapter 7 of this report.	-	106
5.3.3	Calibration	Comparative measurement with the reference method under field conditions according to EN 12 341 [T2]; Relation between the gravimetrically determined reference concentration and the measured signal shall be determined as a continuous function.	Refer to Module 5.2.3.	-	107
5.3.4	Cross sensitivity	Not more than 10% of B_1.	No interferences which led to deviations of more than 1.2 µg/m³ between nominal value and measured signal, caused by humidity, contained in the measured medium, could be detected. Negative influences on the measured value caused by varying relative air humidity were not detected.	yes	109
5.3.5	Daily averages	24 h mean values shall be possible; time needed for filter changes shall not exceed 1% of the averaging time.	With the described system configuration and with a measurement cycle of 60 min, the formation of valid daily averages on the basis of 24 single measurements is possible.	yes	111
5.3.6	Constancy of sample volumetric flow	At least 3% of the nominal value during sampling and at least 5% for instantaneous values.	All determined daily averages deviate less than ± 3 %, all individual values less than ± 5 % from the nominal value.	yes	113
5.3.7	Tightness of the sampling system	Leakage shall not exceed 1% of the sampling volume.	The maximum determined leakages have been 1.8 % for device 1 (SN 17010) as well as 2.4 % for device 2 (SN 17011). According to the minimum requirement, the leak rate shall not be greater than 1 % of the sample flow rate.	no	117
5.4	Requirements for multiple-component measuring systems	Shall be fulfilled for each individual component during simultaneous operation of all measuring channels; generation of hourly mean values shall be ensured during sequential operation.	Not applicable.	-	118

Minimum requirement	Specification	Test result	Fulfilled	Page
Additional test criteria according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“				
Determination of the in-between-instrument uncertainty ubs [9.5.2.1]	Shall be determined in the field for two identical systems according to point 9.5.2.1 of guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“.	The in-between-instrument uncertainty between the candidates ubs is at maximum 1.57 µg/m³ and thus below the required value of 2.5 µg/m³.	yes	120
Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6]	Determination of the expanded uncertainty of the devices under test according to point 9.5.2.2ff of Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“.	The determined uncertainties WCM are below the specified expanded relative uncertainty Wdqo of 25 % (particulate matter) for all data sets without the usage of corrective factors.	yes	127
Application of correction factors or terms [9.7]	Correction factors may be applied if the highest expanded uncertainty which has been calculated exceeds the relative expanded uncertainty specified in the requirements on the data quality of ambient air quality measurements according to EU Guideline [7]. The corrected values must comply with the requirements according to point 9.5.2.2ff. of Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“.	The candidate systems fulfil the requirements on the data quality of ambient air quality measurements during the test already without application of correction factors.	yes	140

2 Task definition

2.1 Type of test

Met One Instruments, Inc. has commissioned TÜV Rheinland Immissionsschutz und Energiesysteme GmbH with the performance of a suitability test of BAM-1020 with PM2.5 pre-separator. The test was conducted as a complete suitability testing.

2.2 Objective

The AMS shall determine the content of $PM_{2.5}$ suspended particulate matter in ambient air within the concentration range of 0 to 1,000 µg/m^3.

The measuring system BAM-1020 with PM_{10} pre-separator is already suitability-tested and published in the German Bundesanzeiger.

Declaration of suitability: BAnz.: 12.04.2007 No. 75, page 4139, based on

TÜV-report no. 936/21205333/A of 06.12.2006

The suitability test was carried out based on the current standards for suitability tests while taking into account the latest developments.

The test was performed in consideration of the following standards:

- Standard VDI 4202 sheet 1, „Minimum requirements for suitability tests of automatic ambient air measuring systems – Point-related measurement methods of gaseous and particulate pollutants“, June 2002 [1]
- Standard VDI 4203 sheet 3, „Testing of automatic measuring systems - Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants“, August 2004 [2]
- Standard EN 14907, „Ambient air quality - Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter“, German version EN 14907: 2005 [3]
- Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of July 2009 [4]

3 Description of the tested measuring system

3.1 Measuring principle

The ambient air measuring system BAM-1020 is based on the measuring principle of beta-attenuation.

The principle of the radiometric determination of mass is based on the physical law of attenuation of beta-rays when passing a thin layer of material. There is the following relationship:

$$c\left(\frac{\mu g}{m^3}\right) = \frac{10^6 A\left(cm^2\right)}{Q\left(\frac{l}{min}\right)\Delta t(min)\mu\left(\frac{cm^2}{g}\right)} \ln\left(\frac{I_0}{i}\right)$$

with:

C	particle-mass concentration	A	sampling area for particles (filter spot)
Q	sampling flow rate	Δt	sampling time
µ	mass absorption coefficient	I_0	beta count rate at the beginning (clean)
I	beta count at the end (collect)		

The radiometric determination of mass is calibrated in the factory and is checked within the scope of internal quality assurance hourly at the zero point (clean filter spot) and at the reference point (built-in reference foil) during operation. With the help of the generated data, measured values at zero and reference point can be easily affiliated. They can be compared with any stability requirements (drift effects) respectively with the nominal value for the reference foil (factory setting).

3.2 Functionality of the measuring system

The particle sample passes the $PM_{2.5}$ pre-separator, consisting of a PM_{10}-sampling inlet and a $PM_{2.5}$ Sharp Cut Cyclone SCC, with a flow rate of 1 m³/h and arrives *via* the sampling tube at the measuring instrument BAM-1020.

Within the scope of the test work, the measuring system was operated with the sample heater BX-830 (Smart Inlet Heater).

The heater can be controlled with the help of two control process variables respectively with their combination:

1. The maximum relative humidity RH at the filter tape (factory setting: 45 %)
2. The temperature difference Delta-T between ambient temperature and temperature at the filter tape (factory setting: 5 °C)

As soon as the relative humidity RH is 1 % below the nominal value or the critical value for Delta-T is exceeded, the heater is switched off. Thereby the criterion for Delta-T is the striking one, which means that if the relative humidity RH is above the nominal value, but the value for Delta-T is above or equal the critical value, the heater is switched off.

During the test work, the candidates were installed in an air-conditioned trailer. In this configuration, the control of the heater by the Delta-T criterion is not feasable. For this reason, the heater was only controlled by RH during both the laboratory and field tests.

The particles are collected on the glass fiber filter tape for subsequent radiometric measurement.

One measurement cycle (incl. automatic check of the radiometric measurement) consists of the following steps (setting: measuring time for radiometry 8 min):

1. The initial count of the clean filter tape I_0 is performed at the beginning of the cycle for a period of eight minutes.
2. The filter tape is advanced four windows and the sampling (vacuum pumping) begins on the spot in which I_0 was just measured. Air is drawn through this spot on the filter tape for approximately 42 minutes.
3. At the same time the second count I_1 occurs (at a point on the tape 4 windows back) for a period of eight minutes. The purpose of the measurement is to perform the verification for instrument drift caused by varying external parameters such as temperature and relative humidity. A third count I_2 occurs with the reference membrane extended over the same place on the tape. Eight minutes before the end of sampling time, another count I_{1x} occurs on the same point of the tape. With the help of I_1 and I_{1x}, the stability at the zero point can be monitored.

4. After sampling, the filter tape is moved back four windows to measure the beta ray absorption through the section that has collected dust (I_3). Finally the concentration calculation is performed to complete the cycle.

5. The next cycle begins with step 1

Figure 1 gives an overview on the sampling- and measurement part of the BAM-1020.

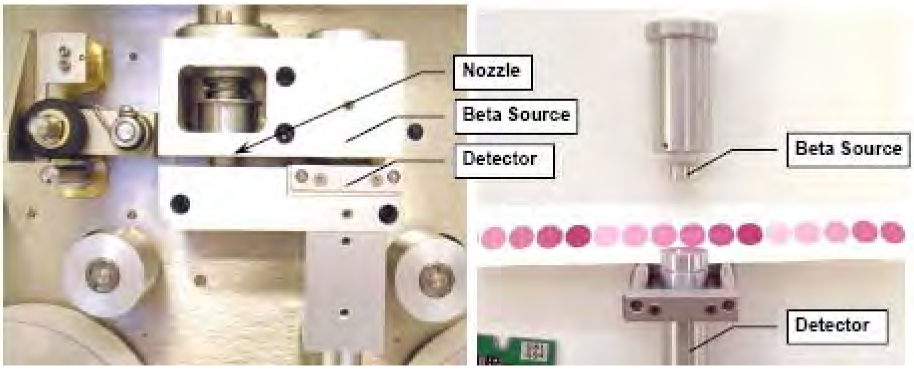


Figure 1: BAM-1020 – Overview on sampling and measurement part

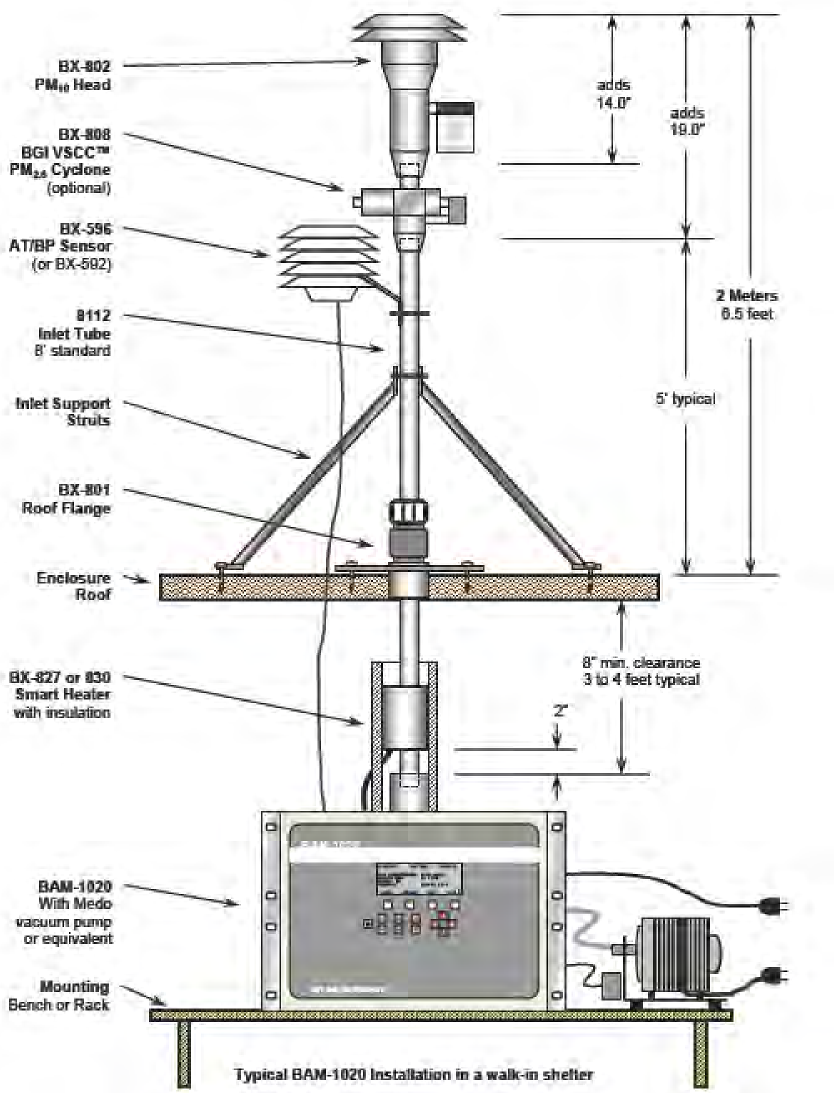
During the suitability test work, a cycle time of 60 min with a time need of 8 min for the radiometric measurement was set.

Therefore the cycle time consists of 2 x 8 min for the radiometric measurement (I_0 & I_3) as well as approximately 1-2 min for filter tape movements. Thus the effective sampling time is around 42 min.

3.3 AMS scope and layout

The ambient air measuring system BAM-1020 is based on the measuring principle of beta-attenuation.

The tested measuring system consists of the PM_{10}-sampling inlet BX-802, the $PM_{2.5}$ Sharp Cut Cyclone SCC BX-807, the sampling tube, the sample heater BX-830, the combined pressure and temperature sensor BX-596 (including radiation protection shield, as an alternative the ambient temperature sensor BX-592), the vacuum pump BX-127, the measuring instrument BAM-1020 (incl. glass fiber filter tape), the respective connecting tubes and lines as well as adapters, the roof flange as well as the manual in English language.



Typical BAM-1020 Installation in a walk-in shelter

Figure 2: Overview of the BAM-1020 measuring system (shown here with the $PM_{2.5}$ VSCC BX-808 (configuration for US-EPA approval) instead of $PM_{2.5}$ SCC BX-807)

The measuring instrument BAM-1020 offers the possibility to connect up to 6 different sensors at the available analogue inputs. For example, besides the combined pressure and temperature sensor BX-596 respectively the ambient temperature sensor BX-592, the connection of sensors for the air pressure BX-594, the wind direction (BX-590), for the wind velocity (BX.591), for the air humidity (BX-593) as well as for solar radiation (BX-595) is possible.

Concerning the sampling inlets,an US-PM_{10} sampling inlet (type: BX-802, manufactured according to Guideline EPA 40 CFR Part 50) is available. The sampling inlet serves as a pre-separator for the suspended particulate matter in the fraction PM_{10}. Directly downstream of the PM_{10} sampling inlet, a Sharp Cut Cyclone SCC (BX-807) is used for the separation of particles in the range of 2.5 µm to 10 µm. The instruments are operated with a constant, regulated volume flow of 16.67 l/min = 1.0 m³/h.

As an alternative option (though untested herein), it is possible to use TSP-sampling inlets or PM_{10}-sampling inlets without SCC.

Figure 3: US- PM-sampling inlet BX-802 for BAM-1020

Figure 4: Sharp Cut Cyclone SCC BX-807 for BAM-1020

Figure 5: Sampling inlet BX-802 + SCC BX-807

The sampling tube connects the sampling inlet and the measuring instrument. The length of the sampling tube was 1.65 m during the test, differing lengths can be used dependent upon the local site requirements

The sample heater BX-830 is installed at the lower end of the sampling tube (approximately 50 mm above the instrument inlet of BAM-1020). The operation of the heating systems is performed as described in point 3.2 Functionality of the .

Figure 6: Sample heater BX-830

The vacuum pump BX-127 is connected to the measuring instrument at the end of the sampling path with a hose. The pump is controlled via the measuring system on actual volume in relation to the ambient conditions (Mode ACTUAL)

The measuring system BAM-1020 contains, besides the radiometric measurement part, the glass fiber filter tape incl. transport system, large parts of the pneumatic system (flow measurement by mass flow sensor), the control unit of the sample heater and all necessary electronic parts and microprocessors for the control and operation of the measuring system as well as for communication with the system.

Figure 7: Measuring instrument BAM-1020

Figure 8: BAM-1020 measuring systems installed in the trailer (Two candidates included for the suitability test plus a third candidate for experimental purposes (different configuration of heater))

Figure 9: Vacuum pump

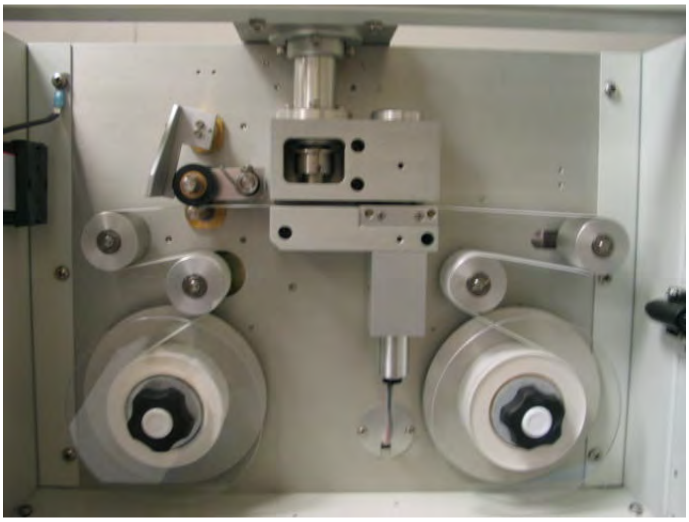


Figure 10: Front view BAM-1020, front cover opened

The handling of the measuring systems is done *via* a soft keypad in combination with a display at the front of the instrument. The user is able to get stored data, to change parameters and to perform several tests to control the functional capability of the measuring system.

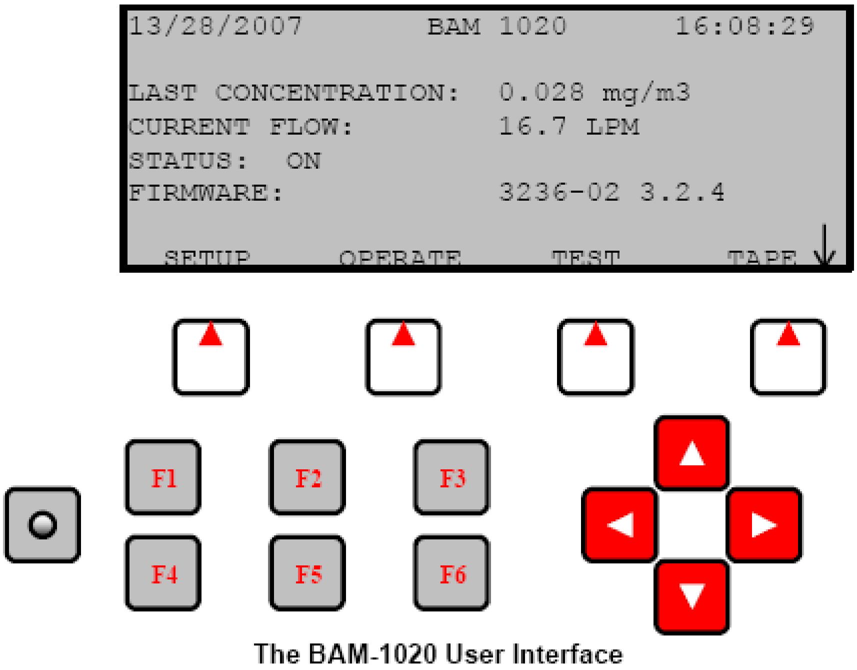


Figure 11: Display + soft keypad of BAM-1020

The main screen of the user display can be found on the top level – here the actual time and date, the last 1h-concentration value, the actual flow rate, the firmware version as well as the status of the instrument are displayed.

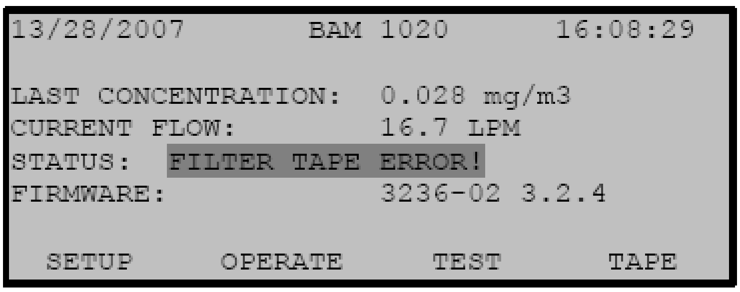
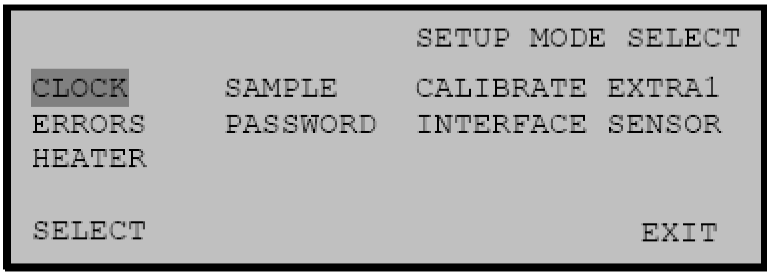


Figure 12: Main screen of user display

Via the function keys F1 to F6, different functions can be easily called from the top level. For example it is possible, to access actual information on the last concentration values as well as measured values from other sensors (such as ambient temperature), error messages and on stored data for the measurements of the last ten days.

Starting from the top level, one can furthermore access on the following sub-menus *via* soft key:

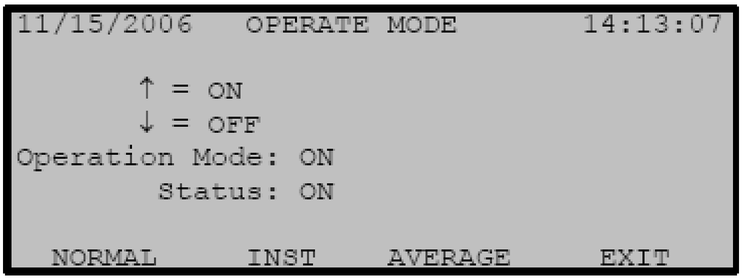
1. Menu „SETUP“ (Press soft key „SETUP“):
   The configuration and setting of parameters of the measuring system is done in the menu „SETUP“. The user can do settings for parameters like for instance date/time, sampling time, measuring range, flow rate, output of measured values (actual or standard conditions), change of pass word, interfaces, external sensors and sample heater.



The SETUP Menu

Figure 13: Menu „SETUP“

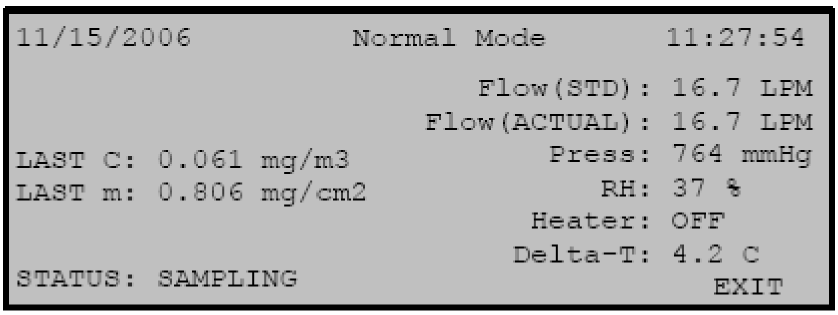
2. Menu „OPERATION“ (Press soft key „OPERATION“):
   In the menu „OPERATION“, it is possible to call up information during the operation of the measuring system. As long as the operating mode is switched to „ON“, the measuring system will be in operation according the settings. An interruption of the ongoing measurement can be done either by switching the operating mode to „OFF“, by calling up the menus „SETUP“, „TEST“ or „TAPE“ during the ongoing operation or in case of a severe malfunction (e.g. filter tape breakage).



The OPERATE Menu

Figure 14: Menu „OPERATION“

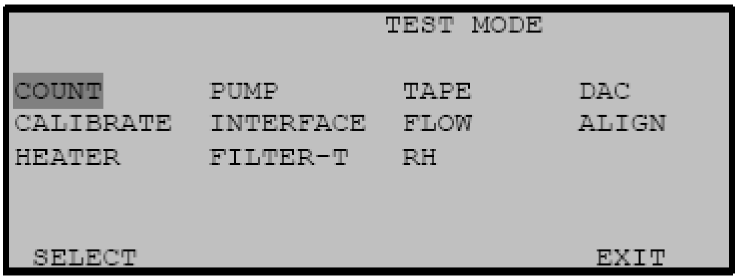
In the submenus NORMAL, INST and AVERAGE, the actual measured values of the system can be displayed in different manner. The most usual way of displaying is the “NORMAL” screen. Here the user can view the most important parameters relevant for operation.



The NORMAL Menu

Figure 15: Sreenshot „NORMAL“

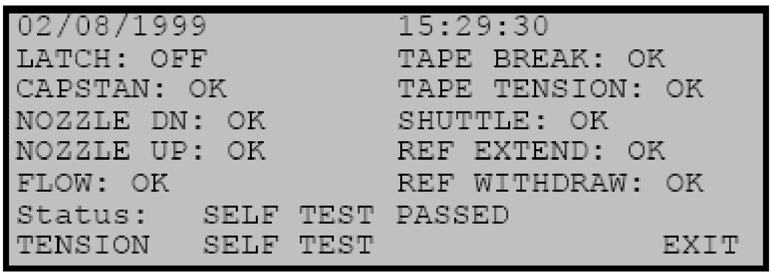
3. Menu „TEST“ (Press soft key „TEST“):
   In the menu „TEST“, the user can perform several tests for checking the hardware and components, e.g. a check of the radiometric measurement (reference foil test), a check of the flow rate or a calibration of temperature and pressure sensors as well as of the flow rate is possible.



The TEST Menu

Figure 16: Menu „TEST“

4. Menu „TAPE“ (Press soft key „TAPE“):
   In the menu „TAPE“, it is possible to start at any time (= aborting the ongoing measurement) an extensive self test of the measuring system. In this self test, which takes around 4 min, several mechanic parts (e.g. the filter transport system) are tested on functional capability and the flow rate and the condition of the filter tape (tension, crack of tape) are checked. In case of irregularities or unallowable deviations, an error message „FAIL“ is displayed and a specific search for the problem can start. If the self test can be performed without problems, the status „SELFTEST PASSED“ is displayed and the operation can start. The performance of this test is generally recommended after each restart of the measurement following an abort, or after changing of the filter tape.



Self-Test Status Screen

Figure 17: Screen shot „TAPE/SELF TEST“

Besides direct communication *via* keys/display, there are numerous possibilities to communicate *via* different analogue outputs, relais (status and alarm messages) as well via RS-232 interfaces. The RS232-interfaces allow for connection with a printer, PC or modem. The communication with the instrument can be done for instance with the software Hyper-Terminal.

The serial interface #1 serves for data transfer and transmission of the instrument status. This interface together with a modem is often used for remote control.

The following system menu is available:

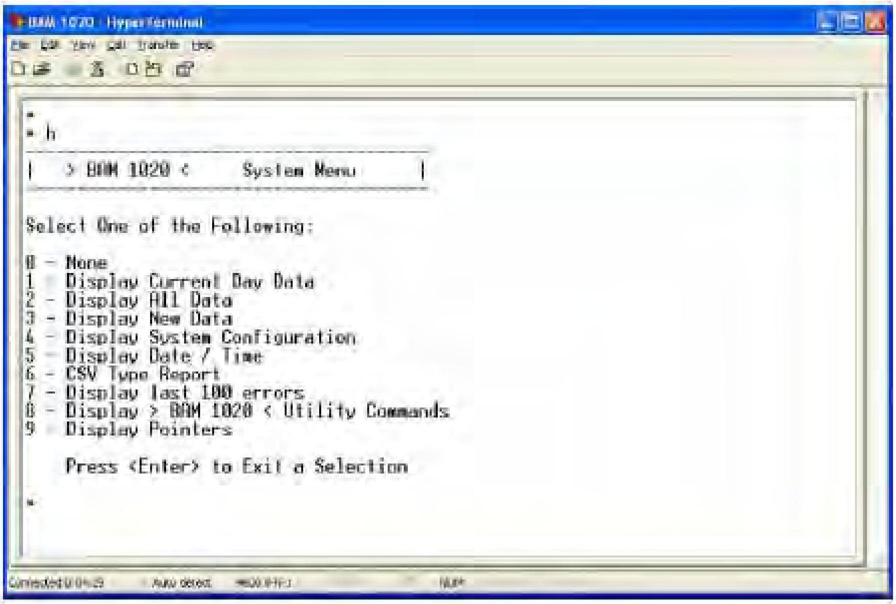


Figure 18: Communication via serial interface #1 – system menu

During the test work, the measured data have been remotely downloaded once a week. They are suitable for further data integration to daily mean values in an external spreadsheet. The following picture shows an example of data, which have been downloaded in this way.

Station	10																					
Time	Conc(ug/m3)	Qtot(m3)	BP(mmH)	WS(MPS)	WS(MPS)	RH(%)	Delta(C)	AT(C)	Stab(ug)	Ref(ug)	E	U	M	I	L	R	N	F	P	D	C	T
2/9/2009 8:00	16	0.701	749.4	5.9	0.7	16	22.3	1.9	-0.8	827.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 9:00	18	0.701	749.7	5.9	0.7	17	21.8	2.5	-1.9	830.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 10:00	9	0.701	749.5	5.9	0.7	18	20.7	3	-3.5	830.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 11:00	9	0.701	749.8	5.9	0.7	18	19.4	3.5	-2.9	828	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 12:00	8	0.701	749.9	5.9	0.7	19	17.7	4.5	-0.7	828.9	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 13:00	7	0.701	749.6	5.9	0.7	20	16.3	5.9	-1.2	828.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 14:00	11	0.7	749.5	5.9	0.7	20	16.1	6.3	-3	828.4	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 15:00	12	0.7	749.2	5.9	0.7	20	16.5	5.9	0	826.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 16:00	11	0.7	748.8	5.9	0.7	20	16.5	5.9	-3.8	824.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 17:00	13	0.701	748.1	5.8	0.7	20	17.1	4.9	1.9	829.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 18:00	15	0.701	747.3	5.8	0.7	21	17.3	4.2	-0.2	828	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 19:00	20	0.701	746.8	5.8	0.7	22	17	3.9	0.7	831.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 20:00	18	0.7	745.9	5.8	0.7	24	17.1	3.1	-3.2	827.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 21:00	17	0.701	744.2	5.7	0.7	25	17	2.5	-0.4	828.5	0	0	0	0	0	0	0	0	0	0	0	0

Conc(µg(m³)): concentration value in µg/m³ reported to ambient conditions

Qtot(m³): total sample volume in m³ (here at 42 min sampling time)

BP(mm-Hg): ambient pressure in mm-Hg

WS (MPS): wind speed, not active in this case

RH(%): relative humidity below the filter tape in % - used for control of the sample heater

Delta(C): ambient temperature minus the temperature at filter tape – used for control of the sample heater, not active in this case

AT(C): ambient temperature in °C

Stab(µg): result of the internal zero measurement in µg of I_1 and I_{1x} (refer to chapter 3.2 of this report)

Ref(µg): result of the internal reference foil measurement in µg/cm² of I_2 (refer to chapter 3.2 of this re port)

E, U, M, I, L, R,

N, F, P, D, C, T: Status messages (relais), refer to manual chapter 6.5

Via the system menu (number 4 – Display System Configuration) it is furthermore possible to display and print out the actual parameter setting of the BAM-1020 for the purpose of information and diagnosis (refer to Figure 19)

BAM 1020 Settings Report
2/18/2009 9:40

Station ID	10
Firmware	3236-07 5.0.1
K	0.933
BKGD	-0.0014
usw	0.3
ABS	0.828
Range	1
Offset	-0.015
Clamp	-0.015
Conc Units	ug/m3
Conc Type	ACTUAL
Count Time	8
Cv	1.01
Qo	0
Flow Type	ACTUAL
Flow Setpt	16.7
Std Temp	25
High Flow Alarm	20
Low Flow Alarm	10
Heat Mode	AUTO
Heat OFF (%)	6
RH Ctrl	YES
RH SetPt	45
RH Log	YES
DT Ctrl	NO
DT SetPt	99
DT Log	YES
BAM Sample	42
MET Sample	60
Cycle Mode	STANDARD
Fault Polarity	NORM
Reset Polarity	NORM
Maintenance	OFF

EUMILRNFPDCT
0

AP	150
Baud Rate	9600
Printer Report	2
e3	0
e4	15

Channel	1	2	3	4	5	6
Sensor ID	255	2	255	255	255	35
Channel ID	255	254	255	255	255	254
Name	BP	WS	WS	RH	Delta	AT
Units	mmH	MPS	MPS	%	C	C
Prec	1	1	1	0	1	1
FS Volts	2.5	1	1	0.5	2.5	2.5
Mult	300	44.7	44.7	32	-147.1	95
Offset	525	0	0	-26	95.8	-40
Vect/Scalar	S	S	S	S	S	S
Inv Slope	N	N	N	N	N	N

Calibration	Offset	Slope
Flow	0.089	0.973
AT	0	
BP	0	
RH	-0.213	
FT	0	

Figure 19: Typical print out of the parameter setting of BAM-1020

The serial interface #2 serves only as a printer output and can be connected to a printer or a PC. It offers the possibility of continuous recording of actual information on the measurements.

For external check of the zero point of the measuring system and for determination of the background value BKGD (offset correction for concentration values) according to the manual chapter 7.7, a zero filter (BX-302, Zero Filter Calibration Kit) is mounted at the device inlet. The use of this filter allows the provision of particle-free air.

Figure 20: Zero filter BX-302 during field application

With the available valve, it is also possible to check the tightness of the measuring system with the zero filter BX-302 according to the manual chapter 5.3 .

For the audit of the inlet flow rate according to the manual chapter 5.6, an adapter BX-305 (Flow Inlet Adapter Kit) is available. As this kit is compliant in manufacture to the zero filter kit BX-802 except for the HEPA-filter itself, it is also possible to check the tightness of the measuring system with its available valve according to the manual chapter 5.3.

Table 2 contains an overview of important technical specifications of the ambient air measuring system BAM-1020.

Table 2: Device-related data BAM-1020 (Manufacturer's data)

Dimensions / weight	BAM-1020
Measuring system	310 x 430 x 400 mm / 24.5 kg (without pump)
Sampling line	1.65 m (different lengthes available)
Sampling inlet	BX-802 (US)
Energy supply	100/115/230 V, 50/60 Hz
Power consumption	75 W, main unit
Ambient conditions	
Temperature	-30 - +60 °C (manufacturer´s data) +5 - +40 °C in suitability test
Humidity	non condensing
Sampling flow rate	16.67 l/min = 1 m³/h
Radiometry **Radiator**	^{14}C, <2,2 MBq (< 60 µCi)
Detector	Scintillation probe
Check procedure	Hourly internal zero and reference point checks (reference foil), deviations from the nominal value are recorded.
Parameter of filter change	
Measurement cycle (cycle time)	1 min – 200 min Default: 60 min
Measuring time radiometry	selectable 4,6 or 8 min for $PM_{2.5}$: 8 min
Sampling time	depending on measuring time radiometry 50, 46 or 42 min for $PM_{2.5}$: 42 min
Parameter sample heater BX-830	
maximum temperature difference filter tape – ambient temperature	Default: 5°C
Nominal value for relative humidity at filter tape	Default: 45 %
Buffer capacity (internal)	approx. 180 days for 1h-measuring values
Analogue output	0 – 1 (10) V or 0 – 16 mA / 4 – 20 mA – can be set to 0-0.100, 0.200, 0.250, 0.500, 1.000, 2.000, 5.000 or 10.000 mg/m³
Digital output	2 x RS 232 – interface for data transmission and remote control
Status signals / error messages	available, for an overview refer to chapter 8 in the manual

4 Test program

4.1 General

The suitability test has been performed with two identical devices of the serial numbers SN 17010 and SN 17011.

The test was performed with firmware version 3236-07 5.01 (Status July 2008).

The firmware has been constantly developed and optimized up to version 3236-07 5.0.10 during the test program. The changes up to version 3236-07 5.0.5 have been already presented in a statement and have been assessed positively by the responsible working group „Test reports“. The additional changes from version 3236-07 5.0.5 to version 3236-07 5.0.10 are described in Figure 64 on page 179 in the appendix.

No influences on the system performance are expected from the changes which were made on the firmware up to version 3236-07 5.0.10.

The laboratory tests for the determination of system characteristics were followed by a field test of several months at different test sites.

All concentrations, determined under operation conditions, are presented in µg/m³.

No structural changes were made on the candidates during the suitability testing.

The following report comprises a description of each minimum requirement according to standards [1,2,3,4] in number and wording.

4.2 Laboratory test

The laboratory test was carried out with two identical devices of BAM-1020 measuring system with the serial numbers SN 17010 and SN 17011.

According to the Standards [1,2,3], the following test program was specified for the laboratory test:

- Description of system functions
- Determination of detection limits
- Determination of the dependence of zero point / sensitivity on ambient temperature
- Determination of the dependence of zero point / sensitivity on the system voltage

The following devices were used to determine the system characteristics during laboratory test:

- Climatic chamber (temperature range from –20 °C to +50 °C, precision better than 1 °C)
- Adjustable isolating transformer
- Zero filter kit BX-302 for external zero point check.
- Reference foil (built-in fixed in the devices)

The measured values were recorded in the devices. The stored measured values were read *via* Hyperterminal with the help of a notebook.

Section 6 describes the laboratory tests and the results.

4.3 Field test

The field test was carried out with two identical systems of the serial numbers:

Device 1:	SN 17010
Device 2:	SN 17011

The following test program was specified for the field test:

- Determination of the comparability of the candidates according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Determination of the comparability of the candidates and the reference methods according to the Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"
- Sampling flow stability check
- Determination of the calibration efficiency and analysis function record
- Determination of reproducibility
- Determination of temporal changes of zero point and sensitivity
- Leak test on the sampling system
- Inspection of the dependency of the measured values on humidity
- Determination of the maintenance interval
- Determination of availability
- Determination of the total uncertainty of the candidates.

The following devices were used for the field test:

- Measurement cabinet of the UK partners, air-conditioned to approx. 20 °C
- Weather station (WS 500 of the company ELV Elektronik AG) for the determination of meteorological characteristics such as air temperature, air pressure, air humidity, wind velocity, wind direction and rainfall
- Two reference equipment LVS3 for $PM_{2.5}$ according to point 5
- Gas meter, dry
- Mass flow rate measuring device Type 4043 (Manufacturer: TSI)
- Measuring device Metratester 5 (Manufacturer: company Gossen Metrawatt) for the determination of power consumption
- Zero filter kit BX-302 for particle-free air generation
- Reference foil (built-in fixed in the devices)

Two BAM-1020 systems and two reference equipment for $PM_{2.5}$ were simultaneously operated for 24 h each during the field test. The reference equipment for $PM_{2.5}$ was operating discontinuously, *i.e.* the filters must be manually changed after sampling.

The PM_{10} sampling inlets BX-802 and the $PM_{2.5}$ cyclones BX-807 of the candidates were cleaned approx. every 4 weeks. In general the sampling inlet shall be cleaned according to the manufacturer´s instructions while taking into account the local suspended particulate matter concentrations.

The flow rate was tested on each candidate and each reference device prior to and after each change of location with a dry gasmeter respectively a mass flow meter, which could be connected to the air inlet of the systems *via* a hose assembly.

Measurement sites and site of the measuring devices

The candidate systems as well as the reference systems have been installed in the field test in such a way that only the sampling inlets are located above the roof of the measurement cabinet. The central units of both candidate systems and of both reference systems were installed inside the climate-controlled measurement cabinet. The connection of the central units with the sampling inlets was realised for the BAM-1020 -systems with the sampling tube and for the LVS3 with an extension tube.

The field test was carried out at the following sites:

Table 3: Field test site

No.	Measurement site	Period	Characterisation
1	Teddington (UK), Summer	07/2008 – 11/2008	Urban background
2	Cologne, parking lot, Winter	12/2008 – 04/2009	Urban background
3	Bornheim, parking lot at motorway, Summer	08/2009 – 10/2009	Rural structure + traffic influences
4	Teddington (UK), Winter	12/2009 – 02/2010	Urban background

Figure 21 to Figure 24 present the course of the PM-concentrations at the field test sites (recorded by the reference methods).

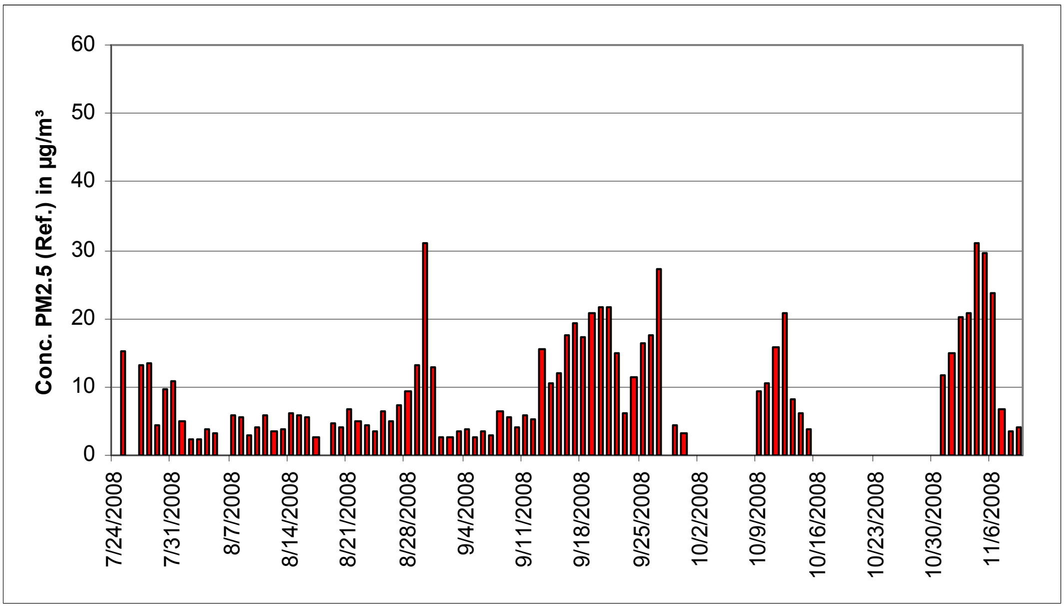


Figure 21: PM$_{2.5}$ concentration (reference) at the site „Teddington, Summer“

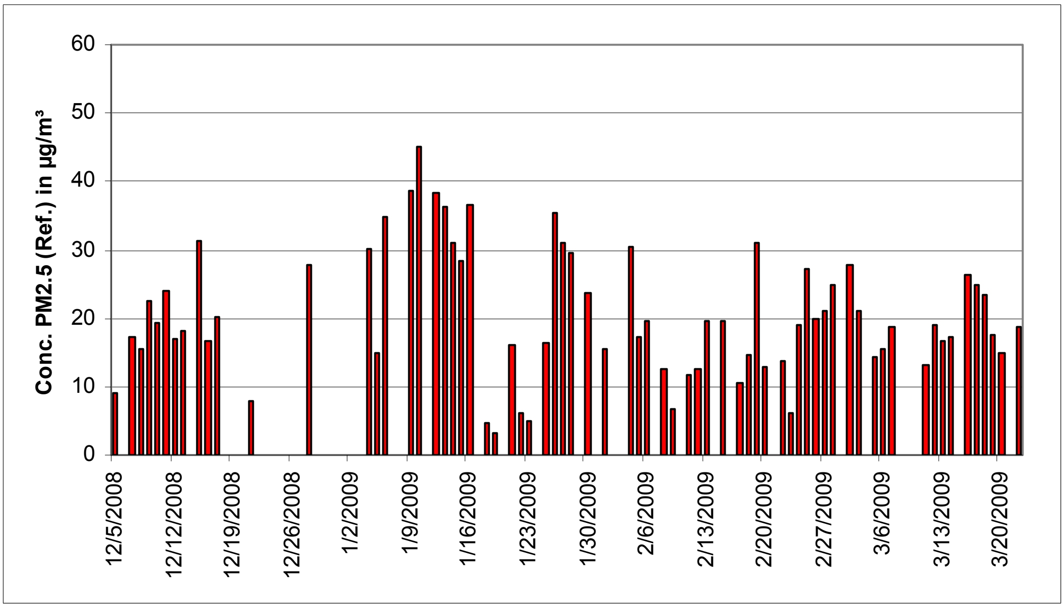


Figure 22: PM$_{2.5}$ concentration (reference) at the site „Cologne, Winter“

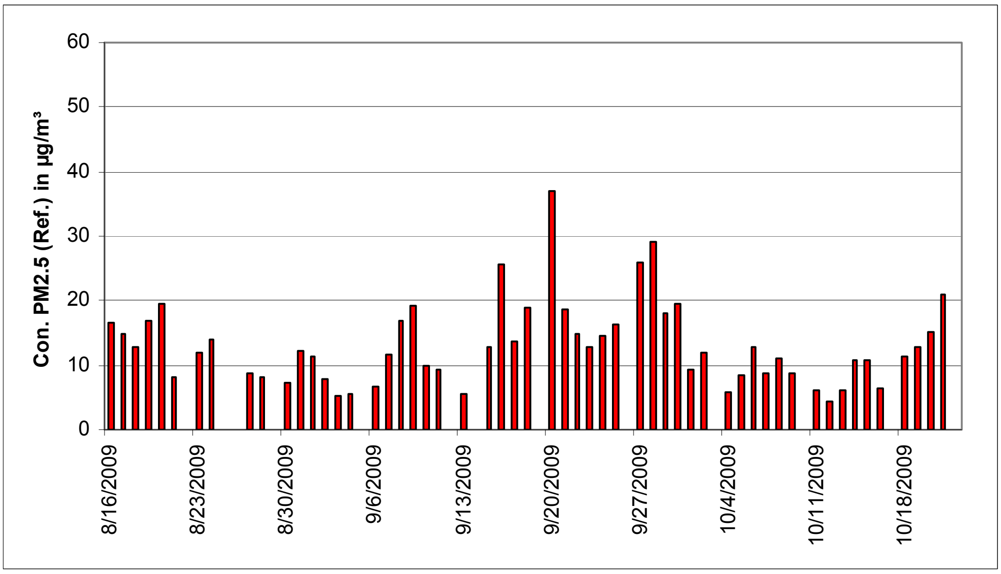


Figure 23: $PM_{2.5}$ concentration (reference) at the site „Bornheim, Summer“

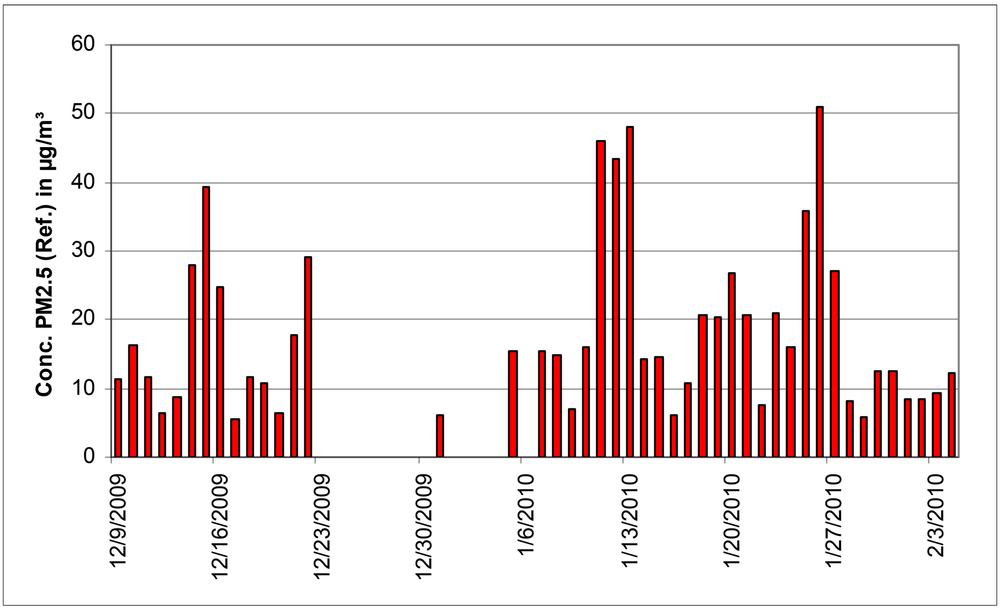


Figure 24: $PM_{2.5}$ concentration (reference) at the site „Teddington, Winter“

The following pictures show the measuring container at the field test sites in Teddington, Cologne (parking lot) and Bornheim (motorway parking lot).

Figure 25: Field test site Teddington

Figure 26: Field test site Cologne, parking lot

Figure 27: Field test site Bornheim, motorway parking lot

A data acquisition device for meteorological characteristics was installed to the container in addition to the devices for dust measurement. Data for air temperature, air pressure, air humidity, wind velocity, wind direction and rainfall were continuously collected and saved as half-hourly averages (Germany) and 15 minute averages (UK).

The installation of the measuring cabinet as well as the arrangement of the sampling probes were characterised by the following measures:

• Container roof:	approx. 2.5 m
• Sampling height for candidates / reference devices	approx. 1.13 / 0.51 m above container roof (resp. approx. 3.63 / 3.01 m above ground)
• Vane:	approx. 4.5 m above ground

The following Table 4 presents an overview on the most important meteorological data of the four sites and the particulate matter relations during the test. No meteorological data are available for the location in Teddington, UK, prior to September 17th 2008. Refer to section 5 and 6 for detailed results.

Table 4: Ambient conditions at the field test site (daily averages)

	Teddington (UK), Summer*	Cologne, parking lot Winter	Bornheim, motorway parking lot, Summer	Teddington (UK), Winter
No. of paired values Reference $PM_{2.5}$ (total)	81	75	58	45
$PM_{2,5}$ fraction from PM_{10} under ambient conditions [%]				
Range	22.3 – 83.2	42.4 – 92.9	40.3 – 81.8	41.6 – 90.6
Average	53.9	73.8	60.5	70.3
Air temperature [°C]				
Range	4.2 – 15.4	-14 – 17.8	3.3 – 25.3	-3.7 – 9.8
Average	11.2	3.9	15.4	2.7
Air pressure [hPa]				
Range	984 – 1016	971 – 1030	995 – 1022	984 – 1037
Average	1000	1008	1010	1008
Rel. Air humidity [%]				
Range	64 – 95	48 – 85	44 – 82	77 – 98
Average	81.4	71.4	68.1	89.6
Wind velocity [m/s]				
Range	0.0 – 1.8	0.0 – 6.9	0.0 – 4.4	0.0 – 2.4
Average	0.5	2.0	0.4	0.6
Rainfall [mm]				
Range	not available	0.0 – 26.9	0.0 – 20.0	0.0 – 11.7
Average		2.5	1.9	1.8

* Weather data available after 2008-09-17

Sampling period

EN 14907 defines a sampling period of 24 h ± 1 h.

While the sampling period was constantly set to 24 h during the field tests (10:00 – 10:00 for Teddington and Cologne) and 7:00 – 7:00 (Bornheim), it was reduced for some laboratory tests to obtain a higher number of measured values.

Data handling

All paired reference values determined during the field tests were subject to statistical testing according to Grubbs (99 %) to prevent influences of obviously implausible data on the measuring results. Paired values which are identified as significant outliers can be discarded until the critical value of the test statistic is exceeded,. The July 2009 version of the Guidance [4] stipulates, that not more than 2.5 % of the paired values in total for each field test site may be identified and removed as outliers.

Within the scope of the „Combined MCERTS and TÜV PM Equivalence Testing“ program we agreed with our British partners not to discard any measured value for the candidates unless the implausibility is caused due to technical reasons.

Table 5 presents an overview on the paired values (reference measurement) which were identified and removed as significant outliers for each location.

Table 5: Overview on outliers – reference, measured component $PM_{2.5}$

Graph Number	Site	Sampler	Number of data-pairs	Maximum Number that can be deleted	Number Identified	Number Deleted	Number of data-pairs remaining
A	Teddington Summer	$PM_{2.5}$ Leckel	83	2	2	2	81
B	Cologne Winter	$PM_{2.5}$ Leckel	77	2	3	2	75
C	Bornheim Summer	$PM_{2.5}$ Leckel	60	2	2	2	58
D	Teddington Winter	$PM_{2.5}$ Leckel	46	1	2	1	45

The following data pairs have been removed:

Table 6: Removed data pairs reference $PM_{2.5}$ according to Grubbs

Test site	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Teddington, Summer	07/24/2008	32.5	27.8
Teddington, Summer	07/26/2008	16.1	13.8
Cologne, Winter	01/20/2009	11.2	8.4
Cologne, Winter	02/03/2009	34.0	37.4
Bornheim, Summer	08/25/2009	13.8	20.3
Bornheim, Summer	10/22/2009	27.0	24.3
Teddington, Winter	01/06/2010	13.5	16.0

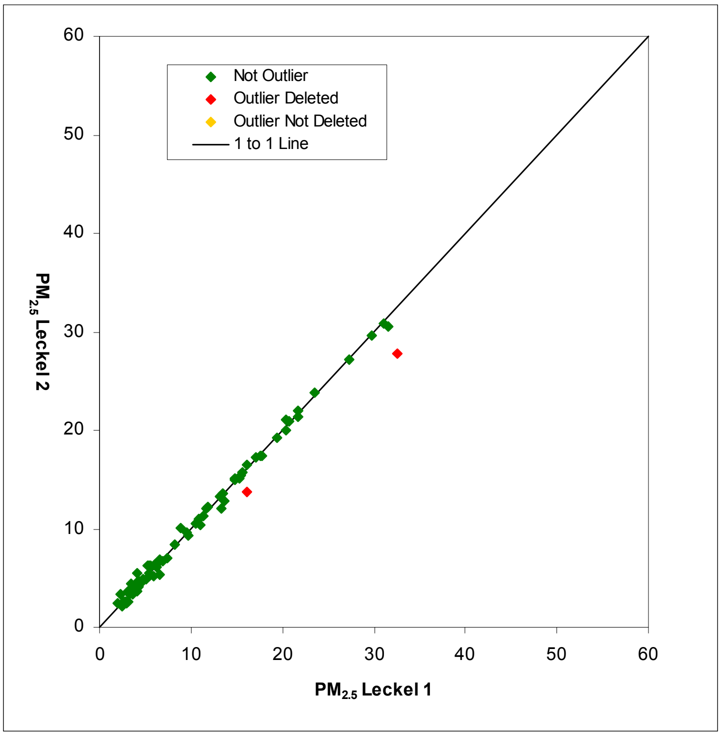


Figure 28: Grubbs test results for $PM_{2,5}$ reference method, Teddington (Summer)

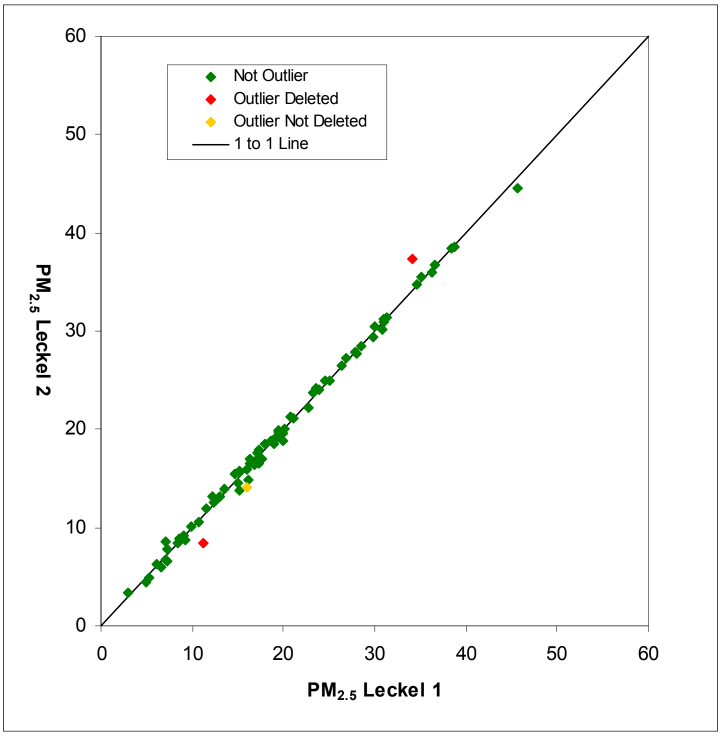


Figure 29: Grubbs test results for $PM_{2,5}$ reference method, Cologne (Winter)

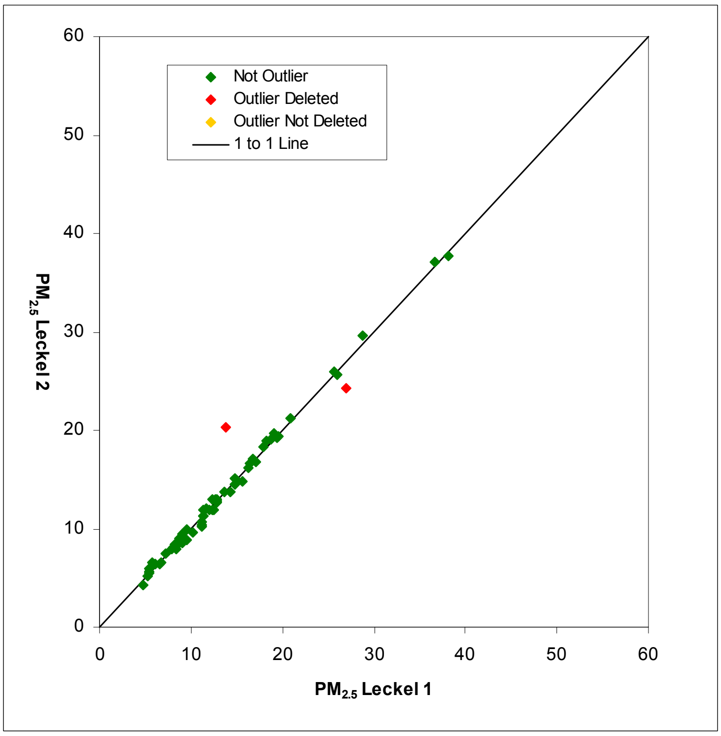


Figure 30: Grubbs test results for $PM_{2,5}$ reference method, Bornheim (Summer)

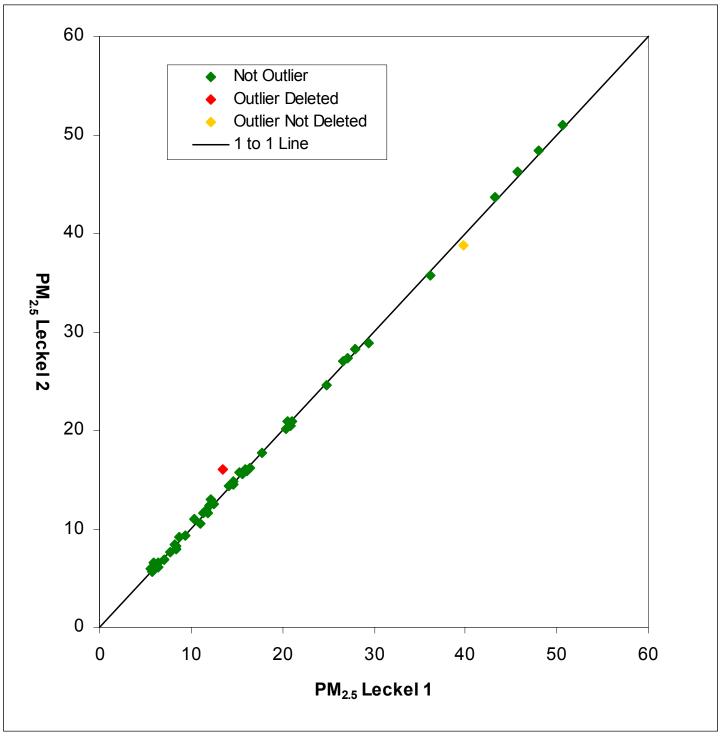


Figure 31: Grubbs test results for $PM_{2,5}$ reference method, Teddington (Winter)

Handling of filters – mass determination

The following filters were used for the suitability test:

Table 7: Used filter material

Measuring device	Filter material, Type	Manufacturer
Reference devices LVS3	Emfab™, ∅ 47 mm	Pall

The filter material EMFAB™ (teflon-coated glass fibre filters) was used in the scope of the „Combined MCERTS and TÜV PM Equivalence Testing“ program by special request of our British partner, because according to [8], they consider it most appropriate for the test.

The filter handling conforms to the requirements of EN 14907.

The procedures of filter handling and weighing are described in detail in Annex 2 of this report.

5 Reference measurement procedures

The following devices were used during the field test in accordance with EN 14907:

1. Reference equipment for $PM_{2.5}$:

Small filter device”Low Volume Sampler LVS3”
Manufacturer: Ingenieurbüro Sven Leckel, Leberstraße 63, Berlin, Germany
Date of manufacture: 2007
$PM_{2.5}$-Sampling inlet

Two reference devices were simultaneously operated with a controlled volume flow of 2.3 m³/h. The accuracy of the volume flow control is below <1 % of the nominal volume flow under standard conditions.

The sampling air is sucked in *via* the rotary vane vacuum pump through the sampling inlet for the small filter device LVS3. The sampling air volume flow is measured with a measuring orifice which is installed between filter and vacuum pump. In order to collect any dust created by the abrasion of the vanes, the incoming air passes a separator before flowing to the air outlet.

The electronic measuring equipment of the LVS3 small filter device displays the incoming sampling air volume in standard or operating m^3 as soon as the sampling is complete.,

To determine the $PM_{2.5}$ concentration, the laboratory performed a gravimetric determination of the amount of suspended particulate matter on the respective filters. The obtained result was then divided by the respective volume of sampling air in operating m^3.

6 Test results

6.1 4.1.1 Display for measured values

The measuring system shall be fitted with a display for measured values.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

The measuring device was checked by the presence of a display for measured values.

6.4 Evaluation

The measuring device comprises a display for measured values. The respective measured concentration value from the last measurement cycle can be indicated on different screens of the users display.

6.5 Assessment

The measuring device comprises a display for measured values.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Figure 32 shows the user´s display with the measured concentration value from the last measurement cycle.

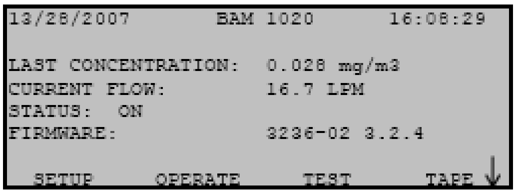


Figure 32: Display of measured concentration value from the last measurement cycle

6.1 4.1.2 Easy maintenance

Necessary maintenance for the measuring systems should be possible without larger effort, if possible from outside.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

Necessary regular maintenance works were carried out according to the instructions of the operating manual.

6.4 Evaluation

The following maintenance works should be carried out:

1. Check of device status
   The device status can be monitored and controlled by controlling the system itself or controlling it on-line.
2. In general the sampling inlet shall be cleaned according to the manufacturer´s instructions with taking into account the local suspended particulate matter concentrations (during suitability test e very 4 weeks).
3. Monthly cleaning of the device. This includes also the cleaning of the nozzle area above the filter tape. In any case, the measuring system has to be cleaned after each measuring operation.
4. Check of the filter tape stock – a 21 m-filter tape is hereby sufficient for approximately 60 days in case of a measurement cycle of 60 min. It is recommended, to check as a matter of routine the filter tape stock at every visit of the measurement site.
5. According to the manufacturer, a flow rate check and a leak check shall be carried out every 4 weeks. Furthermore a plausibility check of the ambient temperature and air pressure measurement is recommended within this context.
   These workings can be done together with the workings according to point 4.
6. Replacement of filter tape after approx. 2 months (measurement cycle: 60 min). After the replacement, it is strongly adviced to perform a selt-test according to chapter 3.5 of the manual.
7. According to the manufacturer, the calibration of the flow rate should be performed every 2 months.
8. The muffler at the pump should be replaced semi-annually.
9. The sensors for the ambient temperature, air pressure, filter temperature and filter rH have to be checked every 6 months according to the manual.
10. The flow controller, the pump and the sample heater have to be checked every 6 months according to the manual.
11. Once a year, a 72 h background test with the help of the zero filter kit BX-302 according to the manual point 7.7 should be performed
12. Once a year the carbon vanes of the vacuum pump (only rotary vane pump) have to be checked and replaced if necessary during an annual base maintenance.
13. During the annual basic maintenance, the sampling tube should be inspected and cleaned.

For the performance of the maintenance work, the instructions in the manual have to be respected. All procedures can be performed with commonly available tools.

It is generally recommended to perform a self-test according to chapter 3.5 of the manual after each action, which interrupts the measurement operation.

6.5 Assessment

Maintenance works can be carried out with commonly available tools taking reasonable time and effort. The workings according to point 6ff have to be done during shutdown of the system. These workings are only necessary in a two month interval as well as semiannually or annually. During the remaining time, the maintenance can be basically restricted to the check of contaminants, plausibility checks and possible status/error messages.

Minimum requirements fulfilled? yes

6.6 Detailed representation of test results

The maintenance works were carried out during the test in accordance with the instructions given in the manual. No problems were noticed while following the described procedures. All maintenance works could be done with customary tools without taking much time and effort.

6.1 4.1.3 Function test

Particular instruments for function tests shall be considered as part of the device and thus shall be evaluated in the corresponding sub-tests.

Test gas units shall indicate readiness by status signals and shall allow direct or remote access to control functions via the measuring system.

The measurement uncertainty of the test gas unit shall not exceed 1% of B_2 within three months.

6.2 Equipment

Manual, zero filter kit BX-802, built-in reference foil.

6.3 Carrying out the test

To check the zero point of the radiometric measurement, it is harken back to the count rates I_1 respectively I_{1x}, which are determined on a clean filter tape spot at every measurement cycle (refer to point 3.2 Functionality of the). The zero point of the radiometric measurement is thereby determined according to the following equation:

$$C_0\left[mg/m^3\right] = \frac{A}{Q} * \frac{K}{mu2} * \ln\left(\frac{I_1}{I_{1X}}\right)$$

with

C_0	particle mass concentration at ZP	A	particle collection area (filter spot)
Q	sampling flow rate	K, mu2	coefficients beta measurement
I_1	initial beta count rate	I_{1X}	final beta count rate

In order to check the stability of the sensitivity of the radiometric measurement, it is harken back to the count rates I_1 (clean filter spot) respectively I_2 (clean filter spot + retracted reference foil), which are determined at every measurement cycle (refer to point 3.2 Functionality of the). The mass density m [mg/cm²] of the reference foil is calculated device-internal from the determined count rates. The value is continuously compared to the nominal value ABS, which has been determined in the factory and in case of a deviation of >5% to the nominal value, an error message is generated.

Hence there is the possibility to determine the zero point as well as the reference value (automatically) for each measurement cycle (here: once per hour). The obtained hourly values at zero point and at reference point are made available via the serial interface and are easily available for evaluation with an external spreadsheet. Within the scope of the test, the results of the internal tests have been compressed to suitable mean values and been evaluated (e.g. 24-h-mean for drift investigations).

Furthermore there is also the possibility to check the zero point of the measuring device externally. For this a zero filter (BX-302 Zero Filter Calibration Kit) is installed at the device inlet. The use of this filter allows the provision of particle-free air.

Besides the external zero point check for the measuring device, this procedure is also used for the regular determination of the background value BKGD (offset correction for the concentration values) according to the manual chapter 7.7.

Within the scope of the test work, a determination of the zero point by using the zero filter was also performed approx. every 4 weeks.

6.4 Evaluation

All instrument functions, which are listed in the manual, are available and can be activated. The current status of the system is monitored continuously and is indicated by a series of different status messages (operational, alarm and error status).

The measuring system carries out by default an internal check of the zero point (zero measurement) as well as of the sensitivity (measurement with reference foil) at every measurement cycle. It must be pointed out, that only the mass density can be determined by the application of the reference foil. Therefore a direct comparison with the reference values is not possible. For the purpose of evaluation, the percental changes of the determined mass densities have been calculated.

An external check of the zero point by using the zero filter (BX-302 Zero Filter Calibration Kit) is also possible at any time.

6.5 Assessment

All system functions listed in the manual are available, activatable and functioning. The current system status is continuously monitored and displayed by a set of different status messages (operation, warning and error messages).

The results of the device-internal checks of the zero point and of the radiometric measurement as well as the external zero point checks with zero filter during the field investigations are described in chapter 6.1 5.2.9 Zero drift and in chapter 6.1 5.2.10 Drift of the measured value in this report.

Minimum requirements fulfilled? yes

6.6 Detailed description of test results

Refer to point 6.1 5.2.9 Zero drift
and 6.1 5.2.10 Drift of the measured value

6.1 4.1.4 Setup- and warm-up times

The set-up times and warm-up times shall be specified in the instruction manual.

6.2 Equipment

A clock was required for this test.

6.3 Carrying out the test

The AMS were started up according to the description given by the manufacturer. Necessary setup- and warm-up times were recorded separately.

Necessary constructional works prior to the measurement, such as the installation of an inlet through the container roof, were not included in this test.

6.4 Evaluation

The setup time comprises the time needed for all necessary works from system installation to start-up.

The measuring system must be protected from weather inconsistencies (e.g. in an outdoor cabinet of the system manufacturer or an acclimated measuring container). Extensive construction work is required in order to lead the sample tube through the roof of a measuring container. A non-stationary application is therefore only assumed together with the belonging peripheral devices.

- Unpacking and installation of the measuring system (in a rack or on a table)
- Connection of the sampling tube + PM_{10}-sampling inlet + $PM_{2.5}$ SCC
- Installation of the heating system
- Connection of the pump
- Mounting of ambient air sensor + radiation protection shield (nearby the sampling inlet)
- Connection of all connecting and control lines
- Connection of power supply
- Switch-on of the measuring system
- Insertion of the filter tape
- Performance of self-test according to point 3.5 in the manual
- Check of the tightness and of the flow rate
- Optional connection of peripheral recording and control systems (data logger, PC with HyperTerminal) to the respective interfaces

The performance of these actions and therewith the set-up time takes 1 to 2 hours.

The warm-up time contains the time need between the start of operation of the measuring system and the readiness for measurement.

After switching on the system and the successful performed self-test, the measuring system remains in a waiting position until reaching the next hour. When reaching the hour, the next measurement cycle as described in point 3.2 Functionality of the . The sampling starts according to the set measurement time for the radiometry (during the suitability test 8 min) immediately after the radiometric measurement I_0 (zero value of filter spot for sampling).

If required, possible changes of the basic parameterization of the measuring system can likewise be performed within few minutes by personal, familiar with the devices.

6.5 Assessment

The setup- and warm-up times were determined.

The measuring system can be operated at different measurement sites with manageable effort. The set-up time is approximately 1 to 2 hours and the warm-up time is at maximum the time need of a complete measurement cycle (here: 60 min).

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this test.

6.1 4.1.5 Instrument design

The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. The main elements are:
Instrument shape (e.g. bench mounting, rack mounting, free mounting)
Mounting position (e.g. horizontal or vertical mounting)
Safety requirements
Dimensions
Weight
Power consumption

6.2 Equipment

A measuring device for power consumption measurement and a scale were used for this test.

6.3 Carrying out the test

The installation of the delivered systems was compared with the description given in the manuals. The specified power consumption was continuously tested (24h) under standard operation conditions on three days during field test.

6.4 Evaluation

The measuring system has to be installed in horizontal mounting position, independent from atmospheric conditions. At this, the system should be installed on an even plane (e.g. table). The installation in a 19“rack is also possible.

The dimensions and the weights of the measuring system are in compliance with the specifications in the manual.

The power consumption of the measuring system with the used pump is specified by the manufacturer with at maximum 370 W. During 3 tests, each with 24 h, this specification was checked. At no time the mentioned value was exceeded during these investigations. The mean power consumption during the investigation for a measurement cycle of 60 min (42 min sampling) was approximately 150 W.

6.5 Assessment

The instrument design specifications listed in the operating manual are complete and correct.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 4.1.6 Security

The AMS shall have a means of protection against unauthorized access to control functions.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

The operation of the measuring device is carried out *via* the keypad at the front panel or *via* the RS232-interfaces and modem from an external computer.

The menu “Setup” is completely protected by a password, except for the sub-point time setting. An alteration of the set parameters without the knowledge of the password is not possible.

An adjustment of the sensors for the ambient temperature, air pressure as well as for the flow rate measurement in the menu „Test/Flow“ as well as of the sensors for the control of the sample heater in the menu „Test/Heater“ is only possible *via* several key sequences.

It must be pointed out, that the current measurement cycle is interrupted by pressing the keys „Setup“, „Test“ or „Tape“ and the next measurement cycle does not begin until the following hour.

As an outside installation of the measuring device is not possible, additional protection is given by installation at locations to which unauthorized people have no access (e.g. a locked measurement cabinet).

6.4 Evaluation

Unintended adjustment of instrument parameters is avoided by the password protection of the menu “Setup”. The adjustment of sensors for the flow rate measurement and for the operation of the sample heater can only be done *via* several key sequences. Moreover there is an additional protection against unauthorized intervention by the installation in a locked measurement cabinet.

6.5 Assessment

The AMS is protected against unauthorized and unintended adjustment. In addition, the AMS shall be locked in a measuring cabinet.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 4.1.7 Data output

The output signals shall be provided digitally (e.g. RS 232) and/or as analogue signals (e.g. 4 mA to 20 mA).

6.2 Equipment

PC with software „HyperTerminal", data logger Yokogawa (for analogue signal)

6.3 Carrying out the test

The test was carried out using an electronic data recording system of the type Yokogawa (analogue output, only test in laboratory) and a PC with the software „HyperTerminal"(digital output, serial interfaces RS 232 #1 & #2).

The data recording systems were connected to the analogue as well as digital output. The test was performed by comparing the measured values from the display, analogue and digital output in the laboratory.

6.4 Evaluation

The measured signals are offered at the rear side of the instrument in the following way:

Analogue:	0-1 resp. 10 V resp. 0–16 mA / 4-20 mA concentration range selectable
Digital:	*via* 2xRS 232-interface - *via* direct or modem connection to a computer, the device can be completely controlled – e.g. it is possible to readout the buffer containing all past measurement data (serial interface #1).

The determined measured values have been output as both analogue and digital signals in compliance with the indicated value in the instrument buffer.

6.5 Assessment

Measured signals are offered analogue (0-1 resp. 10 V resp. 0–16 mA / 4-20 mA) and digital (via RS 232).

The connection of additional measuring and peripheral devices to the respective ports of the devices is possible.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Figure 33 shows a view of the rear side of the instrument with the respective measured value outputs.

Figure 33: View on rear of the device BAM-1020

6.1 4.2 Requirements for mobile measuring systems

Measuring systems for mobile applications shall also comply with the requirements on measuring systems for stationary applications in the case of mobile application. The measuring system shall be in a permanent operational stand-by mode during mobile application, e.g. measurements in running traffic, time-limited measurements at different site or measurements on aircraft.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

Within the scope of the field test, the measuring system was tested at several field test sites.

6.4 Evaluation

The measuring systems have been designed for fixed installation in a measurement station or cabinet. A mobile application is only possible together with a measurement cabinet.

The permanent operational stand-by for time-limited measurements at different sites is ensured when considering the conditions of mounting (choice of measurement site, infrastructure).

For a mobile application, the set-up and warm-up times have to be considered beside the mounting conditions.

6.5 Assessment

In the context of the field test, the measuring system was operated at several different sites, but cannot be operated in moving vehicles.

Minimum requirements fulfilled? no

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.1 General

The manufacturer's specifications shall not be contrary to the results of the suitability test.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

The test results are compared with the specifications given in the manual.

6.4 Evaluation

Found deviations between the first draft of the manual and the actual design were resolved.

6.5 Assessment

Differences between the instrument design and the descriptions given in the manual could not be detected.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Refer to point 6.4 of this module.

6.1 5.2.1 Measuring range

The upper limit of measurement range of the measuring systems shall be greater or equal to reference value B_2.

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

It was tested, whether the upper limit of measuring range of the measuring system is greater or equal to the reference value B_2

6.4 Evaluation

The following measuring ranges can be set at the measuring system:
0 – 0.100, 0 – 0.200, 0 – 0.250, 0 – 0.500, 0 – 1.000, 0 – 2.000, 0 – 5.000 as well as 0 – 10.000 mg/m³.

During the suitability test, the measuring range has been set to 0 – 1.000 mg/m³ = 0 – 1,000 µg/m³.

Measuring range: 0 – 1.000 µg/m³ (standard)

Reference value: VDI: B_2 = 200 µg/m³.

6.5 Assessment

A measuring range of 0 to 1,000 µg/m³ is set by default. Other measuring ranges in the range between at minimum 0-100 µg/m³ and at maximum 0-10,000 µg/m³ are possible.

The upper limit of measuring range of the measuring system is greater than the reference value B_2.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.2.2 Negative output signals

Negative output signals or measured values may not be suppressed (live zero).

6.2 Equipment

No additional equipment required.

6.3 Carrying out the test

The AMS was tested on its ability to display negative output signals in the laboratory and in the field.

6.4 Evaluation

The measuring system can output negative values via the display as well as via the analogue and digital outputs.

6.5 Assessment

Negative measuring signals are displayed directly and are output correctly via the respective measured value outputs by the measuring system.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.2.3 Analytical function

The relationship between the output signal and the value of the air quality characteristic shall be represented by the analytical function and determined by regression analysis.

6.2 Equipment

Refer to point 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6]

6.3 Carrying out the test

For dust measuring devices for $PM_{2.5}$ measurements, the test should be carried out according to point 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6].

6.4 Evaluation

The comparability of the measuring devices according to point 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6] was proven within the framework of the test.

The entire data record (251 valide data pairs for SN 17010 and 253 valid data pairs for SN 17011) were used for determining the calibration or analytical function.

The characteristic data of the calibration function

$$y = m * x + b$$

were determined by orthogonal regression. The analytical function is the reversed calibration function and described as follows:

$$x = 1/m * y - b/m$$

The slope m of the regression line characterizes the sensitivity of the measuring device; the ordinate intercept b characterizes zero point.

This results in the characteristic data presented in Table 8.

Table 8: Results of the calibration and analytical function

Device No.	Calibration function		Analytical function	
	Y = m * x + b		x = 1/m * y - b/m	
	m	B	1/m	b/m
	µg/m³ / µg/m³	µg/m³	µg/m³ / µg/m³	µg/m³
SN 17010	0.969	0.989	1.032	1.021
SN 17011	1.041	0.377	0.961	0.362

6.5 Assessment

A statistically firm correlation could be proven between the reference method and the instrument reading.

The candidates fulfil the criteria of the equivalence test according to chapter 7 of this report without the application of the determined analytical function with the as factory settings implemented calibration factors in the devices

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Refer to chapter 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6].

6.1 5.2.4 Linearity

Reliable linearity is given, if deviations of the group averages of measured values about the calibration function are smaller than 5 % of B_1 in the range of zero to B_1, and smaller than 1 % of B_2 in the range of zero to B_2.

6.2 Equipment

Refer to module 5.3.1)

6.3 Carrying out the test

The test should be carried out according to minimum requirement 5.3.1 „Equivalency of the sampling system“ for particle measuring devices.

6.4 Evaluation

Refer to module 5.3.1.

6.5 Assessment

The test should be carried out according to minimum requirement 5.3.1 „Equivalency of the sampling system“ for particle measuring devices.

Refer to module 5.3.1.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Refer to module 5.3.1.

6.1 5.2.5 Detection limit

The detection limit of the measuring system shall be smaller or equal to reference value B_0. The detection limit shall be determined in the field.

6.2 Equipment

BX-302 zero filter kit for zero point check.

6.3 Carrying out the test

The determination was carried out for the devices no. SN 17010 and SN 17011 by installing zero filters to the inlet of each measuring device. Particle-free air was sampled for 15 days of continuous measurement (24h periods). The detection limits were determined during the laboratory tests since a particle-free air supply over a long period was not possible under field conditions.

6.4 Evaluation

The detection limit X is determined from standard deviation s_{x0} of the measured values for both measuring devices and particle-free sampling air. It corresponds to the standard deviation of the average value x_0 of the measured values x_{0i} multiplied with the student factor.

$$X = t_{n-1;0,95} \cdot s_{x0} \qquad \text{with} \cdot s_{x0} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Reference value: $B_0 = 2$ µg/m³

6.5 Assessment

The detection limit has been determined from the investigations to 1.33 µg/m³ for device 1 (SN 17010) and to 1.09 µg/m³ for device 2 (SN 17011).

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 9: Detection limit

		Device SN 17010	Device SN 17011
No. of values n		15	15
Average of zero values $\overline{x_0}$	µg/m³	-0.55	-1.09
Standard deviation s_{x0}	µg/m³	0.62	0.51
Student factor $t_{n-1;0,95}$		2.14	2.14
Detection limit X	µg/m³	**1.33**	**1.09**

The single values for the determination of the detection limit can be found in annex 1 in the appendix.

6.1 5.2.6 Response time

The response time (90%-time) of the measuring system shall be smaller or equal to 5 % of the averaging time (180 s).

According to Standard VDI Sheet 3, point 5.3, this test point is not relevant for particulate measuring systems with pre-separation, based on a physical measurement method.

6.2 Equipment

Not applicable.

6.3 Carrying out the test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable.

6.1 5.2.7 Ambient temperature dependency of zero point

The temperature dependency of the measured value at zero concentration shall not exceed the reference value B_0 if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or by 20 K in the range of +20 °C to +40 °C.

6.2 Equipment

Climate chamber adjusted to a temperature range of +5 °C to +40 °C, zero filter kit BX-302 for zero point check.

6.3 Carrying out the test

The complete measuring systems were operated in a climate chamber in order to evaluate the dependency of zero point on ambient temperature. Both candidates SN 17010 and SN 17011 were supplied with particle-free sampling air by installing a zero filter at the device inlet. The ambient temperatures in the climate chamber were varied according to the following sequence 20 °C – 5 °C – 20 °C – 40 °C – 20 °C. The measured values at zero point were recorded (3 times per temperature step) after an equilibration time of approximately 24 h per temperature step. Relative humidity was kept constant.

6.4 Evaluation

The measured values for the concentration measurements were read out and evaluated. The absolute deviation in µg/m³ per temperature step, related to the start point of 20 °C, was considered.

Reference value: B_0 = 2 µg/m³.

6.5 Assessment

A maximum influence of the ambient temperature on the zero point of -1.6 µg/m³ was calculated.

In order to calculate the uncertainty according to point 6.1 5.2.21 Total uncertainty -1.20 µg/m³ was used for SN 17010 and -1.60 µg/m³ for SN 17011.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 10: Ambient temperature dependency of zero point, deviation in µg/m³, average of three measurements

Temperature		Deviation	
Start temperature	End temperature	Device 1 (SN 17010)	Device 2 (SN 17011)
°C	°C	µg/m³	µg/m³
20	5	0.3	1.0
5	20	-1.2	0.4
20	40	-1.0	-1.6
40	20	0.6	0.2

The results of the three individual measurements are presented in Annex 2 of the appendix.

6.1 5.2.8 Ambient temperature dependency of the measured value

The temperature dependency of the measured value in the range of reference value B_1 shall not exceed 5 % of the measured value if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or by 20 K in the range of +20 °C to +40 °C.

6.2 Equipment

Climate chamber adjusted to a temperature range of +5 °C to +40 °C, built-in reference foils

6.3 Carrying out the test

For the investigation of the dependence of the measured values on the ambient temperature, the complete measuring systems have been operated in the climate chamber. To check the stability of the sensitivity of the radiometric measurement for the candidates SN 17010 and SN 17011, it is harken back to the count rates I_1 (clean filter spot) and I_2 (clean filter spot + retracted reference foil),determined at every measurement cycle (refer to point 3.2 Functionality of the). The mass density m [µg/cm²] of the reference foil is calculated device-internal from the determined count rates.

The ambient temperatures in the climate chamber were varied in triple repetition in the order 20 °C, – 5 °C, – 20 °C, – 40 °C and – 20 °C. After a respective time for equilibration of approximately 6 h per temperature step, the measured values at the reference point have been recorded. The relative humidity was kept constant.

6.4 Evaluation

The percentage change of the determined mass density has been calculated for each temperature step relative to the start point of 20 °C.

Note that only mass densities (and not concentrations) can be simulated by the application of the built-in reference foil. As such, a consideration in the range of B_1 (= 25 µg/m³) was not possible.

6.5 Assessment

No deviations greater than -0.2 % were determined for device 1 (SN 17010). For device 2 (SN 17011) deviations did not exceed 0.3 % of the initial value at 20 °C.

0.05 µg/m³ (=-0.2 % of 25 µg/m³) were used for SN 17010 and 0.08 µg/m³ (=0.3 % of 25 µg/m³) for SN 17011 to calculate uncertainty according to point 6.1 5.2.21 Total uncertainty.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 11: Ambient temperature dependency of sensitivity SN 17010 & SN 17011, deviation in %, average of three measurements

Temperature		Deviation	
		Device 1 (SN 17010)	Device 2 (SN 17011)
Start temperature °C	End temperature °C	built-in reference foil %	built-in reference foil %
20	5	0.0	0.0
5	20	0.0	0.1
20	40	0.2	0.3
40	20	0.0	0.0

The results of the three individual measurements are presented in annex 2 of the appendix.

6.1 5.2.9 Zero drift

The temporal change in the measured value at zero concentration shall not exceed the reference value B_0 in 24 h and in the maintenance interval.

6.2 Equipment

Zero-filter kit BX-302

6.3 Carrying out the test

The test was periodically carried out in the context of the field test over a time period of approximately 20 months in total.

The measuring systems were operated with zero-filter at the inlet approximately once a month (including at the beginning and at the end of each test site) for a time period of at least 24 h, and the measured zero values were evaluated.

The daily zero point check, required in the test plan, is in principle possible for this measuring system by evaluating the device-internal check of the zero point of the radiometric measurement. Hereby the count rates I_1 and I_{1x}, which are determined on a clean filter tape spot at every measurement cycle (refer to point 3.2 Functionality of the) are evaluated. Within the scope of the test, a daily evaluation of the full dataset has not been incuded due to reasons of practicability (large amount of data). However as an example a graphic presentation of the results for the candidate SN 17011 at test site Cologne (Winter) has been carried out in Figure 36 and in Figure 37.

The evaluation of the internal zero point measurement leads to no interruption of the ongoing measuring operation at all.

6.4 Evaluation

The evaluation is based on 24hmeasured values obtained with the regular external zero point measurements by comparison of the respective values to those of the previous and to those of the first test.

6.5 Assessment

The detected values are all within the allowed limits of B_0 = 2 µg/m³ during the maintenance interval.

Minimum requirement fulfilled? yes

1.8 µg/m³ was used for SN 17010 and 1.6 µg/m³ for SN 17011 to calculate uncertainty according to point 6.1 5.2.21 Total uncertainty.

6.6 Detailed representation of test results

Table 12 and Table 13 contain the determined measured values for the zero point and the calculated deviations related to the previous value and related to the start value in µg/m³. Figure 34 and Figure 35 show a graphic interpretation of the zero point drift over the time period of testing.

Table 12: Zero point drift SN 17010, with zero filter

Date	Measured value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³
07/24/2008	1.4	-	-
08/18/2008	-0.8	-2.2	-2.2
09/23/2008	1.0	1.7	-0.4
10/16/2008	1.8	0.8	0.3
11/10/2008	-0.1	-1.8	-1.5
12/03/2008	-1.2	-1.2	-2.7
01/07/2009	0.4	1.6	-1.0
02/02/2009	-0.7	-1.1	-2.1
03/04/2009	-1.5	-0.8	-2.9
04/02/2009	0.2	1.7	-1.2
08/13 & 08/14/2009	0.1	-0.1	-1.3
09.14.2009	-0.1	-0.2	-1.5
10.23.2009	-0.1	0.0	-1.5
12.07.2009	0.9	1.0	-0.5
01.04.2010	0.4	-0.5	-1.0
02.05.2010	-0.3	-0.7	-1.7

Table 13: Zero point drift SN 17011, with zero filter

Date	Measured value	Deviation from previous value	Deviation from start value
	µg/m³	µg/m³	µg/m³
07/24/2008	-1.3	-	-
08/18/2008	-1.1	0.2	0.2
09/23/2008	-0.6	0.4	0.6
10/16/2008	-0.8	-0.1	0.5
11/10/2008	-0.2	0.6	1.1
12/03/2008	-0.3	-0.1	1.0
01/07/2009	0.7	0.9	1.9
02/02/2009	-0.4	-1.1	0.8
03/04/2009	-1.1	-0.7	0.2
04/02/2009	0.4	1.5	1.6
08/13 & 08/14/2009	-1.3	-1.6	0.0
09.14.2009	0.3	1.6	1.6
10.23.2009	-0.2	-0.6	1.0
12.07.2009	0.5	0.8	1.8
01.04.2010	0.8	0.3	2.1
02.05.2010	1.6	0.8	2.9

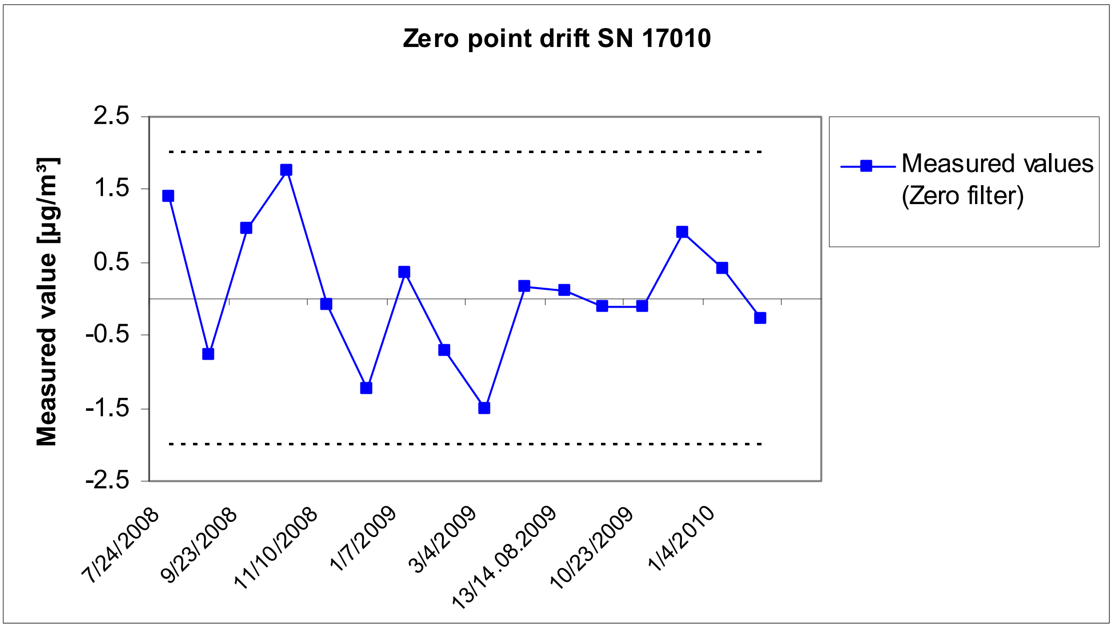


Figure 34: Zero point drift SN 17010

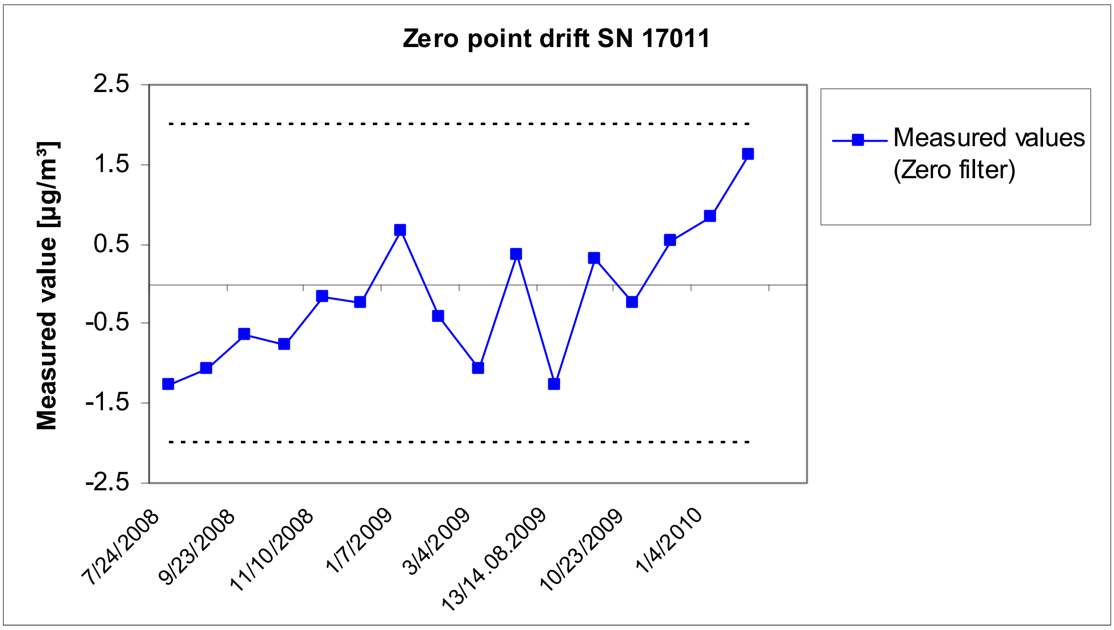


Figure 35: Zero point drift SN 17011

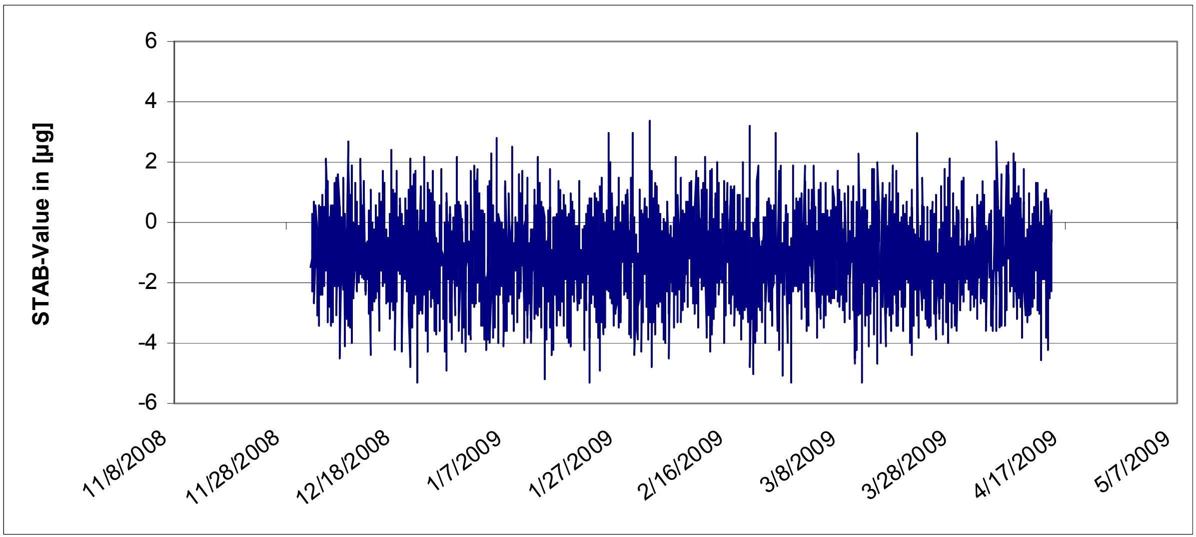


Figure 36: Internal zero point check, SN 17011, Cologne (Winter), Measured values for stability from each cycle (1 x per hour)

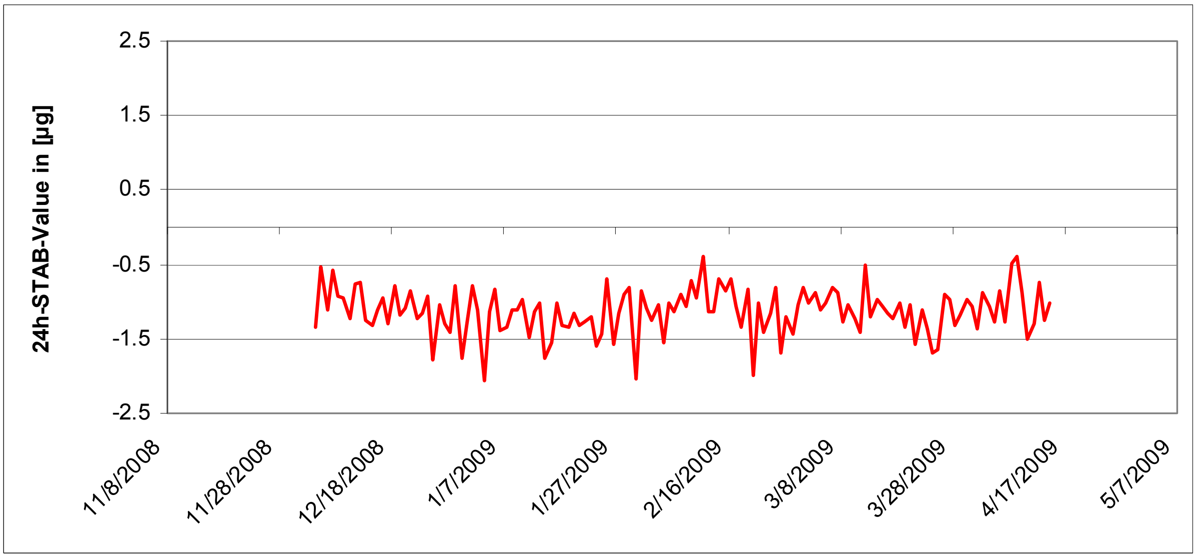


Figure 37: Internal zero point check, SN 17011, Cologne (Winter), 24h-mean values of measured values for stability from each cycle

6.1 5.2.10 Drift of the measured value

The temporal change in the measured value in the range of reference value B_1 shall not exceed 5 % of B_1 in 24 h and in the maintenance interval.

6.2 Equipment

Built-in reference foil.

6.3 Carrying out the test

The test has been performed within the scope of the field test over a time period of approximately 20 months in total.

The daily reference point check, required in the test plan, is in principle possible for this particulate measuring system by evaluating the device-internal check of the stability of the sensitivity of the radiometric measurement. The count rates I_1 (clean filter spot) and I_2 (clean filter spot + retracted reference foil) are determined at every measurement cycle (refer to point 3.2 Functionality of the). The mass density m [µg/cm²] of the reference foil is calculated device-internal from the determined count rates.

Within the scope of the test, a daily evaluation of the full dataset has not been included due to reasons of practicability (large amount of data). However an example evaluation and graphical presentation of the results for the time periods during which the devices were in parallel operated with zero filters is included.

The evaluation of the internal reference point measurement leads to no interruption of the ongoing measuring operation at all.

6.4 Evaluation

The evaluation is based on the measured results of the internal reference point check by comparison of the respective values to those of the previous and to those of the first test

Note that only mass densities (and not concentrations) can be simulated by the application of the built-in reference foil. A consideration in the range of B_1 (= 25 µg/m³) was not possible because of this reason.

6.5 Assessment

The measuring system carries out a regular device-internal check of the sensitivity of the radiometric measurement during each measurement cycle. This test leads to no interruption of the ongoing measuring operation. The values for the drift of the sensitivity, determined within the scope of the test, were at maximum 0.5 % (SN 17010) and -0.5 % (SN 17011) in the maintenance interval.

To calculate uncertainty according to point 6.1 5.2.21 Total uncertainty, 0.13 µg/m³ (=0.5 % of 25 µg/m³) was used for SN 17010 and -0.13 µg/m³ (=-0.5 % of 25 µg/m³) was used for SN 17011.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 14 and Table 15 show the determined values in % of the respective previous value and the initial value. Figure 38 and Figure 39 show a graphical representation of the drift of the measured value (related to the previous value).

Table 14: Drift of the measured value for SN 17010

Date	Measured value	Deviation to previous value	Deviation to start value
	µg/cm²	%	%
07/24/2008	830.2	-	-
08/18/2008	828.6	-0.2	-0.2
09/23/2008	829.3	0.1	-0.1
10/16/2008	829.1	0.0	-0.1
11/10/2008	828.5	-0.1	-0.2
12/03/2008	829.7	0.1	0.0
01/07/2009	830.2	0.1	0.0
02/02/2009	828.5	-0.2	-0.2
03/04/2009	828.1	0.0	-0.2
04/02/2009	828.8	0.1	-0.2
08/13 & 08/14/2009	833.2	0.5	0.4
09.14.2009	833.7	0.1	0.4
10.23.2009	833.7	0.0	0.4
12.07.2009	833.9	0.0	0.4
01.04.2010	832.6	-0.2	0.3
02.05.2010	833.4	0.1	0.4

Table 15: Drift of the measured value for SN 17011

Date	Measured value	Deviation to previous value	Deviation to start value
	µg/cm²	%	%
07/24/2008	824.4	-	-
08/18/2008	826.4	0.2	0.2
09/23/2008	822.3	-0.5	-0.3
10/16/2008	822.1	0.0	-0.3
11/10/2008	822.3	0.0	-0.3
12/03/2008	822.2	0.0	-0.3
01/07/2009	823.2	0.1	-0.1
02/02/2009	822.1	-0.1	-0.3
03/04/2009	822.2	0.0	-0.3
04/02/2009	822.3	0.0	-0.3
08/13 & 08/14/2009	825.6	0.4	0.1
09.14.2009	829.4	0.5	0.6
10.23.2009	829.8	0.0	0.6
12.07.2009	828.7	-0.1	0.5
01.04.2010	828.8	0.0	0.5
02.05.2010	828.7	0.0	0.5

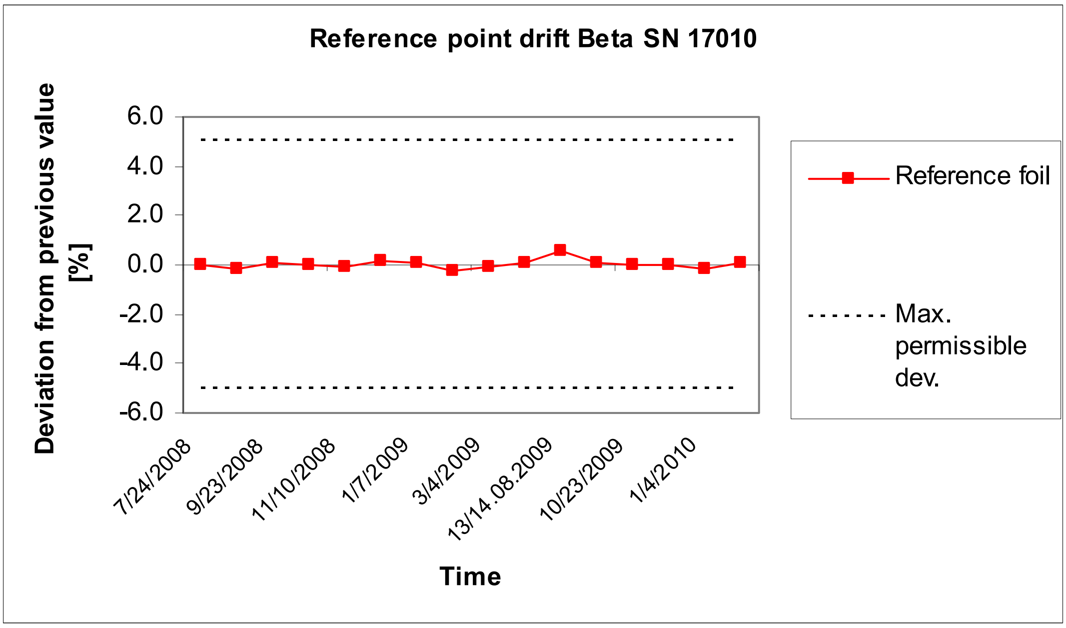


Figure 38: Drift of the measured value for SN 17010

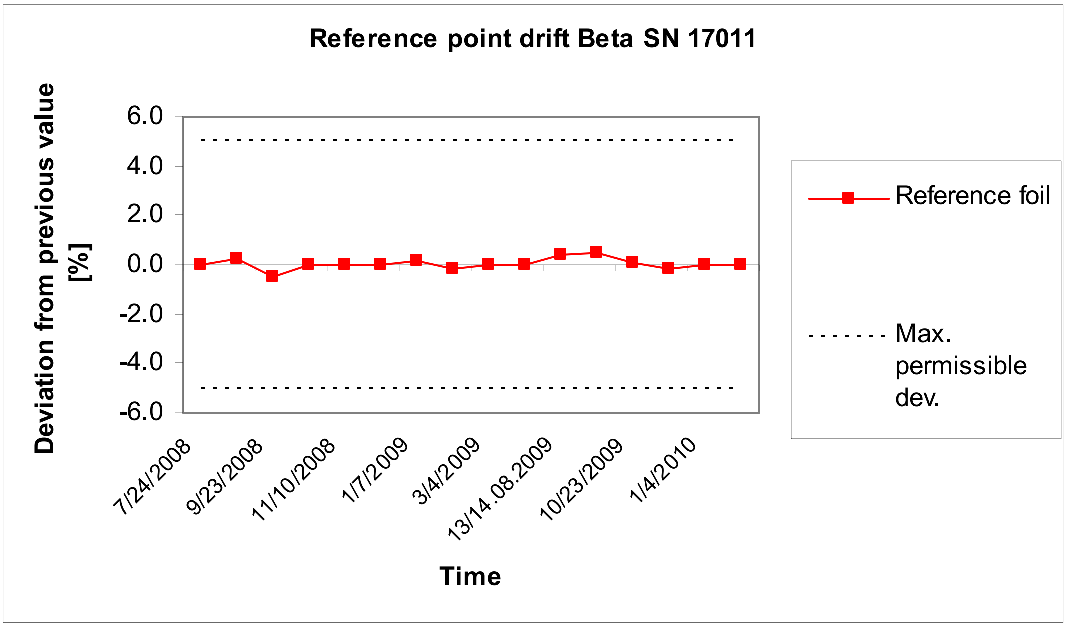


Figure 39: Drift of the measured value for SN 17011

6.1 5.2.11 Cross sensitivity

The absolute values of the sum of the positive and the sum of negative deviations caused by cross-sensitivities of interfering components in the measured sample shall not exceed B_0 at the zero point and shall not exceed 3 % of B_2 in the range of B_2. The concentration of interfering components shall correspond to the B_2 value of the respective interfering component. If reference values have not been specified, the test institute shall specify and declare suitable reference values in agreement with other test institutes.

This test point is not relevant for particulate measuring systems. Instead, the minimum requirement in 5.3.4. is required. For this reason, the results of this test are presented in module 5.3.4.

6.2 Equipment

Not applicable.

6.3 Carrying out the test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable.

6.1 5.2.12 Reproducibility R_D

The reproducibility R_D of the measuring system shall be determined by parallel measurements with two identical measuring systems and shall be at least equal to 10. B_1 shall be used as the reference value.

6.2 Equipment

The measuring devices described in chapter 5 were used for this test.

6.3 Carrying out the test

Reproducibility R_D is defined as the maximum deviation of two randomly chosen single values which were obtained under equal conditions in relation to each other. This test has been carried out with two identical devices which were simultaneously operated during the field test. The measured data from all four field tests was used for this test.

6.4 Evaluation

Reproducibility R_D is calculated as follows:

$$R_D = \frac{B_1}{U} \geq 10 \quad \text{where} \quad U = \pm s_D \cdot t_{(n;0,95)} \quad \text{and} \quad s_D = \sqrt{\frac{1}{2n} \cdot \sum_{i=1}^{n} (x_{1i} - x_{2i})^2}$$

- R_D = Reproducibility R_D at B_1
- U = Uncertainty
- B_1 = 25 µg/m³
- s_D = Standard deviation from parallel measurements
- n = No. of parallel measurements
- $t_{(n;0,95)}$ = Student factor for 95 % certainty
- x_{1i} = Measured signal of device 1 (e.g. SN 17010) at i^{th} concentration
- x_{2i} = Measured signal of device 2 (e.g. SN 17011) at i^{th} concentration

.

6.5 Assessment

Reproducibility R_D in the field was 10 for the complete data set.

Minimum requirement fulfilled? yes

A value of 10 (all test sites) was used to calculate uncertainty according to point 6.1 5.2.21 Total uncertainty.

6.6 Detailed representation of test results

Table 16 summarizes the results of the test. Figure 44 to Figure 50 show a graphical representation of the test results.

Note: The determined uncertainties of each site are related to the reference value B_1.

Table 16: Concentration averages, standard deviation, uncertainty range and reproducibility R_D in the field, measured component PM_{10}

Site	No.	$\bar{c}$ (SN 17010)	$\bar{c}$ (SN 17011)	$\bar{c}_{ges}$	s_D	t	U	R_D
		µg/m³	µg/m³	µg/m³	µg/m³		µg/m³	
Teddington (Summer)	97	11.2	10.5	10.9	1.055	1.985	2.09	12
Cologne (Winter)	127	24.4	25.7	25.1	1.704	1.979	3.37	7
Bornheim (Summer)	66	12.9	13.4	13.2	1.110	1.997	2.22	11
Teddington (Winter)	55	15.5	16.6	16.1	0.941	2.004	1.89	13
All sites	345	17.1	17.6	17.4	1.338	1.967	2.63	10

- $\bar{c}$ (SN 17010): concentration averages device SN 17010
- $\bar{c}$ (SN 17011): concentration averages device SN 17011
- $\bar{c}_{ges}$: concentration averages of the devices SN 17010 & SN 17011

The results of the individual measurements are presented in annex 4 of the appendix.

6.1 5.2.13 Hourly mean values

The measurement method shall allow formation of hourly mean values.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

The measuring systems were tested on the formation of hourly mean values.

6.4 Evaluation

According to the valid Directive [7], the limits for particulate matter PM_x are related to an averaging time of at least 24 hours. Hence, formation of hourly mean values is not required for measuring systems for monitoring the respective limits. The tested measuring systems operates by default with a measurement cycle of 60 min and thus outputs every hour a new measured value. Hence the measuring system allows an on-line measurement of the particulate concentrations with hourly resolution.

6.5 Assessment

The formation of hourly averages for the component $PM_{2.5}$ is not necessary for the monitoring of the relevant limit values, but possible..

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

In the following figures, the course of the suspended particulate matter concentrations during the time period from 03/09/2009 until 03/28/2009 (Cologne, parking lot) as well as the correlation between both candidates on basis of 1 h-mean values is shown. The suitability of the measuring system for on-line measurement of the particulate concentrations with hourly resolution and therefore the possibility to supply information on the time courses of PM concentrations is satisfactorily demonstrated.

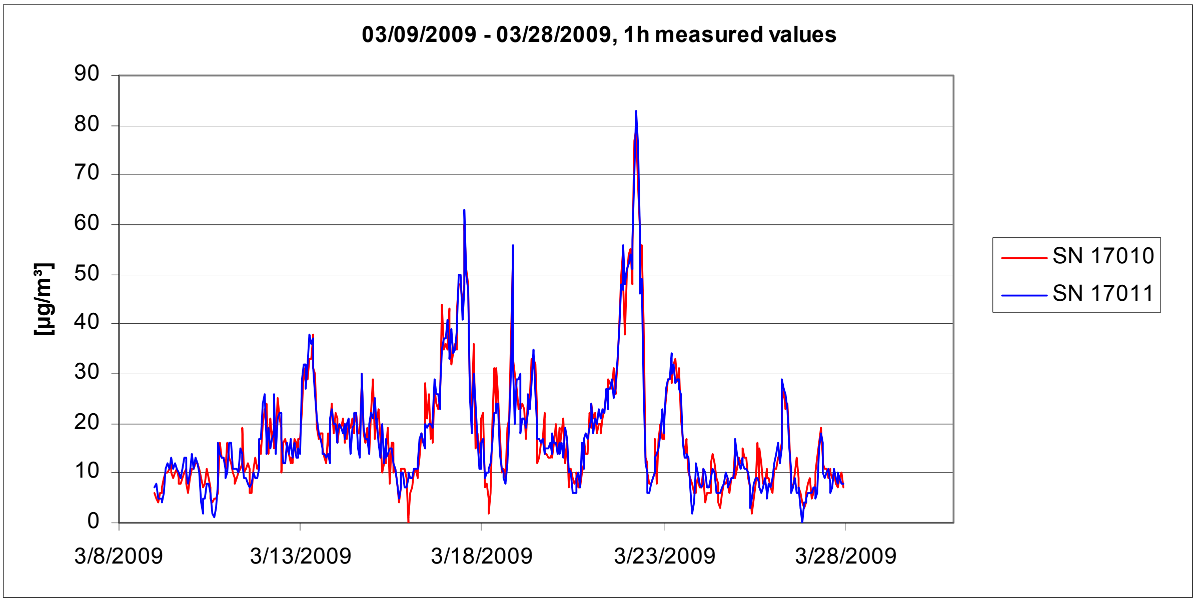


Figure 40: Tme series of 1h-mean $PM_{2.5}$ concentrations from 03/09/2009 to 03/28/2009.

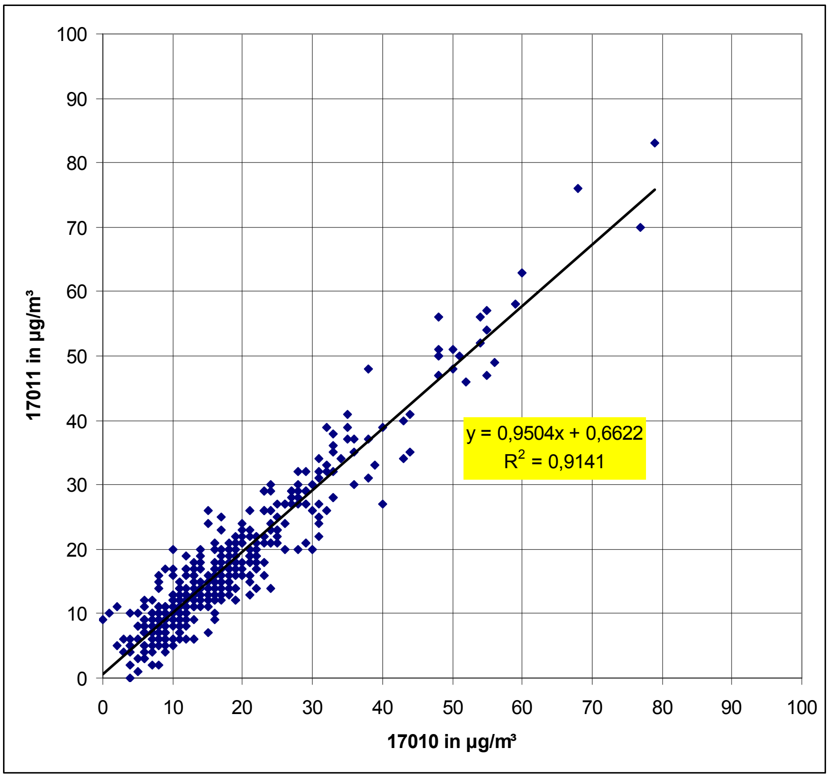


Figure 41: SN 17010 vs. SN 17011, 03/09/2009 until 03/28/2009, 1h-mean values

6.1 5.2.14 Mains voltage and frequency

The change in the measured values at reference value B_1 caused by normal changes in the mains voltage in the interval (230 +15/-20) V shall not exceed B_0. In addition, for mobile applications the change in the measured value caused by changes in frequency of the mains voltage in the interval (50 ± 2) Hz shall not exceed B_0.

6.2 Equipment

Adjustable isolating transformer, built-in reference foils.

6.3 Carrying out the test

To evaluate the dependency of the measured signal, the mains voltage was reduced from 230 V to 210 V and afterwards increased to 245 V *via* the intermediate stage of 230 V.

To check the dependence of the measured values on the mains voltage for the candidates SN 17010 and SN 17011, it is harken back to the count rates I_1 (clean filter spot) respectively I_2 (clean filter spot + retracted reference foil), which are determined at every measurement cycle (refer to point 3.2 Functionality of the). The mass density m [µg/cm²] of the reference foil is calculated device-internal from the determined count rates.

Since the measuring system is not intended for mobile use, an additional test on the dependency of the measured signal on frequency was omitted.

6.4 Evaluation

The percentile change of the determined mass density value at span point was considered in relation to the starting point at 230 V for each test step.

It should be noted, that only mass densities (and not concentrations) can be simulated by the application of the built-in reference foil, a consideration in the range of B_1 (= 25 µg/m³) was not possible for this reason.

6.5 Assessment

The assessment of the minimum requirements was based on the statements above.

No deviations > 0.1 % for device 1 (SN 17010) and > -0.1 % for device 2 (SN 17011) caused by mains voltage changes could be detected.

Minimum requirement fulfilled? yes

A value of 0.03 µg/m³ (=0.1 % of 25 µg/m³) was used for SN 17010 and -0.03 µg/m³ (=-0.1 % of 25 µg/m³) for SN 17011 to calculate uncertainty according to point 6.1 5.2.21 Total uncertainty.

6.6 Detailed representation of test results

Table 17 shows a summary of the test results.

Table 17: Dependence of the measured value (Radiometry) on the mains voltage, Deviation in %, SN 17010

Mains voltage		Deviations Radiometry	
		Device 1 (SN 17010)	Device 2 (SN 17011)
Start voltage	End voltage	Reference foil	Reference foil
V	V	%	%
230	210	0.1	0.0
210	230	0.0	-0.1
230	245	0.0	0.0
245	230	0.1	-0.1

The results of the individual measurements are presented in annex 3 of the appendix.

6.1 5.2.15 Power outage

In case of malfunction of the measuring system or failure in the mains voltage, uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

A power outage was simulated in order to determine whether the device will remain intact and will be ready for measurement as soon as the mains voltage returns.

6.4 Evaluation

Uncontrolled gas emission is not possible as the devices neither need operation nor calibration gases.

In case of a power loss, the measuring system restarts independently at the next measurement cycle upon reaching the next hour (refer to point 6.1 4.1.4 Setup- and warm-up times).

6.5 Assessment

All instrument parameters are protected against loss by buffering. The measuring system is in the normal operating condition after the restoration of the power supply and continues independently taking measurements upon reaching the next hour.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.2.16 Operating states

Measuring systems shall be able to telemetrically transmit important operating states by status signals.

6.2 Equipment

Modem, PC for data acquisition (RS 232-host-device)

6.3 Carrying out the test

A modem has been connected to the measuring system. By remote data recording, *i.e.* the status signals of the device have been recorded.

6.4 Evaluation

The measuring system allows the complete telemetric check and control of the measuring system. There is a series of read, write and control commands available. A complete overview can be found in the manual of the measuring system.

6.5 Assessment

The measuring systems can be controlled and monitored extensively from an external PC *via* a modem.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.2.17 Switchover

Switchover between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

The measuring device can be monitored as well as partly controlled by the user at the device or by telemetric remote control. The internal checks of the zero and reference point are an integral part of each measurement cycle and are stored in the device respectively offered *via* the serial interface.

Some functions, *i.e.* the performance of the extensive self-test of the measuring system, can only be activated directly at the device.

6.4 Evaluation

All operational procedures can be monitored by the user at the device as well as by telemetric remote control. The internal checks of the zero and reference point are an integral part of each measurement cycle and are stored in the device and can be interogated *via* the serial interface.

6.5 Assessment

Generally all necessary operations for functional check and calibration can be monitored directly at the device or *via* telemetric remote control.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.2.18 Availability

The availability of the measuring system shall be at least 90 %.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

Start time and end time of the availability tests were defined by the start and end of the field tests at each site. All measurement interruptions, *e.g.* due to system outage or maintenance works, were considered for this test.

6.4 Evaluation

Table 18 and Table 19 show a compilation of the operation, maintenance and malfunction times. The measuring systems have been operated over a time period of 373 measuring days during the field test. This time period includes 12 days of zero filter operation (refer to annex 4).

Losses caused by external influences, which cannot be attributed to the device itself, have been recorded on 08/06/2008 and 08/07/2008 (48 h due to power loss). Furthermore, all measuring systems were shut down between 10/17/2008 and 20/20/2008 (for SN 17011 additionally shut down on 08/12/2009 (repair of SN 17010)). Therefore the total operating time is reduced to 367 (SN 17010) respectively 366 (SN 17011) measuring days.

The following malfunctions of the devices have been observed:

There have been 3 days of loss for SN 17010 because of a broken filter tape. Moreover irregularities (spikes) in the concentration and in the stability values (internal zero check) have been recorded at the beginning of test site Bornheim. It was found that the detector (Photomultiplier Tube (PMT)) of the device was responsible for the spikes due to unknown reasons. The detector was changed on-site on 08/12/2009. The parameters for device calibration, implemented in the device, remained untouched. The trouble with the detector lead in total to a device outage of 4 days.

There has been 1 day of loss for SN 17011 due to a stuck reference foil and another 2 days due to cracked filter tape.

No further malfunctions of the devices have been observed.

The regular cleaning of the sampling inlets in the maintenance interval, the change of the filter tape (approx. every 2 months) and the regular check of the flow rates respectivley of the tightness have in each case lead to outages of less than 1 h per device (outage time = 1 cycle). The performance of these actions have lead to outages of less than 1 h per device (in total 16 times during the test) and do not lead to the rejection of the affected daily mean value.

6.5 Assessment

The availability amounts to 97.9 % for device SN 17010 and 99.0 % for device SN 17011 without test-related outage times. Those included, the availability amounts to 94.6 % for device SN 17010 and 95.7 % for device SN 17011.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 18: Determination of availability (without test-related outages)

		Device 1 (SN 17010)	Device 2 (SN 17011)
Operating time	h	8808	8784
Outage time	h	168	72
Maintenance	h	16	16
Actual operating time	h	8624	8696
Availability	%	97.9	99.0

Table 19: Determination of availability (including test-related outages)

		Device 1 (SN 17010)	Device 2 (SN 17011)
Operating time	h	8808	8784
Outage time	h	168	72
Maintenance incl. zero filter	h	288 + 16	288 + 16
Actual operating time	h	8336	8408
Availability	%	94.6	95.7

6.1 5.2.19 Converter efficiency

In the case of measuring systems with a converter, the efficiency of the converter shall be at least 95 %.

According to Standard VDI Sheet 3, point 5.3, this test point is not relevant for particulate measuring systems with pre-separation, based on a physical measurement method for mass determination.

6.2 Equipment

Not applicable.

6.3 Carrying out the test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable.

6.1 5.2.20 Maintenance interval

The maintenance interval of the measuring system shall be determined and specified. The maintenance interval should be 28 days if possible, but at least 14 days.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

This test was done in order to determine which maintenance proceedures are required at which period to maintain correct functionality of the measuring system. Moreover, the results of the drift test for zero and span point according to module 5.2.9 and module 5.2.10 were included into the determination of the maintenance interval.

6.4 Evaluation

No unacceptable drifts were detected for the measuring systems during the entire field test period.

Therefore, the maintenance interval is determined by scheduled maintenance proceedures (refer to module 4.1.2).

During operation, the maintenance works can be limited to contamination, plausibility and status / error message checks.

6.5 Assessment

The maintenance interval is defined by necessary maintenance proceedures and is 1 month.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Necessary maintenance works can be found in module 4.1.2 of this report and in chapter 7 of the operating manual.

6.1 5.2.21 Total uncertainty

The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the EU Daughter Standards on air quality [G11 to G13].

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

The expanded total uncertainty of the AMS was determined for individual concentration values within the short time ambient air limit range and average concentration values within the long time ambient air limit range. The determined parameters of the measuring devices were compiled.

The following reference values were set:

Short time ambient air limit value:

$PM_{2.5}$ 35 µg/m³ (Source: EN 14907, pt 9.4 in consideration of Table 2)

Long time ambient air limit value:

$PM_{2.5}$ 25 µg/m³

6.4 Evaluation

The expanded total uncertainty of the measuring system was determined according to VDI Standard 4202, sheet 1, annex C [1].

6.5 Assessment

The individual uncertainties of each test parameter were included in the calculation of the expanded total uncertainty. The worst result was taken in case more than one individual result was available

The determined total uncertainties were 14.64 % respectively 15.29 % for U(c) and 10.05 % respectively 12.35 % for $U(\bar{c})$.

Table 20 to Table 23 show the individual values. All calculated values are below the required total uncertainties of 25 %.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 20: Expanded measurement uncertainty U(c) for device SN 17010, $PM_{2.5}$, reference value: 35 µg/m³

Performance characteristic for Device SN 17010	Requirement	Result		Uncertainty u	Square of uncertainty u²
				µg/m³	(µg/m³)²
Reproducibility R_D	≥ 10	10		2.00	4.00
In-between uncertainty u_{Bs} according to guide	≤ 2,5 µg/m³	1.38	µg/m³	0.80	0.63
Temperature dependence at zero point	≤ 2 µg/m³	-1.20	µg/m³	-0.69	0.48
Temperature dependence at measured value (Beta)	≤ 5 % of B1	0.05	µg/m³	0.03	0.00
Drift at zero point	≤ 2 µg/m³	1.80	µg/m³	1.04	1.08
Drift at measured value (Beta)	≤ 5 % of B1	0.13	µg/m³	0.07	0.01
Mains voltage (measured value Beta)	≤ 2 µg/m³	0.03	µg/m³	0.02	0.00
Cross-sensitivities	≤ 2,5 µg/m³	0.30	µg/m³	0.17	0.03
Uncertainty of test standard	≤ 1 µg/m³	1.00	µg/m³	0.58	0.33
				Σu²	6.56
				U(c) = 2u(c)	5.12
				U(c) / Ref.	14.64

Table 21: Expanded measurement uncertainty U(c) for device SN 17011, $PM_{2.5}$, reference value: 35 µg/m³

Performance characteristic for Device SN 17011	Requirement	Result		Uncertainty u	Square of uncertainty u²
				µg/m³	(µg/m³)²
Reproducibility R_D	≥ 10	10		2.00	4.00
In-between uncertainty u_{Bs} according to guide	≤ 2,5 µg/m³	1.38	µg/m³	0.80	0.63
Temperature dependence at zero point	≤ 2 µg/m³	-1.60	µg/m³	-0.92	0.85
Temperature dependence at measured value (Beta)	≤ 5 % of B1	0.08	µg/m³	0.05	0.00
Drift at zero point	≤ 2 µg/m³	1.60	µg/m³	0.92	0.85
Drift at measured value (Beta)	≤ 5 % of B1	-0.13	µg/m³	-0.07	0.01
Mains voltage (measured value Beta)	≤ 2 µg/m³	-0.03	µg/m³	-0.02	0.00
Cross-sensitivities	≤ 2,5 µg/m³	1.20	µg/m³	0.69	0.48
Uncertainty of test standard	≤ 1 µg/m³	1.00	µg/m³	0.58	0.33
				Σu²	7.16
				U(c) = 2u(c)	5.35
				U(c) / Ref.	15.29

Table 22: Expanded measurement uncertainty U(c) for device SN 17010, $PM_{2.5}$, reference value: 25 µg/m³

Performance characteristic for Device SN 17010	**Uncertainty (Single value)**	**Time base**	**Number nk**	**Square of uncertainty (mean value)**
				(µg/m³)²
Reproducibility R_D	2.00	24 hours	365	0.011
In-between uncertainty u_{Bs} according to guide	0.80	1 year	1	0.633
Temperature dependence at zero point	-0.69	1 year	1	0.480
Temperature dependence at measured value (Beta)	0.03	1 year	1	0.001
Drift at zero point	1.04	1 month	12	0.090
Drift at measured value (Beta)	0.07	1 month	12	0.000
Mains voltage (measured value Beta)	0.02	1 year	1	0.000
Cross-sensitivities	0.17	1 year	1	0.030
Uncertainty of test standard	0.58	1 year	1	0.333
			$\Sigma u_m^2(c_k)$	1.579
			$U(\bar{c}) = 2u(\bar{c})$	2.51
			$\frac{U(\bar{c})}{Ref.}$	10.05

Table 23: Expanded measurement uncertainty U(c) for device SN 17011, $PM_{2.5}$, reference value: 25 µg/m³

Performance characteristic for Device SN 17011	**Uncertainty (Single value)**	**Time base**	**Number nk**	**Square of uncertainty (mean value)**
				(µg/m³)²
Reproducibility R_D	2.00	24 hours	365	0.011
In-between uncertainty u_{Bs} according to guide	0.80	1 year	1	0.633
Temperature dependence at zero point	-0.92	1 year	1	0.853
Temperature dependence at measured value (Beta)	0.05	1 year	1	0.002
Drift at zero point	0.92	1 month	12	0.071
Drift at measured value (Beta)	-0.07	1 month	12	0.000
Mains voltage (measured value Beta)	-0.02	1 year	1	0.000
Cross-sensitivities	0.69	1 year	1	0.480
Uncertainty of test standard	0.58	1 year	1	0.333
			$\Sigma u_m^2(c_k)$	2.385
			$U(\bar{c}) = 2u(\bar{c})$	3.09
			$\frac{U(\bar{c})}{Ref.}$	12.35

6.1 5.3.1 Equivalency of the sampling system

The equivalency between the PM_{10} sampling system and the reference method according to EN 12 341 [T5] shall be demonstrated.

6.2 Equipment

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.3 Carrying out the test

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.4 Evaluation

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.5 Assessment

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.1 5.3.2 Reproducibility of the sampling system

The PM_{10} sampling systems of two identical candidate systems shall be reproducible among themselves according to EN 12 341 [T5]. This shall be demonstrated in the field test.

6.2 Equipment

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.3 Carrying out the test

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.4 Evaluation

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.5 Assessment

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable for $PM_{2.5}$ sampling systems. Please refer to chapter 7 of this report.

6.1 5.3.3 Calibration

The PM_{10} candidate systems shall be calibrated in the field test by comparison measurements with a reference method according to DIN EN 12341 [T5]. Here, the relationship between the output signal and the gravimetrically determined reference concentration shall be determined as a steady function.

The $PM_{2.5}$ candidate systems were compared with reference measurements according to EN 14907 during the field test.

The results of these investigations can be found in module 5.2.3.

6.2 Equipment

Refer to Module 5.2.3.

6.3 Carrying out the test

Refer to Module 5.2.3.

6.4 Evaluation

Refer to Module 5.2.3.

6.5 Assessment

Refer to Module 5.2.3.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Refer to Module 5.2.3.

6.1 5.3.4 Cross sensitivity

The interference caused by humidity in the sample shall not exceed 10 % of B_1 in the range of B_1. In case of a heated sampling line, the reproducibility to the gravimetric reference method shall be determined at the specified temperature.

6.2 Equipment

Not required for this minimum requirement.

6.3 Carrying out the test

The interferences caused by humidity contained in the measured medium were determined under field conditions since a test at zero point under lab conditions did not lead to a reliable results and the test is not feasible at span point (in the range of B_1).

Instead, the differences between the determined reference value (= nominal value) and the measured value of the respective candidate system were calculated for days of more than 70 % relative humidity during field test, and the average difference was set as a conservative estimation of the interfering effect of humidity contained in the measured medium.

In addition, the reference-equivalence-functions were determined from the field investigations for days of more than 70 % relative humidity for both candidate systems.

6.4 Evaluation

The average difference between the determined reference value (= nominal value) and the measured value of the respective candidate system was calculated for days of more than 70 % relative humidity during field test, and the relative deviation of the average concentration was determined.

Reference value: B_1 = 25 µg/m³ 10 % of B_1 = 2.5 µg/m³

Further investigations were made to determine whether the comparability of the candidate systems with the reference method according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods" [4] is also given at days of more than 70% relative humidity.

6.5 Assessment

No interferences which led to deviations of more than 1.2 µg/m³ between nominal value and measured signal, caused by humidity, contained in the measured medium, could be detected. Negative influences on the measured value caused by varying relative air humidity were not detected. The comparability of the candidate systems according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods" [4] is even given at days of more than 70 % relative humidity.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 24 shows a summary of the results.

Table 24: Deviation between the candidate system and the reference system at days of more than 70 % relative humidity

Field test, days of >70% relative humidity				
		Reference	SN 17010	SN 17011
Average	µg/m³	16.8	17.1	18.0
Deviation from the average (reference)	µg/m³	-	0.3	1.2
Deviation from the average (reference)	%	-	1.8	7.1
Deviation from B1	%	-	1.2	4.8

The individual values are listed in annex 4 and 5 of the appendix.

The measurement uncertainties W_{CM} of days of more than 70% relative humidity are represented and assessed in Table 25 and Table 26. The individual values are listed in annex 4 and 5 of the appendix.

Table 25: Comparison SN 17010 vs. reference method, rel. humidity > 70 %, all sites

Comparison candidate with reference according to Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"				
Candidate	BAM-1020	SN	SN 17010	
Test site	All test sites, rH>70%	Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Results of regression analysis				
Slope b	**0.991**	**not significant**		
Uncertainty of b	**0.02**			
Ordinate intercept a	**0.457**	**not significant**		
Uncertainty of a	**0.30**			
Results of equivalence test				
Deviation at limit value	**0.20**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**1.80**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**6.00**	**%**		
Expanded measurement uncertainty W_{CM}	**12.00**	**%**		
Status equivalence test	**passed**			

Table 26: Comparison SN 17011 vs. reference method, rel. humidity > 70 %, all sites

Comparison candidate with reference according to Guide "Demonstration of Equivalence of Ambient Air Monitoring Methods"				
Candidate	BAM-1020	SN	SN 17011	
Test site	All test sites, rH>70%	Limit value	30	µg/m³
Status of measured values	Raw data	Allowed uncertainty	25	%
Results of regression analysis				
Slope b	**1.047**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**0.434**	**not significant**		
Uncertainty of a	**0.26**			
Results of equivalence test				
Deviation at limit value	**1.85**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**2.41**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**8.03**	**%**		
Expanded measurement uncertainty W_{CM}	**16.05**	**%**		
Status equivalence test	**passed**			

6.1 5.3.5 Daily averages

The measuring system shall allow for formation of daily averages. In case of filter changes, the time needed for the filter changes shall not exceed 1 % of the averaging time.

6.2 Equipment

A clock was additionally used for this test.

6.3 Carrying out the test

It has been investigated, whether the measuring system allows the formation of a daily average. The time need for a filter change has been determined.

6.4 Evaluation

The measuring system operates by default with a measurement cycle of 60 min. After each measurement cycle, the filter tape is moved forward one position. The data of each measurement cycle are stored and are available for the user for further processing. Furthermore the measuring system allows the formation of a 24-h-mean value, which is outputted in the daily protocol *via* the serial interface.

Within the scope of the suitability test, the cycle time has been set to 60 min with a time need for the radiometric measurement of respectively 8min.

The cycle time therefore consists of 2 x 8 min for the radiometric measurement (I_0 & I_3) as well as approx. 1-2 min for filter tape movements. Hence the sampling time is approx. 42 min per hour.

Thus the available sampling time per measurement cycle is approx. 70 % of the total cycle time. The results from the field investigations according to point 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6] in this report show, that the comparability of the candidates with the reference method could be securely proved in case of this system configuration and thus the formation of daily mean values is securely possible.

6.5 Assessment

With the described system configuration and with a measurement cycle of 60 min, the formation of valid daily averages on the basis of 24 single measurements is possible.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Not required for this minimum requirement.

6.1 5.3.6 Constancy of sample volumetric flow

The sample volumetric flow averaged over the sampling time shall be constant within ± 3 % of the rated value. All instantaneous values of the sample volumetric flow shall be within a range of ± 5 % of the rated value during sampling.

6.2 Equipment

Volumetric flow measuring systems according to point 4

6.3 Carrying out the test

The sample volumetric flow has been calibrated before the first field test site and afterwards checked on correctness and adjusted if necessary before each field test site with the help of a dry gas meter respectively a mass flow meter.

In order to determine the constancy of the sampling volumetric flow, a flow meter was connected to the measuring devices and the flow rate was recorded as 5-second-values and evaluated over a time period of 24 h (= 24 measurement cycles).

6.4 Evaluation

From the determined measured values for the flow rate, the mean value, the standard deviation as well as maximum and minimum value have been determined.

6.5 Assessment

Table 27 presents the results of the check on volumetric flow rate prior to each field test site.

Table 27: Sample volumetric flow rate results

Volumetric flow check prior to	SN 17010,		SN 17011	
Site:	[l/min]	Deviation from nominal value [%]	[l/min]	Deviation from nominal value [%]
Teddington, Summer	16.3	-2.4	16.5	-1.2
Cologne, Winter	16.8	0.6	16.7	0.0
Bornheim, Summer	16.7	0.0	16.9	1.2
Teddington, Winter	16.5	-1.2	16.6	-0.6

Graphical representations of the volumetric flow rates over 24 measurement cycles indicate that all measured values taken during sampling deviate less than ± 5 % from the nominal value (16.67 l/min). Moreover, the deviation of the daily averages from the nominal value is less than ±3 %.

All determined daily averages deviate less than ± 3 %, all individual values less than ± 5 % from the nominal value.

Minimum requirement fulfilled? yes

6.6 Detailed representation of test results

Table 28 and Table 29 present the determined parameters for the volumetric flow rate. Figure 42 and Figure 43 show a graphical representation of the flow rate measurements for both candidates SN 17010 and SN 17011.

Table 28: Performance characteristics for flow rate measurement, SN 17010

No.	Mean [l/min]	Dev. of nominal [%]	STD [l/min]	Max [l/min]	Min [l/min]
1	16.47	-1.35	0.08	16.80	16.40
2	16.47	-1.37	0.08	16.75	16.40
3	16.48	-1.34	0.09	16.80	16.40
4	16.51	-1.17	0.11	16.80	16.35
5	16.50	-1.18	0.12	16.80	16.35
6	16.43	-1.64	0.03	16.60	16.35
7	16.41	-1.71	0.03	16.50	16.35
8	16.44	-1.53	0.07	16.70	16.35
9	16.47	-1.39	0.09	16.80	16.40
10	16.49	-1.24	0.12	16.80	16.35
11	16.49	-1.27	0.12	16.80	16.35
12	16.48	-1.29	0.12	16.80	16.20
13	16.50	-1.19	0.12	16.85	16.35
14	16.49	-1.27	0.12	16.85	16.40
15	16.45	-1.51	0.03	16.55	16.40
16	16.50	-1.19	0.09	16.80	16.45
17	16.50	-1.21	0.09	16.80	16.45
18	16.48	-1.32	0.03	16.55	16.45
19	16.54	-0.95	0.07	16.75	16.40
20	16.53	-1.03	0.02	16.55	16.50
21	16.53	-1.04	0.03	16.55	16.45
22	16.50	-1.19	0.03	16.55	16.45
23	16.56	-0.86	0.09	16.85	16.45
24	16.56	-0.82	0.11	16.85	16.45
Mean 1-24	**16.49**	**-1.25**	**0.08**	**16.85**	**16.20**

Table 29: Performance characteristics for flow rate measurement, SN 17011

No.	Mean [l/min]	Dev. of nominal [%]	STD [l/min]	Max [l/min]	Min [l/min]
1	16.68	-0.12	0.03	16.75	16.65
2	16.65	-0.28	0.02	16.70	16.60
3	16.64	-0.38	0.05	16.70	16.50
4	16.63	-0.41	0.05	16.70	16.35
5	16.62	-0.49	0.05	16.70	16.45
6	16.63	-0.45	0.06	16.70	16.40
7	16.62	-0.45	0.06	16.75	16.45
8	16.62	-0.48	0.06	16.75	16.45
9	16.61	-0.52	0.05	16.70	16.40
10	16.62	-0.51	0.06	16.70	16.45
11	16.58	-0.74	0.05	16.65	16.45
12	16.60	-0.62	0.03	16.65	16.55
13	16.48	-1.34	0.06	16.60	16.30
14	16.48	-1.32	0.04	16.55	16.40
15	16.54	-0.97	0.04	16.65	16.40
16	16.54	-0.98	0.05	16.60	16.45
17	16.48	-1.34	0.06	16.60	16.30
18	16.62	-0.47	0.04	16.70	16.55
19	16.72	0.11	0.04	16.80	16.60
20	16.59	-0.65	0.07	16.75	16.45
21	16.74	0.22	0.04	16.85	16.65
22	16.78	0.47	0.03	16.80	16.70
23	16.80	0.57	0.03	16.85	16.70
24	16.80	0.63	0.03	16.85	16.70
Mean 1-24	**16.63**	**-0.44**	**0.05**	**16.85**	**16.30**

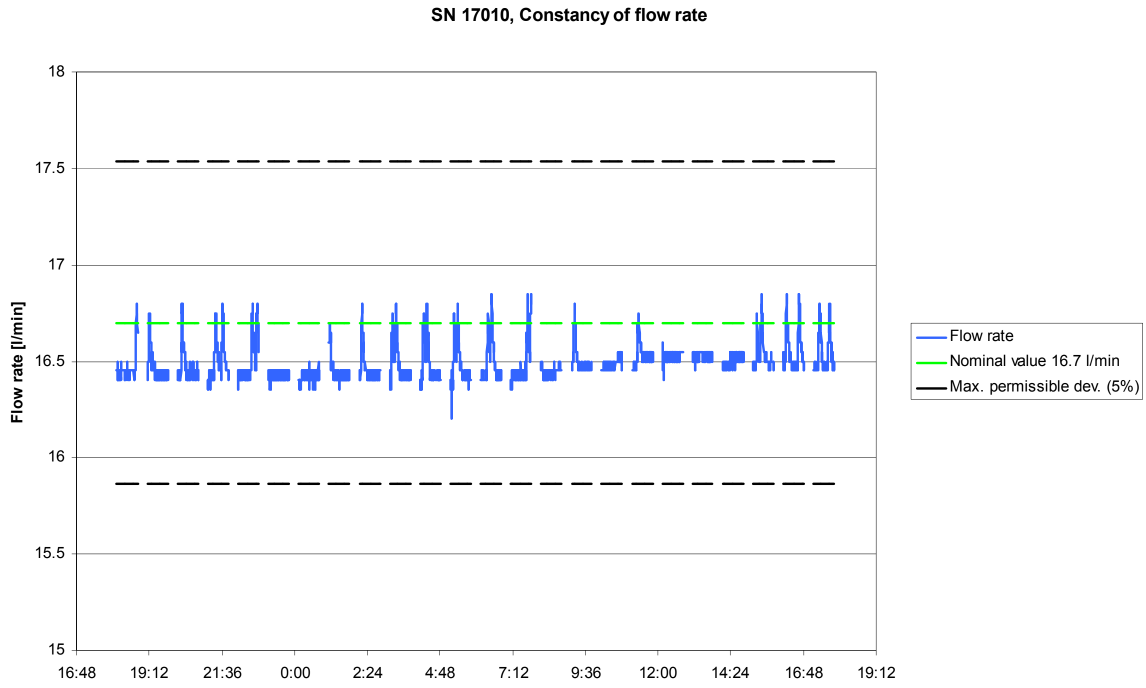


Figure 42: Flow rate of device SN 17010

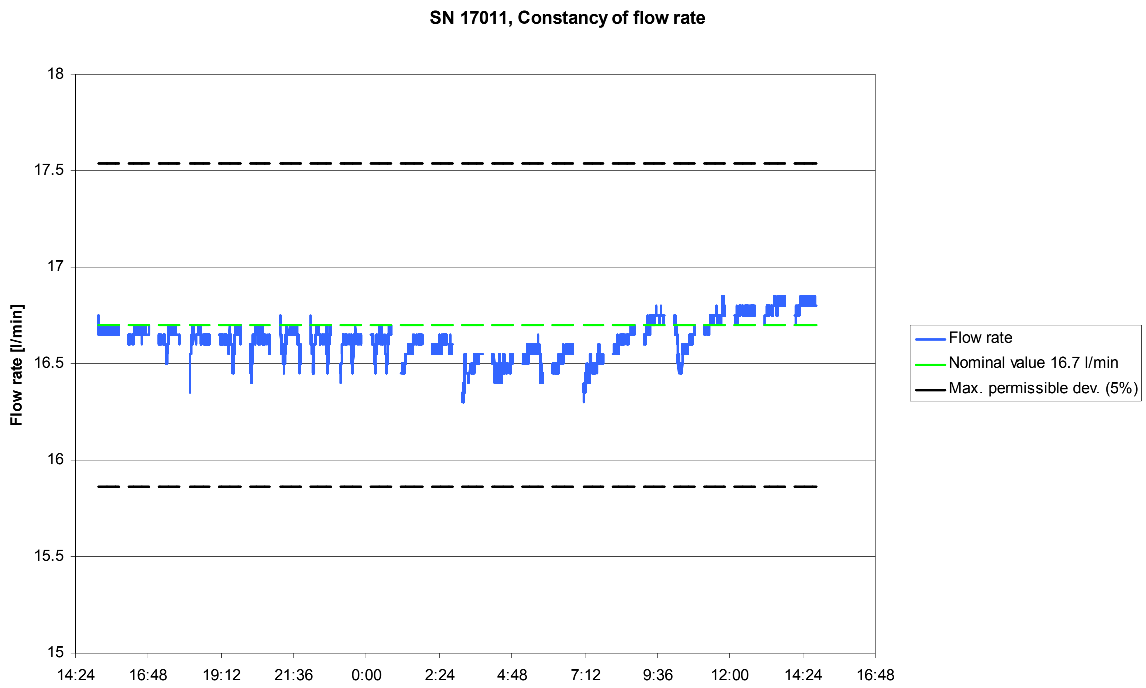


Figure 43: Flow rate of device SN 17011

6.1 5.3.7 Tightness of the sampling system

The complete sampling system shall be checked for tightness. Leakage shall not exceed 1 % of the in taken sample volume.

6.2 Equipment

Zero filter kit BX-302 respektively inlet adapter BX-305

6.3 Carrying out the test

In order to determine the leak rate, the inlet adapter BX-305 has been installed at the inlet of the sampling tube and the ball valve of the adapter has been closed slowly. The leak rate has been determined from the difference between the flow rate with switched-off pump (zero point of flow rate measurement), measured in the device, and the measured flow rate with sealed instrument inlet.

The procedure has been repeated three times during the field test in Cologne.

It is recommended to check the tightness of the measuring device with the help of the described procedure once a month.

6.4 Evaluation

The leak rate has been determined from the difference between the flow rate with switched-off pump (zero point of flow rate measurement), measured in the device, and the measured flow rate with sealed instrument inlet.

The maximum value of the three determined leak rates has been specified.

According to the manufacturer, a maximum leak rate up to 1 l/min is permissible under the prescribed test conditions, as in case of a completely sealed device inlet, a very high vacuum is created in the system (21 inch Hg corresponds to approx. 700 mbar), which is manifold higher than it could possibly be created by filter load during normal operation.

Possible leakages in the system (e.g. contamination in the area of the nozzle at the filter tape caused by filter abrasion) can be safely detected by the precribed method.

6.5 Assessment

The maximum determined leakages have been 1.8 % for device 1 (SN 17010) as well as 2.4 % for device 2 (SN 17011). According to the minimum requirement, the leak rate shall not be greater than 1 % of the sample flow rate.

Minimum requirement fulfilled? no

According to the manufacturer, a maximum leak rate up to 1 l/min (approx. 6 % of 16.7 l/min) is permissible under the prescribed test conditions, as in case of a completely sealed device inlet, a very high vacuum is created in the system (21 inch Hg corresponds to approx. 700 mbar), which is manifold higher than it could possibly be created by filter load during normal operation. Possible leakages in the system (e.g. contamination in the area of the nozzle at the filter tape caused by filter abrasion) can be safely detected by the precribed method

It is recommended to check the tightness of the measuring device with the help of the described procedure once a month.

6.6 Detailed representation of test results

Table 30 contains the determined values from the tightness test.

Table 30: Determination of leak rate

	Flow rate (pump off)	Flow rate (pump on, inlet sealed)				
		1 (12/01/08)	2 (01/26/09)	3 (02/16/09)	Mean	Maximum leak rate
	l/min	l/min	l/min	l/min	l/min	% of nom. value
SN 17010	0.0	0.1	0.3	0.0	0.3	1.8
SN 17011	0.0	0.1	0.4	0.3	0.4	2.4

6.1 5.4 Requirements for multiple-component measuring systems

Multiple-component measuring systems shall comply with the requirements set for each component, also in the case of simultaneous operation of all measuring channels. In case of sequential operation, the formation of hourly averages shall be possible.

6.2 Equipment

Not applicable.

6.3 Carrying out the test

Not applicable.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? -

6.6 Detailed representation of test results

Not applicable.

7 Additional test criteria according to Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods“

7.1 Equivalence Methodology

According to the version of the Guide from July 2009 [4], the following 5 criteria must be fulfilled for the demonstration of equivalence:

1. Of the full dataset at least 20% of the results obtained using the standard method shall be greater than the upper assessment threshold specified in 2008/50/EC for annual limit values *i.e.*: 28 µg/m³ for PM_{10} and currently 17 µg/m³ for $PM_{2.5}$.

2. The intra instrument uncertainty of the candidate must be less than 2.5 µg/m³ for all data and for two sub datasets corresponding to all the data split greater than or equal to and lower than 30 µg/m³ or 18 µg/m³ for PM_{10} and $PM_{2.5}$ respectively.

3. The intra instrument uncertainty of the reference method must be less than 2.0 µg/m³.

4. The expanded uncertainty (W_{CM}) is calculated at 50 µg/m³ for PM_{10} and 30 µg/m³ for $PM_{2.5}$ for each individual candidate instrument against the average results of the reference method. For each of the following permutations, the expanded uncertainty must be less than 25 %:

   - Full dataset;
   - Datasets representing PM concentrations greater than or equal to 30 µg/m³ for PM_{10}, or concentrations greater than or equal to 18 µg/m³ for $PM_{2.5}$, provided that the subset contains 40 or more valid data pairs;
   - Datasets for each individual site.

5. Preconditions for acceptance of the full dataset are that: the slope b is insignificantly different from 1: $|b-1| \leq 2 \cdot u(b)$, and the intercept a is insignificantly different from 0: $|a| \leq 2 \cdot u(a)$.. If these preconditions are not met, the candidate method may be calibrated using the values obtained for slope and/or intercept of all paired instruments together.

The fulfillment of the 5 criteria is checked in the following chapters:

In chapter 7.1 Determination of the in-between-instrument uncertainty u_{bs} [9.5.2.1], the criteria 1 and 2 will be checked.

In chapter 7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6], the criteria 3,4 and 5 will be checked.

In chapter 7.1 Application of correction factors or terms [9.7] there is an exemplary evaluation for the case, that criterio 5 cannot be fulfilled without the application of correction factors or terms.

7.1 Determination of the in-between-instrument uncertainty u_{bs} [9.5.2.1]

The between-sampler uncertainty u_{bs} has to be determined according to point 9.5.2.1 of the Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods".

7.2 Equipment

Not required for this minimum requirement.

7.3 Carrying out the test

The test was carried out at four different sites during field test. Different seasons and varying concentrations for $PM_{2.5}$ were taken into consideration.

Of the complete data set, at least 20 % of the concentration values determined with the reference method, shall be greater than the upper assessment threshold according to 2008/50/EC [7]. For $PM_{2.5}$, the upper assessment threshold is 17 µg/m³.

A minimum of 40 valid paired values were determined at each site. Of the entire data set (4 sites, 251 valid paired values for SN 17010, 253 valid paired values for SN 17011), a total of 33.1% are above of the upper assessment threshold is 17 µg/m³ for the annual mean value of $PM_{2.5}$. The measured concentrations were referred to ambient conditions.

7.4 Evaluation

According to **point 9.5.2.1** of Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods", it is imperative:

The in-between-instrument uncertainty u_{bs} shall be ≤ 2.5 µg/m³. An uncertainty larger than 2.5 µg/m³ between the candidate systems is an indication of unsuitable performance of one or both instruments and that equivalency cannot be declared.

Uncertainty is hereby determined for:

- All sites (complete data set)
- 1 data set with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (Basis: average values of the reference measurement)

The in-between-instrument uncertainty u_{bs} is calculated from the differences of all 24-hour results of the simultaneously operated candidate systems according to the following equation:

$$u_{bs}^2 = \frac{\sum_{i=1}^{n} (y_{i,1} - y_{i,2})^2}{2n}$$

with $y_{i,1}$ and $y_{i,2}$ = results of the parallel measurements of individual 24h-values i
n = No. of 24h-values

7.5 Assessment

The in-between-instrument uncertainty between the candidates u_{bs} is at maximum 1.57 µg/m³ and thus below the required value of 2.5 µg/m³.

Minimum requirement fulfilled? yes

A value of 1.38 µg/m³ for the complete data set was used to calculate uncertainty according to point 6.1 5.2.21 Total uncertainty.

7.6 Detailed representation of test results

Table 31 presents the calculated in-between-instrument uncertainty u_{bs}. A graphical representation is given in Figure 44 to Figure 50.

Table 31: In-between-instrument uncertainty u_{bs} for the devices SN 17010 and SN 17011

Test device	**Site**	**No. of Values**	**Uncertainty u_{bs}**
SN			µg/m³
17010 / 17011	**All sites**	**345**	**1.38**
Single test sites			
17010 / 17011	Teddington, Summer	97	1.13
17010 / 17011	Cologne, Winter	127	1.76
17010 / 17011	Bornheim, Summer	66	1.13
17010 / 17011	Teddington, Winter	55	1.01
Classification *via* reference values			
17010 / 17011	**Values ≥ 18 µg/m³**	**174**	**1.57**
17010 / 17011	Values < 18 µg/m³	74	1.05

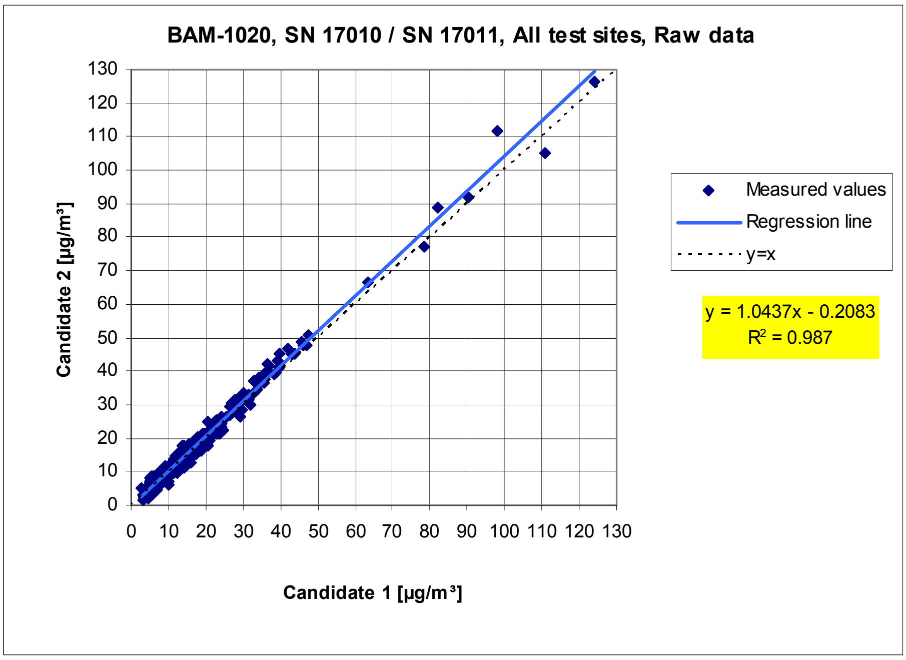


Figure 44: Results of the parallel measurements with device SN 17010 / SN 17011, all test sites

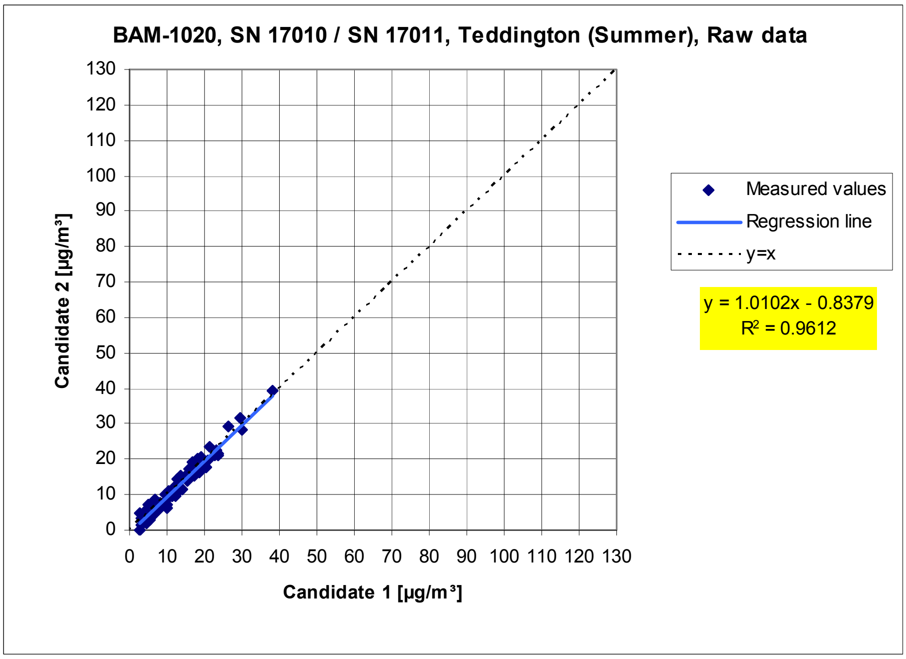


Figure 45: Results of the parallel measurements with device SN 17010 / SN 17011, test site "Teddington, Summer"

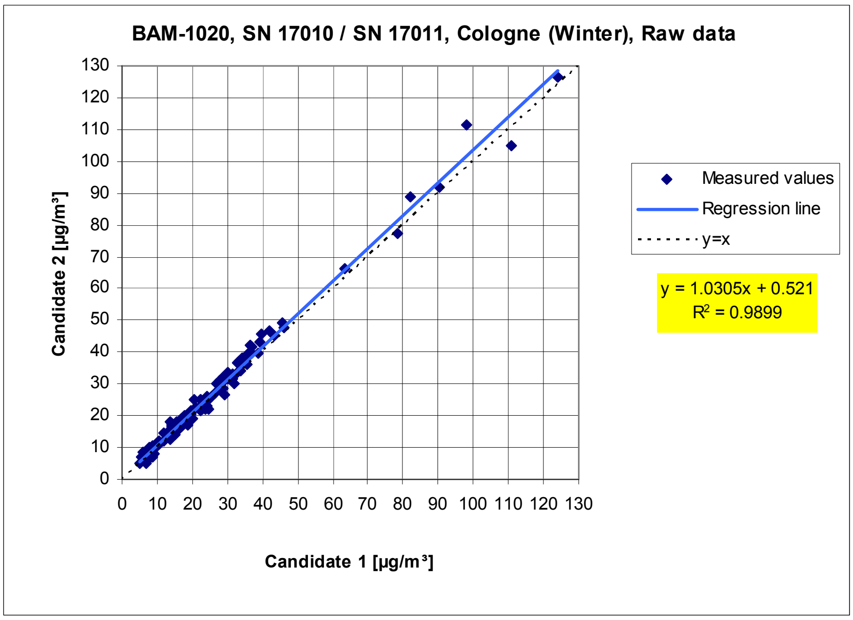


Figure 46: Results of the parallel measurements with device SN 17010 / SN 17011, test site "Cologne, Winter"

Remark: The deviations on the paired values 98.2 µg/m³ / 111.5 µg/m³ (Dec 31, 2008)as well as 110.7 µ/m³ / 105.1 µg/m³ (April 13, .2009) are caused by short-term local peaks (fireworks). As there are no technical reasons, the values have not been removed as outliers from the data pool (refer to chapter 4.3 Data handling)

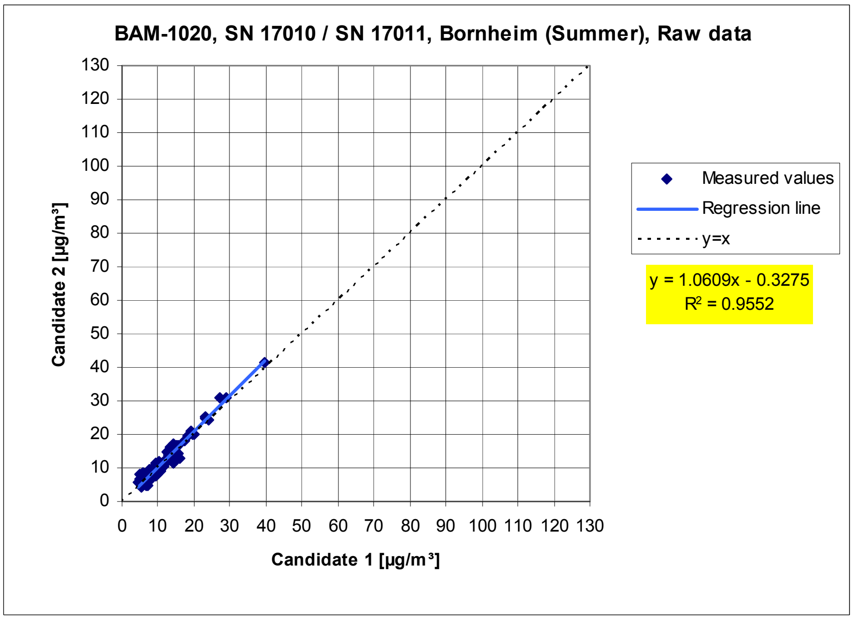


Figure 47: Results of the parallel measurements with device SN 17010 / SN 17011, test site "Bornheim, Summer"

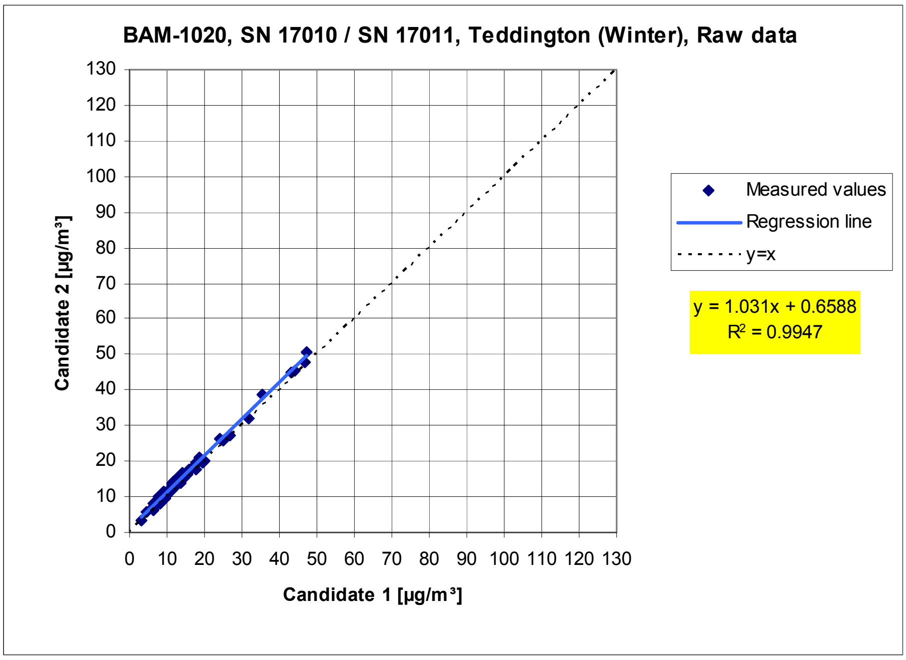


Figure 48: Results of the parallel measurements with device SN 17010 / SN 17011, test site "Teddington, Winter"

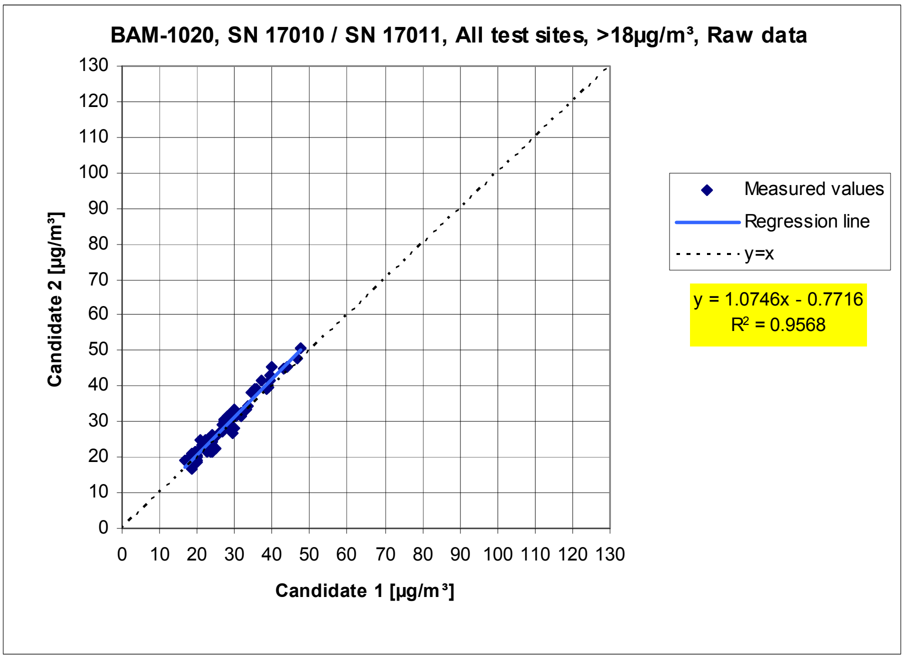


Figure 49: Results of the parallel measurements with device SN 17010 / SN 17011, all test sites, values ≥ 18 µg/m³

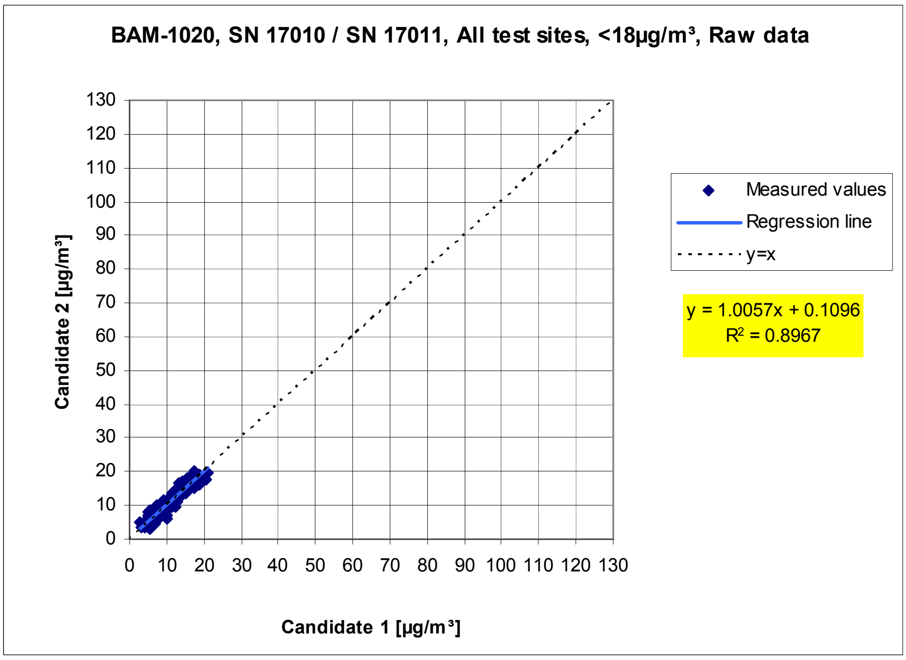


Figure 50: Results of the parallel measurements with device SN 17010 / SN 17011, all test sites, values < 18 µg/m³

7.1 Calculation of the expanded uncertainty of the instruments [9.5.2.2-9.5.6]

The equivalence of the candidate instruments to the reference method has to be demonstrated according to the points 9.5.2.2 to 9.5.4 of the Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods". The highest resulting expanded uncertainty of the candidate method is to compare with the requirements on the data quality of ambient air measurements according to EU-guideline [7].

7.2 Equipment

The devices mentioned in point 5 of the present report were additionally used for this test.

7.3 Carrying out the test

The test was carried out at four different sites during field test. Different seasons and varying concentrations for $PM_{2.5}$ were taken into consideration.

Of the complete data set, at least 20% of the concentration values determined with the reference method, shall be greater than the upper assessment threshold according to 2008/50/EC [7]. For $PM_{2.5}$, the upper assessment threshold is 17 µg/m³.

A minimum of 40 valid paired values were determined at each site. Of the entire data set (4 sites, 251 valid paired values for SN 17010, 253 valid paired values for SN 17011), a total of 33.1% are above of the upper assessment threshold is 17 µg/m³ for the annual mean value of $PM_{2.5}$. The measured concentrations were referred to ambient conditions.

7.4 Evaluation

[Point 9.5.2.2] The calculation of the in-between-instrument uncertainty u_{ref} of the reference devices is carried out prior to the calculation of the expanded uncertainty of the candidates.

The in-between-instrument uncertainty u_{ref} of the reference devices shall be ≤ 2 µg/m³.

Section 7.6 of this test point shows the evaluated results.

A linear correlation $y_i = a + bx_i$ is assumed between the results of both methods in order to evaluate the comparability of the candidates y and the reference procedure x. The correlation between the average values of the reference devices and the candidates is established by orthogonal regression.

Regression is calculated for:

- All test sites
- Each test site separately
- 1 data set with measured values ≥ 18 µg/m³ (Basis: average values of the reference measurement)

For further evaluation, the results of the uncertainty u_{c_s} of the candidates compared with the reference method are described with the following equation, which describes u_{CR} as a function of the PM concentration x_i :

$$u_{CR}^2(y_i) = \frac{RSS}{(n-2)} - u^2(x_i) + [a + (b-1)x_i]^2$$

With RSS = Sum of the (relative) residuals from orthogonal regression

$u(x_i)$ = random uncertainty of the reference procedure if value u_{bs}, which is calculated for using the candidates, can be used in this test (refer to point 7.1 Determination of the in-between-instrument uncertainty u_{bs} [9.5.2.1])

Algorithm for the calculation of ordinate intercept a as well as slope b and its variances by orthogonal regression are described in detail in annex B of [4].

The sum of the (relative) residuals RSS is calculated by the following equation:

$$RSS = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

Uncertainty u_{c_s} is calculated for:

- All test sites
- Each test site separately
- 1 data set with measured values ≥ 18 µg/m³ (Basis: average values of the reference measurement)

Preconditions for acceptance of the full dataset are that:

- The slope b is significantly different from 1: $|b-1| \leq 2 \cdot u(b)$

and

- The intercept a is insignificantly different from 0: $|a| \leq 2 \cdot u(a)$

Where u(b) and u(a) are the standard uncertainties of the slope and intercept, respectively calculated as the square root of their variances. If these preconditions are not met, the candidate method may be calibrated according to point 9.7 of the Guide (refer to 7.1 Application of correction factors or terms [9.7]). The calibration shall only be applied to the full data-set.

[Point 9.5.3] The combined uncertainty of the candidates $w_{c,CM}$ is calculated for each data set by combining the contributions from 9.5.2.1 and 9.5.2.2 according to the following equation:

$$w_{c,CM}^2(y_i) = \frac{u_{CR}^2(y_i)}{y_i^2}$$

For each dataset, the uncertainty $w_{c,CM}$ is calculated at the level of y_i = 30 µg/m³ for $PM_{2,5}$.

[Point 9.5.4] The expanded relative uncertainty of the results of the candidates is calculated for each data set by multiplication of $w_{c,CM}$ with a coverage factor k according to the following equation:

$$W_{CM} = k \cdot w_{CM}$$

In practice: k=2 for large n

[Point 9.6] The highest resulting uncertainty W_{CM} is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [7].
Two results are possible:

1. $W_{CM} \le W_{dqo}$ → Candidate method is accepted as equivalent to the standard method.
2. $W_{CM} > W_{dqo}$ → Candidate method is not accepted as equivalent to the standard method.

The specified expanded relative uncertainty W_{dqo} for particulate matter is 25 % [7].

7.5 Assessment

The determined uncertainties W_{CM} are below the specified expanded relative uncertainty W_{dqo} of 25 % (particulate matter) for all data sets without the usage of corrective factors.

Minimum requirement fulfilled? yes

The following Table 32 shows an overview on all results of the equivalence test for the candidate BAM-1020 for $PM_{2.5}$. The text within the cells is shaded green or red if it passes or fails key criteria. In this example, cells are also shaded corresponding to which of the 5 criteria they relate to in the list of the requirements of the July 2009 version of The Guidance highlighted in point 7.1 Equivalence Methodology above.

Table 32: Overview on equivalence test BAM-1020 for $PM_{2.5}$

$PM_{2.5}$ Smart Heated BAM	33.1% > 17 µg m^{-3}	Orthogonal Regression				Between Instrument Uncertainties	
	W_{CM} / %	n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	Reference	Candidate
All Data	12.6	248	0.967	1.000 +/- 0.012	0.764 +/- 0.204	0.33	1.38
< 18 µg m-3	9.8	174	0.889	0.971 +/- 0.025	1.066 +/- 0.267	0.34	1.05
> 18 µg m-3	15.9	74	0.926	1.031 +/- 0.033	-0.068 +/- 0.919	0.30	1.57

SN 17010	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.931	0.994 +/- 0.030	1.822 +/- 0.372	17.11	19.2
	Cologne Winter	75	0.957	0.980 +/- 0.024	0.960 +/- 0.512	12.79	56.0
	Bornheim Summer	53	0.941	1.052 +/- 0.036	-0.962 +/- 0.527	11.61	20.8
	Teddington Winter	45	0.991	0.970 +/- 0.014	-0.182 +/- 0.300	10.28	35.6
Combined Datasets	< 18 µg m^{-3}	175	0.849	0.955 +/- 0.028	1.137 +/- 0.306	11.46	4.6
	> 18 µg m^{-3}	76	0.907	0.984 +/- 0.035	0.584 +/- 0.975	16.02	100.0
	All Data	251	0.957	0.969 +/- 0.013	0.989 +/- 0.226	12.90	33.5

SN 17011	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.955	1.016 +/- 0.025	1.018 +/- 0.308	14.66	19.2
	Cologne Winter	75	0.977	1.061 +/- 0.019	0.430 +/- 0.405	17.91	56.0
	Bornheim Summer	57	0.901	1.134 +/- 0.048	-1.498 +/- 0.727	23.91	21.1
	Teddington Winter	43	0.992	0.991 +/- 0.014	0.630 +/- 0.293	7.41	32.6
Combined Datasets	< 18 µg m^{-3}	178	0.881	1.021 +/- 0.026	0.634 +/- 0.286	13.44	4.5
	> 18 µg m^{-3}	75	0.929	1.092 +/- 0.034	-1.108 +/- 0.952	19.03	100.0
	All Data	253	0.966	1.041 +/- 0.012	0.377 +/- 0.214	16.28	32.8

KEY

Criterion 1
Criterion 2
Criterion 3
Criterion 4
Criterion 5
Other

When following the 5 criteria detailed in the methodology in point 7.1 Equivalence Methodology in turn, there is the following:

Criterion 1) Greater than 20 % of the data are greater than 17 µg/m³.

Criterion 2) The intra instrument uncertainty of the candidate is less than 2.5 µg/m³.

Criterion 3) The intra instrument uncertainty of the candidate is less than 2.0 µg/m³.

Criterion 4) All of the expanded uncertainties are below 25 %.

Criterion 5) The intercept and slope of the 'All Data' comparison for 17010 are both signifycant. The slope of the 'All Data' comparison for 17011 is significant.

The July 2009 version of The Guidance is ambiguous with respect to which slope and intercept should be used to correct a candidate should it fail the test for equivalence. After communication with the convenor of the EC working group, which is responsible for setting up the Guide, it was decided that the requirement of the November 2005 version of the Guidance are still valid, and that the slope and intercept from the orthogonal regression of all the paired data should be used. These are shaded gold and marked 'other' in the key on the above Table 32.

The 2006 UK Equivalence Report [8] highlighted that this was a flaw in the mathematics required for equivalence as per the November 2005 version of The Guidance as it penalised instruments that were more accurate (Appendix E Section 4.2 therein). This same flaw is copied in the July 2009 version. It is the opinion of TŰV Rheinland and their UK partners that the BAM 1020 for $PM_{2.5}$ is indeed being penalised by the mathematics for being accurate. It is proposed that the same pragmatic approach is taken here that was previously undertaken in earlier studies. Namely: as some of the individual data set slopes are greater than 1, and some are less, there should be no need to correct the data for this slope offset.

In this particular case, the slope of all the paired data for all sites together is 1.000; therefore it is not possible to correct for slope.

The intercept of all the paired data for all sites together is 0.764. Therefore there is an additional evaluation by application of the respective calibration term onto the datasets in chapter 7.1 Application of correction factors or terms [9.7]

The revised July 2009 version of the guide requires that when operating in networks, a candidate method needs to be tested annually at a number of sites and that the number of the instruments to be tested is dependent on the expanded measurement uncertainty of the device. The respective realisation is the responsibility of the network operator or of the responsible authority of the member state. However TÜV Rheinland and their UK partners recommend, that the expanded uncertainty for the full data set is refered to for this, namely 12.6 %, which again would require an annual test at 3 measurement sites (Guide [4], chapter 9.9.2, table 6).

7.6 Detailed representation of test results

Table 33 shows an overview of the in-between-instrument uncertainties u_{ref} of the reference devices during field tests. A summarized representation of the results of the equivalence test incl. the determined expanded measurement uncertainties W_{CM} from the field investigations are shown in Table 34.

Table 33: In-between-instrument uncertainty u_{ref} of the reference devices, measured component $PM_{2.5}$

Reference devices	**Site**	**No. of values**	**Uncertainty u_{bs}**
No			µg/m³
1 / 2	Teddington, Summer	77	0.33
1 / 2	Cologne, Winter	75	0.39
1 / 2	Bornheim, Summer	53	0.30
1 / 2	Teddington, Winter	43	0.27
1 / 2	All test sites	248	0.33

The in-between-instrument uncertainty u_{ref} of the reference devices is < 2 µg/m³ for all sites.

Table 34: Summary of the results of the equivalence test, SN 17010 & SN 17011, raw data

$PM_{2.5}$ Smart Heated BAM	33.1% > 17 µg m-3	Orthogonal Regression				Between Instrument Uncertainties	
	W_{CM} / %	n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	Reference	Candidate
All Data	12.6	248	0.967	1.000 +/- 0.012	0.764 +/- 0.204	0.33	1.38
< 18 µg m-3	9.8	174	0.889	0.971 +/- 0.025	1.066 +/- 0.267	0.34	1.05
> 18 µg m-3	15.9	74	0.926	1.031 +/- 0.033	-0.068 +/- 0.919	0.30	1.57
SN 17010	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.931	0.994 +/- 0.030	1.822 +/- 0.372	17.11	19.2
	Cologne Winter	75	0.957	0.980 +/- 0.024	0.960 +/- 0.512	12.79	56.0
	Bornheim Summer	53	0.941	1.052 +/- 0.036	-0.962 +/- 0.527	11.61	20.8
	Teddington Winter	45	0.991	0.970 +/- 0.014	-0.182 +/- 0.300	10.28	35.6
Combined Datasets	< 18 µg m^{-3}	175	0.849	0.955 +/- 0.028	1.137 +/- 0.306	11.46	4.6
	> 18 µg m^{-3}	76	0.907	0.984 +/- 0.035	0.584 +/- 0.975	16.02	100.0
	All Data	251	0.957	0.969 +/- 0.013	0.989 +/- 0.226	12.90	33.5
SN 17011	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.955	1.016 +/- 0.025	1.018 +/- 0.308	14.66	19.2
	Cologne Winter	75	0.977	1.061 +/- 0.019	0.430 +/- 0.405	17.91	56.0
	Bornheim Summer	57	0.901	1.134 +/- 0.048	-1.498 +/- 0.727	23.91	21.1
	Teddington Winter	43	0.992	0.991 +/- 0.014	0.630 +/- 0.293	7.41	32.6
Combined Datasets	< 18 µg m^{-3}	178	0.881	1.021 +/- 0.026	0.634 +/- 0.286	13.44	4.5
	> 18 µg m^{-3}	75	0.929	1.092 +/- 0.034	-1.108 +/- 0.952	19.03	100.0
	All Data	253	0.966	1.041 +/- 0.012	0.377 +/- 0.214	16.28	32.8

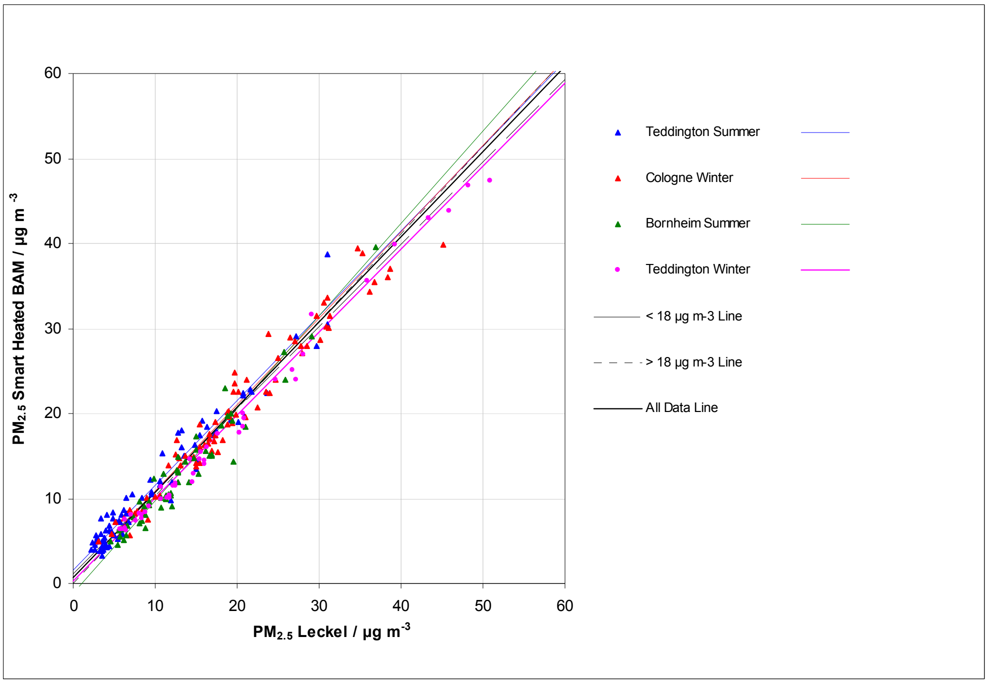


Figure 51: Reference vs. candidate, SN 17010 & SN 17011, all test sites

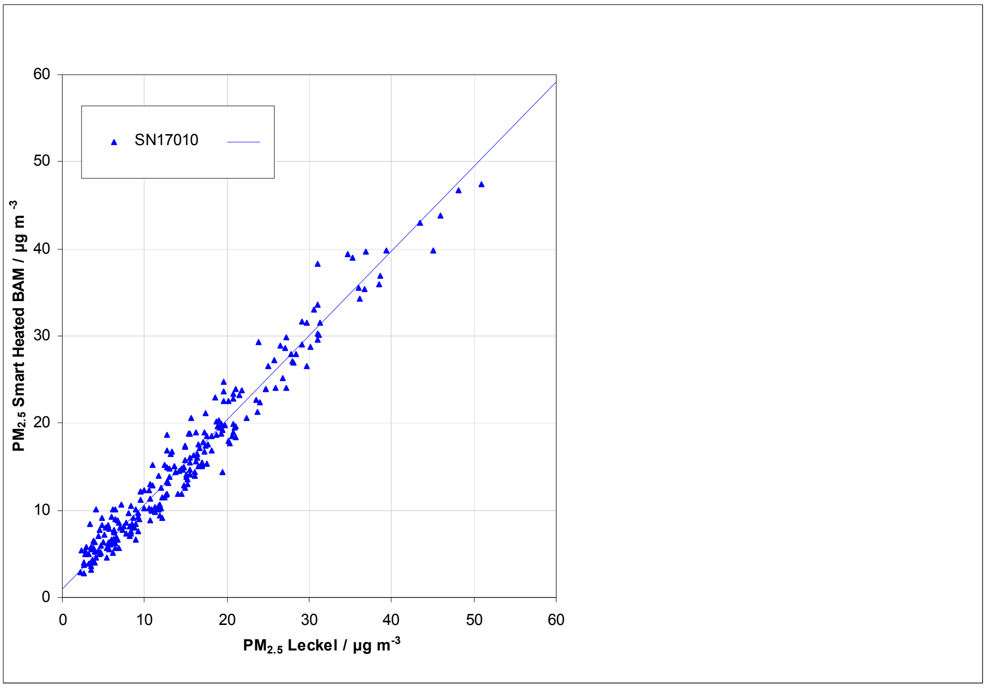


Figure 52: Reference vs. candidate, SN 17010, all test sites

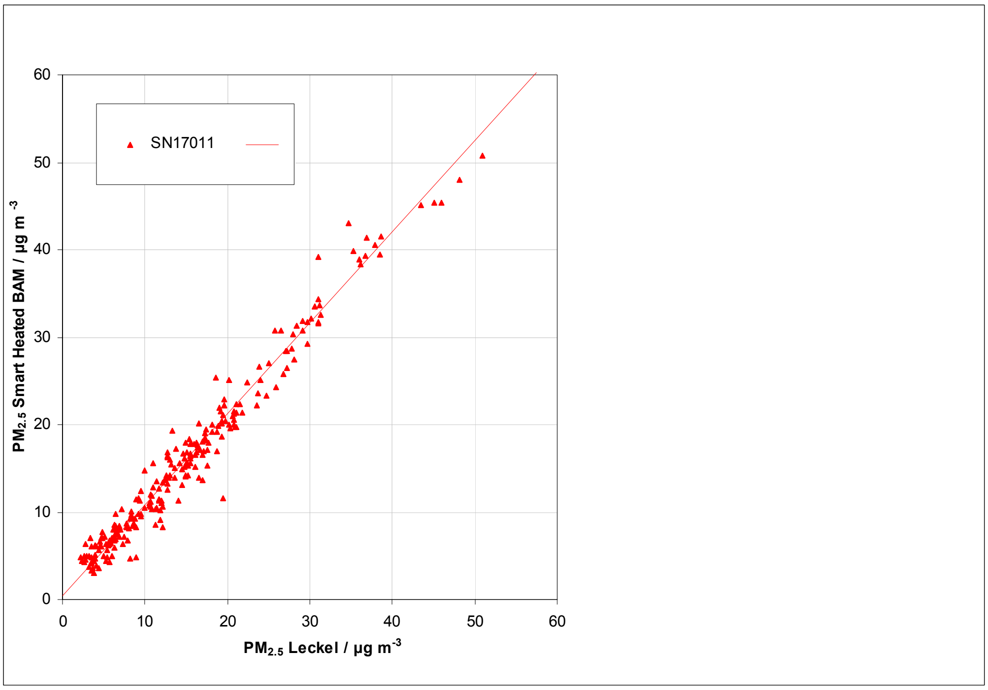


Figure 53: Reference vs. candidate, SN 17011, all test sites

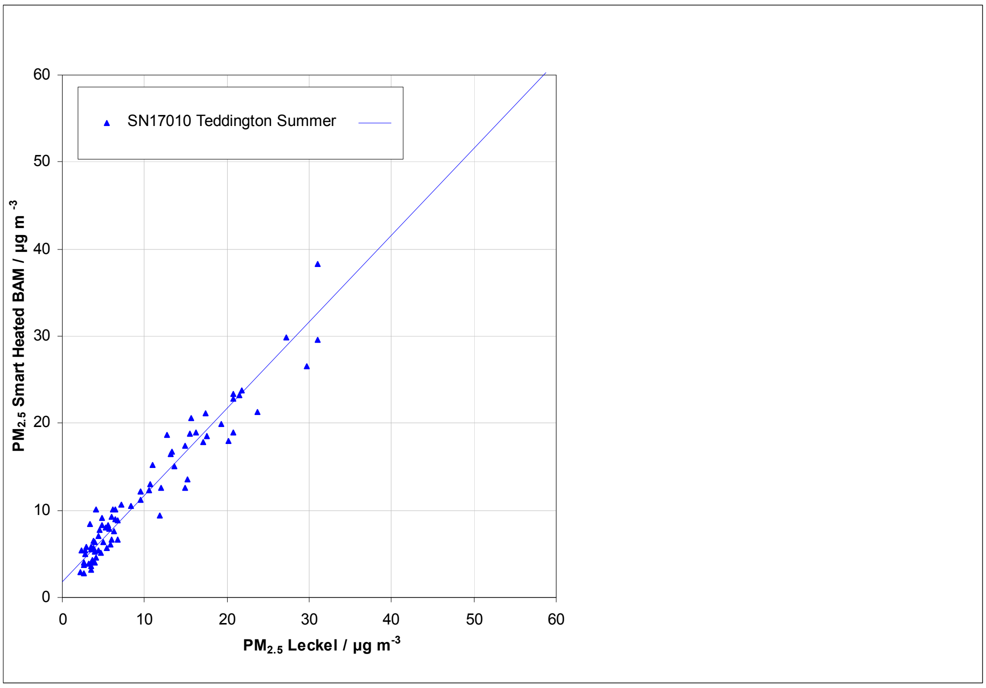


Figure 54: Reference vs. candidate, SN 17010, Teddington, Summer

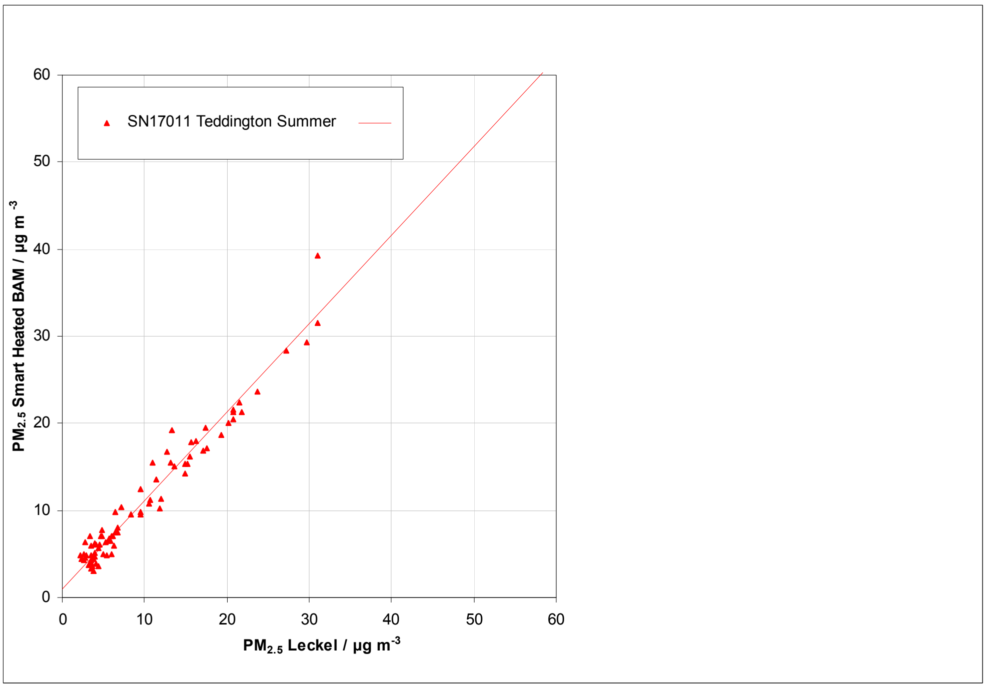


Figure 55: Reference vs. candidate, SN 17011, Teddington, Summer

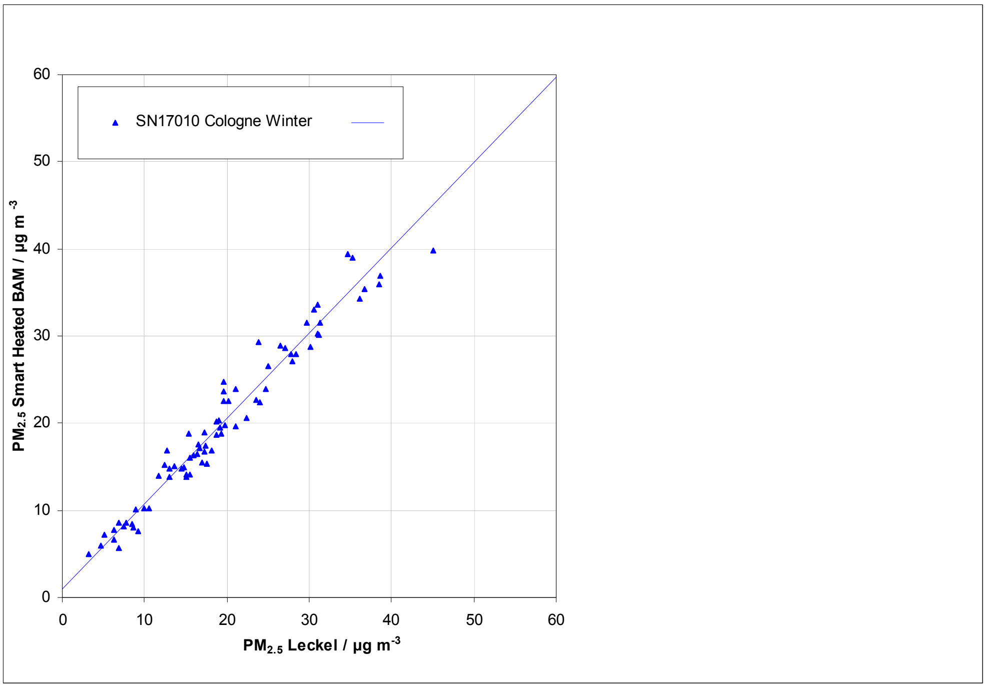


Figure 56: Reference vs. candidate, SN 17010, Cologne, Winter

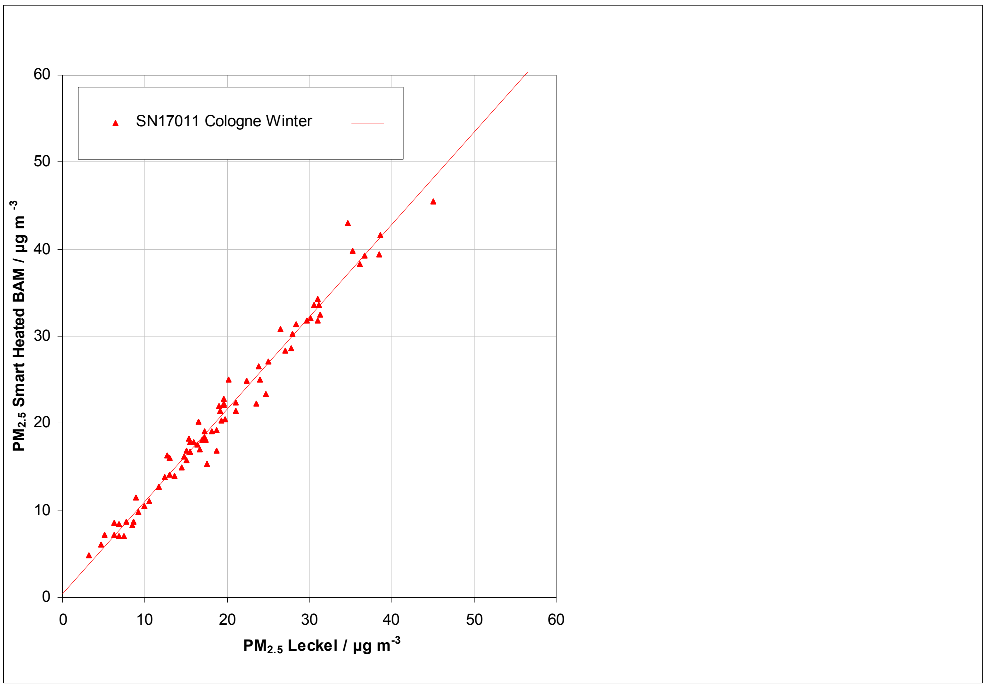


Figure 57: Reference vs. candidate, SN 17011, Cologne, Winter

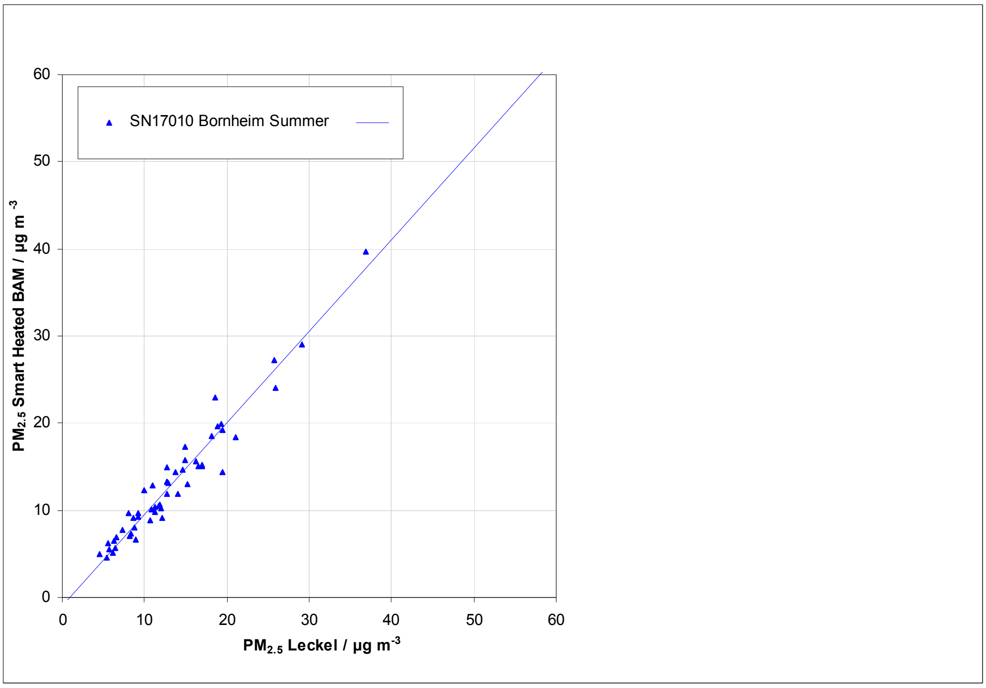


Figure 58: Reference vs. candidate, SN 17010, Bornheim, Summer

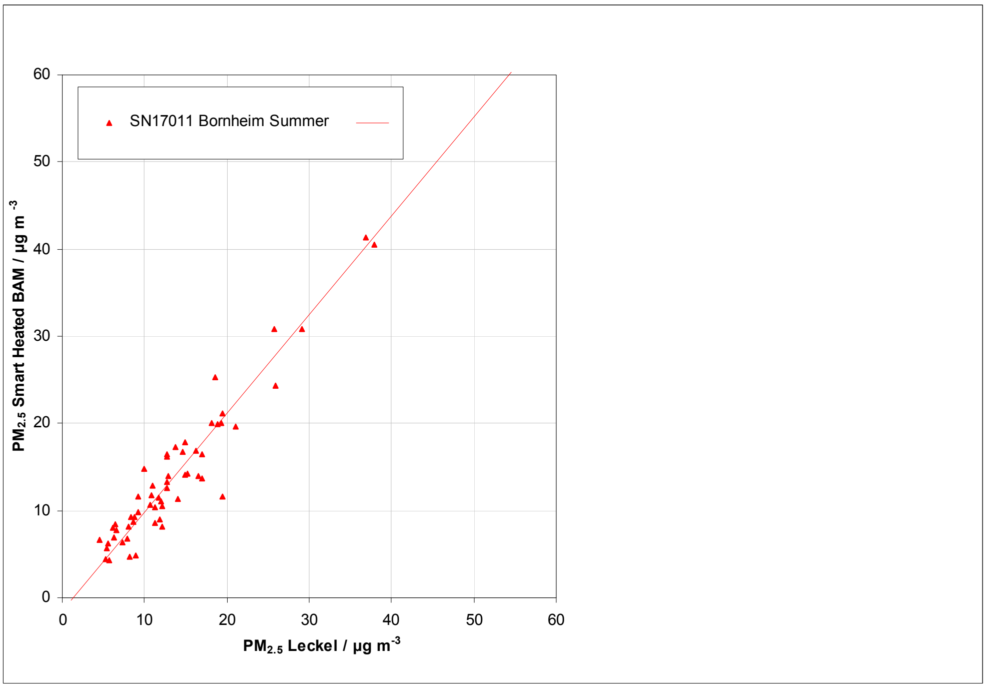


Figure 59: Reference vs. candidate, SN 17011, Bornheim, Summer

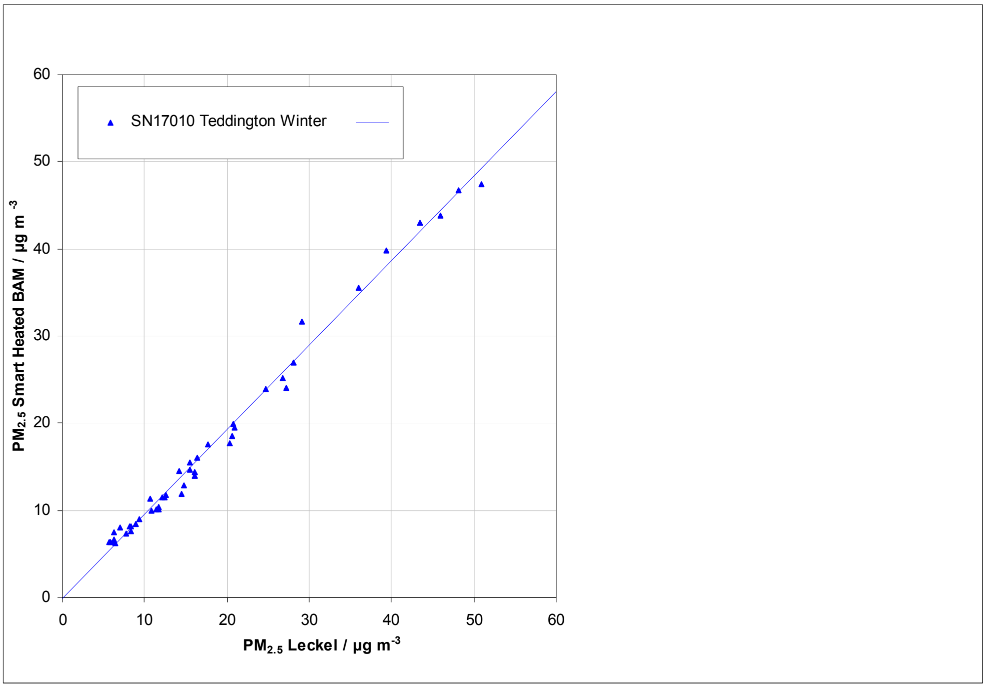


Figure 60: Reference vs. candidate, SN 17010, Teddington, Winter

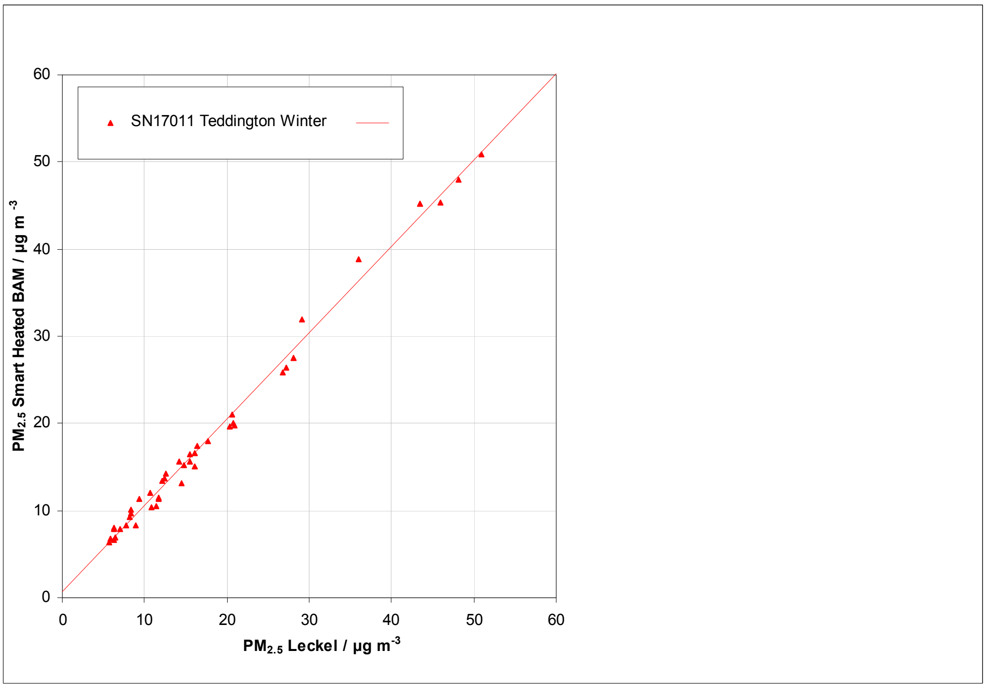


Figure 61: Reference vs. candidate, SN 17011, Teddington, Winter

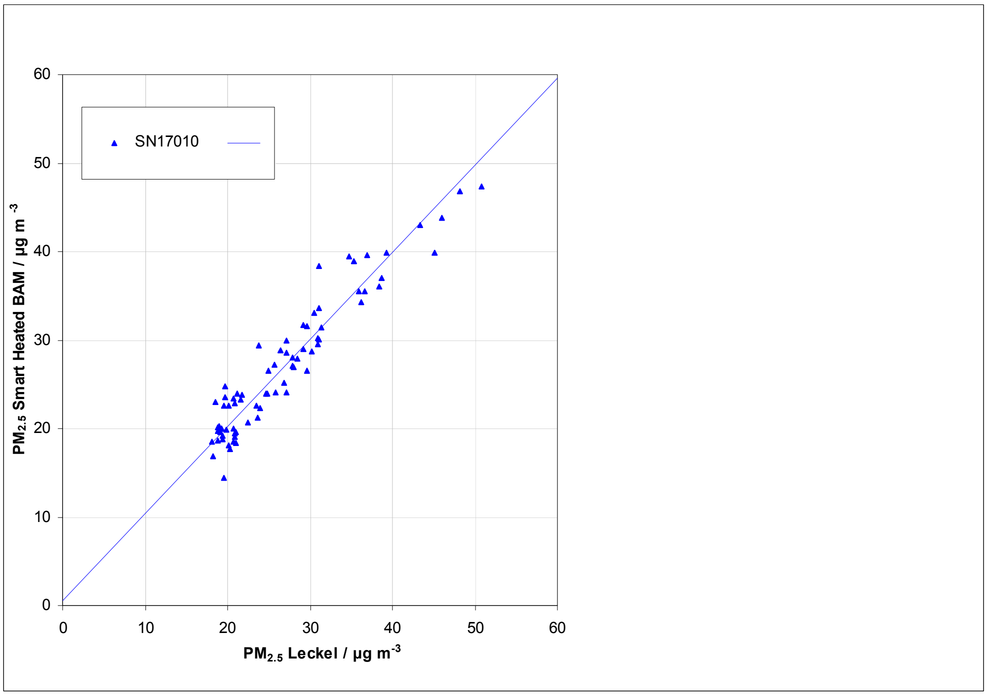


Figure 62: Reference vs. candidate, SN 17010, values ≥ 18 µg/m³

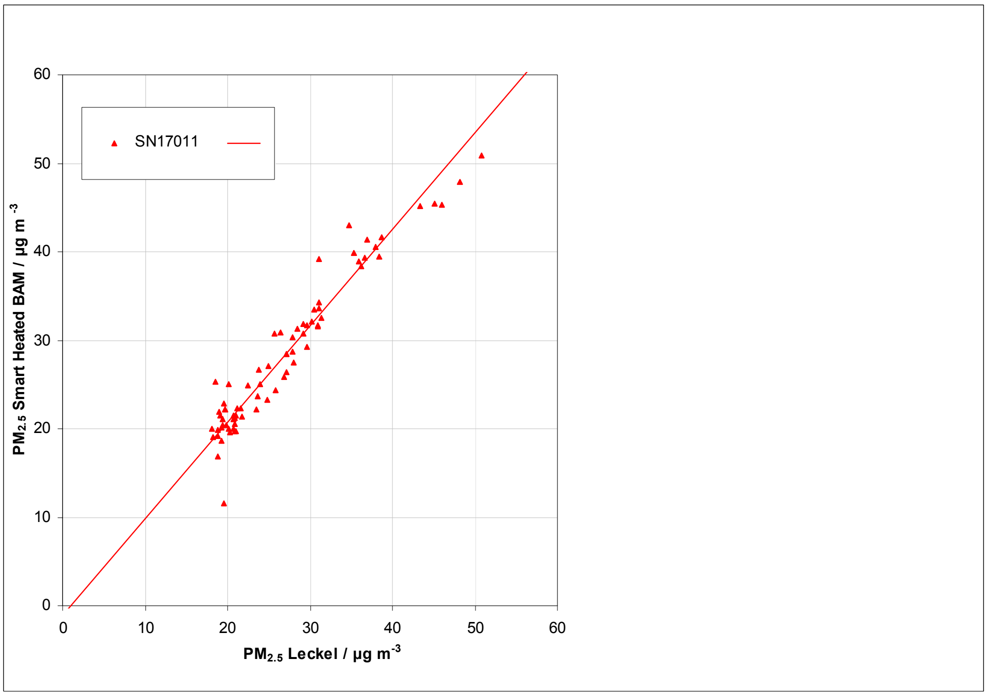


Figure 63: Reference vs. candidate, SN 17011, values ≥ 18 µg/m³

7.1 Application of correction factors or terms [9.7]

If the highest resulting expanded uncertainty of the candidate method is larger than the expanded relative uncertainty, which is defined in the requirements on the data quality of ambient air measurements according to EU-Guideline [7], the application of correction factors or terms is permitted. The corrected values have to fulfil the requirements according to point 9.5.2.2 et seqq. of the Guide „Demonstration of Equivalence of Ambient Air Monitoring Methods".

7.2 Equipment

Not required for this minimum requirement.

7.3 Carrying out the test

Refer to Module 9.5.2.2 – 9.5.6.

7.4 Evaluation

If evaluation of the raw data according to module 9.5.2.2 – 9.5.6 leads to a case where $W_{CM} > W_{dqo}$, which means that the candidate systems is not regarded equivalent to the reference method, it is permitted to apply a correction factor or term resulting from the regression equation obtained from the full data set. The corrected values shall satisfy the requirements for all data sets or subsets (refer to module 9.5.2.2 – 9.5.6).
Moreover, a correction factor may be applied even for $W_{CM} \leq W_{dqo}$ in order to improve the accuracy of the candidate systems.

Three distinct situations may arise:

a) Slope b not significantly different from 1: $|b-1| \leq 2u(b)$,
   Intercept a significantly different from 0: $|a| > 2u(a)$

b) Slope b significantly different from 1: $|b-1| > 2u(b)$,
   Intercept a not significantly different from 0: $|a| \leq 2u(a)$

c) Slope b significantly different from 1: $|b-1| > 2u(b)$
   Intercept a significantly different from 0: $|a| > 2u(a)$

With respect to a)

The value of the intercept a may be used as a correction term to correct all input values y_i according to the following equation.

$$y_{i,corr} = y_i - a$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + u^2(a)$$

with u(a) = uncertainty of the original intercept a, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [6]. RSS is determined analogue to the calculation in module 9.5.2.2 – 9.5.6.

With respect to b)

The value of the slope b may be used as a factor to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b)$$

with u(b) = uncertainty of the original slope b, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 9.5.2.2 – 9.5.6.

With respect to c)

The values of the slope b and of the intercept a may be used as correction terms to correct all input values y_i according to the following equation.

$$y_{i,corr} = \frac{y_i - a}{b}$$

The resulting values of $y_{i,corr}$ may then be used to calculate the following new terms by linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{c\_s}(y_{i,corr}) = \frac{RSS}{(n-2)} - u^2(x_i) + [c + (d-1)x_i]^2 + x_i^2 u^2(b) + u^2(a)$$

with u(b) = uncertainty of the original slope b, the value of which has been used to obtain $y_{i,corr}$ and with u(a) = uncertainty of the original intercept a, the value of which has been used to obtain $y_{i,corr}$.

Algorithms for the calculation of intercepts as well as slopes and their variances by orthogonal regression are described in detail in annex B of [4]. RSS is determined analogue to the calculation in module 9.5.2.2 – 9.5.6.

The values for $u_{c\_s,corr}$ are used for the calculation of the combined relative uncertainty of the candidate systems after correction according to the following equation:

$$w^2_{c,CM,corr}(y_i) = \frac{u^2_{c\_s,corr}(y_i)}{y_i^2}$$

For the corrected data set, uncertainty is calculated at the daily limit value $w_{c,CM,corr}$ by taking as y_i the concentration at the limit value.

The expanded relative uncertainty $W_{CM,corr}$ is calculated according to the following equation:

$$W_{CM',corr} = k \cdot w_{CM,corr}$$

In practice: k=2 for large number of available experimental results

The highest resulting uncertainty W_{CM} is compared and assessed with the requirements on data quality of ambient air measurements according to EU Standard [7].
Two results are possible:

1. $W_{CM} \leq W_{dqo}$ → Candidate method is accepted as equivalent to the standard method.
2. $W_{CM} > W_{dqo}$ → Candidate method is not accepted as equivalent to the standard method.

The specified expanded relative uncertainty W_{dqo} for particulate matter is 25 % [7]

7.5 Assessment

The candidate systems fulfil the requirements on the data quality of ambient air quality measurements during the test already without application of correction factors.

Minimum requirement fulfilled? yes

However, the evaluation of the full data set for both candidates leads to a significant intercept (refer to Table 34). The intercept for the full dataset is 0.764. For this reason an intercept correction has been applied on the full dataset and all datasets have been evaluated again with the corrected values. Also after the correction, all datasets fulfil the requirements on the the data quality and the improvement in the expanded measurement uncertainties is only marginal, though in some cases there is even a slight increase (e.g. Teddington (Winter) for 17010).

The July 2009 version of The Guidance requires that when operating in networks, a candidate method needs to be tested annually at a number of sites corresponding to the highest expanded uncertainty found during equivalence testing. These criteria are banded in 5 % steps (Guide [4], point 9.9.2, table 6). Importantly the highest expanded uncertainty both before and after correction for intercept is SN 17011 for Bornheim Summer which in both cases lies between 20 and 25 %.

Therefore the application of a correction factor for the BAM-1020 for $PM_{2.5}$ is slightly improving the expanded measurement uncertainties but leads to no significant advantage. The proof for equivalence of the candidate BAM-1020 for $PM_{2.5}$ can also be demonstrated without the application of correction factors or terms.

The respective realisation of the above mentioned requirement on ongoing QA/QC in networks is the responsibility of the network operator or of the responsible authority of the member state. However TÜV Rheinland and their UK partners recommend, that the expanded uncertainty for the full data set is refered to for this, namely 12.6 % (uncorrected dataset) respectively 11.6 % (dataset after offset-correction), which again would require an annual test at 3 measurement sites.

7.6 Detailed representation of test results

Table 35 shows the results of evaluations for the equivalence test after application of a correction factor for the intercept onto the full dataset.

Table 35: Summary of the results of the equivalence test, SN 17010 & SN 17011, after intercept correction

$PM_{2.5}$ Smart Heated BAM Corrected by subtracting 0.764	33.1% > 17 µg m-3	Orthogonal Regression				Between Instrument Uncertainties	
	W_{CM} / %	n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	Reference	Candidate
All Data	11.6	248	0.967	1.000 +/- 0.012	0.000 +/- 0.204	0.33	1.38
< 18 µg m-3	10.5	174	0.889	0.971 +/- 0.025	0.302 +/- 0.267	0.34	1.05
> 18 µg m-3	14.9	74	0.926	1.031 +/- 0.033	-0.832 +/- 0.919	0.30	1.57

SN 17010	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.931	0.994 +/- 0.030	1.058 +/- 0.372	14.46	19.2
	Cologne Winter	75	0.957	0.980 +/- 0.024	0.196 +/- 0.512	12.96	56.0
	Bornheim Summer	53	0.941	1.052 +/- 0.036	-1.726 +/- 0.527	11.08	20.8
	Teddington Winter	45	0.991	0.970 +/- 0.014	-0.946 +/- 0.300	14.40	35.6
Combined Datasets	< 18 µg m^{-3}	175	0.849	0.955 +/- 0.028	0.373 +/- 0.306	13.21	4.6
	> 18 µg m^{-3}	76	0.907	0.984 +/- 0.035	-0.180 +/- 0.975	16.67	100.0
	Alle Standorte	251	0.957	0.969 +/- 0.013	0.225 +/- 0.226	13.78	33.5

SN 17011	Dataset	Orthogonal Regression				Limit Value of 30 µg m^{-3}	
		n_{c-s}	r^2	Slope (b) +/- u_b	Intercept (a) +/- u_a	W_{CM} / %	% > 17 µg m^{-3}
Individual Datasets	Teddington Summer	78	0.955	1.016 +/- 0.025	0.254 +/- 0.308	11.85	19.2
	Cologne Winter	75	0.977	1.061 +/- 0.019	-0.334 +/- 0.405	14.00	56.0
	Bornheim Summer	57	0.901	1.134 +/- 0.048	-2.262 +/- 0.727	20.72	21.1
	Teddington Winter	43	0.992	0.991 +/- 0.014	-0.134 +/- 0.293	7.59	32.6
Combined Datasets	< 18 µg m^{-3}	178	0.881	1.021 +/- 0.026	-0.130 +/- 0.286	11.10	4.5
	> 18 µg m^{-3}	75	0.929	1.092 +/- 0.034	-1.872 +/- 0.952	16.67	100.0
	Alle Standorte	253	0.966	1.041 +/- 0.012	-0.387 +/- 0.214	13.52	32.8

8 Recommendations for practical use

Works in the maintenance interval (4 weeks)

The following procedures are required to be undertaken at regular intervals:

- Regular visual inspection / telemetric monitoring
- - Check if device status is o.k.
- - Check if there a no error messages
- - Check if there are no contaminations
- Check of the instrument functions according to the instructions of the manufacturer
- Check of filter tape stock
- Maintenance of the sampling head according manufacturer's specifications
- Every 4 weeks: plausibility check of temperature, pressure sensors, if necessary re-calibration
- Every 4 weeks: leak check and check of the flow rate

Furthermore it is to pay attention to the advices of the manufacturer.

Each measurement cycle, the measuring systems carry out an internal check of the zero point (zero measurement) as well as of the sensitivity (measurement with reference foil). The results of these checks can be used for the continuous check of the stability of the radiometric measurement.

Further maintenance works

The following works are necessary in addition to the regular works in the maintenance interval:

- Replacement of filter tape after approx. 2 months (measurement cycle: 60 min). After the replacement, it is strongly adviced to perform a selt-test according to chapter 3.5 of the manual.
- According to the manufacturer, the calibration of the flow rate should be performed every 2 months.
- The muffler at the pump should be replaced semiannually.
- The sensors for the ambient temperature, air pressure, filter temperature and filter rH have to be checked every 6 months according to the manual.
- The flow controller, the pump and the sample heater have to be checked every 6 months according to the manual.
- Once a year, a 72 h BKGD-test with the help of the zero filter kit BX-302 according to the manual point 7.7 should be performed
- Once a year the carbon vanes of the vacuum pump (only rotary vane pump) have to be checked and replaced if necessary during an annual base maintenance.
- During the annual base maintenance, it is also to pay attention to the cleaning of the sampling tube.

Further details are provided in the user manual.

Department of Environmental Protection

Karsten Pletscher	Dr. Peter Wilbring

Koeln, March 26, 2010
936/21209919/A

9 Literature

[1] Standard VDI 4202, Sheet 1, „Minimum requirements for suitability tests of automated ambient air quality measuring systems – Point-related measurement methods of gaseous and particulate pollutants “, June 2002

[2] Standard VDI 4203, Sheet 3, „Testing of automated measuring systems – Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants “, August 2004

[3] Standard EN 14907, „Ambient air quality - Standard gravimetric measurement method for the determination of the $PM_{2.5}$ mass fraction of suspended particulate matter“, German version EN 14907: 2005

[4] Guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”, English version of July 2009)

[5] Operating manual BAM-1020, Version 9800-RevG

[6] Operating manual LVS3, 2000

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

[8] Report „UK Equivalence Programme for Monitoring of Particulate Matter“, Report No.: BV/AQ/AD202209/DH/2396 of June 5th, 2006

10 Appendix

Annex 1 **Detection limit** **Page 1 of 1**

Manufacturer	Met One Instruments			
Type	BAM-1020	Standards	ZP	Measured value with zero filter
Serial-No.	SN 17010 & SN 17011			

No.	Date	Measured values [µg/m³] SN 17010	SN 17011
1	5/14/2009	-0.76	-0.62
2	5/15/2009	-1.18	-1.45
3	5/16/2009	-0.97	-1.70
4	5/17/2009	-0.01	-1.62
5	5/18/2009	-0.72	-1.33
6	5/19/2009	-0.68	-0.45
7	5/20/2009	0.37	-0.53
8	5/21/2009	-1.72	-1.99
9	5/22/2009	-0.64	-0.91
10	5/23/2009	0.70	-1.45
11	5/24/2009	-1.05	-0.49
12	5/25/2009	-0.80	-0.78
13	5/26/2009	-0.47	-1.16
14	5/27/2009	-0.09	-0.53
15	5/28/2009	-0.22	-1.41
	No. of values	15.00	15.00
	Mean	-0.55	-1.09
	Standard deviation s_{x0}	0.62	0.51
	Detection limit x	1.33	1.09

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Annex 2 **Dependence of zero point / measured value on ambient temperature** **Page 1 of 1**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

Standards
ZP Measured value with zero filter
RP built-in reference foil

			Cycle 1		Cycle 2		Cycle 3			
SN 17010	No.	Temperature [°C]	Measured value MetOne [µg/m³]	Dev. [µg/m³]	Measured value MetOne [µg/m³]	Abw. [µg/m³]	Measured value MetOne [µg/m³]	Dev. [µg/m³]		
ZP	1	20	1.4	-	0.1	-	2.4	-		
	2	5	1.6	0.2	1.7	1.6	1.5	-0.9		
	3	20	-1.0	-2.4	0.7	0.7	0.7	-1.7		
	4	40	-1.3	-2.8	2.1	2.0	0.2	-2.3		
	5	20	0.1	-1.4	1.1	1.0	4.5	2.1		
SN 17011	No.	Temperature [°C]	Measured value MetOne [µg/m³]	Dev. [µg/m³]	Measured value MetOne [µg/m³]	Abw. [µg/m³]	Measured value MetOne [µg/m³]	Dev. [µg/m³]		
ZP	1	20	-0.7	-	-1.6	-	-1.7	-		
	2	5	-0.4	0.3	-0.5	1.0	-0.1	1.6		
	3	20	-0.7	0.0	-1.0	0.5	-1.0	0.6		
	4	40	-2.5	-1.8	-3.0	-1.4	-3.2	-1.5		
	5	20	-1.6	-0.9	-0.7	0.9	-1.2	0.4		
SN 17010	No.	Temperature [°C]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]		
RP	1	20	829.8	-	829.6	-	829.3	-		
	2	5	829.4	0.0	829.3	0.0	829.3	0.0		
	3	20	829.7	0.0	829.7	0.0	829.6	0.0		
	4	40	830.8	0.1	830.7	0.1	831.8	0.3		
	5	20	829.6	0.0	829.3	0.0	829.6	0.0		
SN 17011	No.	Temperature [°C]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]		
RP	1	20	822.9	-	821.9	-	823.3	-		
	2	5	821.8	-0.1	822.4	0.1	823.3	0.0		
	3	20	822.6	0.0	823.3	0.2	823.7	0.0		
	4	40	823.8	0.1	825.4	0.4	826.4	0.4		
	5	20	821.9	-0.1	823.3	0.2	823.8	0.1		

Annex 3 **Dependence of measured value on mains voltage** **Page 1 of 1**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

Standards RP built-in reference foil

			Cycle 1		Cycle 2		Cycle 3	
SN 17010	No.	Voltage [V]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]
RP	1	230	827.7	-	828.6	-	828.4	-
	2	190	828.3	0.1	829.3	0.1	829.9	0.2
	3	230	828.8	0.1	828.2	0.0	828.2	0.0
	4	245	828.1	0.0	828.1	-0.1	829.3	0.1
	5	230	829.8	0.3	828.4	0.0	829.0	0.1
SN 17011	No.	Voltage [V]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]	Measured value foil [µg/cm²]	Dev. [%]
RP	1	230	823.1	-	823.2	-	822.4	-
	2	190	823.2	0.0	822.7	-0.1	823.3	0.1
	3	230	822.1	-0.1	821.6	-0.2	823.7	0.2
	4	245	823.4	0.0	823.1	0.0	822.4	0.0
	5	230	821.8	-0.2	822.5	-0.1	822.6	0.0

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 1 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
1	7/24/2008			32.9	32.0				Zero filter	Teddington
2	7/25/2008	15.4	15.1	22.5	23.6	65.9	13.6	15.3		(Summer)
3	7/26/2008			21.0	21.6		15.5	14.1	Outlier Ref. PM2.5	
4	7/27/2008	13.1	13.2	19.0	19.9	67.8	16.5	15.5		
5	7/28/2008	13.5	13.6	20.3	20.3	66.9	15.0	15.1		
6	7/29/2008	4.2	4.7	11.8	12.1	37.4	7.7	6.0		
7	7/30/2008	9.6	9.5	16.2	16.5	58.4	12.2	9.5		
8	7/31/2008	10.8	11.0	22.2	22.4	49.0	15.2	15.5		
9	8/1/2008	4.2	5.5	16.3	15.5	30.3	9.1	7.7		
10	8/2/2008	2.4	2.2				5.3	4.4	Outlier Ref. PM10	
11	8/3/2008	2.0	2.5	8.2	8.4	26.8	3.0	4.9		
12	8/4/2008	3.4	4.4	9.4	9.6	41.1	5.2	4.7		
13	8/5/2008	3.1	3.6	7.5	7.3	45.1	8.4	7.0		
14	8/6/2008								Power loss	
15	8/7/2008	5.4	6.2	11.9	11.4	50.2			Power loss	
16	8/8/2008	5.2	6.2	9.9	9.6	58.5	7.8	6.7		
17	8/9/2008	2.3	3.3	7.1	7.3	39.3	5.0	6.4		
18	8/10/2008	3.9	4.1	11.7	11.2	34.7	4.0	5.1		
19	8/11/2008	5.6	6.0	13.7	13.5	42.7	6.1	6.4		
20	8/12/2008	3.5	3.5	10.6	10.5	33.2	3.1	3.3		
21	8/13/2008	3.5	3.8	11.8	11.4	31.7	4.2	3.7		
22	8/14/2008	6.1	6.5	11.0	11.1	56.9	7.6	6.0		
23	8/15/2008	5.6	6.3	10.0	11.6	55.4	6.6	5.0		
24	8/16/2008	5.5	5.5				5.7	4.8	Outlier Ref. PM10	
25	8/17/2008	2.7	2.7	8.7	8.5	31.2	3.7	4.3		
26	8/18/2008								Zero filter	
27	8/19/2008	4.6	4.7	12.5	13.0	36.6	5.2	7.0		
28	8/20/2008	3.9	4.1	10.2	10.1	39.6	6.4	6.2		
29	8/21/2008	6.5	6.8	13.2	13.5	50.2	8.9	7.5		
30	8/22/2008	5.2	4.9	9.5	9.3	53.6	6.3	5.0		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 2 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
31	8/23/2008	4.5	4.4	9.2	9.5	47.4	7.0	5.6		Teddington (Summer)
32	8/24/2008	3.5	3.5	8.6	8.7	40.3	5.7	4.3		
33	8/25/2008	6.5	6.5	12.9	13.0	50.0	10.2	9.9		
34	8/26/2008	4.8	4.9	10.7	9.5	47.9	8.3	7.0		
35	8/27/2008	7.4	7.0	13.4	13.6	53.2	10.7	10.4		
36	8/28/2008	9.6	9.3	14.1	14.2	66.8	12.1	12.4		
37	8/29/2008	13.7	12.8	20.1	19.1	67.8	16.8	19.3		
38	8/30/2008	31.6	30.5	43.8	43.2	71.4	38.3	39.2		
39	8/31/2008	13.3	12.1	22.0	21.6	58.5	18.7	16.8		
40	9/1/2008	2.9	2.6	8.1	8.1	33.9	5.5	4.6		
41	9/2/2008	3.0	2.4	11.8	12.4	22.3	4.1	5.0		
42	9/3/2008	3.6	3.3	14.2	14.3	24.2	5.5	6.0		
43	9/4/2008	4.1	3.7				6.5	4.4	Outlier Ref. PM10	
44	9/5/2008	2.6	2.7	7.5	7.6	35.0	2.7		Reference foil 17011 stuck, 4h loss because of repair	
45	9/6/2008	3.4	3.6	8.0	7.6	44.9	4.1	4.8		
46	9/7/2008	3.1	2.7	8.4	8.2	34.8	5.8	4.9		
47	9/8/2008	6.4	6.6	14.7	14.2	45.0	9.0	7.5		
48	9/9/2008	6.0	5.2	14.4	14.2	39.1	8.3	6.4		
49	9/10/2008	4.3	4.1	11.0	10.6	38.6	10.1	6.1		
50	9/11/2008	6.5	5.4	17.2	17.5	34.2	9.2	7.0		
51	9/12/2008	5.5	5.1	9.4	9.1	57.3	8.0	6.4		
52	9/13/2008	15.5	15.4	20.4	20.7	75.5	18.8	16.2		
53	9/14/2008	10.9	10.3	18.1	17.4	60.0	13.0	11.2		
54	9/15/2008	11.8	12.3	17.5	17.5	68.6	12.5	11.3		
55	9/16/2008	17.7	17.4	24.6	24.2	72.0	18.5	17.1		
56	9/17/2008	19.4	19.2	26.9	28.1	70.3	20.0	18.6		
57	9/18/2008	17.0	17.2	24.5	23.6	71.3	17.9	16.9		
58	9/19/2008	20.7	20.9	29.3	29.4	70.9	22.9	21.3		
59	9/20/2008	21.7	21.4	26.9	26.6	80.6	23.2	22.4		
60	9/21/2008	21.6	22.0	28.6	28.1	76.9	23.8	21.3		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 3 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
61	9/22/2008	14.8	15.0	22.3	22.6	66.3	17.4	15.3		Teddington
62	9/23/2008	6.3	6.1	18.0	17.8	34.5			Zero filter	(Summer)
63	9/24/2008	11.4	11.4	18.8	19.7	59.1		13.5	Filtertape 17010 cracked	
64	9/25/2008	16.1	16.5	26.7	26.4	61.2	19.0	17.9		
65	9/26/2008	17.5	17.4	29.9	29.7	58.5	21.1	19.4		
66	9/27/2008	27.2	27.2	35.7	35.6	76.4	29.9	28.4		
67	9/28/2008						20.4	17.8		
68	9/29/2008	4.3	4.4	7.4	8.5	54.9	5.3	3.6		
69	9/30/2008	3.2	3.3	6.9	6.7	48.3	3.9	3.7		
70	10/1/2008						3.5	2.4		
71	10/2/2008						5.4	3.9		
72	10/3/2008						7.3	5.7		
73	10/4/2008						3.0	1.4		
74	10/5/2008						5.7	3.7		
75	10/6/2008						7.5	6.4		
76	10/7/2008						5.5	5.4		
77	10/8/2008						14.0	11.3		
78	10/9/2008	8.9	10.1	18.4	18.0	52.2	11.2	9.8		
79	10/10/2008	10.5	10.6	19.5	19.6	54.1	12.4	10.8		
80	10/11/2008	15.6	15.8	22.6	22.6	69.5	20.7	17.8		
81	10/12/2008	20.4	21.1	25.9	25.9	80.1	23.4	21.5		
82	10/13/2008	8.3	8.4	14.6	14.4	57.6	10.5	9.5		
83	10/14/2008	6.1	6.4	11.4	12.2	52.7	10.2	7.1		
84	10/15/2008	3.9	3.8	8.2	8.6	46.0	5.7	3.1		
85	10/16/2008								Zero filter	
86	10/17/2008								Not in operation	
87	10/18/2008								Not in operation	
88	10/19/2008								Not in operation	
89	10/20/2008								Not in operation	
90	10/21/2008						7.5	7.5		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 4 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
91	10/22/2008						8.2	7.7		Teddington (Summer)
92	10/23/2008						5.4	4.2		
93	10/24/2008						12.1	10.5		
94	10/25/2008						11.2	9.5		
95	10/26/2008						4.4	2.2		
96	10/27/2008						11.0	9.4		
97	10/28/2008						6.8	8.5		
98	10/29/2008						15.8	17.1		
99	10/30/2008						10.5	11.0		
100	10/31/2008	11.7	12.0	16.9	18.5	66.9	9.5	10.2		
101	11/1/2008	14.8	15.1	18.3	19.2	79.9	12.6	14.2		
102	11/2/2008	20.4	20.0	25.5	25.8	78.7	18.0	20.0		
103	11/3/2008	20.7	20.9	27.0	27.8	76.0	19.0	20.5		
104	11/4/2008	31.1	30.9	37.5	38.4	81.7	29.5	31.6		
105	11/5/2008	29.7	29.6	35.5	36.2	82.8	26.6	29.3		
106	11/6/2008	23.5	23.8	28.2	28.6	83.2	21.2	23.6		
107	11/7/2008	6.8	6.7	15.2	14.7	45.4	6.6	8.0		
108	11/8/2008	3.5	3.5	8.6	9.4	39.1	3.7	4.1		
109	11/9/2008	4.1	4.0	11.5	11.9	34.8	4.5	3.9		
110	12/4/2008						6.2	8.4		Cologne (Winter)
111	12/5/2008	9.1	9.2	12.5	13.0	71.6	7.5	9.9		
112	12/6/2008						13.8	18.0		
113	12/7/2008	17.4	17.2	22.6	22.8	76.1	16.7	18.4		
114	12/8/2008	15.2	15.8	18.2	18.3	84.8	14.1	16.7		
115	12/9/2008	22.7	22.2				20.7	24.9	Outlier Ref. PM10	
116	12/10/2008	19.9	18.8	24.1	23.9	80.6	18.8	20.4		
117	12/11/2008	24.0	24.0	28.3	29.3	83.2	22.4	25.1		
118	12/12/2008	17.3	16.6	19.1	19.5	87.8	15.5	18.1		
119	12/13/2008	17.9	18.5				16.9	19.1	Outlier Ref. PM10	
120	12/14/2008						36.6	42.1		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 5 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
121	12/15/2008	31.3	31.4	34.9	34.7	90.1	31.5	32.5		Cologne
122	12/16/2008	16.8	16.4	19.6	20.4	83.1	17.6	20.2		(Winter)
123	12/17/2008	20.1	20.1	32.3	33.2	61.5	22.5	25.1		
124	12/18/2008						12.1	14.5		
125	12/19/2008			20.3	21.6		10.5	12.1		
126	12/20/2008						7.4	8.9		
127	12/21/2008	7.1	8.5	11.1	11.1	70.5	8.6	8.7		
128	12/22/2008						15.4	15.9		
129	12/23/2008						21.2	22.6		
130	12/24/2008						24.1	25.4		
131	12/25/2008						8.2	7.4		
132	12/26/2008						12.0	12.3		
133	12/27/2008						19.7	20.9		
134	12/28/2008	27.9	27.9	33.7	33.9	82.6	27.0	30.3		
135	12/29/2008						33.5	37.0		
136	12/30/2008						45.7	48.9		
137	12/31/2008						98.2	111.5		
138	1/1/2009						82.0	88.9		
139	1/2/2009						46.3	47.5		
140	1/3/2009						32.9	36.9		
141	1/4/2009	30.0	30.4	35.1	36.7	84.1	28.7	32.1		
142	1/5/2009	14.7	15.4	17.0	16.3	90.3	14.1	16.8		
143	1/6/2009	34.6	34.8	49.7	48.6	70.7	39.4	43.0		
144	1/7/2009								Zero filter	
145	1/8/2009						35.5	36.3		
146	1/9/2009	38.8	38.6	48.6	47.7	80.4	37.0	41.6		
147	1/10/2009	45.7	44.6	48.3	48.8	92.9	39.9	45.4		
148	1/11/2009						41.9	46.5		
149	1/12/2009	38.4	38.4	42.7	42.9	89.7	36.0	39.4		
150	1/13/2009	36.3	36.0	41.7	41.6	86.8	34.3	38.3		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 6 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
151	1/14/2009	31.1	31.3	38.2	38.2	81.5	30.1	33.7		Cologne
152	1/15/2009	28.4	28.5	32.2	32.0	88.6	27.9	31.3		(Winter)
153	1/16/2009	36.6	36.8	39.9	40.2	91.6	35.5	39.3		
154	1/17/2009						16.8	16.5		
155	1/18/2009	5.0	4.4	8.5	7.9	57.3	5.9	6.1		
156	1/19/2009	3.0	3.3	6.7	5.9	50.0	5.0	4.9		
157	1/20/2009			14.2	14.5		9.7	11.0	Outlier Ref. PM2.5	
158	1/21/2009	16.0	16.0	21.2	21.6	74.5	16.3	17.8		
159	1/22/2009	6.2	6.3	9.0	8.6	71.3	7.7	7.2		
160	1/23/2009	5.3	4.9	9.2	9.1	55.5	7.2	7.2		
161	1/24/2009						17.4	18.7		
162	1/25/2009	16.4	16.6	21.0	20.4	79.4	16.4	17.6		
163	1/26/2009	35.1	35.5	44.8	43.8	79.6	38.9	39.9		
164	1/27/2009	31.0	31.2	37.4	37.5	83.0	33.6	34.3		
165	1/28/2009	29.9	29.4	33.5	33.9	87.9	31.5	31.7		
166	1/29/2009						28.4	31.3		
167	1/30/2009	23.6	24.1	29.5	29.2	81.2	29.4	26.6		
168	1/31/2009						7.1	7.9		
169	2/1/2009	15.2	15.6	17.8	18.1	85.9	18.7	18.3		
170	2/2/2009								Zero filter	
171	2/3/2009			41.3	41.0		37.1	39.4	Outlier Ref. PM2.5	
172	2/4/2009	30.9	30.2	34.3	34.2	89.1	33.0	33.5		
173	2/5/2009	17.6	17.1	21.2	21.2	81.9	19.0	19.1		
174	2/6/2009	19.4	19.8	23.5	23.7	83.0	22.5	22.9		
175	2/7/2009						22.9	22.5		
176	2/8/2009	12.4	12.6	16.1	16.1	77.3	15.2	13.8		
177	2/9/2009	7.1	6.7	10.8	10.4	64.9	8.6	7.1		
178	2/10/2009						8.3	8.2		
179	2/11/2009	11.5	11.9	16.8	16.6	70.1	13.9	12.7		
180	2/12/2009	12.2	13.1	21.8	22.7	57.0	16.9	16.4		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 7 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
181	2/13/2009	19.8	19.6	25.9	26.3	75.4	23.6	22.2		Cologne (Winter)
182	2/14/2009						28.9	28.7		
183	2/15/2009	19.5	19.9	24.7	25.1	79.0	24.8	22.2		
184	2/16/2009			17.7	18.2		15.8	16.3	Ref.2 PM2.5 not in operation	
185	2/17/2009	10.7	10.5	12.7	13.1	82.0	10.3	11.0		
186	2/18/2009	15.0	14.5	21.0	21.6	69.2	14.9	16.2		
187	2/19/2009	30.9	31.0	38.8	38.8	79.7	30.2	31.7		
188	2/20/2009	12.9	13.1	18.3	18.3	70.8	14.7	16.0		
189	2/21/2009						23.1	24.7		
190	2/22/2009	13.5	13.9	20.2	20.8	66.7	15.0	14.0		
191	2/23/2009	6.6	6.0	14.6	15.0	42.4	6.6	8.5		
192	2/24/2009	19.1	18.9	29.9	30.5	63.0	20.3	21.9		
193	2/25/2009	26.9	27.3	36.3	35.5	75.4	28.6	28.4		
194	2/26/2009	20.0	19.6	30.7	30.7	64.6	19.8	20.4		
195	2/27/2009	21.1	21.2	28.3	28.2	74.9	24.0	22.4		
196	2/28/2009	25.0	25.0	31.4	31.5	79.6	26.5	27.1		
197	3/1/2009						31.5	33.1		
198	3/2/2009	28.0	27.8	36.9	37.1	75.3	28.0	28.7		
199	3/3/2009	20.8	21.2	25.9	25.7	81.4	19.6	21.4		
200	3/4/2009								Zero filter	
201	3/5/2009	15.2	13.7	15.2	16.0	92.8	14.7	14.9		
202	3/6/2009	16.1	14.8	21.4	21.9	71.6	16.0	17.9		
203	3/7/2009	18.7	18.9	26.1	26.1	71.9	18.7	16.9		
204	3/8/2009						5.6	6.9		
205	3/9/2009						8.0	9.2		
206	3/10/2009						8.3	9.7		
207	3/11/2009	13.0	13.2	21.4	21.6	60.7	13.9	14.2		
208	3/12/2009	19.1	19.2	24.1	24.5	78.8	19.5	21.5		
209	3/13/2009	16.3	16.9	28.8	28.2	58.4	17.1	17.1		
210	3/14/2009	17.2	17.6	25.7	26.3	66.9	17.4	18.2		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 8 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
211	3/15/2009						8.6	10.5		Cologne (Winter)
212	3/16/2009	26.4	26.4	37.0	37.5	70.9	28.9	30.8		
213	3/17/2009	24.5	24.9	36.8	36.7	67.4	24.0	23.3		
214	3/18/2009	23.2	23.8	38.1	38.6	61.3	22.6	22.2		
215	3/19/2009	17.3	17.9	28.5	29.2	61.0	15.4	15.3		
216	3/20/2009	16.0	14.1	26.1	27.0	56.7	13.8	15.8		
217	3/21/2009						43.5	45.4		
218	3/22/2009	19.0	18.5	32.7	32.1	57.8	20.1	19.2		
219	3/23/2009	9.9	10.1	20.8	20.4	48.6	10.2	10.4		
220	3/24/2009	8.5	8.9	15.7	16.0	54.8	8.0	8.7		
221	3/25/2009	9.2	8.8	14.0	14.4	63.2	10.1	11.4		
222	3/26/2009	7.2	7.8	10.9	11.5	67.0	8.2	7.1		
223	3/27/2009	8.4	8.4	12.9	12.3	67.0	8.5	8.4		
224	3/28/2009	7.3	6.5	9.3	8.9	75.6	5.7	8.4		
225	3/29/2009						14.2	17.5		
226	3/30/2009						24.2	24.7		
227	3/31/2009						24.1	25.9		
228	4/1/2009						25.7	26.2		
229	4/2/2009								Zero filter	
230	4/3/2009						63.6	66.4		
231	4/4/2009						90.4	92.0		
232	4/5/2009						78.4	77.4		
233	4/6/2009						31.7	29.9		
234	4/7/2009						22.2	21.4		
235	4/8/2009						7.0	4.8		
236	4/9/2009						9.2	8.3		
237	4/10/2009						17.3	17.4		
238	4/11/2009						35.5	38.5		
239	4/12/2009						124.1	126.7		
240	4/13/2009						110.7	105.1		

Annex 4 **Measured values from the field test sites, related to ambient conditions**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
241	8/9/2009	38.1	37.7					40.5	17010 shows spikes in	Bornheim
242	8/10/2009							29.4	measured value and in stability	(Summer)
243	8/11/2009	12.4	11.9					10.6	values	
244	8/12/2009	9.6	10.0						Change of PMT for 17010	
245	8/13/2009								Zero filter	
246	8/14/2009								Zero filter	
247	8/15/2009						11.5	10.7		
248	8/16/2009	16.5	16.7	22.8	22.8	72.8	15.0	13.9		
249	8/17/2009	15.0	15.0	24.1	23.7	62.7	15.7	14.1		
250	8/18/2009	12.4	13.0	20.1	19.7	63.7	13.3	13.3		
251	8/19/2009	16.8	17.2	24.0	24.3	70.3	15.0	13.7		
252	8/20/2009	19.6	19.4	33.4	32.7	59.1	14.4	11.6		
253	8/21/2009	8.0	8.2	18.9	18.7	43.0	9.7	8.1		
254	8/22/2009						10.8	9.6		
255	8/23/2009	11.7	12.0	17.2	17.6	68.1	10.7	9.1		
256	8/24/2009	14.3	13.8	19.1	20.4	71.3	12.0	11.3		
257	8/25/2009			21.4	21.2		15.9	12.9	Outlier Ref. PM2.5	
258	8/26/2009						9.2	7.6		
259	8/27/2009	8.7	9.1	15.4	16.1	56.3	6.6	4.8		
260	8/28/2009	8.3	8.0	17.0	16.9	48.1	7.0	4.6		
261	8/29/2009						7.5	6.0		
262	8/30/2009	7.3	7.5	16.8	16.8	43.9	7.8	6.3		
263	8/31/2009	12.3	11.9	22.3	21.0	55.9	9.1	8.2		
264	9/1/2009	11.3	11.3	18.1	18.4	62.0	9.9	8.6		
265	9/2/2009	7.9	8.0	13.3	13.7	58.9		6.8	17010, Filter tape crack	
266	9/3/2009	5.3	5.3	8.0	7.2	69.1		4.4	17010, Filter tape crack	
267	9/4/2009	5.4	5.4	8.9	9.2	60.0	4.5	5.6		
268	9/5/2009						7.9	7.2		
269	9/6/2009	6.7	6.5	10.6	10.6	62.3	6.9	7.7		
270	9/7/2009	11.4	11.9	18.5	18.5	62.8	10.5	11.5		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 10 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
271	9/8/2009	17.0	16.9	25.2	25.0	67.5	15.2	16.5		Bornheim (Summer)
272	9/9/2009	19.4	19.2	38.2	37.5	51.0	20.0	20.1		
273	9/10/2009	10.2	9.6	22.3	21.9	44.7	12.4	14.8		
274	9/11/2009	9.1	9.4	21.0	20.7	44.4	9.2	11.6		
275	9/12/2009						11.4	11.6		
276	9/13/2009	5.4	5.6	12.9	13.8	41.5	6.3	6.2		
277	9/14/2009								Zero filter	
278	9/15/2009	12.6	13.0	17.2	16.8	75.0	15.0	16.2		
279	9/16/2009	25.6	25.9	34.5	33.3	76.0	27.2	30.8		
280	9/17/2009	13.6	13.8	20.8	20.2	66.8	14.3	17.2		
281	9/18/2009	18.7	19.0	24.8	25.6	74.8	19.7	19.9		
282	9/19/2009						23.1	24.7		
283	9/20/2009	36.7	37.1	45.0	45.2	81.8	39.6	41.3		
284	9/21/2009	18.2	19.0	28.7	29.1	64.3	23.0	25.3		
285	9/22/2009	14.9	15.0	27.2	28.1	54.1	17.2	17.9		
286	9/23/2009	12.9	12.7	26.8	27.0	47.5	13.2	16.4		
287	9/24/2009	14.9	14.5	23.0	22.8	64.0	14.7	16.7		
288	9/25/2009	16.3	16.1	28.6	27.4	57.9	15.6	16.9		
289	9/26/2009						14.8	15.3		
290	9/27/2009	26.0	25.7	34.9	35.8	73.0	24.0	24.3		
291	9/28/2009	28.8	29.5	44.4	45.3	65.1	29.0	30.8		
292	9/29/2009	18.0	18.3	28.0	27.8	65.1	18.5	20.0		
293	9/30/2009	19.1	19.7	25.1	25.3	77.2	19.2	21.1		
294	10/1/2009	9.6	8.9	18.5	18.8	49.5	9.7	9.8		
295	10/2/2009	12.0	12.0	25.9	26.1	46.0	10.3	11.1		
296	10/3/2009						5.9	7.7		
297	10/4/2009	5.4	6.0	10.6	11.0	52.6	5.5	4.3		
298	10/5/2009	8.2	8.4	12.5	14.0	62.7	7.4	9.3		
299	10/6/2009	12.8	12.9	17.5	18.8	70.7	13.1	13.9		
300	10/7/2009	8.7	8.5	14.0	14.3	60.9	9.1	8.7		

Annex 4 **Measured values from the field test sites, related to ambient conditions**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
301	10/8/2009	11.2	10.7	16.1	16.7	66.9	12.9	12.8		Bornheim
302	10/9/2009	9.1	8.5	15.6	15.6	56.4	8.1	9.3		(Summer)
303	10/10/2009						10.0	10.1		
304	10/11/2009	5.8	6.6	11.6	12.0	52.4	5.1	8.0		
305	10/12/2009	4.8	4.2	9.9	9.9	45.4	5.0	6.6		
306	10/13/2009	6.2	6.3	12.5	12.5	50.0	6.5	6.8		
307	10/14/2009	11.2	10.3	15.4	15.6	69.6	10.1	11.8		
308	10/15/2009	11.2	10.2	18.0	17.8	59.8	8.9	10.7		
309	10/16/2009	6.5	6.3	16.1	15.8	40.3	5.7	8.5		
310	10/17/2009						8.4	8.5		
311	10/18/2009	11.3	11.3	18.4	18.6	60.9	10.4	10.4		
312	10/19/2009	12.8	12.8	19.6	19.6	65.1	11.9	12.5		
313	10/20/2009	15.6	14.9				13.0	14.2	Outlier Ref. PM10	
314	10/21/2009	20.8	21.2	27.6	28.1	75.6	18.4	19.7		
315	10/22/2009			31.7	32.3		23.3	25.0	Outlier Ref. PM2.5	
316	12/9/2009	11.3	11.6	27.5	27.5	41.6	10.1	10.5		Teddington
317	12/10/2009	16.4	16.2	25.4	25.4	64.2	16.1	17.4		(Winter)
318	12/11/2009	11.8	11.7	20.3	20.2	57.9	10.4	11.4		
319	12/12/2009	6.4	6.5	13.5	13.6	47.6	6.2	6.9		
320	12/13/2009	8.6	9.1	13.4	13.9	65.1	8.4	8.3		
321	12/14/2009	27.9	28.3	35.3	35.3	79.6	26.9	27.4		
322	12/15/2009	39.8	38.8	47.6	47.4	82.8	39.9		17011 Filter tape error	
323	12/16/2009	24.9	24.5	30.0	30.3	82.0	24.0		17011 Filter tape error	
324	12/17/2009	5.7	5.6	10.2	10.1	55.7	6.3	6.4		
325	12/18/2009	11.6	11.9	16.9	17.0	69.3	10.1	11.3		
326	12/19/2009	10.3	11.0	15.4	14.9	70.4	11.3	12.0		
327	12/20/2009	6.2	6.4	11.1	11.0	56.9	6.6	7.9		
328	12/21/2009	17.7	17.7	20.2	20.4	87.2	17.6	17.9		
329	12/22/2009	29.4	28.9				31.7	31.9	Outlier Ref. PM10	
330	12/23/2009						14.7	15.9		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 12 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
331	12/24/2009						16.5	17.5		Teddington (Winter)
332	12/25/2009						9.5	9.7		
333	12/26/2009						3.3	3.2		
334	12/27/2009						4.6	5.7		
335	12/28/2009						17.8	19.2		
336	12/29/2009						8.7	9.9		
337	12/30/2009						8.8	9.3		
338	12/31/2009	6.0	6.5				6.5	6.7		
339	1/1/2010						13.8	13.7		
340	1/2/2010						11.6	12.5		
341	1/3/2010						16.4	17.7		
342	1/4/2010								Zero filter	
343	1/5/2010	15.6	15.5				15.5	16.4		
344	1/6/2010			19.2	19.3		13.0	13.9	Outlier Ref. PM2.5	
345	1/7/2010	15.3	15.7	19.4	20.1	78.4	14.6	15.7		
346	1/8/2010	14.6	14.9	18.3	18.4	80.3	12.9	15.2		
347	1/9/2010	7.1	6.9	14.6	14.9	47.4	8.0	7.9		
348	1/10/2010	16.0	16.1	19.5	19.2	82.9	14.4	15.1		
349	1/11/2010	45.7	46.2	51.8	51.3	89.1	43.9	45.3		
350	1/12/2010	43.2	43.6	48.1	48.0	90.4	43.0	45.2		
351	1/13/2010	48.0	48.3	53.4	53.0	90.6	46.8	47.9		
352	1/14/2010	14.1	14.4	16.2	16.3	87.5	14.6	15.6		
353	1/15/2010	14.6	14.4	26.9	27.1	53.6	11.9	13.2		
354	1/16/2010	6.5	6.1	13.5	13.6	46.1	7.5	8.1		
355	1/17/2010	11.0	10.5	20.6	20.6	52.3	10.0	10.4		
356	1/18/2010	21.0	20.4	27.1	26.9	76.7	18.5	21.0		
357	1/19/2010	20.4	20.2	26.5	26.6	76.4	17.7	19.6		
358	1/20/2010	26.6	27.0	32.0	31.9	83.8	25.1	25.8		
359	1/21/2010	20.5	20.9	27.5	27.9	75.0	20.0	20.0		
360	1/22/2010	7.8	7.6	9.7	9.8	78.5	7.3	8.2		

Annex 4 **Measured values from the field test sites, related to ambient conditions** **Page 13 of 13**

Manufacturer Met One Instruments

Type BAM-1020

Serial-No. SN 17010 & SN 17011

PM2.5, ambient air
Measured values in µg/m³ , ambient cond.

No.	Date	Ref. 1 PM2.5 [µg/m³]	Ref. 2 PM2.5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2.5/PM10 [%]	SN 17010 PM2.5 [µg/m³]	SN 17011 PM2.5 [µg/m³]	Remark	Test site
361	1/23/2010	21.0	20.9	25.8	25.1	82.3	19.5	19.8		Teddington
362	1/24/2010	16.2	15.9	20.7	20.3	78.4	14.0	16.5		(Winter)
363	1/25/2010	36.1	35.8	42.0	42.4	85.1	35.6	38.9		
364	1/26/2010	50.7	51.1	60.4	60.4	84.2	47.4	50.8		
365	1/27/2010	27.1	27.3	38.9	39.1	69.7	24.0	26.4		
366	1/28/2010	8.3	8.0	13.9	14.1	58.3	8.2	9.2		
367	1/29/2010	5.7	6.0	9.4	9.6	61.5	6.3	6.8		
368	1/30/2010	12.4	12.5	17.6	17.6	70.7	11.5	13.7		
369	1/31/2010	12.2	13.0	17.3	16.9	73.5	11.7	14.2		
370	2/1/2010	8.4	8.3	14.7	14.4	57.5	8.1	9.6		
371	2/2/2010	8.3	8.3	12.0	11.7	70.0	7.7	10.1		
372	2/3/2010	9.4	9.3	19.2	19.2	48.6	9.0	11.3		
373	2/4/2010	12.0	12.4	19.7	19.8	61.7	11.5	13.4		

Annex 5 **Ambient conditions at the field test sites** **Page 1 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	7/24/2008	Teddington (Summer)	No weather data available					
2	7/25/2008							
3	7/26/2008							
4	7/27/2008							
5	7/28/2008							
6	7/29/2008							
7	7/30/2008							
8	7/31/2008							
9	8/1/2008							
10	8/2/2008							
11	8/3/2008							
12	8/4/2008							
13	8/5/2008							
14	8/6/2008							
15	8/7/2008							
16	8/8/2008							
17	8/9/2008							
18	8/10/2008							
19	8/11/2008							
20	8/12/2008							
21	8/13/2008							
22	8/14/2008							
23	8/15/2008							
24	8/16/2008							
25	8/17/2008							
26	8/18/2008							
27	8/19/2008							
28	8/20/2008							
29	8/21/2008							
30	8/22/2008							

Annex 5 **Ambient conditions at the field test sites** **Page 2 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	8/23/2008	Teddington (Summer)	No weather data available					
32	8/24/2008							
33	8/25/2008							
34	8/26/2008							
35	8/27/2008							
36	8/28/2008							
37	8/29/2008							
38	8/30/2008							
39	8/31/2008							
40	9/1/2008							
41	9/2/2008							
42	9/3/2008							
43	9/4/2008							
44	9/5/2008							
45	9/6/2008							
46	9/7/2008							
47	9/8/2008							
48	9/9/2008							
49	9/10/2008							
50	9/11/2008							
51	9/12/2008							
52	9/13/2008							
53	9/14/2008							
54	9/15/2008							
55	9/16/2008							
56	9/17/2008		14.5	1005	68.1	0.6	153	
57	9/18/2008		11.6	1007	72.0	0.5	195	
58	9/19/2008		12.8	1012	70.1	0.3	170	
59	9/20/2008		13.1	1011	70.5	0.5	116	
60	9/21/2008		13.2	1008	70.0	0.6	168	

Annex 5 **Ambient conditions at the field test sites**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	9/22/2008	Teddington	14.8	1006	76.5	1.1	211	
62	9/23/2008	(Summer)	14.4	1006	76.0	1.8	228	
63	9/24/2008		14.8	1010	81.9	0.8	168	
64	9/25/2008		13.3	1016	74.7	0.7	89	
65	9/26/2008		13.4	1016	75.6	0.7	146	
66	9/27/2008		12.0	1011	80.6	0.1	206	
67	9/28/2008		13.9	1005	70.7	0.2	300	
68	9/29/2008		14.0	997	71.7	0.3	235	
69	9/30/2008		13.7	984	83.8	0.4	210	
70	10/1/2008		10.4	985	71.9	0.4	232	
71	10/2/2008		9.5	988	69.7	0.7	272	
72	10/3/2008		9.3	999	64.0	0.6	279	
73	10/4/2008		14.1	985	87.0	1.1	179	
74	10/5/2008		10.1	987	88.7	0.6	259	
75	10/6/2008		14.8	991	87.0	0.9	161	
76	10/7/2008		12.7	991	89.6	0.6	219	
77	10/8/2008		9.6	1008	80.6	0.2	276	
78	10/9/2008		13.3	1013	80.2	0.3	184	
79	10/10/2008		12.0	1009	84.4	0.4	210	
80	10/11/2008		12.8	1007	85.9	0.2	198	
81	10/12/2008		15.4	1001	86.5	0.3	206	
82	10/13/2008		12.5	1001	90.9	0.1	209	
83	10/14/2008		14.4	998	90.5	0.3	192	
84	10/15/2008		12.1	994	86.8	0.3	255	
85	10/16/2008		8.2	1001	78.7	0.4	241	
86	10/17/2008		9.0	1002	83.8	0.0	229	
87	10/18/2008		10.6	1001	83.3	0.1	213	
88	10/19/2008		14.0	995	76.3	0.8	192	
89	10/20/2008		11.2	989	90.2	0.4	203	
90	10/21/2008		6.7	999	80.5	0.2	214	

Annex 5 **Ambient conditions at the field test sites** **Page 4 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	10/22/2008	Teddington (Summer)	9.4	1006	80.9	0.2	226	
92	10/23/2008		13.6	1000	79.8	1.0	195	
93	10/24/2008		6.5	1011	85.1	0.2	250	
94	10/25/2008		14.1	1002	81.8	0.9	194	
95	10/26/2008		9.2	995	95.0	0.0	227	
96	10/27/2008		4.2	994	85.6	0.1	285	
97	10/28/2008		4.3	994	81.7	0.5	253	
98	10/29/2008		4.3	984	77.8	0.4	153	
99	10/30/2008		5.3	985	79.6	1.1	161	
100	10/31/2008		5.7	992	80.1	0.9	245	
101	11/1/2008		8.8	989	91.5	1.2	233	
102	11/2/2008		10.1	997	88.9	0.8	224	
103	11/3/2008		10.6	998	93.6	0.9	151	
104	11/4/2008		11.4	1001	86.2	0.8	179	
105	11/5/2008		10.5	998	92.6	0.5	284	
106	11/6/2008		10.5	992	90.7	0.4	161	
107	11/7/2008		No weather data available					
108	11/8/2008							
109	11/9/2008							
110	12/4/2008	Cologne (Winter)	4.4	980	77.0	3.7	61	4.5
111	12/5/2008		5.6	988	76.4	1.7	109	12.1
112	12/6/2008		5.1	1008	81.1	1.7	150	3.6
113	12/7/2008		2.0	1021	82.1	0.1	150	0.3
114	12/8/2008		0.3	1013	80.5	1.1	186	0.3
115	12/9/2008		1.3	1006	82.4	0.3	124	6.5
116	12/10/2008		1.3	1005	81.3	0.2	180	2.1
117	12/11/2008		0.0	1007	81.6	0.5	244	0.0
118	12/12/2008		-0.5	1009	74.3	4.4	108	0.0
119	12/13/2008		0.7	994	69.9	5.3	194	0.0
120	12/14/2008		-0.4	999	78.2	0.4	173	0.0

Annex 5 **Ambient conditions at the field test sites** **Page 5 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	12/15/2008	Cologne	1.6	1009	80.1	0.1	164	0.0
122	12/16/2008	(Winter)	-0.8	1006	81.8	0.3	93	0.0
123	12/17/2008		0.9	1009	84.6	0.4	117	4.2
124	12/18/2008		4.5	1012	81.3	2.1	108	3.9
125	12/19/2008		5.8	1016	74.9	3.1	106	8.3
126	12/20/2008		7.8	1018	81.5	2.2	139	17.1
127	12/21/2008		9.1	1023	77.9	4.2	136	1.5
128	12/22/2008		7.1	1026	80.4	1.6	144	0.3
129	12/23/2008		4.9	1028	82.8	0.1	163	0.0
130	12/24/2008		5.4	1023	79.4	1.2	176	0.0
131	12/25/2008		1.6	1028	68.0	0.6	271	0.0
132	12/26/2008		-1.3	1030	62.5	0.7	266	0.0
133	12/27/2008		-3.4	1027	69.9	0.7	268	0.0
134	12/28/2008		-4.7	1023	71.8	0.6	253	0.0
135	12/29/2008		-2.7	1024	67.3	0.4	258	0.0
136	12/30/2008		-3.3	1022	68.6	0.6	301	0.0
137	12/31/2008		-3.1	1020	75.1	0.8	126	0.0
138	1/1/2009		-2.9	1021	77.5	0.1	159	0.0
139	1/2/2009		No data	1022	No data	No data	No data	0.0
140	1/3/2009		-0.4	1017	68.8	1.5	188	0.0
141	1/4/2009		-0.6	1010	75.6	2.4	161	0.0
142	1/5/2009		-4.0	1015	70.6	0.0	253	1.2
143	1/6/2009		-14.0	1016	76.0	0.4	187	0.0
144	1/7/2009		-6.8	1019	76.6	0.3	161	0.0
145	1/8/2009		-8.5	1023	78.6	0.1	249	0.0
146	1/9/2009		-7.7	1022	71.6	0.3	209	0.3
147	1/10/2009		-5.1	1022	65.5	1.0	198	0.0
148	1/11/2009		-2.4	1021	61.9	2.1	234	0.0
149	1/12/2009		2.3	1011	58.8	4.7	182	0.3
150	1/13/2009		2.4	1006	67.3	2.4	74	3.0

Annex 5 **Ambient conditions at the field test sites** **Page 6 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	1/14/2009	Cologne	2.1	1011	81.4	0.0	147	0.3
152	1/15/2009	(Winter)	1.4	1014	69.4	3.0	209	0.0
153	1/16/2009		2.1	1013	73.2	4.0	171	0.0
154	1/17/2009		5.4	1004	72.4	4.2	117	0.9
155	1/18/2009		3.8	993	73.5	3.7	106	3.5
156	1/19/2009		5.7	983	72.2	5.1	76	5.6
157	1/20/2009		0.3	994	76.8	0.6	160	0.3
158	1/21/2009		2.0	1000	72.8	2.3	128	0.0
159	1/22/2009		4.1	983	72.4	6.9	123	14.5
160	1/23/2009		3.8	971	76.1	4.9	115	12.1
161	1/24/2009		1.9	988	77.2	0.8	158	0.0
162	1/25/2009		1.4	991	72.3	2.4	267	0.0
163	1/26/2009		0.3	999	71.8	0.9	192	0.0
164	1/27/2009		1.3	1009	65.9	0.4	225	0.0
165	1/28/2009		0.1	1013	69.6	0.6	226	0.0
166	1/29/2009		-0.2	1015	67.0	1.8	255	0.0
167	1/30/2009		-0.6	1014	67.2	2.8	237	0.0
168	1/31/2009		0.7	1009	56.2	3.3	284	0.0
169	2/1/2009		-0.3	999	59.4	3.6	289	0.0
170	2/2/2009		3.0	992	62.3	2.2	270	0.0
171	2/3/2009		0.9	992	78.8	0.0	74	0.6
172	2/4/2009		3.1	989	76.5	0.8	138	0.0
173	2/5/2009		No data	987	No data	No data	No data	0.0
174	2/6/2009		2.0	983	83.1	0.0	250	0.3
175	2/7/2009		2.1	988	78.4	2.4	156	0.6
176	2/8/2009		1.8	998	72.0	2.0	131	0.0
177	2/9/2009		4.2	987	74.6	5.4	131	15.3
178	2/10/2009		2.7	994	76.1	6.5	138	16.8
179	2/11/2009		0.9	1007	75.1	1.4	139	2.7
180	2/12/2009		0.8	1012	77.0	0.4	175	0.0

Annex 5 **Ambient conditions at the field test sites** **Page 7 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	2/13/2009	Cologne	0.2	1013	75.7	0.6	208	4.1
182	2/14/2009	(Winter)	-1.6	1021	71.9	0.8	206	0.0
183	2/15/2009		0.6	1017	78.2	0.9	136	10.6
184	2/16/2009		5.7	1011	83.4	3.8	150	21.5
185	2/17/2009		0.5	1017	71.6	1.8	269	0.6
186	2/18/2009		-0.7	1019	62.6	0.8	233	0.0
187	2/19/2009		3.1	1019	68.8	1.2	180	3.9
188	2/20/2009		4.5	1022	80.9	2.2	157	2.4
189	2/21/2009		5.3	1020	74.2	1.2	124	4.4
190	2/22/2009		5.8	1013	78.3	4.5	153	3.9
191	2/23/2009		5.1	1013	71.9	3.1	174	0.6
192	2/24/2009		2.2	1021	75.5	0.9	168	0.0
193	2/25/2009		6.3	1018	71.2	2.9	125	0.6
194	2/26/2009		7.1	1011	69.8	5.0	142	0.6
195	2/27/2009		7.8	1011	79.3	2.2	121	0.9
196	2/28/2009		7.6	1005	76.6	0.7	204	0.0
197	3/1/2009		9.5	1002	74.3	2.1	119	3.0
198	3/2/2009		5.1	1009	70.6	1.4	135	0.0
199	3/3/2009		6.8	996	58.0	5.0	126	0.0
200	3/4/2009		6.9	980	67.7	3.0	96	6.2
201	3/5/2009		4.2	985	81.2	4.0	176	26.9
202	3/6/2009		3.7	998	77.6	4.6	154	6.5
203	3/7/2009		8.0	1003	69.7	1.3	89	0.6
204	3/8/2009		6.2	998	68.3	3.7	121	5.0
205	3/9/2009		5.9	1004	67.8	4.3	119	3.3
206	3/10/2009		5.4	1004	75.7	4.5	124	7.7
207	3/11/2009		5.4	1016	69.7	1.7	96	2.4
208	3/12/2009		7.7	1012	81.9	2.1	158	11.0
209	3/13/2009		8.1	1012	67.9	1.1	155	0.0
210	3/14/2009		9.9	1012	70.3	3.9	177	1.5

Annex 5 **Ambient conditions at the field test sites** **Page 8 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	3/15/2009	Cologne	8.0	1022.9	72.8	2.8	153.4	0.0
212	3/16/2009	(Winter)	7.0	1025.4	72.6	0.1	147.8	0.0
213	3/17/2009		6.1	1027.5	66.7	0.4	204.0	0.0
214	3/18/2009		4.6	1021.1	59.6	0.1	218.6	0.0
215	3/19/2009		5.4	1022.0	57.3	0.6	199.4	0.0
216	3/20/2009		4.6	1023.1	50.9	0.8	234.3	0.0
217	3/21/2009		5.6	1019.3	58.1	1.2	139.8	0.0
218	3/22/2009		8.5	1015.0	63.4	5.3	164.1	0.0
219	3/23/2009		5.3	998.8	71.5	6.5	144.3	9.2
220	3/24/2009		3.5	1001.0	67.4	3.2	114.1	9.2
221	3/25/2009		5.4	994.9	75.6	3.8	131.6	8.6
222	3/26/2009		7.3	993.8	74.3	3.6	95.2	14.5
223	3/27/2009		6.9	990.3	66.5	3.9	91.8	1.8
224	3/28/2009		6.5	994.7	70.8	3.3	122.3	3.9
225	3/29/2009		4.8	1007.7	70.0	0.9	185.6	0.3
226	3/30/2009		5.2	1015.9	65.9	0.7	161.6	0.0
227	3/31/2009		10.3	1013.7	50.7	0.9	210.0	0.0
228	4/1/2009		12.9	1011.2	48.2	1.5	247.4	0.0
229	4/2/2009		14.9	1008.3	55.0	1.2	203.4	0.0
230	4/3/2009		17.0	1008.8	58.6	1.5	116.0	0.0
231	4/4/2009		13.6	1014.1	64.4	0.9	170.3	0.0
232	4/5/2009		11.6	1012.5	68.2	0.6	207.5	0.0
233	4/6/2009		16.0	1002.3	54.5	1.5	226.7	0.0
234	4/7/2009		12.7	1004.8	70.5	1.9	94.5	6.5
235	4/8/2009		13.0	1007.1	66.5	2.5	136.7	0.9
236	4/9/2009		15.5	1005.1	62.0	1.5	189.4	0.0
237	4/10/2009		17.7	999.7	53.3	1.4	203.8	0.0
238	4/11/2009		17.8	1001.1	56.5	0.5	148.4	0.0
239	4/12/2009		15.1	1002.6	73.3	0.9	166.7	0.0
240	4/13/2009		12.4	1002.0	76.5	0.1	184.0	0.0

Annex 5 **Ambient conditions at the field test sites** **Page 9 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	8/9/2009	Bornheim	20.0	1008.6	72.3	0.0	defective	0.0
242	8/10/2009	(Summer)	19.8	1007.4	66.0	0.2	defective	0.3
243	8/11/2009		19.0	1010.6	70.5	0.5	defective	0.6
244	8/12/2009		18.7	1009.0	73.5	0.0	defective	20.0
245	8/13/2009		17.1	1008.7	77.3	0.1	defective	1.8
246	8/14/2009		17.3	1010.0	70.2	0.0	defective	0.0
247	8/15/2009		22.3	1007.1	56.2	0.0	defective	0.0
248	8/16/2009		22.1	1006.5	64.5	0.0	defective	0.0
249	8/17/2009		20.1	1007.5	64.9	0.4	defective	0.0
250	8/18/2009		20.4	1012.2	57.7	0.0	defective	0.0
251	8/19/2009		24.5	1010.2	53.9	0.2	defective	0.0
252	8/20/2009		25.3	1008.2	61.5	0.5	defective	17.1
253	8/21/2009		17.2	1013.3	65.4	0.0	defective	0.3
254	8/22/2009		17.4	1015.6	60.6	0.0	defective	0.0
255	8/23/2009		19.3	1009.3	55.6	0.4	defective	0.0
256	8/24/2009		23.0	1000.2	55.5	0.8	defective	1.5
257	8/25/2009		19.4	1004.1	74.1	0.1	defective	5.0
258	8/26/2009		16.1	1006.9	74.6	0.0	defective	0.0
259	8/27/2009		23.4	1005.8	56.4	0.0	defective	0.0
260	8/28/2009		17.7	1006.0	57.9	0.6	defective	0.0
261	8/29/2009		14.9	1012.1	57.6	1.1	defective	0.0
262	8/30/2009		15.7	1012.1	59.6	0.3	defective	0.0
263	8/31/2009		23.5	1005.5	44.4	0.8	defective	0.0
264	9/1/2009		14.0	1004.3	80.3	0.0	defective	12.4
265	9/2/2009		17.5	1001.8	65.9	0.0	defective	2.4
266	9/3/2009		15.8	995.9	63.8	1.3	defective	2.4
267	9/4/2009		14.1	1001.3	67.6	1.0	defective	3.9
268	9/5/2009		13.1	1013.4	70.0	0.6	defective	4.4
269	9/6/2009		14.7	1015.2	68.4	0.0	defective	0.0
270	9/7/2009		18.1	1013.4	64.0	0.0	defective	0.0

Annex 5 **Ambient conditions at the field test sites**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	9/8/2009	Bornheim	20.6	1013.2	57.8	0.0	defective	0.0
272	9/9/2009	(Summer)	20.6	1016.5	63.6	0.5	defective	0.0
273	9/10/2009		15.7	1022.1	68.9	0.3	defective	0.0
274	9/11/2009		15.7	1021.5	63.1	0.2	defective	0.0
275	9/12/2009		15.9	1016.8	64.1	0.1	defective	0.0
276	9/13/2009		12.9	1011.7	77.1	0.8	defective	1.2
277	9/14/2009		13.2	1009.2	76.8	0.7	defective	6.8
278	9/15/2009		15.4	1008.4	76.4	0.0	defective	0.0
279	9/16/2009		17.2	1007.2	71.9	0.2	defective	0.0
280	9/17/2009		14.6	1010.2	70.1	0.0	defective	0.0
281	9/18/2009		18.0	1008.2	68.1	0.0	defective	0.0
282	9/19/2009		19.7	1007.3	70.0	0.0	defective	0.0
283	9/20/2009		18.7	1012.3	72.3	0.0	defective	0.0
284	9/21/2009		14.9	1016.8	71.4	0.0	defective	0.0
285	9/22/2009		16.9	1016.5	64.3	0.0	defective	0.0
286	9/23/2009		17.4	1016.4	70.9	0.0	defective	0.0
287	9/24/2009		13.8	1015.9	79.1	0.0	defective	0.6
288	9/25/2009		13.2	1017.9	69.2	0.0	defective	0.0
289	9/26/2009		13.7	1017.5	65.9	0.0	defective	0.0
290	9/27/2009		14.2	1017.1	66.9	0.0	defective	0.0
291	9/28/2009		14.7	1014.5	69.6	0.0	defective	0.0
292	9/29/2009		15.7	1011.3	72.6	0.0	defective	0.3
293	9/30/2009		15.5	1007.7	77.0	0.0	defective	1.2
294	10/1/2009		12.0	1007.4	74.9	0.1	defective	2.1
295	10/2/2009		10.9	1008.6	66.9	0.0	defective	0.0
296	10/3/2009		13.4	1002.1	63.9	0.5	defective	0.0
297	10/4/2009		11.8	1005.3	75.4	0.4	defective	3.3
298	10/5/2009		13.1	1003.9	80.0	0.8	defective	6.5
299	10/6/2009		15.9	1003.5	82.3	0.0	defective	10.3
300	10/7/2009		19.2	1000.6	75.9	0.1	defective	8.6

Annex 5 **Ambient conditions at the field test sites** **Page 11 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	10/8/2009	Bornheim	10.7	1010	78.6	0.4	defective	0.0
302	10/9/2009	(Summer)	12.1	1009	69.1	0.2	defective	12.4
303	10/10/2009		13.2	1005	80.0	0.2	defective	4.2
304	10/11/2009		11.9	1003	76.1	0.8	defective	5.9
305	10/12/2009		9.8	1014	70.9	1.9	defective	2.1
306	10/13/2009		7.4	1019	68.5	0.7	defective	0.0
307	10/14/2009		3.3	1022	67.4	0.1	defective	0.0
308	10/15/2009		5.4	1019	66.9	0.3	defective	0.3
309	10/16/2009		8.8	1013	70.8	4.4	defective	1.5
310	10/17/2009		7.2	1014	69.7	1.1	defective	0.0
311	10/18/2009		5.5	1014	73.1	0.0	defective	0.0
312	10/19/2009		5.6	1008	66.3	0.2	defective	0.0
313	10/20/2009		7.8	999	61.4	4.2	defective	0.0
314	10/21/2009		10.0	995	57.1	1.5	defective	1.2
315	10/22/2009		8.7	996	73.5	0.0	defective	0.0
316	12/9/2009	Teddington	9.8	1017	94.1	0.1	221	0.3
317	12/10/2009	(Winter)	3.9	1028	90.9	0.2	244	0.3
318	12/11/2009		5.7	1029	93.8	0.4	231	0.0
319	12/12/2009		5.8	1026	83.9	0.8	200	0.0
320	12/13/2009		4.2	1022	87.7	0.5	234	0.3
321	12/14/2009		3.4	1017	88.8	0.2	201	0.0
322	12/15/2009		-0.6	1015	87.5	0.2	196	0.3
323	12/16/2009		1.5	1006	96.9	0.2	245	2.8
324	12/17/2009		1.3	1008	85.2	2.4	225	1.3
325	12/18/2009		-0.8	1013	86.6	0.9	281	0.0
326	12/19/2009		-0.1	1002	85.9	0.2	240	1.8
327	12/20/2009		-0.9	995	87.3	0.1	206	0.0
328	12/21/2009		1.1	984	97.3	0.3	187	8.6
329	12/22/2009		-2.1	988	98.3	0.0	218	0.3
330	12/23/2009		2.8	987	95.9	0.4	173	7.1

Annex 5 **Ambient conditions at the field test sites** **Page 12 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
331	12/24/2009	Teddington	4.1	985.9	94.1	0.3	217.3	0.5
332	12/25/2009	(Winter)	4.1	998	94.5	0.2	210	2.3
333	12/26/2009		5.9	995	90.2	0.3	200	0.8
334	12/27/2009		2.4	1000	86.2	0.3	240	0.0
335	12/28/2009		3.7	998	88.6	1.2	80	1.8
336	12/29/2009		4.8	988	95.9	1.7	94	11.7
337	12/30/2009		4.3	992	93.1	1.9	101	5.6
338	12/31/2009		2.3	998	81.8	1.1	207	0.0
339	1/1/2010		-0.1	1008	88.3	0.2	243	0.0
340	1/2/2010		1.6	1016	87.2	0.1	245	0.0
341	1/3/2010		-1.6	1021	88.3	0.3	205	0.0
342	1/4/2010		-3.7	1012	97.2	0.0	232	0.0
343	1/5/2010		0.8	998	89.9	0.7	129	4.8
344	1/6/2010		-2.3	1005	94.3	0.7	215	1.8
345	1/7/2010		-1.2	1013	91.1	0.5	240	0.0
346	1/8/2010		-1.6	1022	91.1	0.8	225	0.3
347	1/9/2010		0.9	1018	79.3	1.8	161	0.0
348	1/10/2010		1.4	1015	90.5	0.7	92	1.3
349	1/11/2010		1.5	1015	86.0	0.3	137	0.3
350	1/12/2010		1.4	1000	85.9	1.5	103	0.0
351	1/13/2010		1.5	998	94.8	0.1	151	8.6
352	1/14/2010		2.5	1008	97.0	0.1	229	0.3
353	1/15/2010		5.6	1011	90.0	1.8	151	1.8
354	1/16/2010		5.7	1003	96.3	0.4	202	9.1
355	1/17/2010		4.1	1019	93.9	0.1	219	0.0
356	1/18/2010		6.2	1021	97.8	0.1	199	0.0
357	1/19/2010		6.4	1012	83.7	1.4	111	1.0
358	1/20/2010		3.0	1012	92.1	0.2	227	3.8
359	1/21/2010		6.1	1015	85.2	1.1	154	0.3
360	1/22/2010		7.6	1014	95.0	0.5	209	7.4

Annex 5 **Ambient conditions at the field test sites** **Page 13 of 13**

No.	Date	Test site	Ambient temperature [°C]	Ambient pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
361	1/23/2010	Teddington	4.8	1018.4	87.0	0.2	262.2	0.0
362	1/24/2010	(Winter)	4.4	1022	91.1	0.1	241	1.3
363	1/25/2010		3.2	1033	80.0	0.9	161	0.5
364	1/26/2010		0.0	1037	83.2	0.5	167	0.0
365	1/27/2010		4.4	1018	85.5	0.3	247	1.0
366	1/28/2010		5.5	1000	86.4	0.5	247	8.1
367	1/29/2010		1.3	992	76.9	0.9	279	0.3
368	1/30/2010		-0.9	1001	84.4	0.2	240	0.0
369	1/31/2010		0.0	1005	91.2	0.1	241	0.0
370	2/1/2010		3.1	1010	83.9	0.4	222	0.3
371	2/2/2010		5.9	1002	89.6	0.3	229	1.0
372	2/3/2010		6.7	1004	91.0	0.2	180	2.0
373	2/4/2010		7.6	997	86.1	1.3	153	2.3

Annex 6: Firmware version

Remark

The test was performed with the software version 3236-07 5.01 (status July 2008).

The software has been constantly developed and optimized up to version 3236-07 5.0.10 during the test program. The changes up to version 3236-07 5.0.5 have been already presented in a statement and have been assessed positively by the responsible working group „Test reports“. The additional changes from version 3236-07 5.0.5 to version 3236-07 5.0.10 are described in Figure 64.

No influences on the system performance are expected from the changes which were made on the software up to version 3236-07 5.0.10.

Met One Instruments

March 10, 2010

TÜV Rheinland Immissionsschutz und Energiesysteme GmbH
Karsten Pletscher

Am Grauen Stein
D - 51105 Köln

Dear Mr. Pletscher,

We have changed our BAM-1020 Firmware to adapt further market requirements and to remove some errors. The following list shows the changes made from Firmware 5.0.5 to the new Version 5.0.10.

1. Changes to Version 5.0.6
   Output of the standard BAM Data files allowed now also through the Report Processor Option.
2. Changes to Version 5.0.7
   This version fixes an error where at rare circumstances a mechanical error in the filter transport mechanism would not be detected and could cause a display of the previous measurement value without an error flag.
3. Changes to Version 5.0.8
   Error fix with external reset signal when configured in „early cycle mode" where the internal clock was not always synchronized correctly.
4. Changes to Version 5.0.9
   Added support for the BX-596-1 Sensor. (Automatic recognition of connected Met One Sensors with AutoID). The new BX-596-1 has an expanded Temperature and Ambient Pressure range (from -50C to 50C and from 400mmHg to 825 mmHg).
5. Changes to Version 5.0.10
   Output of the BH-Protocol has changed. In addition a second output protocol was implemented for the serial interface to allow a simpler communication with a variety of external data loggers.

As you can see from the list above the changes are related to expanding functionality, repairing Software errors, improving the Bayern Hessen Protocol and an expansion of build in output functions.

The implementation of the BX-596-1 was necessary for costumers in cold regions e.g. in Alaska and for those in higher mountain regions. The function of the sensor inside the firmware has not been changed, except for the proper scaling.

In our opinion the changes above have no negative influence on the function of the approved instrument.

Please do the necessary steps to include the new Software Version in our existing type approval.

Best Regards

Dr. Herbert Schlösser
VP Particulate Air Business Division

Figure 64: Firmware changes from version 5.0.5 to version 5.0.10

Appendix 2

Filter weighing methodology

A) German sites (Cologne and Bornheim)

A.1 Carrying out the weighing

All weightings are done in an air-conditioned weighing room. Ambient conditions are 20°C ±1°C and 50 % ±5 % relative humidity, which conforms to the requirements of Standard EN 14907.

The filters used in the field test are weighed manually. The filters (including control filters) are placed on sieves for the purpose of conditioning to avoid overlap.
The specifications for pre- and post-weighing are specified beforehand and conform to the Standard.

Before sampling = pre-weighing	After sampling = post-weighing
Conditioning 48 h + 2 h	Conditioning 48 h + 2 h
Filter weighing	Filter weighing
Re-conditioning 24 h +2 h	Re-conditioning 24 h + 2 h
Filter weighing and immediate packaging	Filter weighing

The balance is always kept ready for use. An internal calibration process is started prior to each weighing series. The standard weight of 200 mg is weighed as reference and the boundary conditions are noted if nothing out of ordinary results from the calibration process. Deviations to prior measurements conform to the Standard and do not exceed 20 µg (refer to Figure 65).
All six control filters are weighed afterwards and a warning is displayed for control filters with deviations > 40 µg during evaluation. These control filters are not used for post-weighing. Instead, the first three acceptable control filters are used while the others remain in the protective jar in order to replace a defective or deviating filter, if necessary. Figure 66 shows an exemplary process over a period of more than 4 months.

All filters which deviate more than 40 µg between the first and second weighing are excluded during the pre-weighing process. Filters which deviate more than 60 µg are not considered for evaluation after post-weighing, as conforming to standards.

Weighed filters are packed in separate polystyrene jars for transport and storage. These jars remain closed until the filter is placed in the filter holder. Virgin filters can be stored in the weighing room for up to 28 days before sampling. Another pre-weighing is carried out if this period is exceeded.

Sampled filters can be stored for not more than 15 days at a temperature of 23 °C or less. The filters are stored at 7 °C in a refrigerator.

A2 Filter evaluation

The filters are evaluated with the help of a corrective term in order to minimize relative mass changes caused by the weighing room conditions.

Equation:

$$Dust = MF_{post} - (M_{Tara} \times (MKon_{post} / MKon_{pre})) \qquad (F1)$$

$MKon_{pre}$ = average mass of the 3 control filters after 48 h and 72 h pre-weighing

$MKon_{post}$ = average mass of the 3 control filters after 48 h and 72 h post-weighing

M_{Tara} = average mass of the filter after 48 h and 72 h pre-weighing

MF_{post} = average mass of the loaded filter after 48 h and 72 h post-weighing

Dust = corrected dust mass of the filter

This shows that the method becomes independent from weighing room conditions due to the corrective calculation. Influence due to the water content of the filter mass between virgin and loaded filter can be controlled and do not change the dust content of sampled filters. Hence, Point EN 14907 9.3.2.5 is fulfilled.

The below example of the standard weight between November 2008 and February 2009 shows that the allowed deviation of not more than 20 µg on the previous measurement is not exceeded.

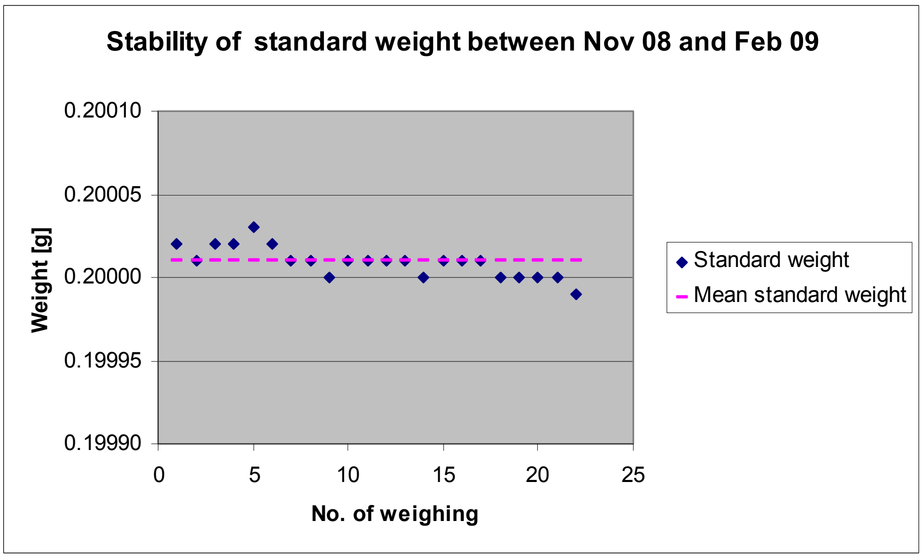


Figure 65:: Stability of standard weight

Table 36: Stability standard weight

Date	Weighing No.	Standard weight	Deviation from prev. weighing
		g	µg
12.11.2008	1	0.20002	
13.11.2008	2	0.20001	-10
10.12.2008	3	0.20002	10
11.12.2008	4	0.20002	0
17.12.2008	5	0.20003	10
18.12.2008	6	0.20002	-10
07.01.2009	7	0.20001	-10
08.01.2009	8	0.20001	0
14.01.2009	9	0.20000	-10
15.01.2009	10	0.20001	10
21.01.2009	11	0.20001	0
22.01.2009	12	0.20001	0
29.01.2009	13	0.20001	0
30.01.2009	14	0.20000	-10
04.02.2008	15	0.20001	10
05.02.2009	16	0.20001	0
11.02.2009	17	0.20001	0
12.02.2009	18	0.20000	-10
18.02.2009	19	0.20000	0
19.02.2009	20	0.20000	0
26.02.2009	21	0.20000	0
27.02.2009	22	0.19999	-10

Highlighted yellow = average value

Highlighted green = lowest value

Highlighted blue = highest value

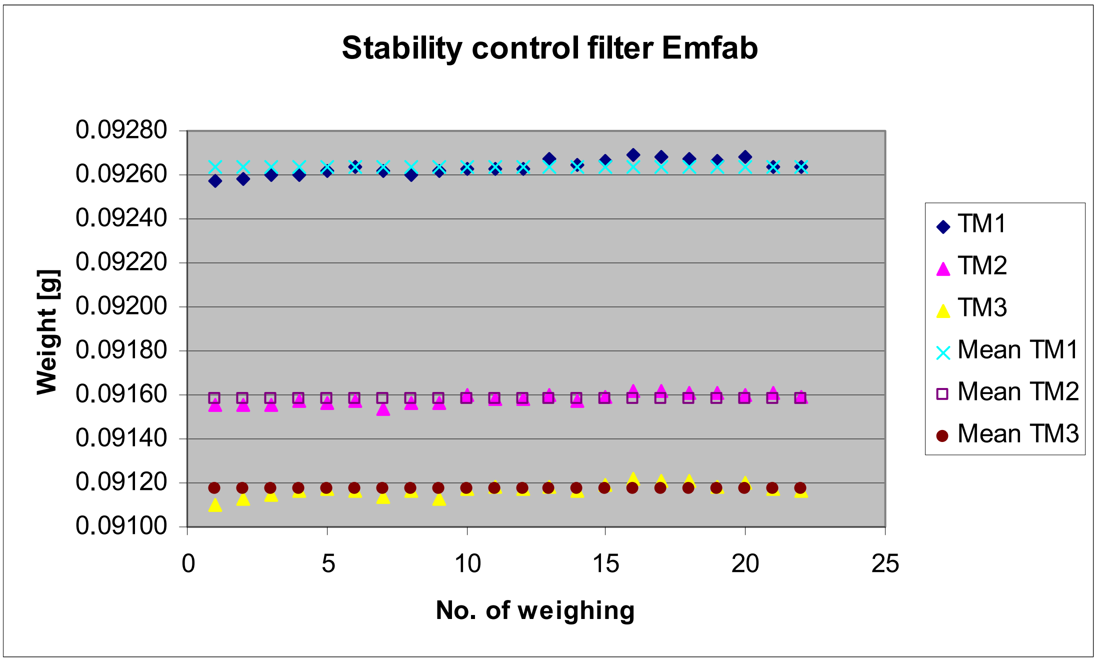


Figure 66:: Stability of the control filters

Table 37: Stability of the control filters

	Control filter No.		
Weighing No.	TM1	TM2	TM3
1	0.09257	0.09155	0.09110
2	0.09258	0.09155	0.09113
3	0.09260	0.09155	0.09115
4	0.09260	0.09157	0.09116
5	0.09262	0.09156	0.09117
6	0.09264	0.09157	0.09116
7	0.09262	0.09154	0.09114
8	0.09260	0.09156	0.09116
9	0.09262	0.09156	0.09113
10	0.09263	0.09160	0.09117
11	0.09263	0.09158	0.09118
12	0.09263	0.09158	0.09117
13	0.09267	0.09160	0.09118
14	0.09265	0.09157	0.09116
15	0.09266	0.09159	0.09119
16	0.09269	0.09162	0.09122
17	0.09268	0.09162	0.09121
18	0.09267	0.09161	0.09121
19	0.09266	0.09161	0.09118
20	0.09268	0.09160	0.09120
21	0.09264	0.09161	0.09117
22	0.09264	0.09159	0.09116
Average	0.09264	0.09158	0.09117
STD.	3.2911E-05	2.4937E-05	2.8558E-05
rel. STD	0.036	0.027	0.031
Median	0.09264	0.09158	0.09117
lowest value	0.09257	0.09154	0.09110
highest value	0.09269	0.09162	0.09122

Highlighted yellow = average value

Highlighted green = lowest value

Highlighted blue = highest value

B) UK site (Teddington)

B.1 Implementation of Weighing Protocols

NPL (National Physical Laboratory) were subcontracted to weigh filters manually for the field study. In line with EN14907 filters were kept in the weighing room for less than 28 days; the glove box used for weighing was maintained at (20 ± 1) °C and (50 ± 5) %; and filters were weighed twice before and after sampling. Table 38 summarises the conditioning and weighing timescales utilised:

Table 38: conditioning and weighing timescales

Pre Sampling	Post Sampling
Condition minimum of 48 hours Weigh Filters Condition 24 hours Weigh Filters	Condition 48 hours Weigh Filters Condition 24 hours Weigh Filters

At the start of each weighing session the balance was exercised to remove mechanical stiffness, and then calibrated. At the start and end of each batch of filters, a 50 and 200 mg check weight were weighed. In line with the recommendations of the UK PM Equivalence Report, filters were weighed relative to a 100 mg check weight, and not a tare filter, as the latter was shown to lose mass over time. Four filters were weighed between check weights, as the balance drift over time had been shown to be small.

The **Check weight Mass (CM)** of the filter was calculated for each weighing session using **E A.1** below:

$$CM = \frac{(m_{check,Beg} + m_{check,End})}{2} \qquad \textbf{E A.1}$$

Where:

$M_{check,bef}$ = Mass of check weight weighed immediately prior to sample filter.

$M_{check,aft}$ = Mass of check weight weighed immediately after sample filter.

The **Relative Mass (RM)** of the filter was calculated for each weighing session using **E A.2** below:

$$RM = m_{filter} - CM \qquad \textbf{E A.2}$$

Where:

m_{filter} = Mass of sample filter

Particulate Mass (PM) is calculated using the following equation in accordance with EN14907.

$$PM = \left(\frac{RM_{End1} + RM_{End2}}{2}\right) - \left(\frac{RM_{Beg1} + RM_{Beg2}}{2}\right) \qquad \textbf{E A.3}$$

Where:

Pre1 denotes weighing session 1 prior to sampling

Pre2 denotes weighing session 2 prior to sampling

Post1 denotes weighing session 1 after sampling

Post2 denotes weighing session 2 after sampling

Pre Spread (S_{Pre}), Post Spread (S_{Post}) and Blank Spread (S_{Blank}) were calculated using the following equations:

$$S_{Pre} = RM_{Anf1} - RM_{Anf2} \quad \textbf{E A.4}$$

$$S_{Post} = RM_{End1} - RM_{End2} \quad \textbf{E A.5}$$

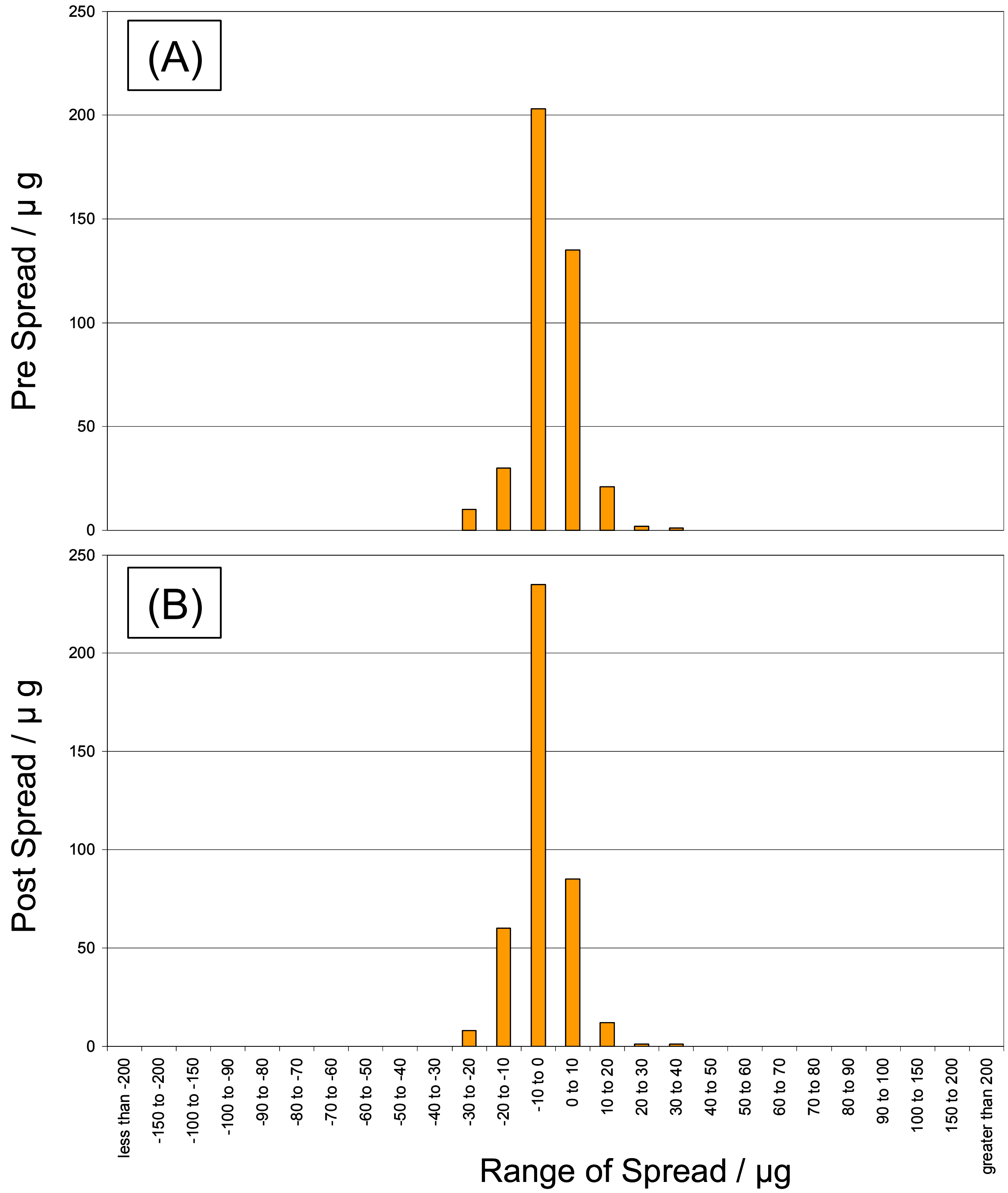
$$S_{Blank} = \left(\frac{CM_{End2} + CM_{End1}}{2}\right) - \left(\frac{CM_{Anf2} + CM_{Anf1}}{2}\right) \quad \textbf{E A.6}$$

As with the UK PM Equivalence Report [11], it was not possible to weigh all filters within the 15 day timeframe suggested in EN14907. However, as filters were removed immediately from the reference samplers and placed in the refrigerator, it was not necessary to determine if $T_{Ambient}$ exceeded 23 ºC. It is felt that as 15 days was impractical for a relatively small scale field study, it is less likely to be attainable if this methodology were adopted by a National or Regional network, and as such, the methodology employed herein is representative of how the reference samplers would be operated in practice.

B.2 Analysis of Protocols Employed

The distributions of pre and post weight for all Emfab filters weighed relative to the tare filter and checkweight are shown in Figure 67. If filters lose relative mass between weightings, then the distribution will be shifted to the right, whereas if there is a gain in the relative mass the distribution will shift to the left. EN14907 states that unsampled filters should be rejected if the difference between the masses of the two pre weightings is greater than 40 µg. Similarly, EN14907 states that sampled filters should be rejected if the difference between the masses of the two post weightings is greater than 60 µg. Filters were not rejected based on these criteria. The observed distributions of repeat mass measurements are considered unlikely to have had a significant effect on the results.

Figure 67: Distribution for Emfab filters of (**A**) Pre spread weighed relative to the checkweight and (**B**) Post spread weighed relative to the checkweight.



Appendix 3

Manual

BAM 1020
PARTICULATE MONITOR
OPERATION MANUAL

BAM-1020-9800 REV G

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Table of Contents

1 INTRODUCTION

1.1 About This Manual

This document is organized with the most important information toward the front of the manual, such as site selection, installation, setups, and field calibrations.

Sections and sub-sections marked with an Information Symbol contain critical information which all BAM-1020 owners and operators should read and understand. Toward the back are sections that provide in-depth information on subjects such as theory, diagnostics, accessories, and alternate settings. These sections provide valuable information which should be consulted as needed. Electronic versions of this manual are also available.

1.2 Technical Service

This manual is structured by customer feedback to provide the required information for setup, operation, testing, maintaining, and troubleshooting your BAM-1020 unit. Should you still require support after consulting your printed documentation, we encourage you to contact one of our expert Technical Service representatives during normal business hours of 7:00 a.m. to 4:00 p.m. Pacific Standard Time, Monday through Friday. In addition, technical information and service bulletins are often posted on our website. Please contact us and obtain a Return Authorization (RA) number before sending any equipment back to the factory. This allows us to track and schedule service work and expedite customer service.

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E-Mail:	service@metone.com	Web:	www.metone.com
Address:	Technical Services Department Met One Instruments, Inc. 1600 NW Washington Blvd. Grants Pass, OR 97526		

1.3 BAM: Beta Attenuation Monitor

The Met One Instruments model BAM-1020 automatically measures and records airborne particulate concentration levels using the principle of beta ray attenuation. This method provides a simple determination of concentration in units of milligrams or micrograms of particulate per cubic meter of air. A small ^{14}C (Carbon 14) element emits a constant source of high-energy electrons known as beta particles. These beta particles are detected and counted by a sensitive scintillation detector. An external pump pulls a measured amount of dust-laden air through a filter tape. After the filter tape is loaded with ambient dust, it is automatically placed between the source and the detector thereby causing an attenuation of the beta particle signal. The degree of attenuation of the beta particle signal is used to determine the mass concentration of particulate matter on the filter tape, and hence the volumetric concentration of particulate matter in ambient air. A complete description of the measurement cycle is included in Section 4. In addition, an in-depth scientific explanation of the theory of operation and the related equations is included toward the back of the manual.

1.4 Beta Radiation Safety Statement

The Met One Instruments BAM-1020 contains a small ^{14}C (Carbon 14) beta radiation-emitting source. The activity of the source is **60 µCi** ±15µCi (microcurries), which is below the "Exempt Concentration Limit" as defined in 10 CFR Section 30.70 – Schedule A. The owner of a BAM-1020 is not required to obtain any license in the United States to own or operate the unit. The owner of a BAM-1020 may elect to return the entire unit to Met One Instruments for recycling of the ^{14}C source when the unit has reached the end of its service life, although the owner is under no obligation to do so. Under no circumstances should anyone but factory technicians attempt to remove or access the beta source. The beta source has a half-life of about 5730 years, and should never need to be replaced. Neither the ^{14}C source nor the beta particle detector are serviceable in the field. Should these components require repair or replacement, the BAM-1020 must be returned to the factory for service and recalibration.

1.5 Model BAM-1020 PM_{10} USEPA Equivalent Method

The Met One Instruments, Inc. Model BAM-1020 is designated as an equivalent method for PM_{10} monitoring by the United States Environmental Protection Agency on August 3, 1998.

Designation Number: **EQPM-0798-122**

The EPA designation applies to G, -1, G-1, and later BAM-1020 PM_{10} Beta Attenuation Monitors, when used in conjunction with the following requirements. Users are advised that configurations that deviate from this specific description may not meet the applicable requirements of 40 CFR Parts 50 and 53.

- The BAM-1020 is operated to obtain a daily average of the hourly measurements, with a filter change frequency of one hour.
- The inlet must be equipped with the standard BX-802 EPA PM_{10} inlet head.
- The unit must be used with standard glass fiber filter tape.
- The unit may be operated with or without any of the following options: BX-823 inlet tube extension, BX-825 heater kit, BX-826 230V heater kit, BX-828 roof tripod, BX-902 exterior enclosure, BX-903 exterior enclosure with temperature control, BX-961 mass flow controller, BX-967 internal calibration device.
- The SAMPLE TIME parameter must be set for 50 minutes.

1.6 Model BAM-1020 $PM_{2.5}$ USEPA Equivalent Method

The Met One Instruments, Inc. Model BAM-1020 Beta Attenuation Mass Monitor - $PM_{2.5}$ FEM Configuration, is designated as an equivalent method for $PM_{2.5}$ monitoring in accordance with 40 CFR Part 53 by the United States Environmental Protection Agency as of March 12, 2008.

Designation Number: **EQPM-0308-170**

All of the following parameters and conditions must be observed when the BAM-1020 is operated as a $PM_{2.5}$ FEM particulate monitor:

- The inlet must be equipped with an EPA-designated $PM_{2.5}$ Very Sharp Cut Cyclone (VSCC™-A by BGI, Inc.). The Met One stock number for the VSCC™ is BX-808.
- The inlet must be equipped with a standard EPA PM_{10} inlet head. Met One BX-802.
- The unit is operated for hourly average measurements. The $PM_{2.5}$ concentration is calculated (external to the BAM) as a daily average of the hourly concentration measurements made by the BAM-1020.
- The unit must be equipped with firmware revision 3.2.4 or later.
- The BAM-1020 must be operated in proper accordance with this operation manual, revision F or later. A supplemental BGI Inc. manual is also supplied with the VSCC™.
- The unit must be equipped with a BX-596 ambient temperature and barometric pressure combination sensor. This is used for flow control and flow statistics.
- The unit must be equipped with the internal BX-961 automatic flow controller, and must be operated in Actual (volumetric) flow control mode.
- The unit must be equipped with a BX-827 (110V) or BX-830 (230V) Smart Inlet Heater, with the heater RH regulation setpoint set to 35%, and Delta-T control disabled.
- The unit must be equipped with the 8470-1 rev D or later tape control transport assembly with close geometry beta source configuration. All BAM-1020 units manufactured after March 2007 have these features standard. Older units will have to be factory upgraded and re-calibrated to the latest specifications.
- The unit must be operated with standard glass fiber filter tape.
- The COUNT TIME parameter must be set for 8 minutes.
- The SAMPLE TIME parameter must be set for 42 minutes.
- The BX-302 zero filter calibration kit is a required accessory. This kit must be used to audit the BKGD (background) value upon unit deployment and periodically thereafter, as described in the BX-302 manual.
- The unit may be operated with or without a BX-823 eight foot inlet tube extension and with or without weatherproof outdoor enclosures BX-902 or BX-903.

1.7 BAM-1020 Specifications

PARAMETER	SPECIFICATION
Measurement Principle:	Particulate Concentration by Beta Attenuation.
US-EPA Existing Designations:	PM_{10}: EPA EQPM-0798-122 $PM_{2.5}$: Class III EPA EQPM-0308-170
Standard Range:	0 - 1.000 mg/m^3 (0 - 1000 μg/m^3)
Optional Ranges:	0 - 0.100, 0.200, 0.250, 0.500, 2.000, 5.000, 10.000 mg/m^3 (special applications)
Accuracy:	Exceeds US-EPA Class III $PM_{2.5}$ FEM standards for additive and multiplicative bias.
Resolution:	± 0.1 μg/m^3
Lower Detection Limit: (2σ) (1 hour)	Less than 4.8 μg/m^3 from 0.000 to 0.100 mg/m^3 (less than 4.0 μg/m^3 typical)
Lower Detection Limit: (2σ) (24 hour)	Less than 1.0 μg/m^3
Measurement Cycle Time:	1 Hour
Flow Rate:	16.7 liters/minute. Adjustable 0-20 LPM range. Actual or Standard flow.
Filter Tape:	Continuous glass fiber filter, 30mm x 21m roll. > 60 days/roll.
Span Check:	Automatic 800ug (typical) span foil verified hourly.
Beta Source:	^{14}C (carbon-14), 60 µCi ±15 µCi (< 2.22 X 10^6 Beq), Half-Life 5730 years.
Beta Detector Type:	Photomultiplier tube with organic plastic scintillator.
Operating Temp. Range:	0 to +50°C
Ambient Temp. Range:	-30° to +60°C
Ambient Humidity Range:	0 to 90% RH, non-condensing.
Humidity Control:	Actively controlled inlet heater module, 10 - 99% RH setpoint.
Approvals:	US-EPA, CE, NRC, TUV, CARB
User Interface:	Menu-driven interface with 8x40 character LCD display and dynamic keypad.
Analog Output:	Isolated 0-1 VDC output standard. 0-10V, 4-20mA, 0-16mA switch-selectable.
Serial Interface:	RS-232 2-way serial port for PC or modem communications.
Printer Output:	Output-only serial port, data or diagnostic output to a PC or serial printer.
Telemetry Inputs:	Clock Reset (voltage or contact closure), Telemeter Fault (contact closure).
Alarm Contact Closures:	Data Error, Tape Fault, Flow Error, Power Failure, Maintenance.
Compatible Software:	MicroMet Plus®, Comet™, HyperTerminal®, ProComm Plus®.
Error Reporting:	User-configurable. Available through serial port, display, and relay outputs.
Memory:	4369 records (182 days @ 1 record/hr).
Power Supply:	100 - 230 VAC, 50/60 Hz.
Weight:	24.5 kg (54 lbs) without external accessories.
Unit Dimensions:	H x W x D = 31cm x 43cm x 40cm (12.25” x 17” x 16”).

*Specifications may be subject to change without notice.

2 SITE SELECTION AND INSTALLATION

2.1 Unpacking and Inspection

If any damage to the shipment is noticed before unpacking, **a claim must be filed with the commercial carrier immediately**. Notify Met One Instruments after notification of the commercial carrier.

Remove the unit and accessories from the shipping boxes and compare the received items to the packing list. Make sure you have all of the required items for the type of installation you plan to perform.

The BAM-1020 is shipped with two white foam rings and a white plastic shim inside the front of the unit, which prevent the moving parts of the tape control assembly from being damaged in transit. Do not remove the foam rings until the BAM-1020 is ready to be installed. These rings must be replaced anytime the unit is being transported in order to avoid damaging the tape control mechanism.

Please keep the special box and foam packing material that the BAM-1020 was shipped in, to re-use in the event that you must return the unit to the factory. Met One is not responsible for any damages to the unit if returned in non-original packaging, or without the foam rings in place. Contact Met One for replacement packing materials if necessary.

2.2 Enclosure Selection

The BAM-1020 unit is not weatherproof or water resistant, and is designed to be mounted in a weatherproof, level, vibration free, dust free, and temperature controlled environment where the operating temperature is between 0^{o} C and $+50^{o}$ C, and where the relative humidity is non-condensing and does not exceed 90%. There are two standard configurations described below for providing a weatherproof location in which to install the unit. Please contact Met One if you plan to have a non-standard mounting or enclosure configuration.

1. **A walk-in building or mobile shelter with a flat roof:** This is often a pre-fabricated shelter, a trailer shelter, or a room in an existing permanent building. The BAM is mounted on a bench-top or in an equipment rack, often with a variety of other instruments installed in the same shelter. The inlet tube of the BAM must extend up through the roof with appropriate hardware. AC power must be available. Instructions for this type of installation are included in this section of the manual.
2. **BX-902/903 environmentally controlled mini enclosure:** Sometimes nicknamed “dog house” enclosures, these small pre-fabricated enclosure are just big enough for the BAM and related accessories, and are installed on the ground or on the roof of a larger building. They are available with a heater (BX-902), or with a heater and air conditioner (BX-903). These enclosures are custom designed by Met One to accept the BAM-1020, and are supplied with a supplemental setup and installation manual.

NOTE: The air temperature inside any enclosure in which a BAM-1020 is installed must be held as constant as possible over the course of the hour. This is important because the unit measures the beta particles through a small gap of air around the filter tape at the beginning and the end of each hour. If the air temperature inside the enclosure has changed by more than about 2 degrees C during this time, the concentration measurement can be affected on the order of several micrograms. Met One recommends logging the air temperature inside the enclosure to monitor this effect. The exact temperature is not critical as long as it fluctuates as little as possible during any one hour.

2.3 Site Selection

Selection of a proper site for the BAM-1020 is critical for accurate measurements. In many cases, these items must be correctly addressed in order for the collected data to be acceptable for regulatory requirements, such as EPA PM_{10} and $PM_{2.5}$ equivalent methods. Specifications for the site selection can be found in EPA document EPA-450/4-87-007 May 1987 "Ambient Monitoring Guidelines for Prevention of Significant Deterioration", as well as 40 CFR, Part 58. In any case, the Code of Federal Regulations takes precedence.

Inlet Height:

- The inlet should be located in the "breathing zone", between 2 and 15 meters above ground level. If the BAM is to be installed in an enclosure at ground level, then the inlet height must two meters or greater above the ground.
- If the inlet is located on (or through) a rooftop, the total height should be no more than 15 meters from the ground level. The inlet height should be two meters above roof surface of the building that the unit is installed in. This matches the specified inlet height of most FRM samplers.
- If the BAM-1020 is to be co-located with other particulate instruments, such as FRM filter-based samplers or other BAM units, then the air inlet must be the same height as the inlet of the other samplers.
- The BX-902 and BX-903 environmental shelters are designed to locate the inlet two meters above whatever surface they are placed on.
- Make sure to account for the height of the PM_{10} and/or $PM_{2.5}$ heads when planning the inlet tube length. Met One can supply a variety of tube lengths up to 8-feet long.
- The maximum allowable total inlet tube length is 16 feet between the BAM-1020 and the bottom of the inlet head.
- If the BAM inlet is the highest point on a building, then lightning rods must be installed to prevent destruction of the BAM during electrical storms.

Inlet Radius Clearance:

- The BAM-1020 inlet must have a one meter radius free of any objects that may influence airflow characteristics, including the inlet of another instrument.
- If a BAM-1020 is to be installed at a station with other BAM or FRM sampler, the inlets of each sampler must be no less than one meter apart from each other.
- If the BAM is to be collocated with another BAM instrument or FRM sampler, then the inlets must be spaced between one and two meters apart. Two meters is recommended where possible.
- If installing near a PM_{10} SSI Hi-Volume sampler, then the distance between the inlet of the BAM-1020 and the Hi-Vol should be no less than three meters.
- The BAM-1020 inlet must be located at least two meters from obstructions such as short walls, fences, and penthouses.
- If located beside a major obstruction (such as a building) then the distance between the unit and the building must be equal to twice the height of the building.

- The inlet must be at least 20 meters from the drip line of any overhanging trees.
- There must be at least a 270 degree arc of unrestricted airflow around the inlet. The predominant direction of concentration movement during the highest concentration season must be included in the 270 degree arc.

Particulate Sources: To avoid possible errors in the concentration measurements, the inlet must be located as far as possible from any artificial sources of particulate, such as blowers, vents, or air conditioners on a rooftop. Especially if any of these types of devices blow air across the inlet of the BAM-1020. Even sources of filtered air must not blow across the inlet.

Spacing from Roadways: The BAM-1020 should usually not be located directly next to a major highway or arterial roadway, as vehicle exhaust will dominate the concentration measurement. This effect can be difficult to predict accurately as shifting winds may direct the plume toward or away from the BAM inlet.

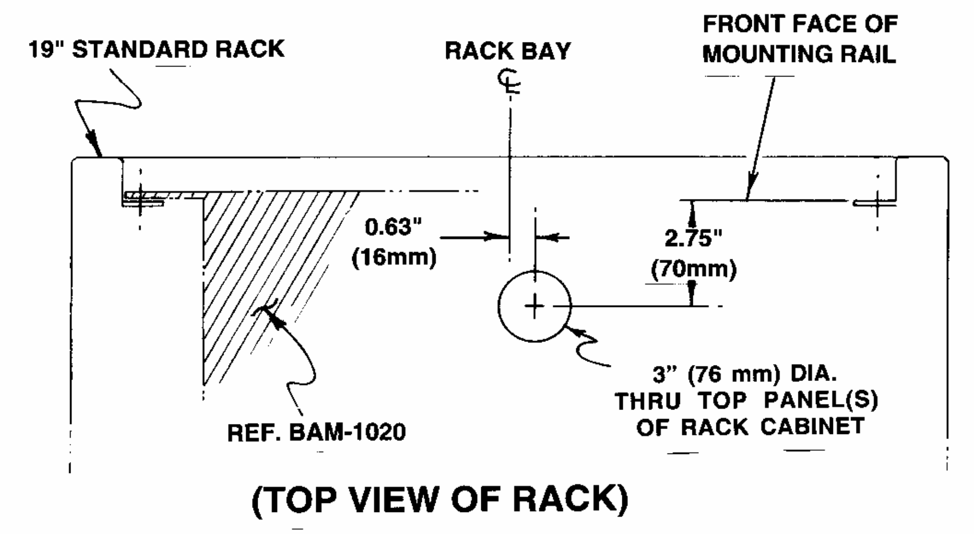
- Roads with a daily traffic volume of less than 3,000 vehicles are generally not considered major sources of pollutants, and in this case the BAM must be located at least five meters from the nearest traffic lane.
- The BAM must be located at least 25 meters from any elevated roadway greater than five meters high.
- The unit should be located as far as possible from unpaved roadways, as these also cause artificial measurements from fugitive dust.
- The unit should not be installed in unpaved areas unless year-round vegetative ground cover is present, to avoid the affects of re-entrained fugitive dust.

2.4 Mounting Options in a Walk-In Shelter

When the BAM-1020 is to be located in a walk-in shelter, the unit will have to be installed either in an equipment rack or on a bench-top. Met One recommends using an equipment rack when possible, as it does a better job of keeping the unit level and in the correct placement. A rack also tends to be a cleaner installation and is more space-efficient. However, either method may be used as long as the mounting is level and allows the inlet tube to be perfectly vertical. Met One supplies brackets standard rack-mount screws with each unit. Take the following into account when planning your mounting:

- **Rear Access:** It is important that your mounting leaves plenty of access to the rear of the BAM-1020 unit for wiring connections and maintenance. At least five inches is required. Full access to the back is recommended whenever possible.
- **Top Access:** It is necessary to have a minimum of eight inches clearance between the top of the BAM inlet receiver and the bottom of the shelter ceiling to accommodate the smart inlet heater which mounts on the inlet tube directly above the BAM.
- **Mobile Shelters:** If the BAM-1020 is being installed into an equipment rack in a mobile shelter or van, the instrument **must** be supported from the bottom in addition to the rack brackets, due to additional strain. The foam shipping rings must also be inserted any time a mobile shelter is moved with the BAM-1020 inside.
- **Rack Modifications:** It is often necessary to modify the top of the equipment rack by cutting a hole to allow the inlet tube to extend through to the ceiling. The drawing below shows the location of the hole. **Note:** The inlet heater is a cylinder which installs

on the inlet tube two inches above the top of the inlet receiver of the BAM-1020. If the BAM unit is to be mounted high in the rack, it may be necessary to make the hole in the top of the rack larger in order to clear the heater diameter. The heater is supplied with an insulation tube cover which may be modified as needed. Make sure these parts are going to fit before installing the BAM-1020.



Rack top modifications for inlet tube clearance

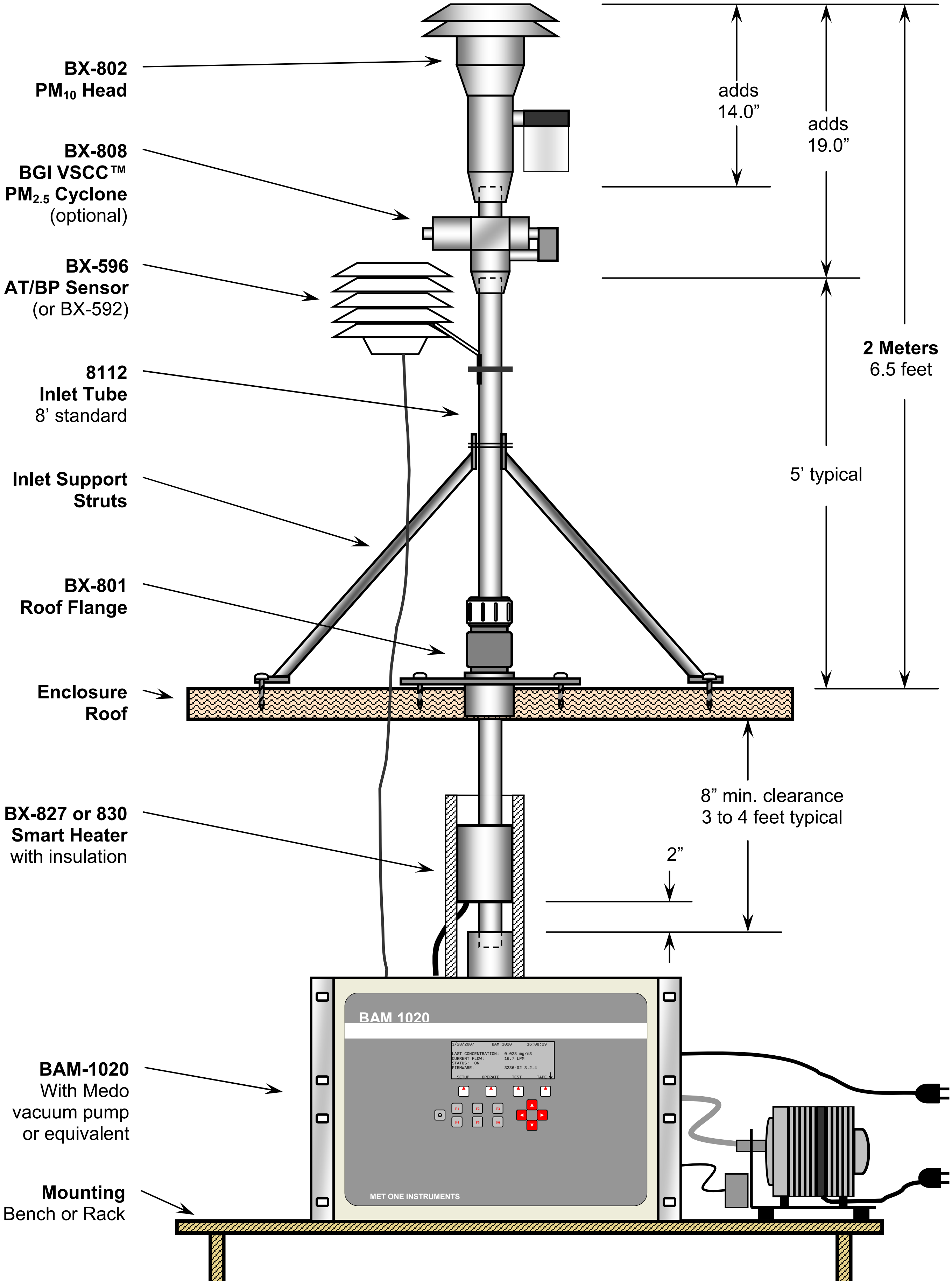
2.5 Installation Instructions in a Walk-In Shelter

Installation of the BAM-1020 should be performed by personnel familiar with environmental monitoring equipment. There are no special precautions or handling concerns except for the normal level of care required for handling scientific equipment. Refer to the diagrams on the following pages.

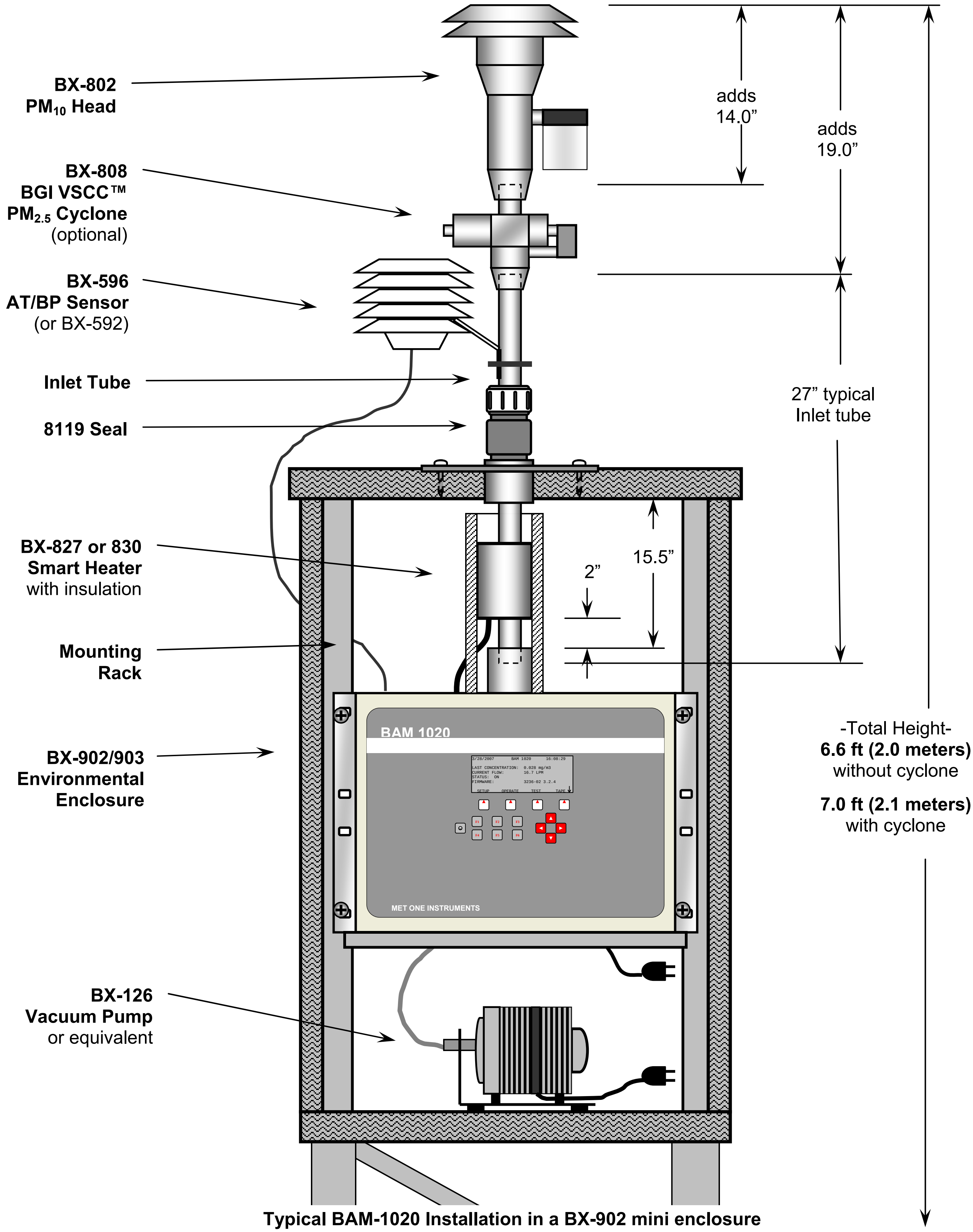
1. **Roof Modifications:** Determine the exact location where the BAM inlet tube will pass through the roof of the enclosure, and drill a 2 ¼" or 2 ½" diameter hole through the roof at that location. Make sure the hole is directly above where the BAM inlet receiver is to be located, as the inlet tube must be perfectly vertical. A plumb-bob is useful for determining where to locate the hole. **Note:** The inlet receiver on the BAM is slightly to the left (0.6 in, 15 mm) of the center line of the unit. See diagrams.
2. **Waterproof Flange:** Apply all-weather caulking around the top of the hole, and install the BX-801 roof flange onto the hole. It is usually best if the threaded barrel of the flange assembly is installed downward, into the hole. Secure the flange in place with four lag bolts or self-tapping screws (not supplied). Caulk around the screws to prevent leaks. Apply Teflon tape to the threads of the gray plastic watertight fitting, and screw it into the roof flange.
3. **Inlet Tube:** Remove the white cap and rubber seal from the flange assembly. This makes it easier to install the inlet tube, as the rubber seal is a tight fit around the tube. Lower the inlet tube through the flange assembly in the roof and into the inlet receiver on the BAM Make sure the inlet tube is fully seated.
4. **Inlet Alignment:** It is very important for the inlet tube to be perpendicular to the top of the BAM. The nozzle may not close properly if there is binding caused by misalignment. A simple check is to rotate the inlet tube back and forth by hand (before

tightening the roof flange seal or the BAM inlet set screws). If the inlet tube is installed straight, then the tube should rotate fairly easily while inserted into the BAM. If it does not rotate, check the inlet tube for vertical alignment or move the BAM slightly.

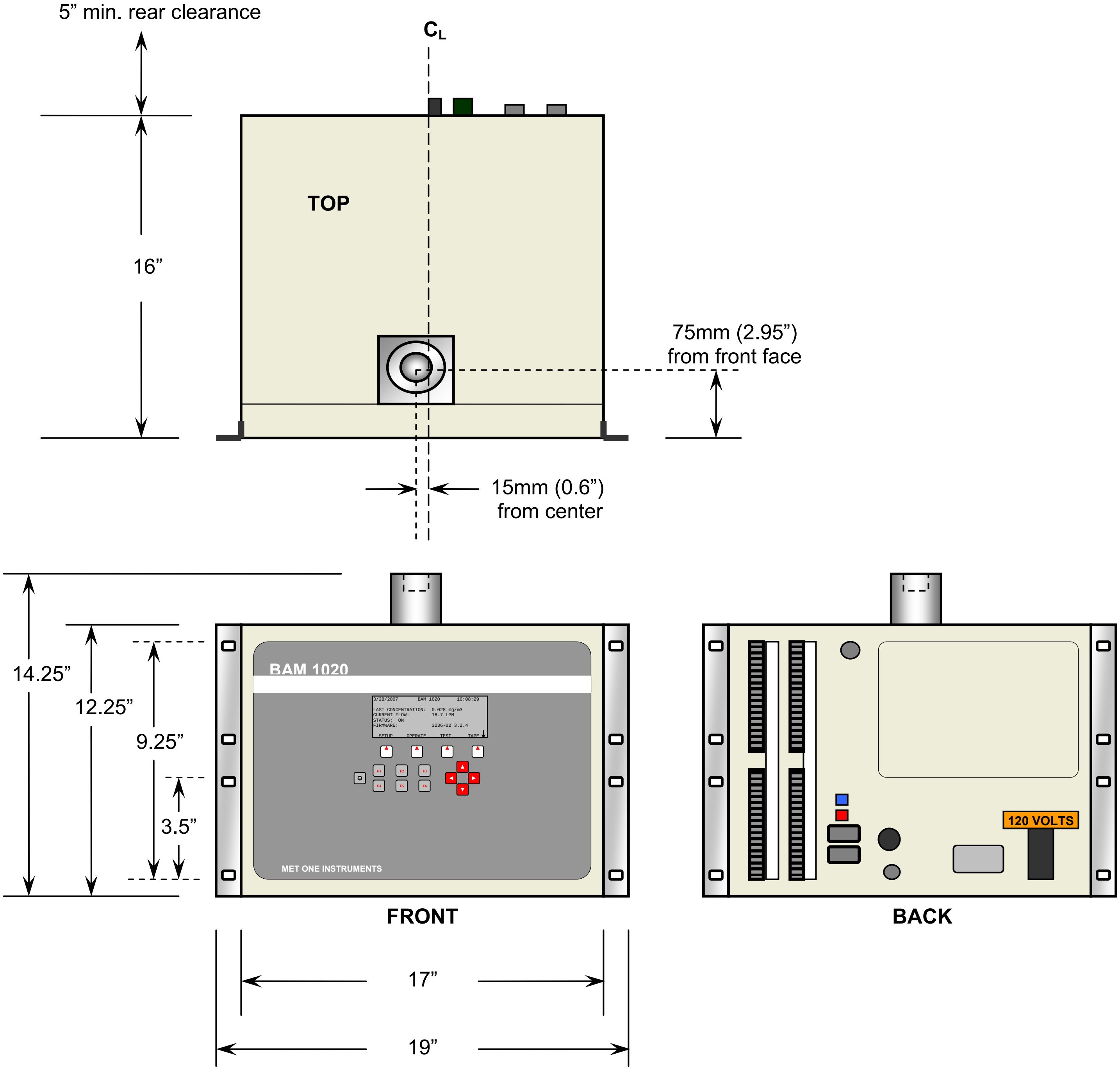
5. **Smart Heater:** Before tightening the inlet tube in place, the BX-827 or BX-830 smart inlet heater (used on most BAM-1020 units) must be installed on the tube. Pull the inlet tube up out of the inlet receiver, and pass the tube through the hole in the heater body (the cable end is the bottom). Then re-insert the inlet tube into the BAM. Position the bottom of the heater unit **two inches** above the top of the inlet receiver on the BAM, and securely tighten the two set screws in the heater to fasten it to the tube. Included with the smart heater is a 12” tube of insulation. The tube is split down its length for easy application. Wrap the insulation around the heater body and peel back the adhesive cover strip to secure in place. The insulation may be cut to fit if needed.
6. **Inlet Tightening:** Slide the black rubber seal and white cap down over the top of the inlet tube and into the roof flange. It is easier if you wet the rubber seal with water or alcohol first. Tighten the white plastic cap.
7. **Support Struts:** The BX-801 inlet kit usually comes with two angled aluminum struts to support the inlet tube above the roof and prevent the inlet from moving in the wind. These struts are typically fastened (about 90 degrees apart) to the inlet tube with a supplied hose clamp. The bottom ends of the struts should be fastened to the roof with lag bolts (not supplied). Note: Some installations may require different methods or hardware for supporting the inlet tube. Support the tube in the best manner available.
8. **Temperature Sensor:** Most BAM-1020 units are supplied with a BX-592 (temperature) or BX-596 (temperature and pressure) sensor, which is attached to the inlet tube above the roof. The sensor cable must feed into the shelter to be attached to the BAM. In some cases it is easiest to simply drill a 3/8” hole through the roof about six inches away from the inlet tube, then feed the cable through the hole and caulk around it to prevent leaks. In some applications there may be a better place to feed the cable into the shelter. Route the cable into the shelter in the best manner. The BX-596 attaches directly to the inlet tube with a supplied U-bolt. If using a BX-592, fasten the aluminum cross-arm to the inlet tube, and clip the temperature probe to the cross-arm.
9. **Inlet Separator Heads:** If the BAM-1020 is to be configured for FEM $PM_{2.5}$ monitoring, then install the $PM_{2.5}$ Very Sharp Cut Cyclone (BGI VSCC™) onto the top of the inlet tube beneath the BX-802 PM_{10} head. For PM_{10} monitoring, the BX-802 is installed on the inlet tube with no cyclone. Use o-ring lubricant as needed.
10. **Inlet Tube Grounding:** Tighten the two ¼”-20 set screws located in the inlet receiver of the BAM to secure the inlet tube. This also creates a ground connection for the inlet tube, as static electricity can build up on the inlet under certain atmospheric conditions and cause errors. This is very important in areas near electromagnetic fields, high voltage power lines, or RF antennas. Check the connection by scraping away a small spot of the clear anodizing near the bottom of the inlet tube, and use a multimeter to measure the resistance between this spot and the “CHASSIS” ground connection on the back of the BAM. It should measure just a couple of Ohms or less if a good connection is made with the set screws. If not, remove the set screws and run a ¼-20 tap through the holes. Then reinstall the screws and check the electrical resistance again. **Note:** Anodized aluminum surfaces are non-conductive.



Typical BAM-1020 Installation in a walk-in shelter



Typical BAM-1020 Installation in a BX-902 mini enclosure



BAM-1020 mounting dimensions

2.6 Electrical Connections

Each BAM-1020 is factory configured to run on either 120 or 230 volt AC power. Your shelter must be wired for power to run the BAM, the pump, and any other AC powered devices such as computers, data loggers, other instruments, etc. A good earth-ground connection point near the BAM unit is highly recommended. Have a qualified electrical contractor provide power according to all local codes. After the BAM unit is installed and power is provided, connect the electrical accessories as follows. Refer to the diagram below.

1. **BAM-1020 Power:** Plug the BAM-1020 into the AC power mains with the provided power cord. Note: There are two fuses located inside the BAM power switch module, which can be accessed by prying open the small cover surrounding the switch. The power cord must be removed in order to open the cover.

   Met One recommends plugging the BAM-1020 unit into a battery back-up UPS (uninterruptible power supply) since even a momentary power outage will reset the BAM and stop an entire hour's worth of data collection. A small computer-style UPS of 300 Watts or greater is usually sufficient. The vacuum pump usually does not need to be connected to the UPS as the BAM can compensate for short pump power outages. If the pump is to be backed up as well, then a much larger UPS is required.
2. **Chassis Ground:** Connect one of the terminals marked "CHASSIS" on the back of the BAM to a ground point as close as possible to the instrument. Use the green/yellow ground wire supplied with the unit. A ground rod is recommended, but a cold water pipe, or junction box safety ground are other possible connection points. Note: the BAM-1020 also uses the standard safety ground line inside the power cord.
3. **Pump Connection:** Decide on a location to place the air pump. The best location is often on the floor under the rack or bench, but it may be up to 25 feet away if desired. Route the air tubing from the pump to the back of the BAM unit, inserting it firmly into the compression fittings on both ends. The tubing should be cut to the proper length and the excess saved for replacements. The pump is supplied with a 2-wire signal cable which the BAM uses to turn the pump on and off. Connect this cable to the terminals on the back of the BAM marked "PUMP CONTROL" The end of the cable with the square black ferrite filter goes to the BAM, but the polarity of the wires is not important. Either the red or black wire can go to either terminal. Connect the other end of the cable to the two terminals on the pump.
4. **Temperature/Pressure Sensor:** The BX-596 or BX-592 temperature sensor should already be installed onto the inlet tube, and the sensor cable routed to the BAM-1020. Connect the cable to the terminals on the back of the BAM as follows:

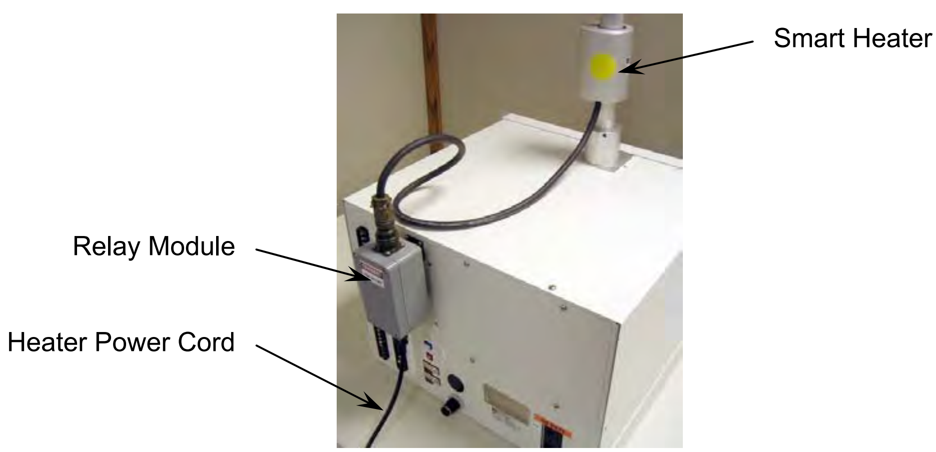
BX-596 AT/BP Sensor	
Wire Color	**Terminal Name**
Yellow	Channel 6 SIG
Black/Shield	Channel 6 COM
Red	Channel 6 POWER
Green	Channel 6 ID
White	Channel 7 SIG

BX-592 AT Sensor	
Wire Color	**Terminal Name**
Yellow or White	Channel 6 SIG
Black/Shield	Channel 6 COM
Red	Channel 6 POWER
Green	Channel 6 ID

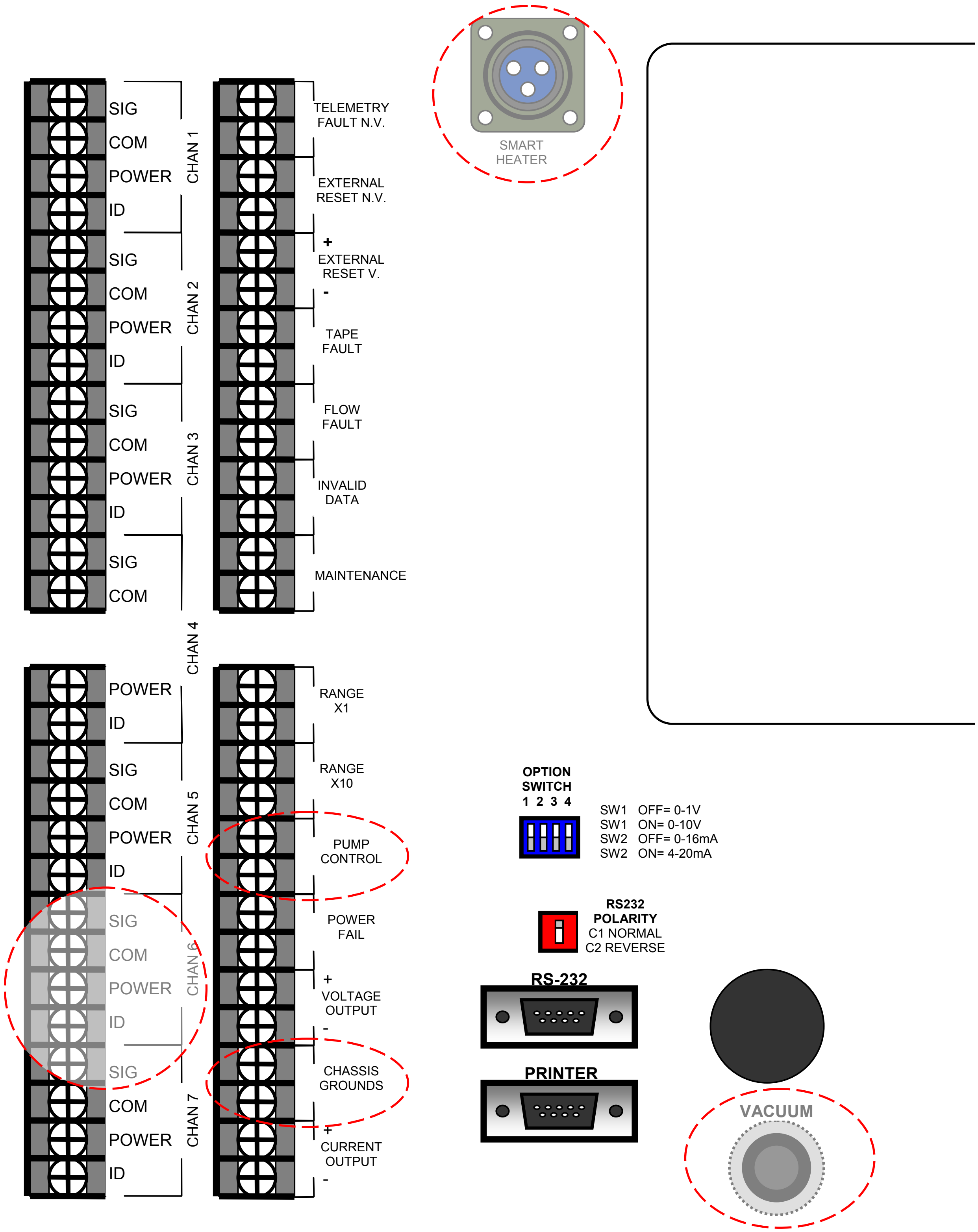
Additional Met One BX-500 series sensors may be connected to BAM channels 1 through 5 to log various other meteorological parameters. Details on these sensor connections are given in Section 10.2 of this manual.

5. **Smart Heater:** There are two possible versions of the BX-827/830 Smart Heater electrical connection. If the Smart Heater kit was supplied with a gray relay module (units built after May, 2008 as shown below), then plug the relay module into the mating control connector on the back of the BAM, and connect the Smart Heater to the green connector on the top of the relay module. The relay module has its own power cord to supply power to the heater. **Note:** The connector on the back of the BAM has been changed to prevent connecting the heater directly to the BAM.

   On previous versions of the kit, the Smart Heater assembly simply plugs directly into the back of the BAM-1020, and power is supplied internally by the BAM. If the BAM is configured like this, then simply plug the heater cable directly into the mating green metal connector on the back of the BAM-1020.



6. **Optional Data Logger Connection:** The BAM-1020 has an analog output which may be recorded by a separate data logger if required. Connect the terminals on the back of the BAM marked ”VOLT OUT +, -“ to the data logger with 2-conductor shielded cable (not supplied). Polarity must be observed. Information on configuring this analog output is provided in Section 8 of this manual. A current loop output is also available.
7. **Other Connections:** The BAM-1020 has a variety of telemetry I/O relays and error relays located on the back of the unit. There are also RS-232 data connections. These items are described in Section 8 and Section 9 of this manual.



BAM-1020 back panel connections

3 INITIAL SETUP OF YOUR BAM-1020

This section describes the process for setting up and configuring your BAM-1020, as well as the basic steps required to put the unit into operation. Some of the topics in this section will direct you to other sections of this manual for more detailed information. It is assumed that the unit is already installed and sited as described in Section 2. In some cases it is useful to first set up the BAM-1020 unit on a test bench before deployment or installation in order to explore the functions of the unit and perform setups. The following steps for starting up your unit are described in this section:

1. **Power on and warm up the unit.**
2. **Familiarize yourself with the user interface.**
3. **Load a roll of filter tape.**
4. **Perform a Self-Test.**
5. **Set the real-time clock, and review your SETUP parameters.**
6. **Perform a leak check and a flow check.**
7. **Return to the top-level menu and wait for automatic start at the top of the hour.**
8. **View the OPERATE menus during the cycle.**

3.1 Power On

The BAM-1020 has a power switch located on the back of the unit directly above the power cord. Verify that the unit is plugged in to the correct AC voltage, and that any electrical accessories are correctly wired before turn the unit on. (Section 2.6) When power is switched on the main menu screen should appear after a few seconds as shown below. The unit will probably flash an error indicating that there is no filter tape installed. Note: Units running revision 3.1 or earlier firmware will display a slightly different main menu screen.

```
3/28/2007       BAM 1020      16:08:29

LAST CONCENTRATION:  0.028 mg/m3
CURRENT FLOW:        16.7 LPM
STATUS:  FILTER TAPE ERROR!
FIRMWARE:            3236-02 3.2.4

  SETUP     OPERATE     TEST      TAPE
```

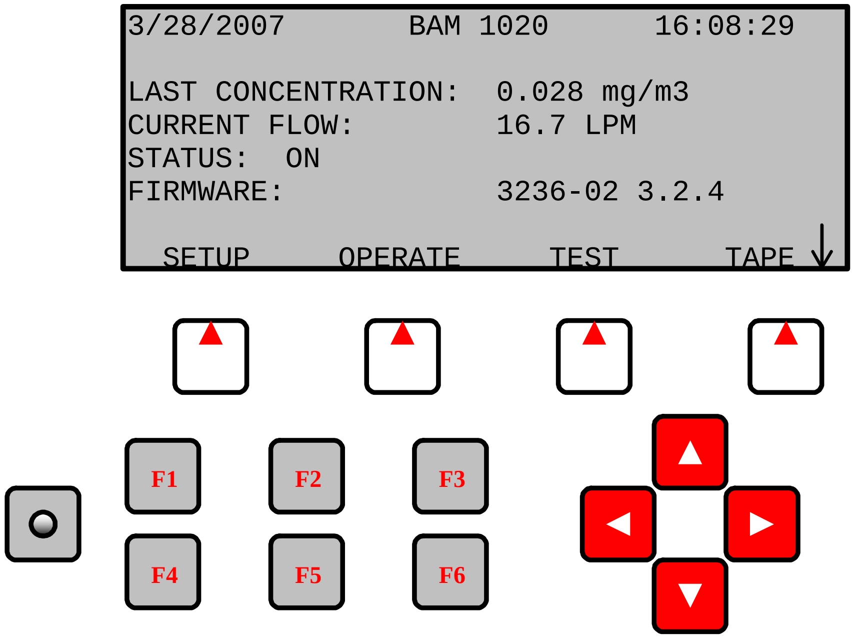
The Main Menu Screen

3.2 Warm-up

The BAM-1020 must warm up for **at least one hour** before an operation cycle is started. This is because the beta detector contains a vacuum tube which must stabilize every time the unit is powered up. This also allows the electronics to stabilize for optimal operation. This applies any time the unit is powered up after being off for more than a moment. Instrument setups and filter tape installation can be performed during this warm up time. Most agencies choose to discard the first few hours of concentration data after the BAM is powered up.

3.3 *Using the Keypad and Display*

When the BAM-1020 is powered up it will display the main (top level) menu on the LCD display. This menu is the starting point for all functions of the BAM-1020 user interface.



The BAM-1020 User Interface

Soft Keys:
Directly beneath the display are four white buttons called “soft-keys” or “hot-keys”. These are dynamic keys who’s function changes in response to a menu option displayed directly above each key on the bottom row of the display. Whatever menu option is displayed above one of these keys is the function which that key will perform in that particular menu. These are used throughout the entire menu system for a wide variety of functions. For example, modifications made within a menu are usually not saved unless a SAVE soft-key is pressed. EXIT is also another common soft-key function.

Arrow (Cursor) Keys:
The four red arrow keys are used to scroll up, down, left, and right to navigate in the menu system, and to select items or change fields on the screen. The arrow keys are also often used to change parameters or increment/decrement values in the menu system.

Contrast Key:
The key with a circular symbol on it is for adjusting the light/dark contrast on the LCD display. Press and hold the key until the desired contrast is achieved. It is possible to overadjust the contrast and make the entire display completely blank or completely dark, so be careful to set it to a visible level or it may appear that the unit is not operating.

Function Keys F1 to F6:
The function keys serve as shortcuts to commonly used menu screens, and can be safely pressed at almost any time without interrupting the sample cycle. The **F** keys are only functional from the main menu screen or for entering passwords. The factory default password is F1, F2, F3, F4.

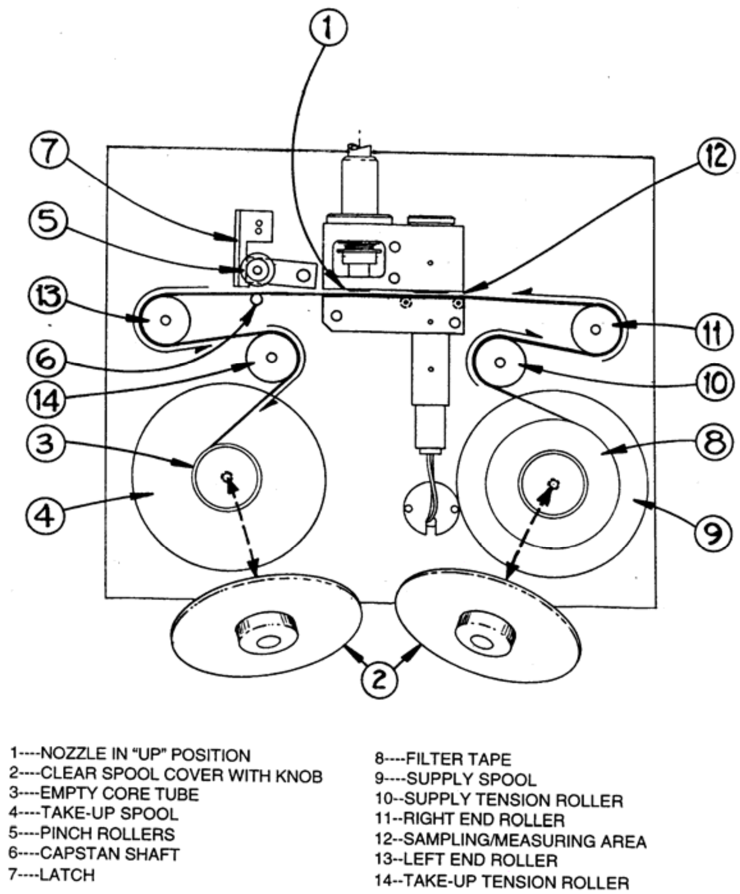
F1 Current: This key is a shortcut to the OPERATE > INST screen, used to display the instantaneous data values that are being measured by the BAM-1020. See section 3.12. The F1 key can be used without interrupting a sample cycle.
F2 Average: This key is a shortcut to the OPERATE > AVERAGE screen, used to display the latest average of the data recorded by the BAM-1020. See Section 3.13. The F2 key can be used without interrupting a sample cycle.
F3 Error Recall: This key allows the user to view the errors logged by the BAM-1020. The errors are sorted by date. The last 12 days which contain error records are available, and up to the last 100 errors can be viewed. The F3 key can be used without interrupting a sample cycle.
F4 Data Recall: This key allows the user to view the data stored in the BAM-1020, including concentrations, flow, and all six external channels. The data is sorted by date, and the user can scroll through the data hour-by-hour using the soft-keys. Only the last 12 days which contain data records are available in this menu. The F4 key can be used without interrupting a sample cycle.
F5 Transfer Module: This key is used to copy the memory contents to an optional transfer storage module to retrieve the digital data without a computer. This function is rarely used. Met One recommends downloading the data with a laptop, computer or modem connection.
F6 (Blank): This key is not assigned a data function.

3.4 Filter Tape Loading

A roll of filter tape must be loaded into the BAM-1020 for sampling. One roll of tape should last more than 60 days under normal operation. It is important to have several spare rolls of tape available to avoid data interruptions. Met One recommends wearing lint-free cotton gloves when handling the tape. Some agencies save the used rolls of tape for post-sampling analysis, although there is no guarantee that the sampled spots have not been contaminated. Used filter tape should never be "flipped over" or re-used! This will result in measurement problems. Loading a roll of filter tape is a simple matter using the following steps:

1. Turn the BAM-1020 on and enter the TAPE menu (Note: This is not the same as the TEST > TAPE menu). If the nozzle is not in the UP position, press the TENSION soft-key to raise the nozzle.
2. Lift the rubber pinch roller assembly and latch it in the UP position. Unscrew and remove the clear plastic spool covers.
3. An empty core tube **MUST** be installed on the left (take-up) reel hub. This provides a surface for the used tape to spool-up on. Met One supplies a plastic core tube to use with the first roll of tape. After that, you can use the empty core tube left over from your last roll to spool-up the new roll. Never fasten the filter tape to the aluminum hub.
4. Load the new roll of filter tape onto the right (supply) reel, and route the tape through the transport assembly as shown in the drawing. Attach the loose end of the filter tape to the empty core tube with cellophane tape or equivalent.
5. Rotate the tape roll by hand to remove excess slack, then install the clear plastic spool covers. The covers will clamp the rolls to the hubs to prevent slipping.
6. Align the filter tape so that it is centered on all of the rollers. Newer units have score marks on the rollers to aide in visually centering the tape.

7. Unlatch and lower the pinch roller assembly onto the tape. **The BAM will not function if the pinch rollers are latched up, and it has no way of automatically lowering the roller assembly!**
8. Press the TENSION soft-key in the TAPE menu. The BAM-1020 will set the tape to the correct tension and alert you if there was an error with the process. Exit the menu.



Filter Tape Loading Diagram

3.5 Self-Test

The BAM-1020 has a built-in self-test function which automatically tests most of the tape control and flow systems of the unit. The self-test should be run right after each time the filter tape is changed, and it can also be used if the operator suspects a problem with the unit. More detailed diagnostic menus are also available in the BAM, and those are described in the troubleshooting section.

The self-test feature is located in the TAPE menu. Press the SELF TEST soft-key to start the test. The tests will take a couple of minutes, and the BAM-1020 will display the results of each tested item with an **OK** or a **FAIL** tag. If all of the test items are OK, the status will show SELF TEST PASSED as shown in the drawing below. If any item fails, the status will show ERROR OCCURRED.

```
02/08/1999          15:29:30
LATCH: OFF          TAPE BREAK: OK
CAPSTAN: OK         TAPE TENSION: OK
NOZZLE DN: OK       SHUTTLE: OK
NOZZLE UP: OK       REF EXTEND: OK
FLOW: OK            REF WITHDRAW: OK
Status:   SELF TEST PASSED
TENSION   SELF TEST               EXIT
```

Self-Test Status Screen

LATCH: This will show OFF if the photo interrupter senses that the pinch rollers are unlatched as in normal operation. It will show ON if the roller assembly is latched in the up position. The tape cannot move if the rollers are up!
CAPSTAN: The unit will rotate the capstan shaft forward and backwards and will check if the photo interrupter sees the shaft rotating. The Capstan shaft is what moves the filter tape back and forth.
NOZZLE DN: The unit will attempt to lower the nozzle, and will check if the nozzle motor has moved to the down position with a photo interrupter. It is possible for the nozzle to become stuck in the UP position, even if the nozzle motor has successfully moved to the DOWN position. For this reason, proper inlet alignment and maintenance is necessary.
NOZZLE UP: The unit will attempt to raise the nozzle, and will check if the nozzle motor has moved to the up position with a photo interrupter.
FLOW: The unit will attempt to turn the pump on, and will then look for output on the flow sensor. This test takes about a minute and will fail if the pump is not connected.
TAPE BREAK: The unit will move the supply and take-up motors to create slack in the filter tape, and look for proper operation of the tensioner photo interrupters.
TAPE TENSION: The unit will tension the filter tape, and then check the condition of the tensioner photo interrupters.
SHUTTLE: The unit will attempt to move the shuttle beam left and right, and will check the motion with a photo interrupter.
REF EXTEND: The unit will attempt to extend the reference membrane, and will check the motion with a photo interrupter.
REF WITHDRAW: The unit will attempt to withdraw the reference membrane, and will check the motion with a photo interrupter.

3.6 Initial SETUP Settings Considerations

The BAM-1020 comes pre-programmed with a wide array of default values for the settings which govern the measurement and calibration. Many of these values will not be changed, as the default values are accurate for the majority of applications. You will need to review the Setup Menus in Section 6 of this manual and decide if any values need to be changed. At the very least, review the following parameters:

1. Set the system clock in the SETUP > CLOCK menu. The BAM-1020 clock may drift as much as a couple of minutes per month. It is important to check the clock at least once per month to ensure the samples are performed at the correct times.
2. Review the BAM SAMPLE, COUNT TIME, MET SAMPLE, RANGE, and OFFSET values in the SETUP > SAMPLE menu.

3. Review the FLOW RATE, FLOW TYPE, CONC TYPE, and HEATER CONTROL settings in the SETUP > CALIBRATE menu.
4. Review the scaling of any external sensors in the SETUP > SENSORS menu.
5. Review the Smart Heater control settings in the SETUP > HEATER menu.

3.7 Initial Leak Check and Flow Check

Perform a leak check and flow check/calibration as described in Section 5. Become comfortable with these processes, as they will be performed often.

3.8 Starting a Measurement Cycle

When the preceding steps of Section 3 have been completed, exit out to the main top level menu. The "Status" line should display "ON" (no errors). If so, the unit will start at the top (beginning) of the next hour, and will continuously operate until it is commanded to stop. The unit will stop if the operator sets the Operation Mode to OFF or enters any of the SETUP or TEST menus. The BAM-1020 will also stop itself if a non-correctable error is encountered, such as broken filter tape or failed air flow.

3.9 The Flow Statistics Screen

In the main BAM-1020 menu screen a small arrow has been added to the bottom right corner. When the DOWN ARROW button is pressed the BAM will display the FLOW STATISTICS screen as shown below. This screen displays the flow, temperature and pressure statistics for the current measurement cycle. Pressing the ARROW DOWN key while in this screen will further scroll down to the remaining parameters below the viewable area of the display. This screen will not interrupt the sample. This function is only available with revision 3.2 firmware or later.

```
03/28/2007   FLOW STATISTICS    16:26:30
 SAMPLE START: 2007/03/28 16:08:30
      ELAPSED: 00:18:00
    FLOW RATE: 16.7 LPM
 AVERAGE FLOW: 16.7 LPM
      FLOW CV: 0.2%
↓      VOLUME: 0.834m3
                                 EXIT
    FLOW FLAG: OFF
           AT: 23.0
       MAX AT: 23.5
   AVERAGE AT: 23.0
       MIN AT: 22.5
           BP: 760
       MAX BP: 765
   AVERAGE BP: 760
       MIN BP: 755
```

The FLOW STATISTICS Screen

3.10 The OPERATE Screen

Press OPERATE soft-key at the main menu to enter operate menu as shown below. This will not interrupt the sample if already running.

```
11/15/2006   OPERATE MODE       14:13:07

       ↑ = ON
       ↓ = OFF
Operation Mode: ON
        Status: ON

  NORMAL     INST    AVERAGE     EXIT
```

The OPERATE Menu

The DOWN arrow can be used to set the Operation Mode from ON to OFF. This will stop the measurement cycle, but will not power-down the BAM-1020. **NOTE: If the operator sets the Operation Mode to OFF, or the unit stops itself due to an error, it will still automatically set the mode back to ON at the top of the hour, and try to run a new cycle!** The only ways to prevent the unit from automatically starting a cycle are to power off the unit, leave the unit in a TEST or SETUP menu, or leave the pinch rollers latched in the UP position.

The OPERATE menu has three soft-key options for viewing the operating status and sensor measurements while the unit is operating: NORMAL, INST, and AVERAGE.

3.11 The NORMAL Screen

Normal Mode is the primary operation screen which displays most of the important parameters of the sample progress in one place, as shown below. Many operators leave their BAM-1020 in the NORMAL screen whenever the unit is operating, instead of the Main menu.

```
11/15/2006         Normal Mode      11:27:54
                            Flow(STD): 16.7 LPM
                         Flow(ACTUAL): 16.7 LPM
LAST C: 0.061 mg/m3            Press: 764 mmHg
LAST m: 0.806 mg/cm2              RH: 37 %
                              Heater: OFF
                             Delta-T: 4.2 C
STATUS: SAMPLING                        EXIT
```

The NORMAL Menu

The **LAST C** value indicates the last concentration record, updated at the end of the cycle. The **LAST m** value indicates the last measured value of the reference span membrane. The value should be very close or equal to the expected value (**ABS**). The other values are instantaneous measurements.

3.12 The INSTANTANEOUS Screen

The INST (Instantaneous) screen displays the instantaneous data values that are being measured by the BAM-1020. This screen is useful for monitoring the current reading of any optional sensors that may be connected to the BAM-1020. All values except **Conc** (concentration) and **Qtot** (total flow volume) are current. The Conc represents the concentration of the last period. Qtot represents total flow volume during the last period.

```
11/15/2006  CAL DATA FLAG: OFF   11:27:54
          Eng Units            Eng Units
1 Conc    0.010 mg  2 Qtot    .834 m3
3 WS      0.000     4 WD      0.000
5 BP      0.000     6 RH      0.000
7 SR      0.000     8 AT      0.000

          TOGGLE FLG VOLT/ENG    EXIT
```

The Instantaneous Menu

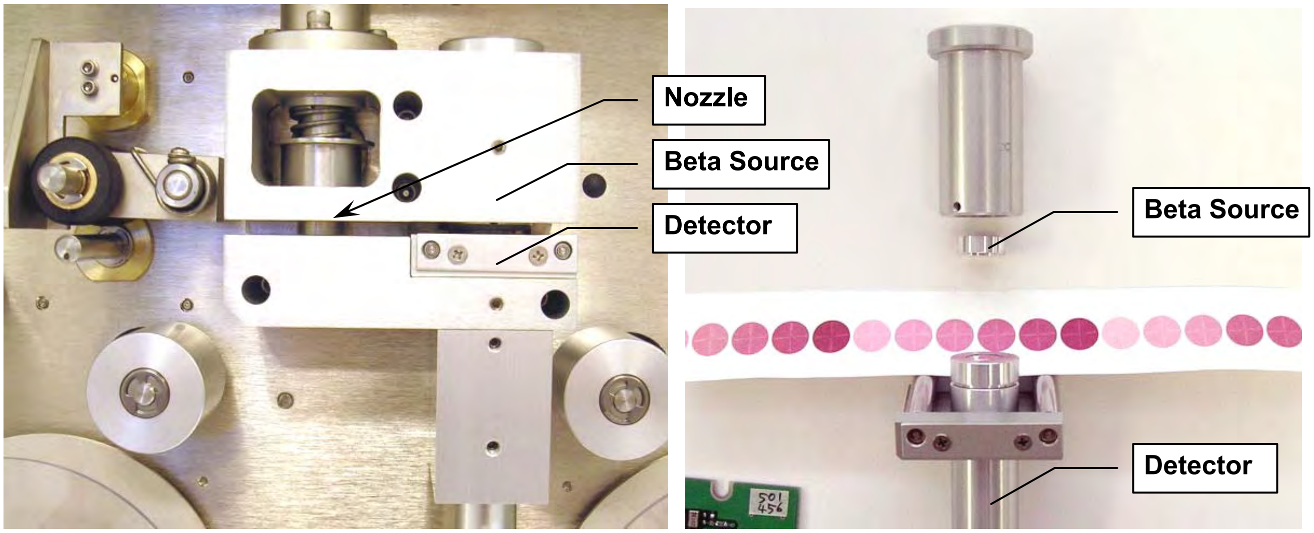
The TOGGLE FLG soft-key in this menu allows the user to set the CAL DATA FLAG value ON or OFF, which marks the data with an **M** flag to indicate a maintenance was performed during that time, such as a flow check. This feature is rarely used, as most maintenance requires stopping the sample anyway. The VOLT / ENG soft-key toggles the displayed values between units and voltages, useful for diagnostic checks on external sensors.

3.13 The AVERAGE Screen

The AVERAGE screen is similar to the INST screen, except that the concentration and flow are presented as the previous hour’s average values, and the six external datalogger channels are average values over the average period of the data logger (set by the MET SAMPLE value in the SETUP > SAMPLE menu - usually also 60 minutes).

4 THE MEASUREMENT CYCLE

This section describes the measurement and timing cycle of the BAM-1020 instrument. A clear understanding of the measurement is helpful for the effective operation and maintenance of the unit. For advanced information on the underlying theory and mathematics of the measurement see Theory of Operation, Section 11.



BAM-1020 Sample and Measurement Stations

4.1 The One-Hour Cycle Timeline

The BAM-1020 is almost always configured to operate on 1-hour cycles. The unit has a real-time clock which controls the cycle timing. You will see from the following timeline that the unit makes two 8-minute beta measurements, and one 42-minute air sample, for a total of 58 minutes. The other two minutes are used for tape and nozzle movements during the cycle.

This example shows the timeline if the unit is set for a COUNT TIME of 8 minutes (required for $PM_{2.5}$). If the unit is set for 4 minutes, then the beta counts at the beginning and end of the hour will be only 4 minutes long, with a 50-minute air sample in between. Again, the total adds up to 58 minutes. **Note:** This cycle will be slightly altered if the unit is operated in the special Early Cycle mode with an external datalogger. See Section 8.

1. **Minute 00:** The beginning of an hour. The BAM-1020 immediately advances the filter tape forward one “window” (the next fresh, unused spot on the tape). This takes a few seconds. The new spot is positioned between the beta source and the detector, and the BAM begins counting beta particles through this clean spot for exactly eight minutes. (I_0)
2. **Minute 08:** The BAM-1020 stops counting beta particles through the clean spot (I_0), and moves the tape exactly four windows forward, positioning that same spot directly under the nozzle. This takes a few seconds. The unit then lowers the nozzle onto the filter tape and turns the vacuum pump on, pulling particulate-laden air through the filter tape (the spot in which I_0 was just measured) for 42 minutes at 16.7 liters per minute.
3. **Minute 50:** The BAM-1020 turns the vacuum pump off, raises the nozzle, and moves the filter tape backwards exactly four windows. This takes a few seconds, and puts the spot that was just loaded with particulate back between the beta source and the

detector. The BAM begins counting beta particles through this (now dirty) spot of tape for exactly eight minutes (I_3).

4. **Minute 58:** The BAM-1020 stops counting beta particles through the dirty spot (I_3). The unit uses the I_0 and I_3 counts to calculate the mass of the deposited particulate on the spot, and uses the total volume of air sampled to calculate the concentration of the particulate in milligrams or micrograms per cubic meter of air. The BAM then sits idle and waits a few moments for the remaining time in the hour to expire.
5. **Minute 60:** The beginning of the next hour. The BAM-1020 instantly records the just-calculated concentration value to memory and sets the analog output voltage to represent the previous hour's concentration. The unit advances a new fresh spot of tape to the beta measurement area and the whole cycle starts over…

4.2 Automatic Span Check During The Cycle

While the vacuum pump is on and pulling air through the filter tape, (as described above) the BAM-1020 doesn't have anything else to do, so it performs an automatic check of its calibration (a span check), and checks for instrument drift caused by varying external parameters such as temperature, barometric pressure, and relative humidity. No span corrections are made. This check is performed every hour automatically as follows:

1. **Minute 08:** (When the BAM-1020 has just finished moving the clean spot to the nozzle and turned the pump on) there is another clean spot of filter tape upstream four windows, between the beta source and the detector. This same spot will stay there for the entire time the pump is on (usually 42 minutes), as the tape cannot move with the nozzle down. The BAM begins counting the beta particles through this spot for exactly eight minutes (I_1).
2. **Minute 16:** The BAM-1020 stops counting beta particles through this spot (I_1), and extends the Reference Membrane between the beta source and the detector, directly above the spot of filter tape that was just measured. The Reference Membrane is an extremely thin film of clear Mylar held in a metal tongue. The membrane usually has a mass of about .800 mg. The BAM starts counting beta particles for eight minutes again, this time through the membrane *and* the filter tape spot at the same time (I_2).
3. **Minute 24:** The BAM-1020 stops counting beta particles through the membrane (I_2), withdraws the membrane assembly, and calculates the mass of the membrane **"m"**, as if it were particulate on the filter tape spot.
4. **Minute 42 (typical):** (Eight minutes before the pump stops) The BAM-1020 counts the beta particles through the same spot again (without membrane) for another eight minutes (called $I_{1'}$ or I_1 prime). This checks the ability of the unit to hold a constant output when measuring blank filter tape, and is not otherwise used.

The mass density ***"m"*** (mg/cm^2) of the reference membrane calculated during this automatic process is compared to the known mass of the membrane; the ***"ABS"*** value. During factory calibration, the actual mass of each individual span foil is determined and saved as the ***ABS*** value of the BAM in which it is installed. Each hourly measurement of ***m*** must match the ***ABS*** value within ±5%. If not, the unit records an error for that hour's data. Typically, the hourly value of ***m*** is within just a few micrograms of the expected value. This span check provides a method of internal diagnostics for the measurement system, and for the monitoring of external variables such as temperature variations or pressure changes. The ***ABS*** value is unique to each BAM-1020, and can be found on the calibration sheet.

4.3 Sample Period Description

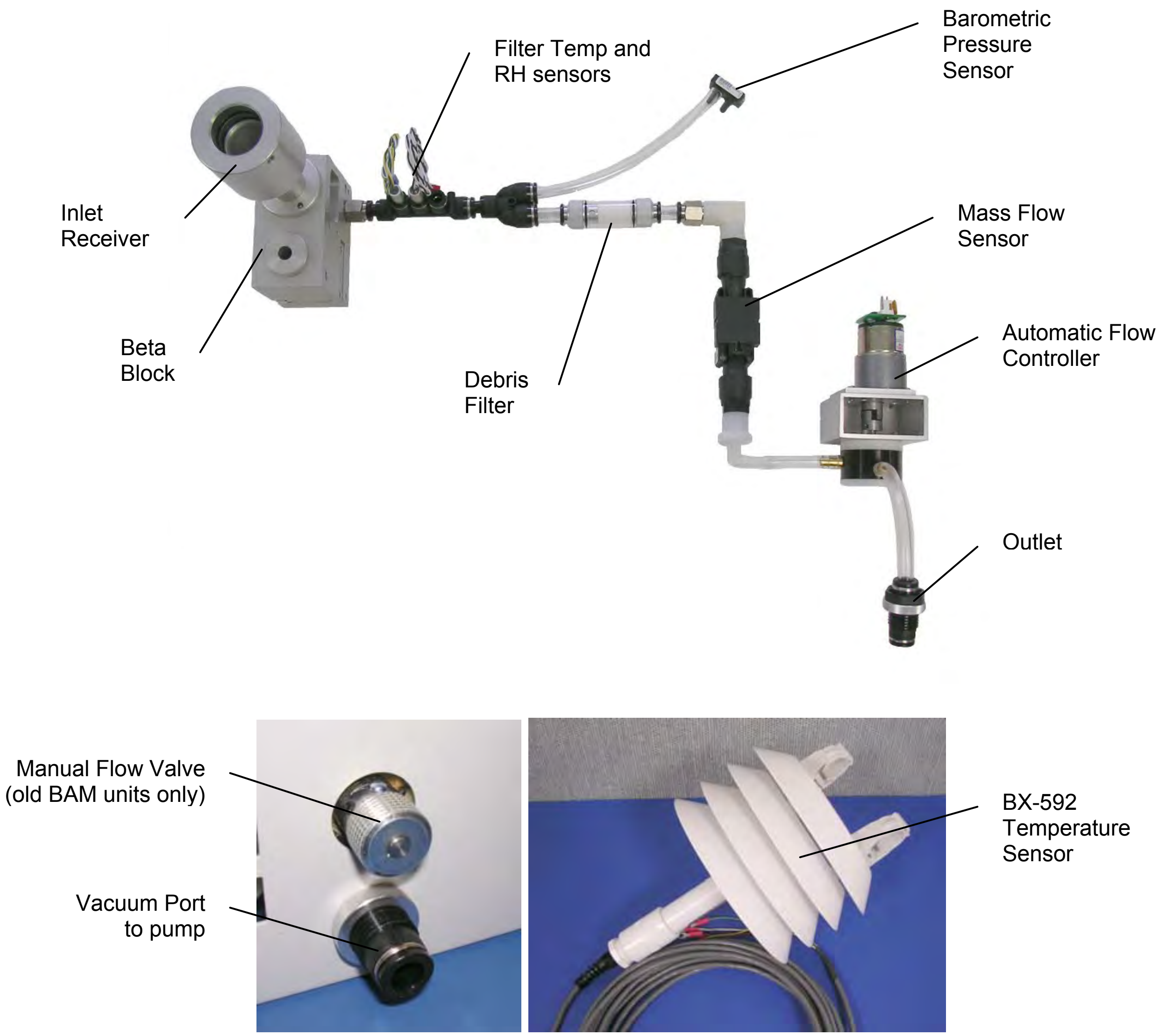
The sample period is the time when the vacuum pump is pulling dust-laden air through the BAM-1020. As the air enters the inlet, it first passes through the external PM_{10} head which has a screen to keep out bugs and debris, and uses inertia to separate out and trap particle larger than 10 microns in size. The air then immediately passes through the Optional $PM_{2.5}$ Very Sharp Cut Cyclone (BGI VSCC™) which further separates out and traps particles larger than 2.5 microns in size.

The air then goes down the inlet and through the filter tape, where the remaining particles are deposited. Some particles smaller than about 0.2 µm may pass through the filter tape and be exhausted. After the sample period is completed and the particulate spot is measured, there is almost always a clearly visible spot of dirt on the filter tape where the particulate was deposited. The BAM-1020 will put the spots very close together on the tape. At exactly midnight, the BAM will skip one spot, leaving a blank spot on the tape. This is a visual aid which separates daily entries on the tape.

5 FLOW SYSTEM and FLOW CALIBRATIONS

5.1 Flow System Diagram

The BAM-1020 airflow control system is very simple and effective, consisting of a few rugged components. Proper operation of the flow system is critical if accurate concentration data is to be obtained from the unit. The key aspects of proper flow system maintenance are **Leak Checks, Flow Checks, and Nozzle Cleaning**. These processes are described in this section. Met One recommends performing a leak check and nozzle cleaning before flow calibrations, as a leak can affect the flow. Flow calibrations require a reference flow meter and a reference standard for ambient temperature and barometric pressure. NIST traceable standards are required in many applications. Met One suggests the BGI DeltaCal® brand (available from Met One as the BX-307 option). It includes flow, temperature and pressure standards in one unit.



BAM-1020 Flow System

5.2 Flow Type Descriptions

The BAM-1020 is designed to operate with an airflow rate of 16.7 liters per minute (lpm). This is important, because the particle separators (PM_{10} inlets, cyclones, and WINS impactors) require this flow rate in order to properly separate the correct sizes of particles from the air stream. All of these separators use the inertia of the particles as they flow through the inlet to sort out the ones above a certain size (cut point) so that they won't be measured by the instrument. If the airflow rate is not maintained within ±5% of the design value flow rate of 16.67 lpm, then particles of the wrong size may be allowed through or sorted out. Periodic BAM-1020 airflow calibrations must be performed to ensure the unit maintains the flow within the EPA specified range of **±5% (±0.83 lpm)** of the design value, and **±4% (±0.67 lpm)** of NIST traceable flow standards.

This section describes the different types of flow control and regulation schemes used in the BAM-1020. The unit can be set to any of three different flow types: Metered, Standard, or Actual (Volumetric), depending on the hardware available and the desired reporting conditions. All BAM-1020 units have a mass airflow sensor and a barometric pressure sensor. The unit also has ***either*** a manual airflow valve on the back of the unit, ***or*** an automatic flow control valve inside the unit. The unit is usually also equipped with an optional BX-592 or BX-596 ambient temperature sensor. Each flow type requires a different process for auditing and calibrating the flow. To verify or set the flow type of the BAM, go to the SETUP > CALIBRATE menu, and check the FLOW TYPE. NOTE: The concentration reporting conditions can now be set independently of the flow type. See section 6.3.

METERED Flow Control:

Neither automatic flow control, nor flow correction for ambient conditions.
Metered flow control is used for BAM units that have a manual (hand-operated) air flow control valve on the back of the unit. These units do not have an automatic flow controller inside, so the unit cannot automatically adjust the flow to compensate for temperature or barometric pressure changes, or for filter loading. The unit does have a mass flow sensor inside. The flow reading from this sensor is stored in EPA conditions, meaning that the volume of air is calculated with the assumption that the ambient temperature is 25 degrees C, and the barometric pressure is 760mmHg (one atmosphere), regardless of the actual temperature and pressure, even if the unit is equipped with a temperature sensor. Due to the lack of automatic flow control, metered units must be frequently flow calibrated and audited, a process which involves a fair amount of math and takes much longer than ACTUAL flow calibrations. Also, metered units must have the flow rate set at a point slightly above the target rate of 16.7 LPM in order to compensate for the fact that the flow rate will drop as the filter becomes loaded with particulate. Note: If a BAM with an automatic flow controller is set to METERED flow control, then the flow will be controlled to EPA STD conditions.

STD (EPA Standard) Flow Control:

Automatic flow control, but usually no flow correction for ambient conditions.
STD (Standard) flow type is often selected when required by specific EPA monitoring regulations, or when no ambient temperature sensor is available. Standard flow control may be selected on any units which have an automatic flow controller instead of the manual valve (almost all BAM-1020 units have the automatic controller anyway). The flow rate is automatically controlled using EPA (standard) conditions, meaning that the volume of air (and thus the flow rate) is calculated with the assumption that the ambient temperature is a

standard value (default is 25 degrees C), and the barometric pressure is 760mmHg (one atmosphere), regardless of the actual temperature and pressure.

NOTE: At low altitudes and moderate temperature, EPA Standard flow will be very close to the actual volumetric flow rate. However, at high altitudes the difference between Standard and Actual flow will be quite significant, due to lower barometric pressure. Carefully consider this effect when deciding on a flow type to implement.

ACTUAL (Volumetric) Flow Control:

Both automatic flow control, and flow correction for ambient conditions.
Actual (also known as volumetric) flow type is the most accurate flow control mode, and is required for all $PM_{2.5}$ monitoring. The actual flow type is also the easiest and fastest to calibrate and audit. The unit always uses actual ambient air temperature and barometric pressure to correct the flow reading, and the flow rate is continuously and automatically adjusted to correct for changes in ambient conditions and filter loading. The flow values will be stored and displayed in actual volumetric conditions. To operate a BAM in actual flow mode, the unit must have a BX-596 or BX-592 ambient temperature sensor on channel six.

5.3 Leak Check Procedure

Leak checks should be performed at least monthly and whenever the filter tape is changed. Almost all air leaks in the BAM system occur at the nozzle where it contacts the filter tape. **The BAM-1020 has no way of automatically detecting a leak at this interface**, because the airflow sensor is located downstream of the filter tape. There will normally be a very small amount of leakage at the tape, but an excessive leak lets an unknown amount of air enter the system through the leak instead of the inlet. This will cause the total air volume calculation (and the concentration) to be incorrect. **Allowing a leak to persist may cause an unknown amount of data to be invalidated!** Perform the following steps to check for leaks:

1. Remove any PM_{10} and $PM_{2.5}$ heads from the inlet tube. Install a BX-305 or BX-302 leak test valve (or equivalent valve for auditing FRM samplers) onto the inlet tube. Turn the valve to the OFF position to prevent any air from entering the inlet tube.
2. In the TEST > TAPE menu, advance the tape to a fresh, unused spot.
3. In the TEST > PUMP menu, turn on the pump. The flow rate should drop below **1.0 lpm**. If the leak flow value is 1.0 lpm or greater, then the nozzle and vane need cleaning, or there may be another small leak in the system.
4. Resolve the leak and perform the check again. A properly functioning BAM with a clean nozzle and vane will usually have a leak value of about **0.5 lpm** or less using this method, depending on the type of pump used.
5. Turn the pump off, remove the leak test valve, and re-install the inlet heads.

NOTES: The reason for the 1.0 lpm leak flow allowance is due to the test conditions. With the inlet shut off the vacuum in the system is very high, about 21 inHg. This is many times greater than the BAM-1020 will encounter during normal sampling. If the leak reading during this test is less than 1.0 lpm, there should not be a significant leak during normal operation.

Some agencies choose to adopt tighter tolerances for the leak test, such as requiring a leak value of 0.5 lpm or less after the nozzle and vane are cleaned. Most agencies perform as-found leak checks (before cleaning the nozzle and vane) for data validation purposes, since it is often necessary to invalidate data from a BAM which is found to have a significant leak, all the way back to the last known good leak test. The typical recommended threshold for invalidating data is an as-found leak value (before cleaning nozzle and vane) of 1.5 lpm or higher. Again, some agencies adopt tighter standards, such as invalidating data if the as-found leak value is greater than 1.0 lpm.

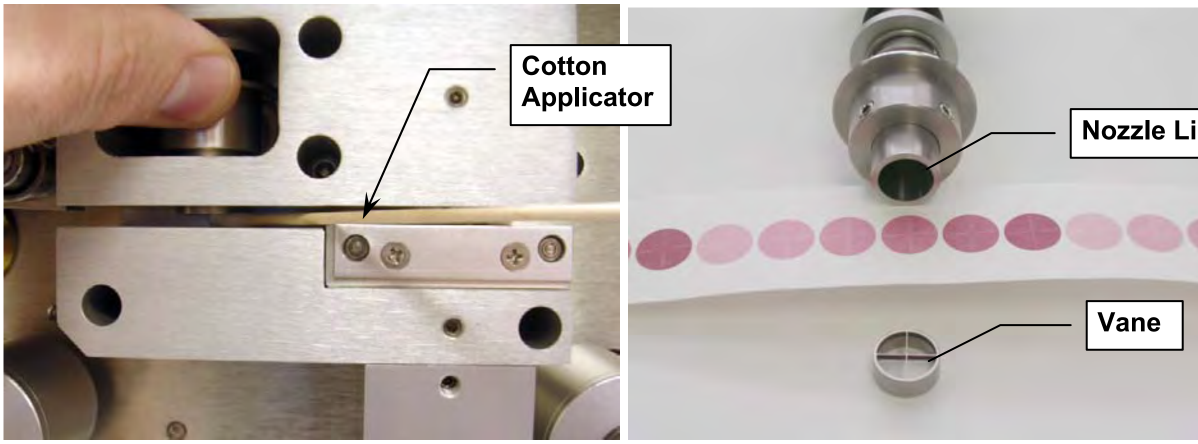
5.4 Leak Isolation and Nozzle Seal Methods

Leaks can be further isolated using a soft rubber sheet with a ¼" hole in it, such as Met One part 7440. The filter tape can be removed and the rubber seal inserted with the hole centered under the nozzle. The seal allows the leak check to be performed as usual, but without any leakage through the filter tape. The leak value should drop to 0.2 lpm or less with this method. A leak can be further isolated by using a part of the seal without a hole. This allows a leak test to be performed only on the system below the filter tape junction. If the nozzle and vane are thoroughly clean, but a leak persists, then see Section 7.5 for some troubleshooting steps for leaks in other parts of the flow system.

5.5 Nozzle and Vane Cleaning

The nozzle and vane (located under the nozzle) must be cleaned regularly to prevent leaks and measurement errors. The cleaning must be done at least each time the filter tape is changed, though monthly cleaning is highly recommended. Some sites will require more frequent cleaning as determined by the site administrator. The worst environment for nozzle contamination seems to be hot, humid environments. This is because damp filter tape fibers more easily stick to the nozzle and vane. The fibers can quickly build up and dry out, creating air leaks or even punching small holes in the filter tape. This will cause measurement errors. Use the following steps to clean the parts. Refer to the photos below.

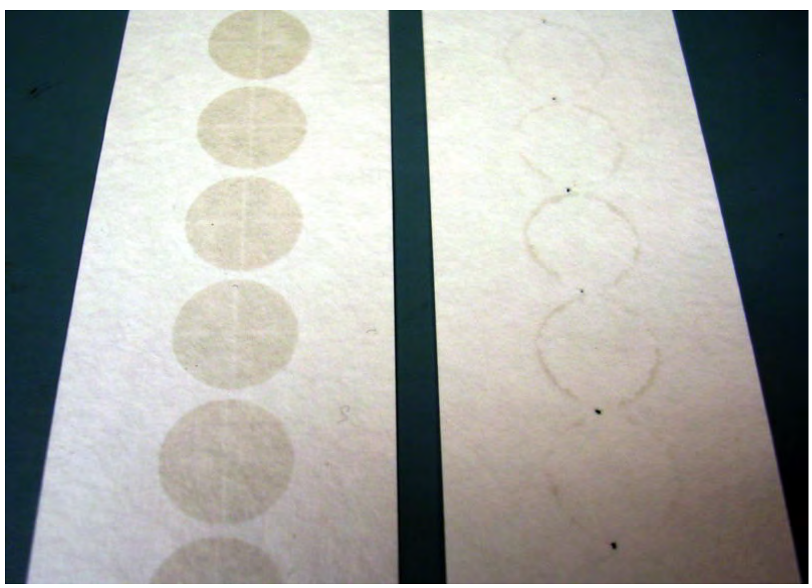
1. Raise the nozzle in the TEST > PUMP menu. Remove the filter tape (if installed) from the nozzle area. It is not necessary to completely remove the tape from the unit.
2. With the nozzle up, use a small flashlight to inspect the cross-hair vane.
3. Clean the vane with a cotton-tipped applicator and isopropyl alcohol. Hardened deposits may have to be carefully scraped off with the wooden end of the applicator or a dental pick or similar tool.
4. Lower the nozzle in the TEST > PUMP menu. Lift the nozzle with your finger and insert another cotton swab with alcohol between the nozzle and the vane. Let the nozzle press down onto the swab with its spring pressure.
5. Use your fingers to rotate the nozzle while keeping the swab in place. A few rotations should clean the nozzle lip.
6. Repeat the nozzle cleaning until the swabs come out clean.
7. Inspect the nozzle lip and vane for any burrs which may cause leaks or tape damage.



Nozzle Cleaning

The figure below shows the difference between good and bad filter tape spots. The tape on the left is from a properly operated BAM-1020 with a clean nozzle and vane. Notice the particulate spots have very crisp edges, are perfectly round, and are evenly distributed.

The tape on the right is from a unit which has not been properly maintained. A spot of debris has built up on the vane, and is punching a pin-hole at the edge of each spot. These holes can allow beta particles to get through un-attenuated which negatively affects accuracy even if the nozzle is not leaking. The spots also show a “halo” effect due to air leaking in around the edged because the debris has built up to the extent that the nozzle no longer seals correctly. These faults are easily corrected and prevented by keeping the nozzle and vane clean.



BAM-1020 hourly filter tape spots

5.6 Field Calibration of Flow System – Actual (Volumetric) Flow Mode

Actual (volumetric) flow calibration is very fast and easy. This type of calibration can only be performed on BAM units which have an automatic flow controller and a BX-592 or BX-596 ambient temperature sensor on channel 6. The unit must also have the Flow Type set to ACTUAL in the SETUP > CALIBRATE menu or the flow calibration screen will not be visible.

```
MULTIPOINT FLOW CALIBRATION
            TARGET    BAM      STD
          AT:         23.8    23.8 C
          BP:          760     760 mmHg
<CAL> FLOW 1: 15.0    15.0    15.0 LPM
      FLOW 2: 18.3    18.3    18.3 LPM
      FLOW 3: 16.7    16.7    16.7 LPM
  CAL      NEXT      DEFAULT    EXIT
```

Actual Flow Calibration Screen

1. Enter the TEST > FLOW menu as shown above. The nozzle will lower automatically when this screen is entered. The “BAM” column is what the BAM-1020 measures for each parameter, and the “STD” column is where you will enter the correct values from your reference standard. The <CAL> symbol will appear next to the parameter selected for calibration. The ambient temperature (AT) and pressure (BP) must be calibrated first, as the BAM uses these to calculate the air flow rate in actual mode.
2. Measure the ambient temperature with your reference standard positioned near the BX-592 or BX-596 ambient temperature probe. Enter the value from your reference standard into the STD field using the arrow keys. Press the CAL hot key to correct the BAM reading. The BAM and STD values should now be the same.
3. Press the NEXT hot key to move the <CAL> indicator to the BP field, and repeat the same steps for barometric pressure.
4. After the temperature and pressure readings are correct, remove the PM_{10} and $PM_{2.5}$ heads from the inlet tube and install your reference flow meter onto the inlet. Press the NEXT hot key to move the <CAL> indicator to the first flow point of 15.0 lpm. The pump will turn on automatically. Allow the unit to regulate the flow until the BAM reading stabilizes at the target flow rate. Enter the flow value from your standard into the STD field using the arrow keys. Press the CAL hot key to correct the BAM reading. **NOTE:** The BAM reading will not change to match the STD until after you have entered all three calibration points.
5. Press the NEXT hot key to move the <CAL> indicator to the second flow point of 18.3 lpm and repeat the process.
6. Press the NEXT hot key to move the <CAL> indicator to the third flow point of 16.7 lpm and repeat the process. Enter the flow value and press <CAL>.
7. **When all of the calibrations are complete, the BAM-1020 flow readings should match the traceable flow standard reading at 16.7 lpm, +/- 0.1 lpm. Exit the calibration menu.**

The DEFAULT hot key can be pressed to reset the user calibration from the selected parameter and replace it with a factory setting. If any of the FLOW parameters are selected, the DEFAULT key will reset the calibrations of all three flow points. This feature can be used to start over with a calibration if difficulty is encountered.

Actual flow calibrations in units with older firmware:
BAM-1020 units with previous revisions of firmware (prior to Rev 3.0) have a different format in the TEST > FLOW menu, as shown below. These units are flow calibrated in the same way as described above, except that the flow calibration is performed at only a single point of 16.7 lpm, not a multi-point calibration as in new units. The correct values from your traceable reference standard device must be entered into the "REFERENCE" column, then the "ADJUST/SAVE" button is pressed to correct the BAM reading. The "NEXT" key selects the parameter to be calibrated. AT and BP must be calibrated first, then the pump is turned on.

```
      ACTUAL FLOW CALIBRATION MODE
F1= RESTORE DEFAULT
                      BAM      REFERENCE
AMBIENT TEMPERATURE:  23.8 C   23.4 C
BAROMETRIC PRESSURE:  741 mmHg 742 mmHg
VOLUMETRIC FLOWRATE:  16.7 lpm 16.9 lpm

ADJUST/SAVE   NEXT     PUMP ON    EXIT
```

Previous Format of the Actual Flow Calibration Screen

5.7 Field Calibration of Flow System – EPA Standard Flow Mode

Flow calibration on units operated in EPA STANDARD flow mode can be done a couple of different ways. If the unit has a BX-592 or BX-596 ambient temperature probe installed, the easiest way to calibrate the flow is to temporarily change the FLOW TYPE from STD to ACTUAL in the SETUP > CALIBRATE menu, then perform an Actual flow calibration as described above. If this method is used, be sure to set the unit back to STD flow when done.

If the unit does not have the temperature sensor then you will not have access to the TEST > FLOW screen. Use the following steps to check the flow instead:

1. Attach your flow standard onto the BAM inlet while the pump cycle is running or turn the pump on in the TEST > PUMP screen. Allow the BAM flow to stabilize.
2. If your reference flow meter has a STANDARD flow reading available, that value can be directly compared to the BAM flow reading. If your flow meter only has a volumetric flow reading, then convert the volumetric flow rate to standard flow $\mathbf{Q_s}$ with the following formula:

$$\mathbf{Q_s = Q_a * (P_a / T_a) * (298 / 760)}$$

T_a = Ambient Temperature (Kelvin) (Kelvin = Celsius + 273)
P_a = Ambient Barometric Pressure (mmHg)
Q_a = Actual Volumetric Flow from Reference Meter

3. Compare the reference flow (converted to STD conditions) to the BAM flow reading (also in STD conditions). The two should match within 1% (about 0.17 LPM). If not, a full flow calibration should be performed. Change the FLOW TYPE to METERED and perform a flow calibration using the $\mathbf{C_v}$ and $\mathbf{Q_0}$ values as described in section 5.8. The sections about the manual flow valve do not apply. Set the flow type back to STD when finished.

5.8 Field Calibration of Flow System – Metered Flow Mode

Metered flow calibration is only performed on BAM-1020 units which have a hand-operated manual flow valve on the back (mostly older units). Because these units do not have automatic flow control, the calibration procedure is much more complicated. The flow must also be more frequently checked due to changes in ambient conditions, which these type of units cannot compensate for. Use the following steps for a full Metered flow calibration. The full calibration only needs to be done once in a while, but the flow should be checked and adjusted often. The process is faster if your reference flow meter can provide standard flow.

1. Advance the filter tape to a fresh spot.
2. Enter the SETUP > CALIBRATE menu. Set the $\mathbf{C_v}$ (coefficient of variability) value to **1.000**, and the $\mathbf{Q_0}$ (flow zero correction) value to **0.000.**
3. Disconnect the pump tubing from the back of the BAM, and turn the pump on in the TEST > PUMP menu. There will not be any air flowing through the unit. Record the flow reading from the BAM display. This is the zero flow $\mathbf{Z_f}$ value.
4. Re-enter the SETUP > CALIBRATE menu and set the $\mathbf{Q_0}$ value to equal the negative of the zero flow value $\mathbf{Z_f}$.
5. Go back to the TEST > PUMP menu and turn the pump back on. Verify that the flow reading on the BAM display now reads 0.0 LPM +/-0.1LPM.
6. Reconnect the pump tubing to the back of the BAM. Remove any PM_{10} and $PM_{2.5}$ heads, and connect your reference flow meter to the inlet.
7. Record the ambient temperature $\mathbf{T_a}$ (Kelvin) from your reference standard, and record the barometric pressure $\mathbf{P_a}$ (mmHg) from the OPERATE > NORMAL screen on the BAM.
8. From the TEST > PUMP menu, turn the pump on and allow the flow to stabilize for 5 minutes. Then record the actual flow from your reference flow meter $\mathbf{Q_a}$, and record the standard flow reading from the BAM display $\mathbf{Q_b}$.
8. Convert the volumetric flow rate $\mathbf{Q_a}$ from your reference meter to EPA standard flow $\mathbf{Q_s}$ with the following formula:

$$\mathbf{Q_s = Q_a * (P_a / T_a) * (298 / 760)}$$

T_a = Ambient Temperature (Kelvin) (Kelvin = Celsius + 273)
P_a = Ambient Barometric Pressure (mmHg)
Q_a = Actual Volumetric Flow from Reference Meter

9. Calculate the final value for $\mathbf{C_v}$:

$$\mathbf{C_v = Q_s / Q_b}$$

10. Calculate the final value for $\mathbf{Q_0}$:

$$\mathbf{Q_0 = -C_v * Z_f}$$

11. In the SETUP > CALIBRATE menu, enter the final values for $\mathbf{C_v}$ and $\mathbf{Q_0}$.
12. Turn the pump on in the TEST > PUMP menu again and verify that the flow reading from the BAM display matches $\mathbf{Q_s}$ within 1%. If not, repeat the entire flow calibration.
13. After the flow is calibrated, use the flow adjustment knob on the rear of the BAM-1020 and adjust the flow until the display reads **17.3 LPM**. This level is within the specification of the PM_{10} particle separator, and will allow for filter loading in high concentration areas. In lower concentration areas the flow can be set at 16.7 LPM.
14. Exit the TEST menu.

Quick Flow Check and Adjustment for Metered Flow:
These steps can be used to do a quick flow check on a Metered Flow BAM with a manual valve while it is in operation.

4. Insert your volumetric flow standard onto the BAM inlet, and allow the BAM flow to stabilize.
5. Record the ambient temperature, ambient pressure, and the volumetric flow from the reference.

T_a = Ambient Temperature (Kelvin) (Kelvin = Celsius + 273)
P_a = Barometric Pressure (mmHg)
Q_a = Actual Volumetric Flow

6. Convert the volumetric flow from the reference to EPA standard conditions:

$$Q_s = Q_a * (P_a / T_a) * (298 / 760)$$

7. Compare the reference flow (converted to STD conditions) to the BAM flow reading (also in STD conditions). The two should match within 1%. If not, a full flow calibration should be performed.
8. If the reference flow (converted to STD conditions) and BAM flow reading match, then adjust the flow adjustment knob on the back of the unit until the BAM flow reading equals **17.3 LPM**.

Manual Flow Compensation for Seasonal Weather Changes:
These steps can be used to periodically adjust the flow rate on a Metered flow BAM with a manual valve to compensate for changes in average local atmospheric conditions. Full flow calibrations should still be performed on a regular basis.

1. Measure the ambient temperature $\mathbf{T_a}$ (Kelvin) at approximately 4:00 PM. This usually represents an average daily temperature.
2. Stop the BAM pump and record the barometric pressure $\mathbf{P_a}$ (mmHg) from the OPERATE > NORMAL screen.
3. Calculate a volume correction term by the following:

$$V = (T_a / P_a)*62.4$$

4. Divide **V** by 24.47 to determine the ratio of EPA flow to Ambient Flow and record as **CALNUM**.
5. Turn the pump on in the TEST > PUMP menu and allow the flow to stabilize for 5 minutes. Then divide the displayed flow by **CALNUM**.
6. Adjust the flow adjustment knob on the back of the BAM-1020 until the BAM flow reading equals **17.3 / CALNUM**. Exit the TEST menu.

Example:
Temp = **300 Kelvin**
Pressure = **710 mmHg**
V = (300/710) * 62.4 = **26.4**
CALNUM = 26.4/24.47 = **1.08**
Adjusted Flow = 17.3/1.08 = **16.0 LPM**
Adjust flow valve until BAM reads 16.0 LPM.

6 SETUP MENU DESCRIPTIONS

The BAM-1020 uses a comprehensive system of setup menus which contain all of the settings and parameters needed to perform the measurement and operation of the unit. Some of these settings are set at factory default values which are correct for most applications, but may be altered by the operator to suit the specific needs of your monitoring program. This section describes the SETUP menu in detail, and should be reviewed when the instrument is put into service to ensure desired operation. Once set, most of the values in the SETUP menus will not need to be changed by the site operator. The SETUP values will not be lost if the unit is unplugged or powered down.

WARNING: Some of the settings in the SETUP menus are unit-specific calibration constants which cannot be changed without affecting the accuracy and proper operation of the unit.

WARNING: Entering the SETUP menu system will require stopping the sample cycle. Older versions of firmware will not warn you before stopping the sample!

Press the SETUP soft-key to enter the menu as shown below. The Setup Menu provides a choice of operations. Use the arrow keys to navigate to the desired field, then press the SELECT soft-key to enter.

```
                      SETUP MODE SELECT
CLOCK     SAMPLE      CALIBRATE EXTRA1
ERRORS    PASSWORD    INTERFACE SENSOR
HEATER

SELECT                            EXIT
```

The SETUP Menu

A brief description of each sub-menu in shown in the table below. Detailed information is provided in the following sub-sections.

Menu	Settings
CLOCK	Date and Time Settings.
SAMPLE	Range, Offset, Sample Time, Count Time, Conc Units, Avg Period, Unit ID, and RS-232 settings.
CALIBRATE	Factory Calibration Values, (C_v, Q_0, ABS, μsw, K, BKGD) Flow rate, Flow type, Heater type.
EXTRA1	Low concentration clamp, e1 – e4, Rarely used.
ERRORS	Analog error selections, Flow limits, Pressure drop limit.
PASSWORD	Password change screen.
INTERFACE	Cycle Mode early/standard, alarm relay polarity.
SENSOR	Meteorological sensor scaling and configuration screens, Channels 1 – 6.
HEATER	RH and Delta-T set-points for Smart Heater. Only visible if Heater Control is set to AUTO.

6.1 CLOCK Screen

The SETUP > CLOCK screen allows for the setting of the time and date. Time is a 24-hour clock only. Use the arrow keys to select and increment/decrement the desired field, then press the SAVE soft-key. The BAM-1020 clock may drift as much as a minute or two per month. Met One recommends checking the clock monthly to ensure correct sample timing.

6.2 SAMPLE Settings Screen – Critical Information

The SETUP > SAMPLE screen is used to set the BAM-1020 sampling and averaging periods, and some other important settings. Review each of these settings carefully. The SAMPLE screen is shown below. The fields can be edited with the arrow keys, then saved with the SAVE soft-key.

```
                          SETUP SAMPLE
RS232 9600 8N1    BAM SAMPLE 042 MIN

STATION # 01      MET SAMPLE  60 MIN
RANGE   1.000 mg  OFFSET  -0.015 mg
CONC UNITS mg/m3  COUNT TIME   8 MIN
  SAVE                        EXIT
```

The SAMPLE Screen

RS-232: This allows you to set the baud rate of the RS-232 serial port. The available values are 300, 600, 1200, 2400, 4800, 9600, 19200, and 38400 baud. Default is 9600. “8N1” means 8 data bits, no parity, 1 stop bit. These handshaking bits cannot be edited.

BAM SAMPLE: This value sets the amount of time that the vacuum pump is on per cycle; the actual sample period (see Section 4.1 for a description of the measurement cycle). The BAM SAMPLE time must be set in response to the COUNT TIME value, since new versions of the BAM-1020 allow the option of setting the count time to 4, 6, or 8 minutes. If the unit is used for $PM_{2.5}$ monitoring, the BAM SAMPLE must be set to 42 minutes with 8 minute count time. PM_{10} monitors are almost always set for 50 minutes.

Count Time	BAM Sample	Used for
4 min	**50 min**	PM10 monitoring
6 min	46 min	not used
8 min	**42 min**	PM2.5 monitoring

The BAM SAMPLE value can be set from 0-200 minutes for custom applications. If set for shorter period, such as 15 minutes, the unit will finish the sampling in 15 minutes and then wait until the end of the hour before beginning a new cycle. This may not leave time for the membrane span check. Only one cycle per hour is allowed, regardless of duration. Setting the value too long may cause the measurement to extend over into the next hour. Contact the Service department before setting this to anything but the values shown in the table.

STATION #: This is a station identification number. This number has a range of 00-99, and will be included in the data reports. When used in a network, every BAM-1020 should be given a different station number. Default value is 01.

MET SAMPLE: This value is the averaging period for the data logger. It sets how often data is written to memory, and can be set to 1,5,15, or 60 minutes. For example, if an external wind speed sensor is attached to the BAM, the MET SAMPLE period could be set to 1 minute. This would cause the BAM to store an average of the WS reading every minute. This value applies to all sensors attached to the unit. **Warning: This setting will affect how long the memory will last before getting full.**

There are **4369 records** available in the BAM memory. A MET SAMPLE period of 60 minutes (1 record per hour) will result in over 182 days worth of memory capacity, but a 1 minute average period will fill up these memory records in only 3 days. When the memory gets full the unit over-writes the oldest data. Met One recommends leaving the MET SAMPLE period set at the default value of 60 minutes unless otherwise required for a particular application. The dust concentration value will always be an hourly average regardless of this setting.

RANGE: The RANGE setting sets the full-scale range of the concentration measurement system, including the digital system and the analog voltage output. The RANGE value is almost never changed from the default setting of **1.000 mg**. This means that the BAM measures a maximum full-scale range of 1000 micrograms above whatever the OFFSET value is set to. The table below shows some examples of the RANGE setting interacting with the OFFSET setting to produce the concentration data outputs of the BAM.

OFFSET Setting	**RANGE Setting**	Resulting Digital Data Range	Resulting Analog Output Range
-0.015 mg	1.000 mg	-0.015 to 0.985 mg	0-1V = -0.015 to 0.985 mg
-0.005 mg	1.000 mg	-0.005 to 0.995 mg	0-1V = -0.005 to 0.995 mg
0.000 mg	1.000 mg	0.000 to 1.000 mg	0-1V = 0.000 to 1.000 mg
0.000 mg	2.000 mg	0.000 to 2.000 mg	0-1V = 0.000 to 2.000 mg

In special cases, the RANGE value may be set to 0.100, 0.200, 0.250, 0.500, 2.000, 5.000, or 10.000 mg. Be sure to account for this value if using a separate data logger to record the BAM-1020 analog output.
Note: Changing the range setting will affect past data already stored to memory. Always download any old data before changing settings, then clear the memory. Firmware version 3.2.4 or later will prompt you to clear the memory before letting you change this setting.

OFFSET: The OFFSET value is used to set the lower end of the BAM-1020 measurement range, and could more accurately be called a “range offset”. The new factory default value for OFFSET is now -0.015 mg. This causes the entire range of the BAM-1020 to shift down slightly so that it can read from -0.015 to 0.985 mg, instead of measuring from 0 to 1.000 mg (assuming the RANGE is set to 1.000 mg). This simply allows the unit to measure slightly negative concentration numbers near zero, which is helpful to differentiate between normal noise and a failure such as punctured filter tape.

The previous default was -0.005 mg, and the value may still be set to -0.005 if needed to work with data logging systems structured around the old setting. Some BAM users choose to set the OFFSET value to 0.000 to avoid confusion, at the expense of not being able to see the true zero noise floor of the unit.

This value also affects the analog output, so that 0 to 1.000 volts equals -0.015 to 0.985 mg, instead of 0.000 to 1.000 mg. This is because the voltage output cannot go negative. You must take this scaling into account if an external data logger is recording the BAM-1020 analog output voltage. Contact the Service department if you plan to set the OFFSET to any value other than -0.000, -0.005, or -0.015 mg.

Note: The OFFSET value is often misunderstood, and should not be confused with the BKGD (zero correction factor) or the "e1" (lower concentration limit clamp) values. Be sure you understand all three of these settings!
Note: Changing the offset setting will affect past data already stored to memory. Always download any old data before changing settings, then clear the memory. Firmware version 3.2.4 or later will prompt you to clear the memory before letting you change this setting.

CONC UNITS: This setting determines the concentration units which the BAM-1020 displays and stores in memory. This can be set to ug/m3 (micrograms) or mg/m3 (milligrams) per cubic meter. This is a new option for the BAM-1020. Past versions have always been set for mg/m3. **Note:** 1 mg = 1000 μg.

COUNT TIME: This is the amount of time the unit takes to perform the I_0 and I_3 counts. Past versions of the BAM-1020 have always been fixed at 4 minutes. The new options allow the count time to be set for 4, 6 or 8 minutes. When used to monitor $PM_{2.5}$, this must be set to 8 minutes. This increases the sensitivity of the unit in lower concentrations. Increasing the count time will require decreasing the sample time. For example, a count time of 4 minutes allows a sample time of 50 minutes, while a count time of 8 minutes allows a sample time of only 42 minutes. The unit will prompt you to change the sample time if you change the count time to an incompatible value.

6.3 CALIBRATE Screen – Critical Information

The SETUP > CALIBRATE screen is where most of the factory-determined calibration parameters for the BAM-1020 are stored. These values are unit-specific, and can also be found on the calibration certificate for the unit in case a setting is accidentally changed. Most of these settings will never be changed without specific information from Met One Instruments. It is good practice to periodically audit the calibration values to verify that they have not been altered. The CALIBRATE screen is shown below.

```
CALIBRATE SETUP
                    FLOW RATE:  16.7
CONC TYPE: ACTUAL   FLOW TYPE: ACTUAL
       Cv:  1.047          Qo:  0.000
      ABS:  0.822         µsw:  0.306
        K:  1.005        BKGD: -0.0030
 STD TEMP: 25C         HEATER: AUTO
  SAVE                         EXIT
```

The SETUP > CALIBRATE Screen

FLOW RATE: This sets the air flow rate for the BAM-1020 sample period. The BAM will continuously regulate the flow to this value (except manual valve models). The flow rate is almost always set for **16.7 liters per minute**, as this is required for all $PM_{2.5}$ and PM_{10} monitoring. The operator may change this value <u>temporarily</u> in order to test the ability of the pump and flow controller to regulate the flow at different levels. The range of this setting is 10 to 20 LPM.

CONC TYPE: This sets the way that the concentration values are reported. If set to ACTUAL, then the concentration is calculated based on the volume of the air at ambient conditions, and a BX-592 or BX-596 temperature sensor is required. If set to STD, the concentration is calculated based on the standard values for temperature and pressure (usually 25C and 760mmHg), even if a temperature sensor is available. This value is usually set to match the FLOW TYPE setting, and must be set to ACTUAL for $PM_{2.5}$ monitoring. Note: BAM units with firmware prior to rev 3.0 does not have this setting available.

FLOW TYPE: This setting selects the flow control scheme used by the BAM-1020. The three possible settings are METERED, STD, and ACTUAL.

- METERED: Usually used for BAM units with a manual flow valve on the back. Flow is reported in EPA conditions.
- STD: EPA Standard flow. The flow is controlled and reported in EPA standard conditions. Used where required by regulations.
- ACTUAL: Actual Volumetric flow is controlled and reported to ambient temperature and pressure conditions. This is required on $PM_{2.5}$ monitors, and is recommended by Met One whenever possible. BX-596 or BX-592 sensor is required.

This is an important parameter to understand. At sea-level and moderate temperatures the difference between these settings will be minimal, but at high elevations or varied temperatures the flow rate can be greatly affected by this setting. **NOTE:** Section 5.2 contains a detailed description of each of these flow types, and should be studied to ensure proper operation of the unit.

Cv: This value is the factory-set Coefficient of Variability for the internal flow sensor. The value of Cv is only changed by the user when performing a flow calibration on manual valve (metered) or STD flow units. ACTUAL flow controlled units almost never need to have this value altered.

Qo: This value is the factory-set zero correction factor for the internal flow sensor. The value of Qo is only changed by the user when performing a flow calibration on manual valve (metered) or STD flow units. ACTUAL flow controlled units almost never need to have this value altered.

ABS: The ABS value is the factory-set mass of the reference membrane foil used during the automatic span check. This value is compared to the measured value each hour (see section 4.2). Each unit's ABS value is different, but is typically around 0.800 mg. **The ABS value is never changed by the operator unless the span membrane is replaced due to damage.**

μsw: This is called the Mu-switch value, and is the factory-set mass absorption coefficient used by the BAM-1020 in the concentration calculations. Typical values are about 0.285 to 0.310. **Warning: This is a unit-specific calibration value which may significantly affect the accuracy of the unit. Never change this value without specific instruction from Met One Instruments.**

K: The K-factor is the factory-set slope correction (multiplier) for the BAM-1020 concentration. The K-factor value is determined by dynamic testing of the BAM-1020 in the factory smoke chamber. This will always be a value between 0.9 to 1.1. All of the stored and displayed data contains this correction. **Warning: This is a unit-specific calibration value which may significantly affect the accuracy of the unit. Never change this value without specific instruction from Met One Instruments.**

BKGD: The BACKGROUND value is the factory-set zero correction (slope offset) for the BAM-1020 concentration. This is determined by running the unit for at least 72 hours with a 0.2 micron zero filter on the inlet. The concentration values over this time are averaged, and the BKGD is the negative of this average. All of the stored and displayed data contains this correction. The BKGD value is typically between 0.000 and -0.005 mg/m^3. Met One does offer a zero filter kit (BX-302) which may be used to audit this value, and comes with complete instructions. **Warning: This is a unit-specific calibration value which may significantly affect the accuracy of the unit.** Note: The BKGD value is not to be confused with the OFFSET (range offset) value in the SETUP > SAMPLE menu. See section 6.2.

STD TEMP: This is the value of standard temperature, used for standard flow or concentration calculations. In the U.S. the value of standard temperature is usually 25 degrees C as mandated by the USEPA. Some other countries use a standard temperature value of 0C or 20C. This setting is not available on units using firmware prior to rev 3.0.

HEATER: This setting selects which mode the Smart Inlet Heater is used in. When set to AUTO, the Smart Heater will use the filter RH and temperature sensors to control the inlet tube heating. When set to MANUAL, the unit will simply turn the heater on all the time regardless of filter conditions. The actual setup parameters for the Smart Heater are located in the SETUP > HEATER menu, which will not appear unless this value is set to AUTO. The operator may safely set this parameter as required. Met One recommends using the AUTO setting. This value must be set to AUTO for $PM_{2.5}$ monitoring.

6.4 EXTRA1 Screen

The settings in the EXTRA1 screen are special settings that have been installed for special applications and generally will never be changed.

e1 Low Concentration Limit. The lowest concentration value the BAM-1020 is allowed to store or display, despite what it measured. Any measurements below this value will be clamped. The range is -0.015mg to +0.010mg, and the default value is -0.015mg. **Note:** This value is not to be confused with the OFFSET value which sets the lower limit of the measurement range, or the BKGD value which is the zero correction.

e2 Not Used.

e3 Membrane OFF Delay. Hysteresis timer, range is 0.000 to 5.000 seconds. Don't change this value unless instructed to do so by Met One.

e4 Membrane Time Out. The time the unit allows for the membrane assembly to move before generating an error. Range is 10.00 to 20.00 seconds. Don't change this value unless instructed to do so by Met One.

6.5 ERRORS Screen

This screen allows the operator the option of reporting BAM-1020 errors with the analog output signal. This type of error indication is used when the operator is limited to a single voltage channel for particulate information, such as when the BAM is connected to certain types of data loggers. In this case, the BAM sets the analog output to **full scale voltage** (usually 1.000 volts) when an error occurs. At the beginning of the next hour, the errors are reset and the output functions normally unless another error occurs. The operator can select which errors, if any, are reported in this manner, by selecting each error from the list below and enabling or disabling it (**1=ON, 0=OFF**) in the error setup screen.

Regardless if a particular error is enabled for the analog output in this manner or not, it will always be reported in the BAM-1020 digital memory, and may be viewed with the display or by downloading the data through the serial port. Some of these errors such as P, R, N, and E may be set to cause the analog output to go full scale, even though there may be nothing wrong with that hour's data. In this case, the concentration data can still be downloaded from the BAM. Some (but not all) errors such as M and L cause the digital concentration value to be set to full scale too, usually .985mg.

This scheme is used because it is rare for an actual valid concentration reading to measure full-scale. However, concentrations at or near zero can be common, so leaving the data value at 0.000 during an alarm could be mistaken for valid data.

```
                        SETUP MODE ERROR
EUMILRNFPDCT AP  FRI FRh
111111111111 150 10  20
1=ON,  0=OFF
 SAVE                          EXIT
```

The ERRORS Screen

E **EXTERNAL RESET:** This error indicates that the system clock time was unable to reset when signaled by an external datalogger. If external reset is successful then no error is logged (see Section 8.2). Sometimes called **INTERFACE RESET**.

U **TELEMETRY FAULT:** This error indicates that an external datalogger has sent an error to the BAM-1020 (on the TELEM FAULT input) indicating that it has encountered a problem. Check the datalogger.

M **MAINTENANCE:** This is a user-set data flag which indicates that calibration or testing was performed during the flagged hour. The "**M**" flag may also be forced ON in the SETUP > INTERFACE menu by setting "Force Maint" to ON, or in the OPERATE > INST screen by pressing the TOGGLE FLG button. M flags cause the digital concentration to read full-scale for that hour.

I **INTERNAL CPU:** This indicates an error in the mass concentration calculation by the central processor. Contact the Service department if these errors begin to occur frequently.

L **POWER FAIL:** This error occurs any time power is cycled or lost, even momentarily. Frequent "**L**" errors usually indicate poor quality AC power. In some cases these errors can be generated by electrical interference (such as large radio antennas or motors) causing an internal reset in the BAM-1020. There are also a variety of power supply upgrades available for some older BAMs which experience frequent L errors. If a BAM experiences frequent L failures even when connected to a UPS, contact Met One for instructions on possible upgrades. This error also causes the digital concentration value to go full-scale.

R **REFERENCE MEMBRANE:** This error indicates that the reference membrane assembly is not physically extending and retracting properly. The error is generated if photo sensors S2 and S3 never change state despite drive commands to the membrane motor, and a timeout of the membrane motion occurred after 15 seconds.

N **NOZZLE STUCK TIMEOUT (or Delta-T exceeded):** This error indicates that the nozzle motor is not operating. The error is triggered if photo sensors S4 and S5 never change state despite drive commands to nozzle motor, and if the sensors do not see the nozzle motor move within 12 seconds of it being turned on. **NOTE:** The nozzle motor lifts the nozzle, but the nozzle is lowered only by its spring. So it is possible for the nozzle to become stuck in the UP position without generating an error! Proper maintenance and inlet alignment prevents this.

The "**N**" error is also used to indicate that the Delta-Temperature set-point was exceeded. This occurs if the sample air temperature (measured below the filter tape) is hotter than the ambient air by at least one degree above the set-point value. This is due to the normal heating of the sample air by the smart heater. In this case, the error is used to simply flag the data. Frequent errors may indicate that the set-point is set too low. In most applications Delta-T control is disabled entirely. See the inlet heater settings instructions in this manual.

F **FLOW ERROR:** This error occurs if the average air flow over the sample period was out of the limits set by the **FRl** (low limit) and **FRh** (high limit) values. The error will also be generated if the flow during any part of the sample period goes out of regulation by more than 5% for more than 5 minutes, or by more than 10% for more than 1 minute. In the later case, the sample is stopped as well. Momentary changes in airflow do not usually trigger the error. This error may begin to occur if the vacuum pump is wearing out, if the muffler is clogged, or due to a fault with the flow sensor, flow controller, or air tubing.

The **“F”** error is also used to indicate if the ambient temperature or barometric pressure sensor has failed or is incorrectly connected (only if the BAM is set for ACTUAL flow or concentration reporting). This applies to auto ID sensors BX-592 and BX-596, the internal filter pressure sensor, and CARB style temperature sensors. The sensor is considered failed if any 1 minute average reading of the sensor is at or beyond the min or max measurement range of the particular sensor.

P **PRESSURE DROP EXCESSIVE:** This error indicates that the vacuum beneath the filter tape has exceeded the limit set by the **AP** value. This is almost always caused by high concentrations, or certain types of particulate clogging the filter tape. When this error occurs, the BAM stops the pump to prevent overheating, completes the measurement early, then waits for the top of the next hour. To increase the amount of particulate which can build up on the tape before this occurs, set the **AP** value higher.

D **DEVIANT MEMBRANE DENSITY:** This error indicates that the reference membrane span check measurement (**m)** for that hour was out of agreement with the expected value (**ABS**) by more than ±5%. If these errors start to occur regularly, it could indicate that the beta detector is beginning to wear out. It can also be caused by a dirty or damaged membrane, or by a membrane assembly that is not extending or retracting fully. Also sometimes called a **BAM CAL** error.

C **COUNT ERROR:** This error indicates that the beta particle counting system is not operating properly, and is activated if the beta count rate falls below 10,000 per 4 minutes. The beta count rate through clean filter tape is usually more than 800,000 per 4 minutes. This error could occur if the beta detector has failed or if something is blocking the beta particles, such as a stuck membrane assembly or debris.

T **TAPE BREAK:** This error indicates that the filter tape is broken or has run out. The error is triggered if photo sensor S6 is ON continuously, despite drive commands to motors M3-M5. Tape supply motor (M3) and tape take-up motor (M4) time out after 10 seconds. Capstan motor (M5) times out after 6 seconds. This error is also generated if the pinch roller assembly has been left latched in the UP position when a measurement cycle starts. Photo sensor S9 is ON any time the latch is set. The BAM-1020 has no way of unlatching and lowering the pinch rollers. It must be done manually. A tape-break error will cause the measurement cycle will stop, and the BAM to repeat the last good concentration value until the filter tape is fixed or replaced.

AP Pressure-drop limit across the filter tape. The default setting is **150** mmHg, and the range is 0-500 mmHg. See the PRESSURE DROP EXCESSIVE error definition above.

FRl Flow Rate Lower Limit. The default setting is **10** lpm, and the range is 0-30 lpm. See the FLOW OUT OF LIMITS error definition above.

FRh Flow Rate Higher Limit. The default setting is **20** lpm, and the range is 1-38 lpm. See the FLOW OUT OF LIMITS error definition above.

6.6 PASSWORD Screen

The SETUP > PASSWORD screen allows the program administrator to change the password required to enter many of the SETUP menus. The password prevents untrained users from accidentally changing critical settings on the unit. The password can be any 4-key combination of the six function keys, F1 to F6. The default password is **F1, F2, F3, F4**. Met One does not recommend changing the password unless truly necessary. Contact the Met One Service department for instructions if the password is lost or forgotten.

6.7 INTERFACE Screen

The SETUP > INTERFACE screen is shown below. These settings are used to configure the BAM-1020 for operation with an external data logger recording the analog output. Most of these settings are rarely used, but the Cycle Mode setting must be reviewed if the analog output is being used.

```
                              Interface Setup

Cycle Mode: STANDARD Force Maint: OFF
Fault Polarity: NORM Split DELTAP: 00300
Reset Polarity: NORM


   SAVE                          EXIT
```

The INTERFACE screen

Force Maint: This can be used to manually toggle the maintenance flag ON or OFF to mark the data when the unit is being worked on, such as during a flow check. This also toggles the Maintenance relay to an external data logger. Rarely used.

Fault Polarity: This sets the polarity of the Telemetry Fault Relay. NORM is normally open, INV is normally closed. Rarely used.

Split DELTAP: Not used.

Reset Polarity: This tells the BAM-1020 the incoming polarity of an external clock reset signal, if used. This signal is used to synchronize the BAM clock to an external data logger. NORM is normally open, INV is normally closed.

Cycle Mode: The Cycle Mode can be set to STANDARD or EARLY. If you are not using the analog output voltage of the BAM-1020, leave this set to STANDARD. See Section 8.2 for a description of the Cycle Modes.

6.8 SENSOR Screen

The SETUP > SENSOR menu is where configurations and setup parameters are located for the six analog input channels used to log external meteorological sensors. Each channel must be configured to accept the sensor before data can be acquired. Description for the parameters are provided below. There is a separate configurable setup screen for each of the six external sensor inputs in the SETUP > SENSOR menu. There are also two internal channels (I1 concentration and I2 flow volume) which can be viewed but not modified.

Met One 500 series meteorological sensors have an Auto ID feature which allows the BAM to automatically recognize the sensor and enter all of the setup parameters for any channel the sensor is attached to. Each channel can also be manually configured by the user for other sensors.

```
                    SETUP CHAN PARAMS

CH     TYPE  UNITS  PREC  MULT   OFFSET
06     AT    C         1  0100.0  -050.0
       SENSOR FS VOLT:  1.000
INV SLOPE:N VECT/SCALAR:S MODE:AUTO ID

  SAVE             ID MODE      EXIT
```

The SENSOR Menu

CH: This field selects the channel to be viewed or edited. Use the up/down arrow keys to select the desired channel.

TYPE: This is the channel name. You can enter any desired name here by using the arrow keys to scroll through the alphabet and other characters.

UNITS: This is the measurement units label for the channel. You can enter a value here by using the arrow keys to scroll through the alphabet and other characters.

PREC: This is the precision field, which sets the number of available decimal places for the Multiplier and Offset parameters.

MULT: This is the slope multiplier. Any input on the channel is multiplied by this amount. The **M** factor in **Y=MX+B.**

OFFSET: This is the slope offset value. Any input on the channel has this amount added to or subtracted from it, after the multiplier is applied. The **B** factor in **Y=MX+B.**

FS VOLT: This is the full-scale voltage output of the sensor. The maximum voltage range that can be supplied by the sensor. This value is usually going to be either 1.000 or 2.500 volts. 2.500 is the maximum setting for this field.

INV SLOPE: This setting allows the channel to recognize a sensor with an inverse slope. This is always set to **N** (no) except for use with thermistor temperature sensors with resistance-only outputs.

VECT/SCALAR: This value sets the averaging method. **S** (scalar) is used for all measurements except wind direction, which uses **V** (vector).

MODE: This field is toggled by pressing the ID MODE soft-key. The value can be set to either MANUAL or AUTO ID. In MANUAL mode, the user can enter their own setup parameters for the channel. AUTO ID mode is used with 500 series sensors, and must be selected in order for the unit to recognize the sensor automatically. **NOTE:** Any manually set parameters for that channel will be lost when changing to AUTO ID mode. Channel 6 must be set to AUTO ID for $PM_{2.5}$ monitoring with the ambient temperature sensor BX-596.

6.9 HEATER Screen

The SETUP > HEATER screen is only visible if the HEATER CONTROL value in the SETUP > CALIBRATE menu is set to AUTO. This menu is used to configure the settings used by the BAM-1020 to control the Smart Inlet Heater. The BAM uses an RH and temperature sensor located below the filter tape in the sample air stream to monitor the conditions of the air as it is being sampled. Tests have shown that as the relative humidity of the ambient air exceeds about 50%, the particulate on the filter tape can begin to absorb moisture and the measured mass will increase. The effect gets worse as the RH increases. The Smart Heater minimizes this effect by actively heating the inlet tube to lower the humidity.

```
Heater Setup
          RH Control:  YES
         RH Setpoint:  35%
          Datalog RH:  YES (Chan 4)
     Delta-T Control:  NO
    Delta-T Setpoint:  99 C
     Datalog Delta-T:  NO (Chan 5)
  SAVE                          EXIT
```

The HEATER Setup Screen

RH Control: If YES is selected, the Smart Heater will be automatically turned on full power whenever the humidity of the sample stream exceeds the RH Setpoint. When the RH falls back below the set point, the heater turns down to a low power heat mode (about 30 Watts) which simulates the older style wrap-around heaters. If this is set to NO, The Smart Heater will stay in low power mode and no further RH control will be performed.

RH Setpoint: The RH Setpoint can be a number from 10% to 99%. This is the relative humidity level that will be maintained at the filter. Met One recommends setting this value at **35%**, which is the equilibration value for FRM filters and is required when monitoring $PM_{2.5}$.

Datalog RH: If YES is selected, the filter RH values will be logged on channel 4 of the BAM-1020. Select YES if you do not have any external sensors attached to channel 4.

Delta-T Control: The BAM-1020 can compare the filter temperature to ambient and calculate the difference (Delta-Temperature), if a BX-592 ambient temp sensor is attached to channel 6. If YES is selected, the Smart Heater will be turned down to low power mode whenever the Delta-T Setpoint is exceeded.

Volatile organic compounds (VOCs) may be lost if the Delta-T is excessive. However, this is usually not a problem with the BAM-1020, because each spot of particulate is sampled for less than an hour before being replaced with a new spot. Met One does not recommend using Delta-T control except in special applications, as it overrides the RH control which has a far greater effect on the concentration measurement. **Note:** Delta-T control must be set to NO for $PM_{2.5}$ FEM monitoring.

Delta-T Setpoint: This can be set from 1 to 99 degrees C. If the filter temperature exceeds the ambient temperature by more than this amount, the Smart Heater will turn down to low power mode, **regardless of the RH level**. An **N** error is logged in the data any time this happens. Note: There is often a few degrees of Delta-T measured even if the heater is OFF, due to mild heating effect of the unit itself. Frequent errors will be logged if the setpoint is too low. Set this value to at least 8 or 10 degrees C if used. Set the value to 99 if not used.

Datalog Delta-T: If YES is selected, the Delta-T values will be logged on channel 5 of the BAM-1020. Select YES if you do not have any external sensors attached to channel 5. **Note:** The measured Delta-T may still be logged even if Delta-T control is set to NO. This is often a useful parameter.

7 MAINTENANCE, DIAGNOSTICS and TROUBLESHOOTING

This section provides information for maintaining your BAM-1020, and for performing diagnostic tests if a problem is encountered. If the unit generates errors on the display or in the data array, first check Section 6.5 to identify the error. Many times there is a simple solution. Persistent errors often signify a failure or impending failure which will require investigation.

7.1 Met One Suggested Periodic Maintenance

Maintenance Item	Suggested Period
Nozzle and Vane Cleaning*	**Monthly**
Leak Check*	**Monthly**
Flow Rate Verification	**Monthly**
Clean Capstan Shaft and Pinch Roller Tires*	**Monthly**
Clean PM10 Head	**Monthly**
Clean PM2.5 Inlet	**Monthly**
Check Error Log*	**Monthly**
Download Digital Data Log*	**Monthly**
Compare BAM-1020 Data to External Datalogger Data (if used)	**Monthly**
Replace Filter Tape	**2 Months**
Run SELF-TEST Function	**2 Months**
Full Flow Audit and Calibration	**2 Months**
Verify BAM-1020 Settings	**2 Months**
Set Real-Time Clock	**2 Months**
Replace or Clean Pump Muffler (if used)	**6 months**
Test Pump Capacity	**6 months**
Test Filter RH and Filter Temperature sensors	**6 months**
Test Smart Heater	**6 months**
Perform 72 hour BKGD (BX-302 zero filter) test	**12 months**
Clean Internal Debris Filter	**12 Months**
Check Membrane Span Foil	**12 Months**
Beta Detector Count Rate and Dark Count Test	**12 Months**
Clean Inlet Tube	**12 months**
Test Analog DAC Output (if used)	**12 Months**
Rebuild Vacuum Pump*	**24 months**
Replace Nozzle O-ring (Special tools required)	**24 months**
Replace Pump Tubing	**24 Months**
Factory Recalibration. Not required except for units sent for major repairs.	**---**

*These items may be performed more often as required.

7.2 Audit Sheet and Test Records

The back of this manual contains a sample of a BAM-1020 Audit Sheet. This is a test record which can be filled out as calibrations, checks, or audits are performed on the unit. The operator is encouraged to make copies of this sample sheet to use as needed. Met One can also supply the original document in a Microsoft Word® format to be modified as needed. Keeping records of calibrations and maintenance is critical for any monitoring program. Most agencies develop their own SOP for maintenance items and test records.

7.3 Self-Test Feature

A primary method of identifying a hardware malfunction in the BAM-1020 is the SELF TEST feature in the TAPE menu. This can identify a large number of the possible mechanical failures in the unit, and is a good place to start if a problem is suspected or if frequent errors are recorded. See Section 3.5 for a description of the self-test process.

7.4 Power-Up Problems

The BAM-1020 must at least be able to power on before any further diagnosis can be performed. There are only a few possible reasons that the unit will fail to power up:

- Make sure that the unit is plugged into the correct AC voltage.
- Check or replace the two fuses (3.15A, 250V) inside the power switch housing. The power cord MUST be removed before the fuse door can be opened, or you will break it. Pry open the top edge of the power switch housing cover to access the fuses.
- It is possible for the display contrast to be set so light that it looks like the unit is OFF when it is really ON. Try holding the contrast key for a few seconds. In rare cases the display may fail completely. If the unit "beeps" when you press the keys, it is ON.
- If the above checks are all OK, there could be a failed power supply inside the unit. Contact Met One for further instructions. Do not attempt to open or repair the power supply assembly unless qualified.

7.5 Basic Problem and Cause/Solution Table

The following table contains information on some of the more common BAM-1020 problems which may be encountered, and some steps to identify and remedy the problems. Met One welcomes customer suggestions for new items to include in this section of future manual revisions! If the solution cannot be found in the following table, then contact one of our expert service technicians for help in resolving your problem.

Problem:	The BAM won't start a measurement cycle.
Cause/Solution:	• The unit is programmed not to start until the beginning of an hour. Make sure the clock is set correctly. • The unit will wait until the beginning of a new hour before it starts, even if the operation mode is set to ON. • Don't expect the pump to turn on until the clean tape count is finished, either 4 or 8 minutes after the start of the hour. • The unit cannot start if the pinch rollers are latched UP! The unit cannot lower them. • Make sure the filter tape is installed correctly. • The unit will never start a cycle if the display is not on the main or OPERATE menu. • The unit will usually display an error and "beep" if it cannot start a cycle

Problem:	The analog output voltage and/or digital concentration reading are full-scale.
Cause/Solution:	• The unit will force these values full-scale to indicate an error. Download the error log. Whenever the unit is started or interrupted this will happen until the next hour.

Problem:	The concentration is reading negative values.
Cause/Solution:	• It is possible for the unit to occasionally read negative numbers if the actual particulate concentration is very low, such as below 3 micrograms. This is because the BAM has a "noise band" of several micrograms. This should not happen often. • If the unit is reading negative numbers hour after hour, it is probably punching holes in the filter tape. These holes can be very small and hard to see. This is almost always caused by debris on the nozzle or vane. Clean the parts. • Make sure the SETUP > CALIBRATE values match the calibration sheet, especially the BKGD value. • The BKGD value may need to be field-audited. Met One supplies the BX-302 zero filter kit for auditing the zero reading of the unit.

Problem:	The airflow rate is too low and won't adjust up to 16.7 lpm.
Cause/Solution:	• The gray plastic pump mufflers clog up after several months. Replace it or drill a hole in the end of it for a temporary fix. The brass mufflers can often be cleaned. • Some users replace the pump muffler with a 30 inch length of air tubing. This will not clog and reduces the pump noise as well as the mufflers do. • The pump may need to be rebuilt after about 2 years. • Medo pumps slowly loose flow capacity as the pump wears out. Eventually, the flow capacity drops below 16.7 lpm when connected to a BAM. • Check the inlet and PM heads for obstructions.

Problem:	The airflow is stuck at a particular rate, and will not change.
Cause/Solution:	• The flow controller unit on some older units can become stuck. If your flow controller does not have a small circuit board mounted directly on the motor, it needs to be upgraded. Contact the Service dept. • Set the flow rate in the SETUP > SAMPLE screen to 14.0 and 17.5 lpm, and turn the pump on in the TEST > PUMP screen. The BAM should try to regulate to these values. If the flow does not change, the flow controller is probably stuck. If the flow regulates lower, but not higher than 16.7 lpm, the pump is probably worn out, or there is a leak. Be sure to set the flow back to 16.7 lpm when done.

Problem:	The nozzle gets stuck in the UP position, or won't press down onto the tape fully.
Cause/Solution:	• This is often caused by a misaligned inlet tube. Make sure it is straight up and perpendicular to the top of the unit. • The nozzle o-ring eventually breaks down and needs to be replaced. Contact Met One for detailed instructions. Special shims are required to reinstall the nozzle. • The brass nozzle bushings may have grit in them. Remove the nozzle and clean the parts. Contact Met One for detailed instructions. BX-308 tool kit required. • Lift the nozzle with your fingers and determine if it feels sticky or gritty.

Problem:	The unit has flow leaks, even after cleaning the nozzle and vane.
Cause/Solution:	• The nozzle may be sticking as described above. Verify that the nozzle up/down motion is smooth and complete. If the nozzle feels sticky or gritty, it will not seal properly. Contact Met One for instructions for removing the nozzle and replacing the internal o-ring. • Check the o-rings on the sharp-cut cyclone (if used). These frequently leak. • Check the zero of the flow sensor in the BAM: Perform another leak check, but disconnect the tubing between the pump and the BAM, so there can be no air flow through the unit. Verify that the flow reading on the BAM reads less than 0.2 lpm. If not, the flow sensor $\mathbf{C_v}$ and $\mathbf{Q_0}$ settings may need to be recalibrated as described in Section 5.8 of the BAM manual.

	• Check for bad o-rings on the BAM inlet receiver. • Remove the BAM case cover and inspect all air fittings inside the BAM. These are compression fittings, and must be fully inserted to prevent leaks. • Inspect the internal and external flow system for split or cracked air tubing.

Problem:	**The unit over-measures or under-measures concentrations compared to a collocated FRM filter sampler.**
Cause/Solution:	• The most common cause is moisture getting on the filter tape or being absorbed by the particulate. Review the Smart Heater settings for proper operation. • Test the filter RH sensor calibration, and log the filter RH on channel 4 if possible. RH should be controlled to 35%. • Verify the flow rate and temperature and pressure calibrations. • Make sure that the K-factor setting has not been changed on the BAM. This would appear as a slope error in the BAM concentration data. • Verify the BKGD (background) value is correct, and perform a 72-hour BX-302 zero filter test to verify. If the BKGD value is not correct, it will offset the BAM data by up to several micrograms. • Check for leaks at the nozzle. A leak can cause either a positive or a negative measurement bias depending if the air leaking around the nozzle is cleaner or dirtier than ambient air. • Verify the collocation setup requirements, especially making sure the inlets are spaced correctly and the same height. • If the analog output of the BAM is being logged by an external datalogger, make SURE the logger's scaling of the BAM output is correct! In most cases, a 0.000 volt analog output on the BAM does NOT equal 0.000mg, but rather -0.015 or -0.005mg. See Section 6.2 and Section 8. Periodically verify that the digital data log from the BAM matches the external logger data. • Single event FRM samplers often perform better than multi-channel FRM samplers. If a multi-channel unit is used, then filter collection must still be performed on a daily basis. If the FRM filters are not properly collected and retained every day, then correlation results with the BAM can suffer. • The daily 24-hour average of the BAM hourly values is calculated externally from the BAM. It is important that the 24 hours worth of BAM data used for correlation to the FRM is the same 24 hour period in which the sampler schedule is run. For example, if the FRM is scheduled to stop for filter changes at 9:00 am each day, but BAM data used for that same day is from midnight to midnight, then a bias can result.

Problem:	**The unit logs frequent "L" Power Failure errors.**
Cause/Solution:	• The 5 volt DC power supply output must be set to 5.25 volts. Contact the Service dept for instructions to check or adjust this. • The CHASSIS terminal needs to be connected to a good earth ground. • Try plugging the BAM into a computer-style UPS. • Even a split second power failure will cause an "L" error. This will interrupt the sample cycle until the top of the next hour. • Local high power RF fields must be avoided if possible. • Some vintages of the DC power supply used in the BAM can be prone to oxidization which can cause the unit to reset frequently. Upgrade parts may be available for certain units. Contact the Service department. • Rarely, some older 220 volt units can experience resets caused by the Smart Heater control wiring inside the BAM. Contact the Service department.

Problem:	**The BAM data shows repeated concentration values hour after hour.**
Cause/Solution:	• Certain error flags, such as the "T" (tape broken) flag will cause the BAM to repeat the last known good concentration value until the error is resolved. Check the error log to identify any errors for those hours. • If the RANGE setting on the BAM is set higher than 1.000mg, them the resolution of the A/D system is reduced to 2 micrograms. If the ambient air concentrations do not

	vary much over several hours, then the BAM data may show repeated values due to lost resolution. Leave the RANGE set to 1.000mg unless very high concentrations are expected.

Problem:	**Frequent “D” membrane density errors.**
Cause/Solution:	• This usually indicates the membrane foil surface is dirty or damaged. It can be cleaned with water rinse. Damaged membranes must be replaced. • The membrane assembly may not be fully extending or retracting properly, which causes the metal part of the assembly to partially or completely block the beta particles. Check the membrane motion.

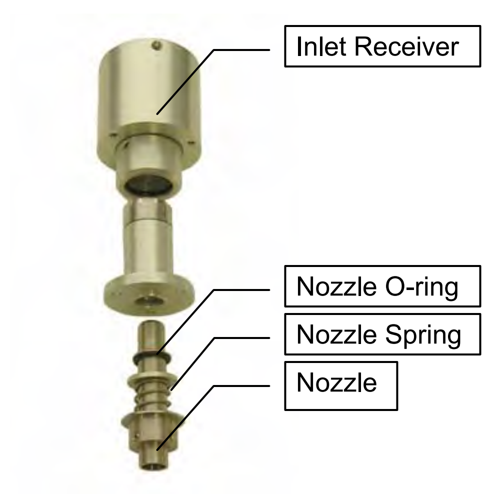
Problem:	**The clock settings are lost when the unit is powered down.**
Cause/Solution:	• The lithium battery on the 3230 circuit board may need to be replaced after about 10 years. It is normal for the clock to drift as much as 1 minute per month.

Problem:	**The filter tape keeps breaking during normal operation.**
Cause/Solution:	• The photo sensors which watch the tape transport motion may be out of alignment. Check the photo sensors as described by section 7.16. • This is sometimes caused by misalignment of the “SHUTTLE” photo sensor or the interrupter flag on the end of shuttle beam inside the BAM.

Problem:	**The display shows “MISSING TEMP PROBE” message.**
Cause/Solution:	• The unit requires a BX-596 or BX-592 ambient temperature sensor if either the CONC TYPE or FLOW TYPE are set to ACTUAL. If no sensor is attached to channel 6 of the BAM, this message will appear. • If the Auto ID line from the temperature sensor is not working, the BAM will not ID the sensor, causing the alarm.

7.6 Nozzle Component Replacement

The nozzle components need periodic inspection, cleaning, and replacement. The nozzle o-ring will need to be replaced every couple of years to prevent the nozzle from starting to stick. The nozzle itself may need to be replaced if it becomes worn or damaged, and should be removed and thoroughly cleaned annually or bi-annually. Complete instructions are available from Met One. A set of shim tools are required for nozzle re-assembly.

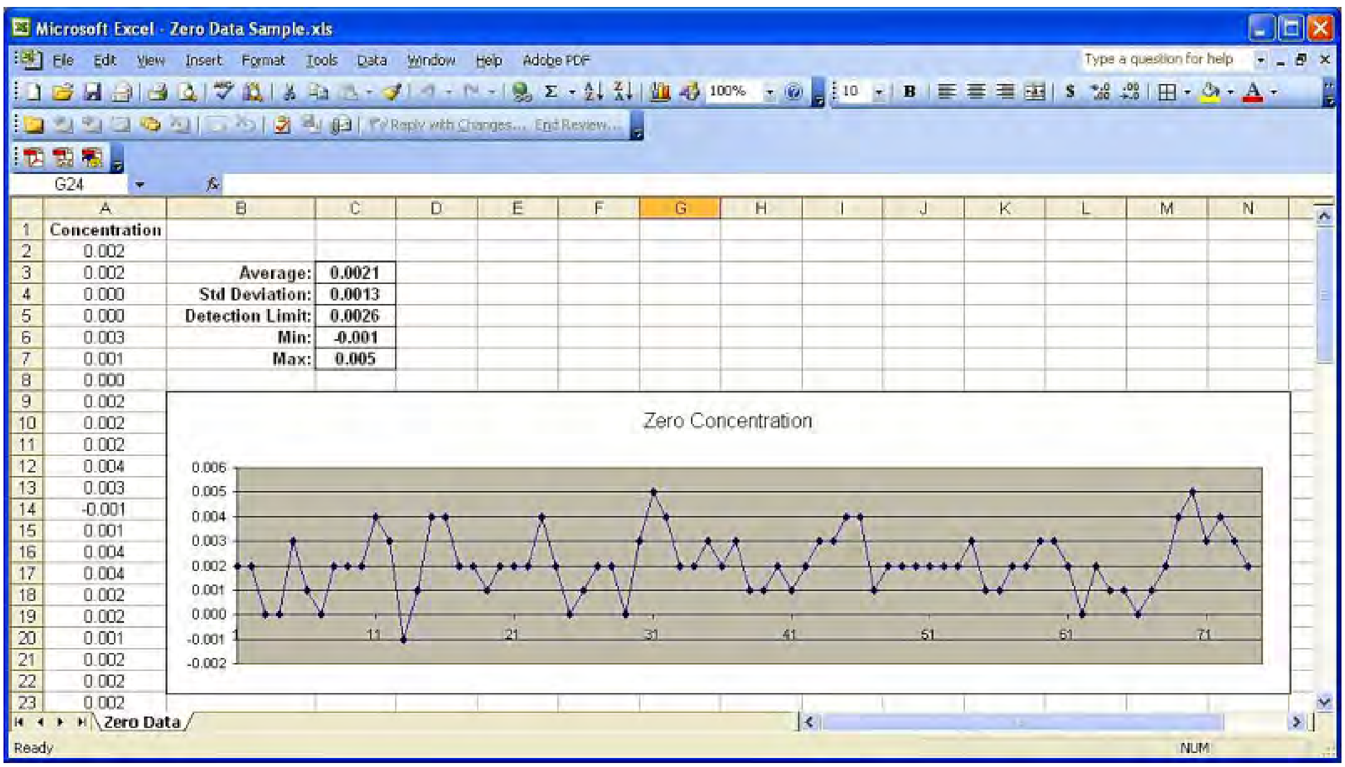


7.7 *Field BKGD Zero Background Tests*

The Background value is a correction offset for the concentration data collected by the BAM-1020 (see section 6.3 for a description of the BKGD value). This value is factory calibrated for each unit under laboratory conditions, and is typically never changed for PM_{10} monitoring.

BAM-1020 units set up to monitor $PM_{2.5}$ must to have this value field verified (and adjusted if necessary) upon deployment, and at least once per year afterwards using the BX-302 Zero Filter Calibration Kit. The test corrects the BKGD value to compensate for minor variations caused by local conditions such as grounding and shelter characteristics. This results in optimum accuracy at lower concentrations typical of $PM_{2.5}$ levels. The test also provides information about the zero noise levels of the unit being tested.

The test involves running the BAM in its normal operating environment with a zero filter on the inlet for at least 72 hours. The new BKGD will then be calculated and entered into the BAM. The test should not be performed during a period of rapidly changing weather. A complete set of instructions for the test are included with the BX-302 kit.



Typical zero background test results

7.8 Test Menu System

The following sub-sections provide information for performing diagnostic checks on the BAM-1020 sub-systems using the TEST menus. Most of these tests will be used for troubleshooting purposes only and are not necessary on properly functioning units. The TEST menu system is accessed by the TEST soft-key from the main menu and is shown below. These screens are used to perform calibrations and audits of various sensors, as well as some advanced diagnostics to resolve failures and errors.

```
                     TEST MODE

COUNT      PUMP       TAPE      DAC
CALIBRATE  INTERFACE  FLOW      ALIGN
HEATER     FILTER-T   RH


 SELECT                          EXIT
```

The TEST Menu

7.9 COUNT test Screen

The TEST > COUNT screen allows the user to check the function of the beta detector and beta source separate from the rest of the mechanical or flow operations. Each count test will take 4 minutes, and will show the number of beta particles counted as they accumulate. The final count value will stay on the display after the counting is finished, and up to six count tests can be displayed on the screen at once. Count tests are usually performed with a clean section of filter tape between the source and detector, as in normal operation. The test also allows the membrane to be extended between the source and detector as well, if desired.

TIME: This shows the time that the count test is started.

COUNT: This is the total number of beta particles counted during the four-minute test. You will see this count rapidly accruing during the test. Typical four-minute count values are between 600,000 and 1,000,000 counts through clean filter tape. The count total will be lower if the membrane is extended, which simulated adding particulate to the tape. If the count total is less than 500,000 then the beta detector is possibly wearing out.

M: Indicates if the membrane is extended (Y), or not extended (N).

MEMBRN: Press this soft-key to extend the membrane between the source and detector.

NO MEMBRN: This soft-key withdraws the membrane.

GO: This soft-key starts the four minute count test. The counting will immediately begin. After four minutes the counting will stop and wait for the operator to initiate another cycle or EXIT.

7.10 PUMP Test Menu

The TEST > PUMP screen is very useful to test the pump and nozzle, and to perform leak checks and nozzle cleaning. See section 5.3 for the leak check procedure. Note: The BAM nozzle motor drives the nozzle UP, but the nozzle is lowered by only its spring tension. It is possible for the nozzle to become stuck in the UP position even if the motor is working and no errors are generated. It is also possible for the nozzle to not fully seat against the filter tape as well. These faults are usually caused by an inlet tube alignment problem, a disintegrated nozzle o-ring, or grime in the nozzle bearings. A good indication of this problem is an irregularly shaped dust spot on the tape, often with a “halo” around it.

```
           NOZZLE/PUMP TEST MODE

NOZZLE: ▼

Flow (STD):  16.7 LPM   PUMP:  ON


MOVE NOZZLE   PUMP ON   PUMP OFF   EXIT
```

The PUMP Test screen

NOZZLE: Nozzle status. UP (▲) or DOWN (▼).

PUMP: Pump status. ON or OFF.

Flow (STD): The air flow rate, displayed in EPA Standard liters/minute.

MOVE NOZZLE: This soft-key will move the nozzle up or down. The test allows for checking proper nozzle movement. Total elapsed time is about 5 seconds. If the pump is ON this operation is disabled.

PUMP ON: This soft-key will turn ON the vacuum pump. The nozzle will automatically be lowered if necessary.

PUMP OFF: This soft-key will turn the pump OFF.

7.11 TAPE Test Menu

The TEST > TAPE menu allows the user to manually move the filter tape forwards or backwards in increments of 12.5mm “windows”. This is useful to test the tape transport mechanism or to move fresh spots of tape for other tests, such as flow or count tests. The nozzle will be automatically raised if necessary, and the tape will take a couple of seconds to move each window.

X: This is the last number of windows moved. This number will be negative if the last move was backwards.

FEED: This is the number of windows you want to move. Use the arrow up/down keys to select up to 10 windows at a time.

FWD: This soft-key will move the filter tape forward amount of the FEED value.

BKWD: This soft-key will move the filter tape backward amount of the FEED value.

7.12 DAC Test Menu – Analog Output Test

The TEST > DAC screen is used to test the function of the analog concentration output voltage and the DAC (digital-to-analog-converter) electronics. Use the up/down arrow keys to set the voltage anywhere from **0.000 to 1.000 volts** in 0.100 increments. Measure the VOLT OUT +/- terminals on the back of the BAM-1020 with a high quality voltmeter and verify that the actual voltage matches the BAM display value within ±0.001 volts at each point. Then attach the voltmeter to the input of your datalogger and repeat the test to verify that the correct voltages get to the input. If the analog output does not match the value on the TEST > DAC screen, contact the Service department for instructions. Note: 1 millivolt = 1 microgram of concentration in most applications. The DAC output cannot go negative.

7.13 CALIBRATE Test Menu

The TEST > CALIBRATE screen is used to perform tests of the reference membrane span check which occurs automatically every sample cycle. This test can be run if the BAM-1020 has been logging **D** errors. Each BAM-1020 has an individually weighed membrane, and this mass **(m)** is measured and displayed during this test. Compare the value from this test with the ABS value on the calibration sheet for your unit. The values must match within 5%. If not, the most common cause is a dirty membrane (dust or lubricant on the foil). The membrane can be carefully cleaned with canned air or clean water rinse. Alcohol is not used because it leaves a film. CD cleaner works well for badly soiled membranes. **Caution: The membrane foil is a thin sheet of polyester and is extremely fragile!** It must be replaced if damaged. Contact the Service department for replacement instructions.

```
          CALIBRATION MODE

REF MBRN: <
COUNT  (Io):        634000
COUNT  (I):         556234
CAL MASS M:         0.801 mg/cm2

START    STOP                 EXIT
```

The CALIBRATE Test Screen

REF MBRN: This indicates if the reference membrane is extended **(>)** or withdrawn **(<)** from the beta particle path.

COUNT (I_0): The total 4-minute beta count through the filter tape only, no membrane.

COUNT (I): The total 4-minute beta count through both the filter and the membrane.

CAL MASS M: This is the calculated calibration mass **(m)** derived from the two count values, the mass which the unit has just measured for the membrane. An average of several of these values should match the **ABS** value within 5%.

START: This soft-key starts the test cycle. Counting will immediately begin. After 4-minutes the **I_0 count** will stop, the membrane will extend, and the **I count** will begin. At the completion of the test the counting will stop and the mass of the membrane will be calculated. The total elapsed time is about 8.1 minutes per test.

7.14 INTERFACE Test Menu

The TEST > INTERFACE screen is used to test the relay inputs and outputs on the back of the BAM-1020. The two inputs (TELEM FAULT and EXT RESET) are tested by applying the appropriate signal to the terminals on the BAM, then verifying that the value on the screen changes in response. The five relay outputs (TAPE BREAK, FLOW ERROR, DATA ERROR, MAINTENANCE and RANGE) are tested by turning them ON or OFF using the arrow keys, then verifying that the outputs on the terminals respond accordingly. Note: RANGE not used.

7.15 FLOW Test Menu

The TEST > FLOW screen is where the very important flow calibrations are performed on most BAM-1020 units. See section 5.6. This screen is also useful to check the ambient temperature and barometric pressure sensors, and for pump and flow controller tests.

7.16 ALIGN Test Menu – Photo Sensor Tests

The TEST > ALIGN menu system is used primarily to factory-test the photo sensors which monitor all of the mechanical movement in the BAM-1020. This is useful if the unit has failed some of the Self-Test parameters. The function of the six ALIGN sub-menus are described in this section. **Note:** Remove the filter tape for these tests, or it will break.

```
                    TEST MODE

NOZZLE   SHUTTLE    IDLER     CAPSTAN
LATCH    REF


SELECT                          EXIT
```

The ALIGN Menu

NOZZLE: This screen tests the two nozzle photo sensors. Use the UP and DOWN soft-keys to move the nozzle, and monitor the status of the **S4** and **S5** photo sensors on the screen.

SHUTTLE: This screen tests the photo sensor which monitors the position of the shuttle beam (the two tape rollers that move together). The status of photo sensor **S7** should only change to ON when the beam is moved all the way to the right side. The shuttle must be moved by hand for this test.

IDLER: This screen tests the photo sensor which monitors the position of the right-side tape tensioner (the spring-loaded tape roller on the right). When the tensioner is in its left position under its spring tension, both photo sensors **S6** and **S1** should be OFF. If the tensioner is moved to the middle of its travel, photo sensor S1 should be ON and S6 OFF. When the tensioner is at the rightmost position, S1 and S6 should both be ON. The tensioner must be moved by hand. The left side tensioner assembly has no sensors to check.

CAPSTAN: This screen tests the two photo sensors which watch the rotation of the Capstan shaft. This is the shaft under the rubber pinch rollers which drives the filter tape forwards and backwards. Press the ADVANCE soft-key to rotate the Capstan counter-clockwise, and the BACKUP soft-key to rotate clockwise. The shaft should rotate one-half of a rotation each time. Photo sensor **S8** should turn ON to stop the shaft at each half-turn, and will be OFF while the shaft is turning. It is helpful to put an ink mark on the end of the shaft to view the rotation.

LATCH: This screen shows the status of the pinch roller latch. If the rollers are latched in the UP position, then **S9** should be ON. S9 should turn OFF if the latch is unhooked.

REF: This screen tests the two photo sensors which monitor the position of the reference membrane assembly. When the EXTEND soft-key is pressed the membrane should extend and the **S2** photo sensor should be ON, and **S3** OFF. When the WITHDRAW soft-key is pressed the membrane should withdraw and the S2 photo sensor should be OFF and S3 ON. It takes a few seconds for the membrane to move.

7.17 HEATER Test Menu

The TEST > HEATER screen is used to force the Smart Heater ON or OFF for testing purposes. The heater takes several minutes to heat up or cool down noticeably. The heater automatically turns back off upon exit from the screen.

7.18 FILTER-T Test Menu – Filter Temperature Sensor

The TEST > FILTER-T screen is used to calibrate the filter temperature sensor located in the air stream beneath the filter tape. When this screen is entered, the BAM will automatically raise the nozzle and turn the pump on. This allows ambient room air to equilibrate the filter temperature sensor without the heating effects of the Smart Heater. Allow the pump to run for at least 5 minutes to allow the sensor to equilibrate. Press the RESET hot key to clear out any past calibration values, then enter the ambient room temperature from your reference standard into the REFERENCE field and press the CALIBRATE hot key. The BAM reading should change to match within **+/- 1 deg C**. The RESET hot key can be used to revert to default calibrations and start over if difficulty is encountered. Older revisions of BAM firmware contain a different test screen for this sensor.

```
FILTER TEMPERATURE CALIBRATION


      BAM:   26.1 C
REFERENCE:   26.1 C


CALIBRATE    RESET                Exit
```

The FILTER-T Test Screen

7.19 RH Test Menu – Filter Humidity Sensor

The TEST > RH screen is used to calibrate the filter relative humidity sensor located in the air stream beneath the filter tape. This screen works just like the FILTER-T screen described above. Allow the pump to run for at least 5 minutes to allow the sensor to equilibrate. Press the RESET hot key to clear out any past calibration values, then enter the ambient room relative humidity from your reference standard into the REFERENCE field and press the CALIBRATE hot key. The BAM reading should change to match within **+/- 4% RH**. The RESET hot key can be used to revert to default calibrations and start over if difficulty is encountered. Older revisions of BAM firmware contain a different test screen for this sensor.

8 EXTERNAL DATALOGGER INTERFACE SYSTEM

This section describes the configuration of the BAM-1020 to work with a separate, external datalogger. The BAM-1020 provides an analog concentration output voltage, as well as an array of relay inputs and outputs. These allow the BAM-1020 to function as a sensor in a larger array of data collection instruments. There are a variety of dataloggers available which are compatible with the BAM-1020 outputs, so consult the manual for your datalogger for the specific setup requirements. Met One can supply a document showing a sample of the setup programming required for several types of datalogger manufactured by under the ESC brand name. Contact the Service department.

8.1 Analog Concentration Output Signal

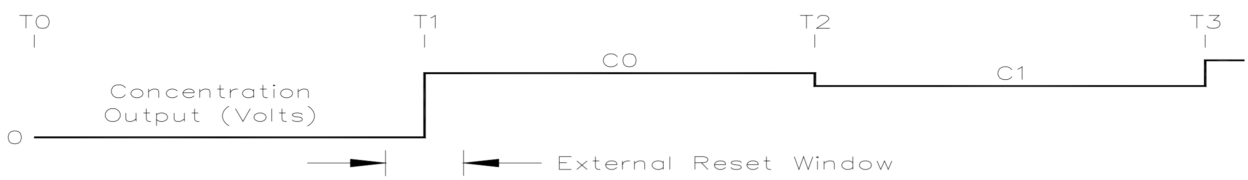
The primary link between the BAM-1020 and an external datalogger is the analog concentration output signal. The analog output type is selectable between isolated voltage (0-1 or 0-10 volt DC) and isolated current (4-20 or 0-16 mA). The rear panel dipswitches are used to select the output as shown in the table below. The one-volt range is by far the most common. The full-scale value of the output voltage corresponds to the full-scale measurement of the BAM-1020, determined by the RANGE and OFFSET setting. See Section 6.2. In the majority of applications, the analog output is set for **0-1 volt = 0 to 1.000mg or 0-1 volt = -.005 to .995mg**. If the OFFSET is set to -0.015 for $PM_{2.5}$, then the analog output is **0-1 volt = -.015 to .985mg.** The analog output should be tested as described in Section 7.12.

SWITCH	ON	OFF
SW1	0-10 vdc	0-1 vdc
SW2	4-20mA	0-16mA
SW3	Not used	Not used
SW4	Not used	Not used

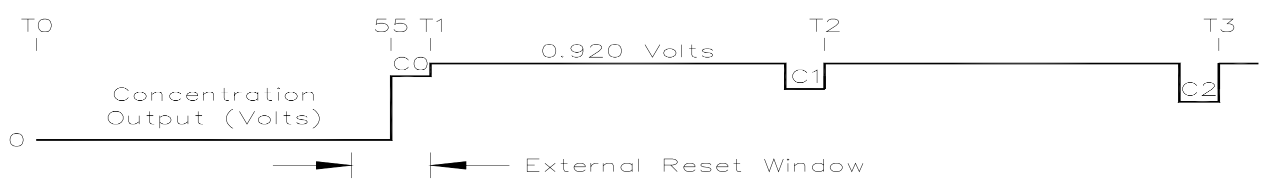
In most cases the analog output is the only channel available between the BAM-1020 and the datalogger, and any errors generated by the BAM must be reported using the same voltage signal. The BAM-1020 will set the analog output to its full-scale reading when any of the selected errors occur. The errors which cause this are selectable, and are described in section 6.5. The external datalogger should be programmed to recognize a full-scale reading as an error, not a valid concentration. This method is used because it is very rare for a concentration reading to exceed the range of the BAM-1020. The digital data values stored in the BAM are unaffected and may be viewed with the display or by downloading.

8.2 *Early Cycle Mode Description*

During a standard BAM-1020 measurement cycle, the unit waits for the beginning of the new hour before it sets the analog output to represent the just-finished hour's concentration. However, some types of dataloggers (such as ESC) must have the concentration value available **before** the new hour starts, or the data will be stored in the wrong hour. The BAM-1020 has a special EARLY cycle mode (in the SETUP > INTERFACE menu) which causes the unit to start and finish the measurement a few minutes early in order to output the concentration voltage for the last 5-minutes of the hour which was just sampled. The datalogger must be programmed to read this value during the window. The BAM-1020 clock and the datalogger clock will usually need to be synchronized because of the critical timing involved. The following describes the timing of the STANDARD and EARLY modes.



STANDARD Cycle Example



EARLY Cycle Example

Analog Output Levels

$\mathbf{C_0}$ represents the concentration output level measured from time $\mathbf{T_0}$ to $\mathbf{T_1}$, where the T labels represent the top (beginning) of an hour (such as 12:00:00). As you can see, the concentration voltage $\mathbf{C_0}$ for the standard cycle is present for the whole <u>next</u> hour following the measurement. In early mode the $\mathbf{C_0}$ voltage for the current hour is present for only the <u>last 5 minutes of the hour just-sampled</u> (minute 55 to 60), and all other times the concentration output voltage is 0.920 volts.

External Reset Windows

An external reset signal may be used to synchronize the BAM-1020 clock to the datalogger. In standard mode the external reset window is plus or minus 5 minutes around the beginning of the hour, but in early mode the external reset window is between minute 50 and 60 only. The clock will not reset if the cycle has not reached the I_3 count. The error log will contain the date and time of the reset attempt. If the I_3 count is in progress, or the cycle is past the I_3 count, then the measurement cycle is canceled. The error log will contain the date and time of the reset. A canceled cycle will also force the analog output to the full-scale values (1.000 volts in standard mode, or 0.920 volts in early mode).

Standard Mode Clock Resets:

Minute 0 to 5:	An external reset signal will change the BAM clock back to the 00:00 of the current hour. If a cycle has already started, it will continue. No error occurs since there is adequate time to complete the cycle.
Minute 5 to 55:	An external reset signal has no effect. The error log will contain the date and time of the reset attempt.
Minute 55 to 60:	If an external reset occurs after a completed cycle (idle condition), then no error occurs. The clock will be set forward to 00:00 of the next hour and a new measurement cycle will start.

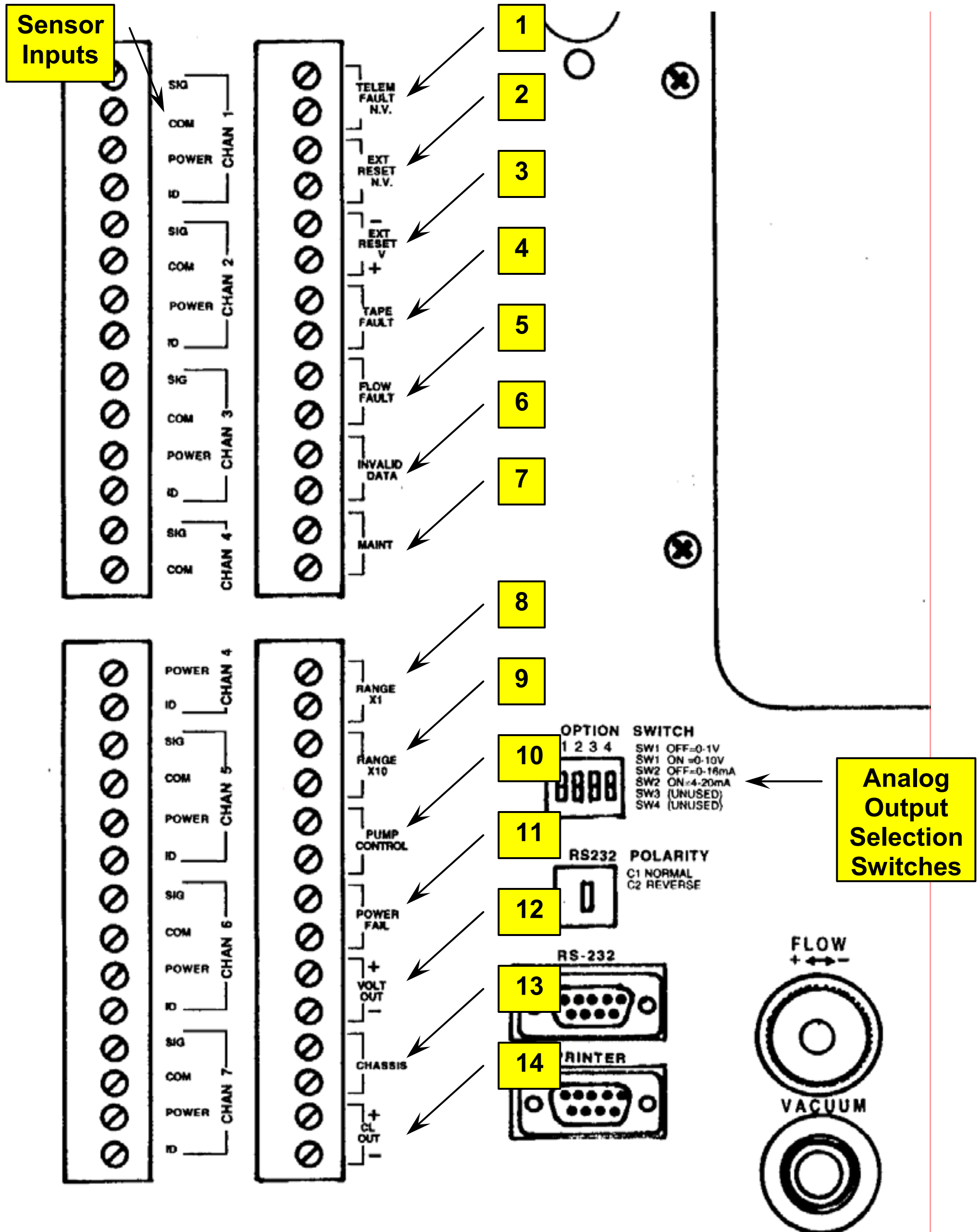
EARLY Mode Clock Resets:

Minute 55 to 60:	The external reset signal changes the clock back to minute 55:00 of the current hour. A new measurement cycle will start at that moment. If a cycle has already started, it will continue. No error occurs since there is adequate time to complete the cycle.
Minute 0 to 50:	The external reset signal has no effect. The error log will contain the date and time of the reset attempt.
Minute 50 to 55:	If an external reset occurs after a completed cycle (idle condition), then no error occurs. The clock will be set forward to minute 55:00 of the current hour and a new measurement cycle will start.

8.3 Telemetry and Error Relays

In addition to the analog output, input and output relay connections are provided on rear panel of the BAM-1020 to allow the unit to be used with an external data logger in a synchronous mode of operation. The function of each input and output is described below. Many of the relay outputs described below are related to BAM-1020 error conditions described in section 6.5.

Note: A **contact-closure input** to the BAM-1020 is achieved by shorting the two terminals on that particular input together, usually with a relay on the external datalogger. The datalogger should not apply any voltage or current to the terminals. **Contact-closure outputs** from the BAM-1020 are provided by the unit shorting the two terminals together with an internal relay, without applying any voltage or current to them. The external datalogger must then sense the closure. **Normally-Open** means that the relay contacts are not shorted together unless a certain condition occurs, while **Normally-Closed** means that the relay contacts are shorted until the condition occurs, then they open.



BAM-1020 Back Panel Relay Connections

1. **TELEM FAULT N.V.** Telemetry Fault Non-Voltage. This input can be used to signal the BAM-1020 that the external telemetry system (datalogger) is not operational. This is a contact-closure input which must be activated for a minimum of 2-seconds. If activated, the BAM will continue to function and will log a “U” error (see section 6.5) and activate the DATA ERROR relay output. This input can be set to normally-open or normally-closed in the SETUP > INTERFACE menu.
2. **EXT RESET N.V.** External Reset Non-Voltage. This input is can be used to synchronize the BAM-1020 clock to the external datalogger, and is often used in EARLY cycle mode (see section 8.2). This is a contact-closure input which must be activated for a minimum of 2-seconds. The input can be set to normally-open or normally-closed in the SETUP > INTERFACE menu.

3. **EXT RESET V** External Reset Voltage. This input is the same as above except the input is activated by a voltage logic level instead of a contact-closure. Max 15mA @ 15V or 5mA @ 5V DC. Five volt logic is typically used for this input.
4. **TAPE FAULT** This is a contact-closure output which will be activated whenever a “T” or tape error is generated (see section 6.5). Polarity is normally-open.
5. **FLOW FAULT** This is a contact-closure output which will be activated whenever an “F” or flow error is generated (see section 6.5). Polarity is normally-open.
6. **INVALID DATA** This is a contact-closure output which will be activated whenever a C, P, N, R, L, I, M, or U error is generated by the BAM (see section 6.5). Polarity is normally-open.
7. **MAINT** This is a contact-closure output which will be activated whenever a maintenance “M” flag is generated (see section 6.5). Polarity is normally-open.
8. **RANGE X1** This contact-closure output is no longer supported. The relay for this channel is now used by the Smart Heater.
9. **RANGE X10** This contact-closure output is no longer supported. The relay for this channel is now used by the Smart Heater.
10. **PUMP CONTROL** This is the low-voltage output which signals the vacuum pump to turn on or off. There is no polarity on this output because the pump controller has a diode bridge input. Connect the two-wire control cable from the pump to these output terminals.
11. **POWER FAIL** This is a contact-closure output which will be activated (closed) whenever a power failure of the 5 volt DC system or an “L” error occurs (see section 6.5).
12. **VOLT OUT** This is the analog concentration output voltage terminal. Typically 0-1 VDC. See section 8.1. Polarity must be observed on this output.
13. **CHASSIS** These are the earth-ground terminals. These must be attached to a solid ground point for best operation of the unit.
14. **CL OUT** Current Loop Output. This is used when the analog output is needed in current loop form instead of voltage. Typically only used if there is a long distance between the BAM and the datalogger. Output is selectable between 4-20mA or 0-16mA.

8.4 Digital Datalogger Interfacing with the BAM-1020

Applications involving digital data transfer between the BAM-1020 and other manufacturer’s digital dataloggers, such as DR DAS™ and Campbell CR-1000™ models among others, have become more common. This typically requires a considerable amount of programming experience with the particular type of logger to be used. Any digital files from the BAM-1020 must be obtained from either the RS-232 two-way serial port, or the RS-232 output-only printer port. There are several possible pitfalls which can be encountered when collecting BAM-1020 data with a digital datalogger.

The most straight-forward way to accomplish digital datalogger interface with the BAM is to configure the printer output port as a fixed width data output as described in Sections 9.5 and 9.4. This causes the BAM-1020 to output a single fixed-width string of data at the end of each sample hour without having to be prompted. The digital logger must be programmed to wait for the data string, then process it appropriately.

The alternative is to program the digital datalogger to send the BAM-1020 the appropriate commands to retrieve data, just like you would when downloading the data with a computer as described in Section 9.4. Typically, the BAM would be sent the appropriate commands to respond with CSV files 6,3 (new data since last download) or 6,4 (last hourly data record only). The digital logger must receive and sort the files appropriately.

The most important consideration when collecting the data in this manner is to remember that the BAM-1020 only measures concentration data once per hour, and during other parts of the hour (especially near the beginning and end of each hour) the BAM is often moving tape transport parts and making mechanical adjustments which **prevent the unit from responding to digital data requests** due to a busy processor. See Section 4. The best solution is to program the digital logger to make a single data request to the BAM at some time during the sample period near the middle of each hour, such as between minute 25 and minute 50. This is especially important if large amounts of data are to be downloaded at once, since it can take more than 10 minutes to download the entire data log. If the download overlaps a mechanical motion by the BAM, then the data can be delayed by several seconds in the middle, or even interrupted entirely. Small digital files (such as the last hourly record only) can be downloaded very quickly, and may be accomplished at almost any time during the hour as long as the timing is carefully controlled. It is highly recommended that the BAM clock be regularly synchronized by the external datalogger to prevent timing problems due to clock drift.

If a datalogger is programmed to digitally request data from the BAM-1020 continuously throughout the hour (such as every minute), then there will almost certainly be a number of requests each hour which will be ignored by the BAM due to mechanical interrupts.

Met One is often able to provide more technical information and support to help our customers develop effective programs for operating certain types of digital dataloggers with the BAM-1020. In addition, we are always eager to hear about new ways that users have found to implement this type of interface. Contact Met One Technical Service.

9 RS-232 SERIAL COMMUNICATIONS – DATA RETRIEVAL

This section describes the methods used to retrieve digital data files through the RS-232 serial communications system on the BAM-1020. The unit has a two-way serial port which may be used with a computer, laptop, modem, digital datalogger, or data transfer module. There is also a configurable output-only serial printer port. Access to the data through the serial port is a simple menu driven interface.

9.1 Serial Port Connections and Settings

The RS-232 serial port on the back of the BAM-1020 handles data transfer and may also be used for instrument setup and operation status checks. The serial port may also be used with an optional modem for remote communications through a phone line (See Section 9.6).

Desktop Computer Connections: The BAM-1020 can be connected to almost any standard PC that has an RS-232 serial port available (COM1 to COM4). Connect the RS-232 port on the back of the BAM-1020 to the COM port connector on the computer with a female-to-female 9-pin null RS-232 cable. (Belkin F3B207-06 is recommended and available from Met One). **CAUTION:** Do not confuse the parallel printer port or video adapter port on your computer with a serial port. Connecting the BAM-1020 to these may cause damage to your computer and the BAM. If in doubt, consult the computer manual before connecting.

Laptop Computer Connections: The BAM-1020 can be connected to most laptop computers. Most older laptops have a regular 9-pin RS-232 serial port, just like a desktop computer. Modern laptops do not usually have RS-232 ports, so a converter will have to be obtained. The easiest and cheapest type is a USB-to-RS232 serial adapter. Met One recommends the Belkin F5U109, available from Met One or a local electronics store. You will still need the Female-to-Female 9-pin RS-232 cable. Certain laptops occasionally have difficulty communicating through this type of adapter. Met One does not recommend converters sold under the Radio Shack brand name. Another option is an RS-232 serial PCMCIA card, such as the Quatech SSP-100 which installs in an expansion card slot in the laptop and provides a serial port for the BAM. This type of adapter is very reliable, but more expensive and takes longer to install and configure. See www.quatech.com for more information.

Communication Settings: The BAM-1020 communicates at 9600 Baud, 8 data bit, no parity, one stop bit. 9600 baud is the default setting which may be changed. The BAM-1020 settings must match these in the SETUP > SAMPLE menu. If unable to communicate, try changing the RS-232 Polarity switch on the back of the BAM-1020. This swaps the polarity of the TX and RX lines (2&3) and functions as a null modem. **NOTE: The BAM-1020 user interface must be in the main top-level menu or OPERATE menu before serial port communication can be established.** The serial port is disabled in all other menus. Also, the LCD display and keypad on the BAM-1020 are disabled whenever RS-232 communication is in progress.

9.2 Met One Communications Software

The BAM-1020 is compatible with several communications software programs available from Met One Instruments:

MicroMet® Plus: A powerful and comprehensive data logging program for meteorological applications which is configurable to collect and manage all data from the BAM-1020.
Comet™: A simple and easy to use communications terminal program which can retrieve data from Met One data loggers, including the BAM-1020. This program replaces the old TUS (Terminal Utility Software) program.

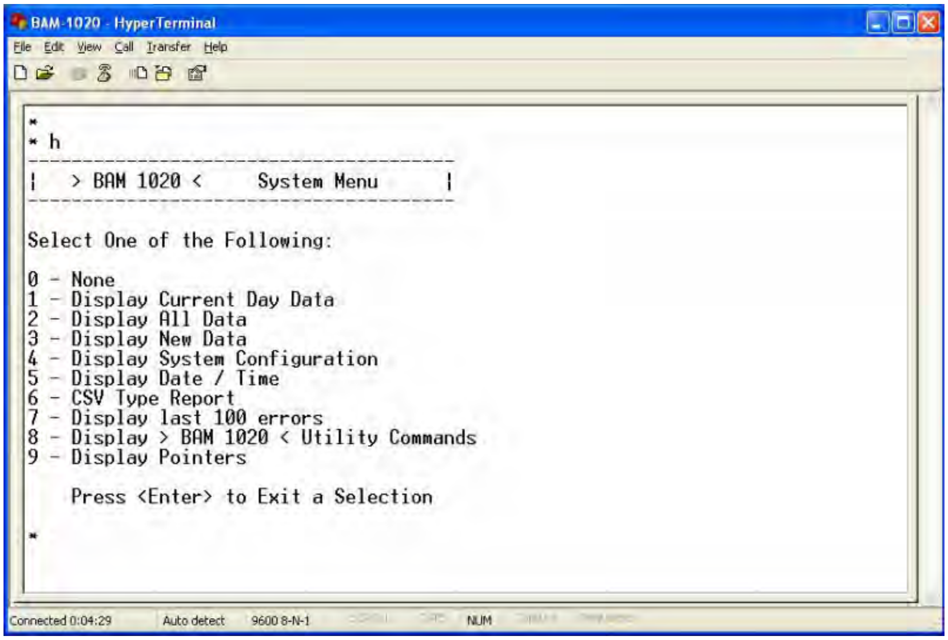
9.3 Downloading Data Using HyperTerminal

The BAM-1020 data can be easily downloaded through the serial port using HyperTerminal® or other simple terminal programs. Nearly all PCs running Microsoft Windows 95® or later operating systems have the HyperTerminal program included. This section describes how to set up this program for communication with the BAM-1020. **Note:** The BAM-1020 display must be on the Main Menu in order to establish communications.

1. Connect the RS-232 port on the back of the BAM to your computer or laptop using the appropriate cable. Connect to the Com1 serial port if available.
2. Open HyperTerminal. (Usually located in the Programs\Accessories\Communications directory). The program will ask you to type a name for the connection. Type “BAM-1020” or a name of your choice, then click “OK”.
3. The “Connect To” window will open. Select COM1 (or another port if used) from the drop-down menu in the “Connect using:” field. Click “OK”. Note: You could also set up the program to dial the BAM through a modem in this window.
4. The “COM1 Properties” window will open. Set the following values in the drop-down menus, then click “Apply” and “OK”.

Bits per second:	**9600**
Data bits:	**8**
Parity:	**None**
Stop bits:	**1**
Flow control:	**None**

5. The main HyperTerminal connection window should now be open. Press the ENTER key three times. The window should respond with an asterisk (*) indicating that the program has established communication with the BAM-1020.
6. Once communication is established, press the **h** key. This should cause the BAM-1020 System Menu to appear on the window as shown below. You can now send any of the characters in the menu to retrieve the desired files. The menu options are described in the following sections.
7. HyperTerminal will only display 100 lines of data in the window. To capture larger files (such as All Data), first select Transfer > Capture Text from the drop-down menu. Select a location for the file, then click the “Start” button. Retrieve the desired files, and HyperTerminal will automatically store them to the text file.
8. When you exit HyperTerminal, it will ask if you want to save your connection. Click “Yes” and a file named BAM-1020.ht will be created in the HyperTerminal folder, which will have all of the settings saved. Use this for future communications with the BAM.



Terminal Window showing BAM-1020 menu

9.4 System Menu File Descriptions

Once a serial connection between the computer and the BAM-1020 has been established as shown above, you will have access to the main BAM-1020 System Menu. Each number 0-9 represents a different data file you can download from the unit. Each file is described below. To get the desired file, simply press the appropriate number on your keyboard. **Note:** After a few minutes, the BAM will stop waiting for a command and you will have to send another **"h"** to reestablish the connection.

File 1: Display Current Day Data

This file will include a text view of the current day's data only. An example of the data format is shown below. The first column is the time, followed by a series of dashes. Each dash represents a possible error. If an error occurred, a letter representing the error will appear in this field. For this example, at 7:00 am an **"L"** error (power failure) occurred. Then at 8:00 an **"M"** error was logged, indicating that the operator was performing maintenance that hour.

The next column is the concentration. Notice that the values went full-scale during the two hours that errors were logged. This indicates invalid data. The Qtot column is total flow volume for the hour. With a flow rate of 16.67 LPM, and a sample time of 50 minutes, this value will be about .834 m^3 per hour. (16.7 * 50 / 1000 = .8335). The remaining six columns are the six datalogger inputs on the BAM. In this example RH was logged on channel 4, and Ambient Temperature was logged on channel 6. The other four channels had nothing attached, but will appear in the array anyway. (The data shown on those channels in this example is only noise.)

```
Report for 04/22/2005 - Day 112    > BAM 1020 <    Station ID:  1

Channel                        01      02      03      04      05      06
Sensor         Conc   Qtot     WS      no      WS      RH      WS      AT
Units          mg/m3  m3       KPH     V       MPS     %       KPH     C
======================================================================
01:00 ------------  0.010  0.834  019.6  0.012  000.3  00017  132.2  008.7
02:00 ------------  0.009  0.834  019.9  0.012  000.3  00018  132.1  007.4
03:00 ------------  0.011  0.834  019.8  0.012  000.3  00018  132.1  006.5
04:00 ------------  0.011  0.833  020.0  0.012  000.3  00018  132.1  006.1
05:00 ------------  0.012  0.833  019.8  0.012  000.3  00018  132.1  005.3
06:00 ------------  0.011  0.834  020.1  0.012  000.3  00018  132.0  005.6
07:00 ----L------  0.995  0.000  020.3  0.012  000.3  00018  132.0  007.4
08:00 ---M------  0.995  0.000  019.8  0.012  000.3  00017  132.1  009.4
09:00 ------------  0.008  0.833  019.9  0.012  000.3  00015  132.2  012.5
10:00 ------------  0.003  0.834  019.5  0.012  000.3  00014  132.2  016.2
11:00 ------------  0.007  0.833  019.5  0.012  000.3  00013  132.2  019.7
12:00 ------------  0.011  0.833  019.5  0.012  000.3  00012  132.0  020.7
13:00 ------------  0.008  0.833  019.1  0.011  000.3  00010  132.0  021.9
14:00 ------------  0.010  0.833  019.2  0.011  000.3  00010  131.9  022.3
15:00 ------------  0.020  0.833  019.1  0.011  000.3  00011  132.0  020.9
16:00 ------------  0.011  0.834  019.3  0.011  000.3  00012  132.1  018.7
17:00 ------------  0.010  0.833  019.5  0.012  000.3  00012  132.2  017.9
18:00 ------------  0.010  0.833  019.4  0.012  000.3  00012  132.1  017.1
19:00 ------------  0.010  0.834  019.4  0.012  000.3  00014  132.2  015.3
20:00 ------------  0.007  0.833  019.6  0.012  000.3  00015  132.1  014.4
21:00 ------------  0.006  0.834  019.5  0.012  000.3  00017  132.1  013.3
22:00 ------------  0.006  0.834  019.7  0.012  000.3  00021  132.0  011.2
23:00 ------------  0.005  0.833  019.6  0.012  000.3  00023  132.0  010.0
00:00 ------------  0.011  0.834  019.9  0.012  000.3  00017  132.2  009.5

Savg            0.009  0.833  019.7  0.012  000.3  00015  132.1  013.2
Vavg            0.000  0.000  000.0  0.000  000.0  00000  000.0  000.0
Data Recovery 100.0 %
```

File 1 data text file example

File 2: Display All Data

This file will download a text file of all of the data stored in the BAM-1020 memory, in the same format as the above example. Be sure to capture text (section 9.3) if downloading this file using HyperTerminal, as it can be fairly large.

File 3: Display New data

This file will contain text of all of the data stored by the BAM-1020, since the last time the data was downloaded. Useful to avoid duplicate data in your database. A flag is set in the BAM indicating where the last download stopped.

File 4: Display System Configuration

This file will contain a list of most of the BAM-1020 settings and calibration values as shown below. This is useful for verifying the setup on a remote BAM, and to send to the factory if service is required. The setting report has been updated and reformatted. Following is an example of the new settings report. Older firmware will show a slightly different report.

```
BAM 1020 Settings Report
06/07/2007  14:19:45
     Station ID, 1
       Firmware, 3236-02 3.2.5
              K, 01.000
           BKGD, 00.000
            usw, 00.301
            ABS, 00.805
          Range, 1.000
         Offset, -0.015
          Clamp, -0.015
     Conc Units, mg/m3
      Conc Type, ACTUAL
             Cv, 01.000
             Qo, 00.000
      Flow Type, ACTUAL
     Flow Setpt, 0016.7
       Std Temp, 25
      Temp Mult, 1.0000
      Pres Mult, 1.0000
      Flow Mult, 1.0000
High Flow Alarm, 20
 Low Flow Alarm, 10
      Heat Mode, AUTO
       Heat OFF, 20
        RH Ctrl, YES
       RH SetPt, 35
         RH Log, YES
        DT Ctrl, NO
       DT SetPt, 99
         DT Log, NO
     BAM Sample, 42
     MET Sample, 60
     Cycle Mode, STANDARD
 Fault Polarity, NORM
 Reset Polarity, NORM
    Maintenance, OFF
   EUMILRNFPDCT
   000000000000
             AP, 000150
      Baud Rate, 9600
 Printer Report, 2
             e3, 00.000
             e4, 15.000

        Channel,       1,       2,       3,       4,       5,       6,
      Sensor ID,     255,     255,     255,     255,     255,     255,
     Channel ID,     255,     255,     255,     255,     255,     255,
           Name,   XXXXX,   XXXXX,   XXXXX,   XXXXX,   XXXXX,   XXXXX,
          Units,     XXX,     XXX,     XXX,     XXX,     XXX,     XXX,
           Prec,       0,       0,       0,       0,       0,       0,
       FS Volts,   1.000,   1.000,   1.000,   1.000,   1.000,   1.000,
           Mult,   1.000,   1.000,   1.000,   1.000,   1.000,   1.000,
         Offset,   0.000,   0.000,   0.000,   0.000,   0.000,   0.000,
    Vect/Scalar,       S,       S,       S,       S,       S,       S,
      Inv Slope,       N,       N,       N,       N,       N,       N,
```

File 4 system configuration file example

File 5: Display Date / Time
This file will show the date, time and serial number of the BAM-1020.

File 6: CSV Type Report
This command will give you three Comma-Separated-Value options which you can select by sending the appropriate number below. Each of the data files are the same as above, except the values in each column are separated by commas (,). This allows the text file to be opened directly by Microsoft Excel® or other spreadsheets. This is the recommended data retrieval method. Be sure to capture text when downloading large files if using HyperTerminal. The CSV reports are also often used when BAM data is downloaded by an external digital datalogger. Following is a list of the files available in CSV format:

2 – Display All Data	(All data)
3 – Display New Data	(Data since last download)
4 – Display Last Data	(Previous hour's data only)
5 – Display All Flow Stats	(All flow stats)
6 – Display New Flow Stats	(Stats since last download)
7 – Display All 5 Min Flow	(5 minute averages of all flow stats)
8 – Display New 5-Min Flow	(5 min averages of flow stats since last download)

Example of a CSV Report of the "LAST DATA" record:
The following example shows a CSV download of the last data record from the BAM-1020. This file download does not reset the data pointer.

1. A series of three carriage returns is sent to the BAM through the serial port.
2. After the third carriage return, the BAM responds with a single asterisk (*) indicating that communication is established. If the BAM is moving the tape, it will respond with "BUSY". If the BAM is not in one of the OPERATION menus, it will not respond at all.
3. A single character "6" is sent to the BAM requesting the file 6 menu (CSV).
4. The BAM responds with the CSV menu options as shown below, ending with ">". The system requesting the files can ignore the menu response.
5. A single character "4" is sent to the BAM, requesting file 4 "Display Last Data".
6. The BAM responds with the Station ID number (in this case 5), then the header info, then the data record.

The data includes date/time stamp, concentration for the last hour (CONC), Flow volume for last hour (Qtot), then all six individual met sensor channels. The labels for these channels will vary, but will always appear in the data array regardless if used or not. In this example the six channels start with "WS" and end with "AT". At the end of the array are twelve error bits, each representing a different possible error. "0" indicates no error of that type, and "1" indicates an error. In this example, the "M" and "T" bits are high, indicating that the unit is taken out of operation, and that the tape has run out.

```
* 6
CSV Type Reports

2 - Display All Data
3 - Display New Data
4 - Display Last Data

5 - Display All Flow Stats
6 - Display New Flow Stats

7 - Display All 5-Min Flow
8 - Display New 5-Min Flow

>4 - Display CSV Data
Station,  5
Time,Conc(mg/m3),Qtot(m3),WS(MPS),WD(DEG),BP(mm),RH(%),Delta(C),AT(C),E,U,M,I,L,R,N,F,P,D,C,T
01/30/08 16:00,  0.084, 0.834, 0.0,0,0,30,57.0,27.1,0,0,1,0,0,0,0,0,0,0,0,0,1,
```

Example of CSV last data report

Example of a CSV Report of the "NEW DATA" records:

This file contains all of the data record since the last download, and resets the pointers. In the following example, the data is retrieved exactly the same way as described above, except that file 3 "new data" is requested. The data starts at the first record since last time it was retrieved (oct 2, 2007 at 17:45). In this example, the MET SAMPLE was set to log the array every 15 minutes, but the particulate concentration value just repeats until the next hour.

```
* 6
CSV Type Reports

2 - Display All Data
3 - Display New Data
4 - Display Last Data

5 - Display All Flow Stats
6 - Display New Flow Stats

7 - Display All 5-Min Flow
8 - Display New 5-Min Flow

>3 - Display CSV Data
Station,  5
Time,Conc(mg/m3),Qtot(m3),WS(MPS),WD(DEG),BP(mm),RH(%),Delta(C),AT(C),E,U,M,I,L,R,N,F,P,D,C,T
10/02/07 17:45,  0.001, 0.700, 0.110,0,0,36,1.3,23.0,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 18:00,  0.001, 0.700, 0.127,0,0,38,1.4,23.2,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 18:15,  0.001, 0.700, 0.130,0,0,38,1.2,23.6,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 18:30,  0.001, 0.700, 0.110,0,0,36,1.1,23.5,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 18:45,  0.001, 0.700, 0.110,0,0,37,1.2,24.0,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 19:00,  0.003, 0.700, 0.127,0,0,38,1.1,24.6,0,0,0,0,0,0,0,0,1,0,0,0,0,
10/02/07 19:15,  0.003, 0.700, 0.129,0,0,38,1.1,24.8,0,0,0,0,0,0,0,0,0,0,0,0,0,
10/02/07 19:30,  0.003, 0.700, 0.109,0,0,37,0.9,24.0,0,0,0,0,0,0,0,0,0,0,0,0,0,
```

Example of CSV new data report

The flow statistics fields available in the CSV menu are described below. These files are not available except on BAM units configured as FEM $PM_{2.5}$ units. A BX-596 sensor is required.

Field	Description
Start	Start time of BAM sample period.
Elapsed	Elapsed BAM sample time.
Flow	Average flow rate for the BAM sample period.
CV	Flow rate coefficient of variance for the BAM sample period.
Volume	Sample volume for the BAM sample period.
Flag	Flow regulation out of range warning flag.
AT	Average ambient temperature for the BAM sample period.
AT Min	Minimum ambient temperature for the BAM sample period.
AT Max	Maximum ambient temperature for the BAM sample period.
BP	Average ambient pressure for the BAM sample period.
AT Min	Minimum ambient pressure for the BAM sample period.
AT Max	Maximum ambient pressure for the BAM sample period.

The 5 minute flow statistics averages are described below. These files are not available except on BAM units configured as FEM $PM_{2.5}$ units. A BX-596 sensor is required.

Field	Description
Time	Event time stamp in seconds since January 1, 1970 00:00:00
Flow	Minute average flow rate for the BAM sample period.
AT	Minute average ambient temperature for the BAM sample period.
BP	Minute average ambient pressure for the BAM sample period.

File 7: Display Last 100 Errors

This file will contain the date, time, and a description of each of the last 100 errors logged by the BAM-1020. This is a useful file for troubleshooting, and it will often be requested by Met One technicians if service is required.

File 8: Display > BAM-1020 < Utility Commands

This file contains a list of the ASCII commands can be sent to the BAM-1020 through the serial port to configure certain parameters or to perform advanced diagnostics. Most of these commands will not be used by the typical operator unless instructed by a factory technician. Some of these commands require a password to access. The password is the same as the F-key sequence used to enter SETUP screens (default password is **1 2 3 4**). The appropriate command character is sent to the BAM to apply the functions shown in the table below.

Command	Command Function
a	**Printer Port Output Configuration.** This sets what is output on the 2nd serial port. Sending this command will prompt the following sub-menu: 1 – Printer Port (default) 2 – Standard Diagnostic Port 3 – Factory Diagnostic Port 4 – Comma Separated Data Output Port
c	**Clear Data Memory.** This command erases all stored data from memory! Password required.
d	**Set Date.** This sets the date on the unit. Password required.
e	**Display Hex EEPROM Setup Values.** This displays the special memory locations where the setup values are stored. Diagnostic only.
f	**Factory Calibration Test.** This is used for factory calibration only!
h or ?	**Display System Menu.** This is the command used to access the data downloading menu options. Become familiar with this command.
i	**Display ID Values.** This command displays the ID codes of the met sensors for diagnostic purposes.
m	**Display Hex Data Memory Values.** This command displays the data memory locations for diagnostic purposes.
p	**Modify Modem Pointer.** Factory use only.
q	**Display Station ID.** This command displays the preset station ID number.
t	**Set Time.** This command sets the time on the unit. Password required.
b	**XMODEM Data Download**. This command allows binary data transfer of the unit memory. Download only. Requires software handshaking. For use with special software only, not terminal programs. Advanced use only.
r	**XMODEM Real-Time Value Download.** This command is only used by special software to scan instantaneous values of sensors, alarms and settings. Requires software handshaking. Advanced use only.
x	**XMODEM EEPROM Value Download.** This command allows quick scanning of non-volatile memory for diagnostic purposed. Advanced use only.
z	**Enable concentration report to PRINTER output.** This command configures the printer port to output a fixed-width concentration report at the end of the sample period. For external loggers.

File 9: Display Pointers
This file is a display of the current status of the data storage memory. The current pointer position and number of full memory locations is shown. Rarely used.

9.5 Printer Output Port

The Printer port on the back of the BAM-1020 is an output-only RS-232 serial interface which may be used with a serial printer or as a diagnostic output to a computer. The printer port output can be configured by using the "**a**" utility command through the main RS-232 port. (See section 9.4) The output may be set for data printouts, fixed-width data output, or one of two diagnostic modes. Diagnostic modes are not used except by a factory technician.

A new configuration has been added for the printer port which enables it to output a fixed-width concentration report at the end of the sample period, which can be used to interface to a serial data logger. This output is enabled by using the **"z"** utility command through the serial port. The output format is date, time, concentration, and flow volume as shown below.

Format in mg/m3 is: **mm/dd/yy hh:mm:ss,+99.999,+9.999**
Format in µg/m3 is: **mm/dd/yy hh:mm:ss,+999999,+9.999**

If the BAM is set to STANDARD cycle mode, the output will occur at the top of the next hour. For example, if a measurement is made over hour 2, then the format would be:

03/28/07 03:00:00, +00.027,+0.834

If the BAM is set to EARLY cycle mode, the output will occur at minute 55:00 for the current hour. For example, if a measurement is made over hour 2, then the format would be:

03/28/07 02:55:00, +00.027,+0.834

9.6 Modem Option

The Met One Instrument BX-996 modem is recommended for use with the BAM-1020, as it is designed to reliably communicate when other modems may not. Note: the RS-232 Polarity switch on the back of the BAM-1020 may need to be set to REVERSE polarity for communication using the modem. If you are using one of the Met One Instruments data acquisition programs such as MicroMet Plus or MicroMet AQ, you need only enter the telephone number of the site in the system setup menu of the program. Multiple telephone numbers can be entered for connection to multiple remote sites.

If you are communicating with a terminal program such as HyperTerminal® or ProComm Plus® you will need to define the serial port configuration in the setup of the program. Set the baud rate to 9600, with 8 data bits, no parity, and 1 stop bit. Use the terminal program's internal dialing command sequence to dial up the BAM-1020. Verify the connection to the BAM-1020 by pressing the <Enter> key until the command prompt asterisk (*) appears. If not, verify the cabling and communications settings. Once connected, the access to the BAM-1020 is the same menu driven interface as used for the direct PC connection.

9.7 Flash Firmware Upgrades

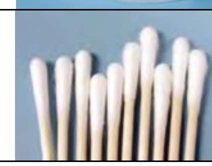
The BAM-1020 now has the capability for flash firmware upgrades. This allows the field operator to reprogram the flash EEPROM through the serial port using the Flash Update Utility. Units with a firmware revision of 3.0 or higher can be flash upgraded. If the unit currently has a revision lower than 3.0, the EEPROM will have to be replaced with a flash compatible chip. The following tasks must be performed whenever firmware is upgraded or the EEPROM is replaced:

1. Download and save all data and error logs before proceeding. These will be cleared during the upgrade process!
2. Record the OFFSET value from the SETUP > SAMPLE screen, and the BKGD value from the SETUP > CALIBRATE screen. A download of the settings file is advised.
3. Update the firmware.
4. The baud rate will default to 38400. Reset as appropriate.
5. Recalibrate the filter temperature and filter RH sensors.
6. Set the values of OFFSET, CONC UNITS, and COUNT TIME in the SETUP > SAMPLE screen.
7. Set the values of CONC TYPE, FLOW TYPE, and BKGD in the SETUP > CALIBRATE screen. Review all other BAM-1020 settings to make sure they are all correct.

10 ACCESSORIES and PARTS

10.1 Consumables, Replacement Parts, and Accessories

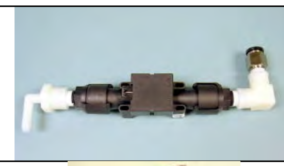
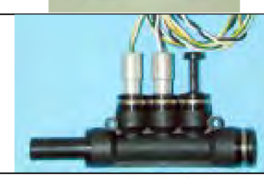
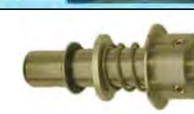
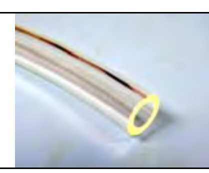
The following parts are available from Met One for maintenance, replacement, service, and upgrades. If unsure about a part you need, please contact the Service department. Some of these parts require technical skills or special considerations before use or installation.

Description	Part Number	Graphic
Consumables		
Filter Tape Roll, Glass Fiber, 60+ days per roll 30mm x 21m	**460130**	
Cotton-Tipped Applicators, nozzle cleaning, 100 pack Solon #362	**995217**	
Tools		
BAM-1020 Service Tool Kit: Includes nozzle shims, spring scales, reel spacer, filter sensor removal tool	**BX-308**	
Leak Test Rubber Nozzle Seal	**7440**	
Membrane Assembly, Replacement, 0.800 mg/cm2	**8069**	
Membrane Assembly, Mid-Range, 0.500 mg/cm2	**BX-301**	
Mass Flow Calibration Kit, 0-20 SLPM	**BX-303**	
Flow Inlet Adapter Kit (Leak Test Valve) Includes short inlet tube	**BX-305**	
Zero Filter Calibration Kit, with valve Required for PM2.5 FEM monitoring Same as BX-305 but with 0.2 micron filter	**BX-302**	
Volumetric Flow Calibration Kit (BGI Delta Cal™) Flow, Temp, and Pressure Reference Standards Met One recommended flow meter	**BX-307**	

Pumps and Pump Parts

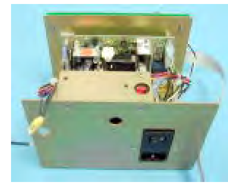
Pump, Medo, 115 VAC, 50/60 Hz, Low Noise	**BX-126**	
Pump, Medo, 230 VAC, 50/60 Hz, Low Noise	**BX-127**	
Pump, Gast, Rotary Vane, 100 VAC, 60 Hz	**BX-123**	
Pump, Gast, Rotary Vane, 115 VAC, 50/60 Hz	**BX-121**	
Pump, Gast, Rotary Vane, 230 VAC, 50 Hz	**BX-122**	
Pump, Gast, Rotary Vane, 230 VAC, 60 Hz	**BX-124**	
Muffler, Medo/Gast Pump, Replacement	**580293**	
Pump Rebuild Kit, Gast	**680828**	
Pump Rebuild Kit, Medo	**680839**	
Pump Service Kit, Filter Replacement, Medo	**8588**	
Pump Controller (Relay Module) Medo/Gast	**BX-839**	

Flow Components

Flow Sensor, Mass, 0-20 LPM, Internal Assembly	**80324**	
Flow Controller Assembly, Replacement Only	**8776**	
Automatic Flow Controller Upgrade Kit	**BX-961**	
Filter Assembly, Pisco In-line	**580291**	
Filter Element Only, Pisco In-line	**580292**	
Filter Temperature and RH Sensor Kit	**BX-962**	
Filter RH Sensor Replacement Only	**9278**	
Filter Temperature Sensor Replacement Only	**9279**	
Nozzle, Stainless Steel, Replacement Part	**8009**	
Nozzle Spring, Replacement	**2998**	
O-Ring, Nozzle	**720066**	
O-Ring, Inlet Receiver, 2 required	**720069**	
O-Ring Kit, BAM	**9122**	
Pump Tubing, Clear, 10mm O.D., 6.5mm I.D. Polyurethane, 25 foot roll standard	**960025**	

Electrical and Electronic Parts

Display, LCD, Front Panel	**2823**	
Circuit Board, CPU	**3230-8**	
Circuit Board, Interface	**3250-1**	

Circuit Board, Rear Panel Interconnect	**3260-1**	
Fuse, BAM-1020, 3.15A, 250V, 5x20mm, 2 Req’d	**590811**	
Motor, with gear box, 4 RPM	**8105-1**	
Motor, with gear box, 10 RPM	**8106-1**	
Power Supply, 115 VAC, 60 Hz	**BX-115**	
Power Supply, 115 VAC, 50 Hz	**BX-116**	
Power Supply, 230 VAC, 60 Hz	**BX-230**	
Power Supply, 230 VAC, 50 Hz	**BX-231**	
Power Supply, 100 VAC, 60 Hz	**BX-100**	
Power Supply, 100 VAC, 50 Hz	**BX-101**	

Inlet Components

PM10 Inlet Head, EPA Specified	**BX-802**	
TSP Sampling Inlet Cap, with bug screen	**BX-803**	
PM2.5 Sharp Cut Cyclone	**BX-807**	
PM2.5 Very Sharp Cut Cyclone, BGI Inc. VSCC™ Required for PM2.5 FEM monitoring	**BX-808**	
PM2.5 WINS Impactor	**BX-804**	
Inlet Roof Mounting Kit, with waterproof roof flange, inlet tube and braces. Specify tube length, 8 feet std	**BX-801**	
Inlet Tube Coupler Assembly, with o-rings Connects two inlet tubes together Inlet tube sold separately	**BX-821**	
Inlet Tube Extension Kit, 4 foot, with coupler and tube	**BX-822**	
Inlet Tube Extension Kit, 8 foot, with coupler and tube	**BX-823**	
Inlet Tube, Aluminum, 8 foot length standard	**8112**	
Inlet Tube, Custom Length Dash number is length in feet, 8’ max per tube	**8112-X**	

Smart Heater Option, 115 VAC	**BX-827**	
Smart Heater Option, 230 VAC	**BX-830**	
Smart Heater Upgrade Kit, 115VAC	**9307**	
Smart Heater Upgrade Kit, 220VAC	**9308**	
BAM Inlet Cleaning Kit Includes pull-rope, tube brush, microfiber rags, cleaning brushes, o-ring grease, cotton applicators. For cleaning inlet tube and PM10, PM2.5 inlets.	**BX-344**	
O-Rings, Cyclone, set of 6	**720097**	
O-Rings, PM10 Head, set of 3	**8965**	

Meteorological Sensors

590 Wind Direction Sensor, Auto ID	**BX-590**	
591 Wind Speed Sensor, Auto ID	**BX-591**	
592 Ambient Temperature Sensor	**BX-592**	
593 Ambient Relative Humidity Sensor	**BX-593**	
594 Ambient Barometric Pressure Sensor, Auto ID	**BX-594**	
595 Solar Radiation Sensor, Auto ID	**BX-595**	
596 AT/BP Combo Sensor Required for PM2.5 FEM monitoring	**BX-596**	
Real-Time Module (RTM), BAM Inlet Particle Sensor	**BX-894**	

Communications Components and Misc. Accessories

Serial Printer Kit	**BX-601**	
Converter for Parallel Printers	**BX-602**	
Modem Kit	**BX-996**	
Serial Cable, 6', DB-9 female/female, null, BAM to PC	**400658**	
Belkin F5U109 USB-to-RS-232 Adapter	**550067**	
Enclosure, Outdoor, Heated, Mfg by Shelter One	**BX-902**	
Enclosure, Outdoor, Heated and Air Conditioned Mfg by Ekto. Available with 2000 or 4000 BTU A/C.	**BX-903** **BX-904**	

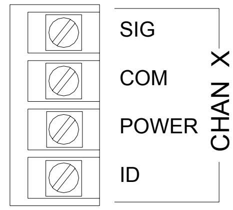
10.2 Series 500 Sensor Configurations

The BAM-1020 has six channels of inputs available on the back of the unit for data logging external sensors. The 500 Series sensors are a set of meteorological sensors designed for direct compatibility with these channels. The sensors each have an auto-identification (ID) signal wire with a voltage unique to that particular type of sensor. When one of these sensors is attached to the BAM, the unit senses this ID voltage and automatically configures the channel to read the sensor with all the correct scaling parameters.

Most BAM-1020 units are equipped with at least the ambient temperature sensor BX-592 because ambient temperature is required on channel six for actual flow control. If the BAM is used for $PM_{2.5}$ monitoring, then the BX-596 sensor is required instead. This is a combination ambient temperature and barometric pressure sensor which attaches to channels six and seven, and provides the EPA required AT/BP measurements for actual flow control and flow statistics.

The scaling and setups values of the series 500 Sensors are provided in the chart below. The unit should automatically set these values in the SETUP > SENSORS menu. The ID MODE must be set to AUTO to identify the sensors, or set to MANUAL to change the parameters.

500 Series Sensor Setup Parameters								
Model	**Type**	**Units**	**Range**	**Mult**	**Offset**	**FS VOLT**	**S/V**	**Inv Slope**
BX-590	WD	Deg	0 to 360	360	0	1.0	V	N
BX-591	WS	mph	0 to 100	100	0	1.0	S	N
		m/s	0 to 44.704	44.70	0	1.0	S	N
BX-592	AT	^{0}F	-22 to +122	144	-22	1.0	S	N
		^{0}C	-30 to +50	80	-30	1.0	S	N
BX-593	RH	%	0 to 100	100	0	1.0	S	N
BX-594	BP	inHg	20 to 32	6	26	1.0	S	N
		mmHg	508.0 to 812.8	152.40	660.40	1.0	S	N
		mbar	677.1 to 1083.6	203.19	880.46	1.0	S	N
BX-595	SR	Ly/ min	0 to 2	2	0	1.0	S	N
		W/M2	0 to 2000	2000	0	1.0	S	N
BX-596	AT/BP	^{0}C	-40 to +55	95	-40	2.5	S	N
		mmHg	525 to 825	300	525	2.5	S	N



BAM-1020 Back Panel Sensor Input Terminal

500 Series Sensor Wiring Connections for BAM-1020

BX-590 Wind Direction Sensor	
Terminal Block	**Cable Wire Color**
SIG	Yellow
COM	Black/Shield
POWER	Red
ID	Green

BX-591 Wind Speed Sensor	
Terminal Block	**Cable Wire Color**
SIG	Yellow
COM	Black/Shield
POWER	Red
ID	Green

BX-592 Ambient Temp Sensor	
Terminal Block	**Cable Wire Color**
SIG	Yellow
COM	Black/Shield
POWER	Red
ID	Green

BX-593 Relative Humidity Sensor	
Terminal Block	**Cable Wire Color**
SIG	Yellow
COM	Green/Shield
POWER	White
ID	Red

BX-594 Barometric Pressure Sensor	
Terminal Block	**Cable Wire Color**
SIG	White
COM	Black/Shield
POWER	Red
ID	Yellow

BX-595 Solar Radiation Sensor	
Terminal Block	**Cable Wire Color**
SIG	Yellow
COM	Black/Shield
POWER	Red
ID	Green

BX-596 Temperature/Pressure Combo Sensor	
Terminal Block	**Cable Wire Color**
Channel 6 SIG	Yellow
Channel 6 COM	Black/Shield
Channel 6 POWER	Red
Channel 6 ID	Green
Channel 7 SIG	White

Notes:

- BX-592 is always connected to channel 6 when used for flow control with a BAM-1020.
- BX-592 or BX-596 is required for actual flow control.
- BX-596 is required for $PM_{2.5}$ monitoring, effective March 2007.

Mounting:

The 500 series sensors typically mount near the top of the BAM-1020 inlet tube with a short cross-arm and related hardware. The sensors may also be mounted to a nearby tripod, such as Met One model 905.

11 THEORY OF OPERATION and MATHEMATICAL ANALYSIS

When the high-energy electrons emanating from the radioactive decay of ^{14}C (carbon-14) interact with nearby matter they loose their energy and, in some cases, are absorbed by the matter. These high-energy electrons emitted through radioactive decay are known as beta rays and the process is known as beta-ray attenuation. When matter is placed between the radioactive ^{14}C source and a device designed to detect beta rays, the beta rays are absorbed and/or their energy diminished. This results in a reduction in the number of beta particles detected. The magnitude of the reduction in detected beta particles is a function of the mass of the absorbing matter between the ^{14}C beta source and the detector.

The number of beta particles passing through absorbing matter, such as dust deposited on a filter tape, decrease nearly exponentially with the mass through which they much pass. Equation 1 shows this relationship.

Equation 1

$$\boxed{I = I_0 e^{-\mu x}}$$

In Equation 1, I is the measured beta ray intensity (counts per unit time), of the attenuated beta ray (dust laden filter tape), I_0 is the measured beta ray intensity of the un-attenuated beta ray (clean filter tape), μ is the absorption cross section of the material absorbing the beta rays (cm^2/g), and x is the mass density of the absorbing matter (g/cm^2).

Equation 1 very closely resembles the Lambert-Beers Law, which is used in spectrometric analysis. Just as the Lambert-Beers Law is an idealization of what is actually observed, Equation 1 is also an idealized simplification of the true processes occurring meant to simplify the corresponding mathematics. However, experimental measurement shows that in properly designed monitors, such as the BAM-1020, the use of this equation introduces no substantial error.

Equation 1 may be rearranged to solve for x, the mass density of the absorbing matter. This is shown in Equation 2.

Equation 2

$$\boxed{-\frac{1}{\mu}\ln\left[\frac{I}{I_0}\right] = \frac{1}{\mu}\ln\left[\frac{I_0}{I}\right] = x}$$

In practice, the absorption cross section is experimentally determined during the calibration process. Once I and I_0 are experimentally measured, it is a simple matter to calculate x, the predicted mass density.

In practice, ambient air is sampled at a constant flow rate (Q) for a specified time Δt. This sampled air is passed through a filter of surface area A. Once x, the mass density of collected particles, has been determined, it is possible to calculate the ambient concentration of particulate matter ($\mu g/m^3$) with Equation 3.

Equation 3

$$c\left(\frac{\mu g}{m^3}\right) = \frac{10^6 A(cm^2)}{Q\left(\frac{liter}{min}\right)\Delta t(min)\mu\left(\frac{cm^2}{g}\right)}$$

In Equation 3, c is the ambient particulate concentration ($\mu g/m^3$), A is the cross sectional area on the tape over which dust is being deposited (cm^2), Q is the rate at which particulate matter is being collected on the filter tape (liters/minute), and Δt is the sampling time (minutes). Combining these equations yields to the final expression for the ambient particulate concentration in terms of measured quantities. This is shown in Equation 4.

Equation 4

$$c\left(\frac{\mu g}{m^3}\right) = \frac{10^6 A(cm^2)}{Q\left(\frac{liter}{min}\right)\Delta t(min)\mu\left(\frac{cm^2}{g}\right)}\ln\left(\frac{I_0}{I}\right)$$

The key to the success of the beta attenuation monitor is due in part to the fact that μ, the absorption cross-section, is almost insensitive to the nature of the matter being measured. This makes the BAM-1020 very insensitive to the chemical composition of the material being collected.

It is instructive to perform a conventional propagation of errors analysis on Equation 4. Doing so, one can develop an equation for the relative measurement error (σ_c/c) as a function of the uncertainty in each of the parameters comprising Equation 4. This leads to Equation 5.

Equation 5

$$\frac{\sigma_c}{c} = \sqrt{\frac{\sigma_A^2}{A^2} + \frac{\sigma_Q^2}{Q^2} + \frac{\sigma_t^2}{t^2} + \frac{\sigma_\mu^2}{\mu^2} + \frac{\sigma_I^2}{I^2\ln\left[{}^{I}\!/_{I_0}\right]^2} - \frac{\sigma_{I_0}^2}{I_0{}^2\ln\left[{}^{I}\!/_{I_0}\right]^2}}$$

Inspection of Equation 5 reveals several things. The relative uncertainty of the measurement (σ_c/c) is decreased (improved) by increasing the cross sectional area of the filter tape (A), the flow rate (Q), the sampling time (t), the absorption cross-section (μ), I and I_0.

In practice, the uncertainty associated with the filter area (σ_A/A), may be minimized by ensuring that the tape is in exactly the same position during the I_0 measurement as in the I measurement phase. Careful design of the shuttle and tape control mechanisms inside of the BAM-1020 results in minimal error here.

The uncertainty in the flow rate (σ_Q/Q) may be minimized by properly controlling the flow of the instrument. For BAM-1020 units with a manual flow valve, this value is on the order of $\pm$ 3%. For BAM-1020 units equipped with the mass flow controller device, (σ_Q/Q) decreases to $\pm$ 1%.

The relative error due to the uncertainly in the absorption cross section (σ_μ/μ), is due to its slight variation as a function of the chemical composition of the matter being monitored. Generally, this relative error is on the order of ± 2-3%, with judicious selection of the calibrated value of μ.

The uncertainty associated with the measurement of I and I_0 has to do with the physical nature of the process leading to the emission of beta particles from the decay of ^{14}C. This process follows Poisson statistics. Poisson statistics show the uncertainty in the measurement of I (σ_I/I) and I_0 (σ_{I0}/I_0) are minimized by increasing the sampling time. Mathematical analysis shows that doubling the sampling time and hence the measured intensity of I or I_0 will reduce the uncertainty of the measurement by a factor of 1.41 (square root of 2).

11.1 Converting Data Between EPA Standard and Actual Conditions

As described in this manual, the BAM-1020 can obtain concentration data using either actual or standard values for ambient temperature and pressure. In some cases, it is necessary to convert past concentration data collected in standard conditions to actual conditions, or the other way around. Note: temperature is in degrees Kelvin (C+273) and pressure is in mmHg.

Equation 6

$$C_{std} = C_{amb} * (P_{std} / P_{amb}) * (T_{amb} / T_{std})$$

Equation 6 can be used to calculate the standard concentration (C_{std}) from the ambient concentration (C_{amb}) data using ambient barometric pressure and temperature data (P_{amb} and T_{amb}) from the same time period in which the ambient concentration was recorded. P_{std} and T_{std} are the values of standard barometric pressure and standard ambient temperature. These values are usually the EPA mandated 760 mmHg and 298 degrees Kelvin (25 C). **Note:** Some other countries use different values for standard temperature and pressure.

Equation 7

$$C_{amb} = C_{std} * (P_{amb} / P_{std}) * (T_{std} / T_{amb})$$

Equation 7 can be used to calculate the ambient concentration (C_{amb}) from the standard concentration (C_{std}) data using the ambient temperature and pressure. It is necessary to have access to valid data for the ambient temperature and pressure for the desired sample hour in order to be able to make the calculations.

Example: You have a data value of 27µg from a BAM which was configured to report data in EPA Standard conditions (298K and 760 mmHg), but you need to know what the concentration would have been in actual conditions. The actual average temperature for the hour in question was 303K and the average pressure was 720mmHg.

$$C_{amb} = C_{std} * (P_{amb} / P_{std}) * (T_{std} / T_{amb})$$
$$C_{amb} = 27 * (720/760) * (298/303)$$
$$C_{amb} = 27 * 0.9474 * 0.9835$$
$$\mathbf{C_{amb} = 25.1\ \mu g}$$

BAM-1020 Audit Sheet

Model: BAM-1020 **Serial Number:**

Audit Date: **Audited By:** ______________________

Flow Audits			
Flow Reference Standard Used:	Model:	Serial No:	Calibration Date:
Temperature Standard Used:	Model:	Serial No:	Calibration Date:
Barometric Pressure Standard Used:	Model:	Serial No:	Calibration Date:

Leak Check Value: as found: lpm as left: lpm

		BAM	Ref. Std.		BAM	Ref. Std.	
Ambient Temperature:	as found:	C	C	as left:	C	C	N/A
Barometric Pressure:	as found:	mmHg	mmHg	as left:	mmHg	mmHg	
Flow Rate (Actual Volumetric):	as found:	lpm	lpm	as left:	lpm	lpm	N/A
Flow Rate (EPA Standard):	as found:	lpm	lpm	as left:	lpm	lpm	N/A

Mechanical Audits

Pump muffler unclogged:	as found	as left	PM10 particle trap clean:	as found	as left	N/A
Sample nozzle clean:	as found	as left	PM10 drip jar empty:	as found	as left	N/A
Tape support vane clean:	as found	as left	PM10 bug screen clear:	as found	as left	N/A
Capstan shaft clean:	as found	as left	PM2.5 particle trap clean:	as found	as left	N/A
Rubber pinch rollers clean:	as found	as left	Inlet tube water-tight seal OK:	as found	as left	
Chassis ground wire installed:	as found	as left	Inlet tube perpendicular to BAM:	as found	as left	

Analog Voltage Output Audit N/A

DAC Test Screen	BAM Voltage Output	Logger Voltage Input
0.000 Volts	Volts	Volts
0.500 Volts	Volts	Volts
1.000 Volts	Volts	Volts

Membrane Audit

LAST m (mg):	
ABS (mg):	
Difference (mg):	
% Difference:	

Flow Control Range

Flow Setpoint	BAM Flow
15.0 LPM	
16.7 LPM	
18.3 LPM	

Setup and Calibration Values

Parameter	Expected	Found	Parameter	Expected	Found	Parameter	Expected	Found
Clock Time/Date			FLOW TYPE			AP		
RS232			Cv			FRl		
STATION #			Qo			FRh		
RANGE			ABS			Password		
BAM SAMPLE			µ sw			Cycle Mode		
MET SAMPLE			K Factor			RH Control		
OFFSET			BKGD			RH Setpoint		
CONC UNITS			STD TEMP			Datalog RH		
COUNT TIME			HEATER			Delta-T Control		
FLOW RATE			e1			Delta-T Setpoint		
CONC TYPE			Errors			Datalog Delta-T		

Last 6 Errors in BAM-1020 Error Log

Error	Date	Time	Error	Date	Time
1			4		
2			5		
3			6		

Audit Notes:

OPERATOR NOTES:

BX-596 AT/BP
SENSOR MANUAL

Met One Instruments, Inc
1600 Washington Blvd.
Grants Pass, Oregon 97526
Telephone 541-471-7111
Facsimile 541-541-7116

About this Manual:

The BX-596 is an optional combination ambient temperature and barometric pressure sensor for use with the BAM-1020 particulate monitor. The BX-596 sensor is a required accessory for all BAM-1020 configured to sample $PM_{2.5}$ levels, effective March 2007. The sensor provides ambient temperature and pressure data to the unit for actual (volumetric) flow control and flow statistics during the hourly sample cycle. The BX-596 is only compatible with BAM-1020 firmware version 3.2.4 or later. This manual describes the installation and operation of the BX-596 sensor. Refer to the BAM-1020 operation manual as needed.

The BX-596-1 is an extended range version for extreme cold or high altitude environments.

BX-596 Temperature/Pressure Sensor Installed on a BAM-1020 Inlet Tube

Specifications:

BX-596	Barometric Pressure	Ambient Temperature
Voltage Output:	0 to 2.5 volts	0 to 2.5 volts
Range:	525 to 825 mmHg	-40 to +55 deg C
Accuracy:	±0.25 mmHg @ 25 C	± 1.5C above -30
ID Voltage:	3.50 volts DC ± .02	

BX-596-1	Barometric Pressure	Ambient Temperature
Voltage Output:	0 to 2.5 volts	0 to 2.5 volts
Range:	400 to 825 mmHg	-50 to +50 deg C
Accuracy:	±1.5 mmHg	± 1.5C full scale
ID Voltage:	4.10 volts DC ± .02	

Installation and Setup:

Ensure that the BAM-1020 is sited and installed properly per the instructions in the operation manual.

During the installation process, you will need to provide an access point for the BX-596 sensor cable to enter the shelter where the BAM-1020 is installed. In some cases it is easiest to simply drill a 3/8” hole through the roof of the shelter about six inches away from the inlet tube, then feed the cable through the hole and caulk around it to prevent leaks.

There may be a better place to feed the cable into the shelter in some applications. The BX-902/903 environmental shelters supplied by Met One have pre-formed access holes in the side to allow the sensor cable to be routed to the BAM-1020. Decide the best way to route the cable into the shelter. The BX-596 comes with a standard 25-foot sensor cable. Longer cables may be ordered if required.

Remove the PM_{10} head and $PM_{2.5}$ cyclone from the top of the BAM inlet tube. Attach the BX-596 to the inlet tube (about 8 to 18 inches from the top) with the supplied U-bolt hardware. Make sure that the sensor is level and tighten the U-bolt securely.

Make sure the BAM-1020 is turned off, then attach the sensor cable to the connector on the bottom of the BX-596. Route the loose end of the cable into the shelter and to the back of the BAM-1020. Coil up any excess length of cable. Attach the cable to the back of the BAM as shown in the following table.

BX-596 AT/BP Sensor Connections		
Wire Color	**Function**	**BAM Terminal**
Yellow	AT Signal Output	Channel 6 SIG
Black/Shield	Ground	Channel 6 COM
Red	+12 VDC	Channel 6 POWER
Green	Auto ID Signal 3.50V	Channel 6 ID
White	BP Signal Output	Channel 7 SIG

Reinstall the PM_{10} head and $PM_{2.5}$ cyclone and seal around the cable hole with silicone if required.

Operation:

When the BAM-1020 is powered up with a BX-596 installed, the unit will automatically sense the ID voltage from the sensor and configure input channels six and seven to read and scale the outputs from the sensor. **Note**: The BX-596 sensor requires BAM-1020 firmware revision 3.2.0 or later. The BX-596-1 extended range version requires BAM-1020 firmware revision 3.6.2 or later. If the BAM firmware is not current enough, then the BAM will not automatically identify and scale the sensor.

Turn ON the BAM-1020 and perform a calibration of the BX-596. Note: The calibration is performed in the TEST > FLOW screen which *will not be available* unless the FLOW TYPE is set to ACTUAL in the SETUP > CALIBRATE screen. You will need a reference standard measurement for ambient temperature and barometric pressure.

```
MULTIPOINT FLOW CALIBRATION
            TARGET    BAM      STD
<CAL>     AT:         23.8    23.8 C
          BP:          760     760 mmHg
      FLOW 1: 15.0    15.0    15.0 LPM
      FLOW 2: 18.3    18.3    18.3 LPM
      FLOW 3: 16.7    16.7    16.7 LPM
  CAL       NEXT      DEFAULT    EXIT
```

1. Enter the TEST > FLOW menu as shown above. The nozzle will lower automatically when this screen is entered. The “BAM” column is what the BAM-1020 measures for each parameter, and the “STD” column is where you will enter the correct values from your reference standard. The <CAL> symbol will appear next to the parameter selected for calibration.
2. Measure the ambient temperature with your reference standard positioned near the BX-596 sensor. Enter the value from your reference standard into the STD field using the arrow keys. Press the CAL hot key to correct the BAM reading. The BAM and STD values should now be the same.
3. Press the NEXT hot key to move the <CAL> indicator to the BP field, and repeat the same steps for barometric pressure.

The DEFAULT hot key can be pressed to reset the user calibration from the selected parameter and replace it with a factory setting. The DEFAULT calibration should be fairly close in most cases.

The BX-596 sensor is almost always calibrated as part of a BAM-1020 flow calibration. Always calibrate the AT and BP channels before calibrating the flow channels, as the flow rate is affected by the temperature and pressure of the ambient air.

The BX-596 temperature output may also be checked in an ice bath. The ice bath test is usually never done except in some cold weather environments. First calibrate the sensor at ambient temperature, then use the following steps:

1. Remove the stop screw from the bottom of the mounting bracket so that the electronics module is free to rotate. Rotate the module counter-clockwise until it disengages from the keyhole slots and comes free from the radiation shield.
2. The sensor comes with an 18 inch long ice bath extension harness. This may be used to allow the temperature bead to reach the ice bath if necessary. Carefully unplug the black temperature bead assembly from the top of the electronics module and install the harness between the bead and the module.
3. Insert the temperature bead into the ice water bath along with your reference sensor. Avoid immersing the bead assembly past the connector.

4. Allow the bead to equilibrate, then compare the AT reading in the TEST > FLOW screen to your reference sensor. The readings should match within ±1.5 degrees C for the BX-596-1 extended range sensor. **Note**: The tolerance for the regular BX-596 standard range sensor is ± 2.5 C in temperatures below -30C.
5. Remove the ice bath harness and reassemble the sensor.

During operation of the BAM-1020, the output from the BX-596 can be viewed from the main flow statistics screen or the OPERATE screens. See the BAM-1020 manual.

Ice Bath Extension Harness

Maintenance:

The BX-596 is designed to be low-maintenance, easy to access, and resistant to harsh environments. There are only a few maintenance items for the sensor besides routine calibration checks.

- Remove the bottom cover and make sure that the four holes in the cover plate are clear and have not been obstructed by insects or debris. These holes allow the air pressure to equilibrate inside the sensor for the barometric pressure reading. Clean the inside of the electronics enclosure every 12 months or as needed.
- Clean the radiation shield assembly at least once per year. Dirty shields reflect away solar radiation less efficiently.
- The circuit board is not intended to be removed or serviced by the customer.
- The black temperature bead assembly may be replaced if the bead becomes damaged. The assembly simply plugs into the top of the electronics module. The sensor will need to be recalibrated any time the temperature bead is replaced.

Technical Support:

Should you still require support after consulting your printed documentation, we encourage you to contact one of our expert Technical Service representatives during normal business hours of 7:00 a.m. to 4:00 p.m. Pacific Standard Time, Monday through Friday. In addition, technical information and service bulletins are often posted on our website. Please contact us and obtain a Return Authorization (RA) number before sending any equipment back to the factory. This allows us to track and schedule service work and expedite customer service.

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TÜV RHEINLAND ENERGY GMBH

DAkkS Deutsche Akkreditierungsstelle D-PL-11120-02-00

ADDENDUM

Addendum to the report on performance testing, report no. 936/21209919/A of 26 March 2010 for the BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter $PM_{2,5}$ manufactured by Met One Instruments, Inc.

TÜV Report: 936/21243375/A
Cologne, 21 September 2018

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TÜV Rheinland Energy GmbH and its Ambient Air Quality department in particular
is accredited for the following activities:

- Determination of emissions and ambient air quality affected by air pollutants and odorous substances,
- Inspection of correct installation, functionality and calibration of continuous emission monitoring systems including systems for data evaluation and remote monitoring of emissions
- Measurements in combustion chambers;
- Performance testing of measuring systems for continuous monitoring of emissions and air quality as well as electronic data evaluation and remote monitoring systems for emissions
- Determination of the stack height and air quality forecasts for hazardous and odorous substances;
- Determination of emissions and ambient air quality affected by noise and vibration, determination of
- sound power levels and noise measurements at wind turbines;

according to EN ISO/IEC 17025.

The accreditation will expire on 10-12-2022 and
covers the scope specified in the annex to certificate D-PL-11120-02-00.

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Table of contents

List of tables

List of figures

1. Summary Overview

Met One Instruments, Inc. commissioned TÜV Rheinland Energy GmbH to carry out performance testing of the BAM-1020 with PM2,5 pre-separator for suspended particulate matter PM2,5 in accordance with the following standards:

- VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated June 2002.
- VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated August 2004
- European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005
- Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods, English version of July 2009 and/or January 2010.

On the basis of the cited standards for testing, the BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter, $PM_{2,5}$, has already been performance-tested and publically announce as such as follows:

- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matte, $PM_{2,5}$; UBA announcement of 12 April 2010 (BAnz. p. 2597, chapter II number 1.1) – original publication
- BAM-1020 with $PM_{2,5}$ pre-separator, for suspended particulate matter, $PM_{2,5}$; UBA announcement of 10 January 2011 (BAnz. p 294, chapter IV 18th notification) – Notification regarding a re-assessment of the leak tightness test, compliance with the requirements of the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods, English version of January 2010
- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matte, $PM_{2,5}$; UBA announcement of 15 July 2011 (BAnz. p. 2725, chapter III, 11th notification) – notification of design changes (alternative pump, tough screen display option) and new software version

- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter, $PM_{2,5}$; UBA announcement of 5 July 2012 (BAnz AT 20.07.2012 B11, chapter IV 5th notification) – Notification of design changes (re-designed back plate) and software changes
- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter, $PM_{2,5}$; UBA announcement of 3 July 2013 (BAnz AT 23.07.2013 B4, chapter V 4th notification) – notification regarding a new software version.
- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter, $PM_{2,5}$; UBA announcement of 25 February 2015 (BAnz AT 02.04.2015 B5, chapter IV 12th notification) – Notification regarding a new pressure sensor because of discontinued production
- BAM-1020 with $PM_{2,5}$ pre-separator for suspended particulate matter, $PM_{2,5}$; UBA announcement of 21 February 2018 (BAnz AT 26.03.2018 B8, chapter V 9th notification) – notification regarding a new software version.

Standard EN 16450 “Ambient air — Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2,5}$) has been available since July 2017. This standard, for the first time, harmonises requirements for the performance testing of automated measuring systems for the determination of dust concentrations (PM_{10} and $PM_{2.5}$) on a European level and will form the basis for the approval of such AMS in the future.

The present addendum presents an assessment of the BAM-1020 measuring system with $PM_{2,5}$ pre-separator regarding compliance with the requirements defined in standard EN 16450 (July 2017). At present, the assessment does not cover the instrument version with touch screen display (BX-970 option), as the necessary adjustments to the firmware have not yet been made for this instrument version.

As most of the performance characteristics and performance criteria defined in chapter 7 of standard EN 16450 (July 2017) have been tested and assessed already in the context of the original performance test, the majority of test results can be taken from and/or re-assessed on the basis of the original test report. It was possible to re-assess some of the original performance data for a number of test criteria. Entirely new tests were performed only for test items 7.4.4 “Flow rate accuracy”, 7.4.8 “Dependence of span on supply voltage” and 7.4.9 “Dependence of reading on water vapour concentration” in Summer 2018. A new test was also performed for test item 7.4.3 “Zero level and detection limit, lower detection limit” in order to submit the GF0.009 filter band used and qualified by Met One Instruments, Inc. since 2013 and manufactured by Whatman to testing. In the meantime, this filter band has completely replaced the type 460130 filter band manufactured by Sibata, which had been used during the original performance test.

On its publication, this addendum will become an integral part of TÜV Rheinland test report no. 936/21209919/A dated 26 March 2010 and will be available online at www.qal1.de.

The BAM-1020 measuring system uses a radiometric measuring principle to determine dust concentrations. A pump sucks in ambient air via the $PM_{2.5}$ pre-separator (consisting of a PM_{10} sampling head and a $PM_{2.5}$ Sharp Cut Cyclone). The dust-loaded sample air is then pulled to a filter tape. The determination of the mass concentration precipitated on the filter tape is then performed relying on the principle of beta absorption.

The tests were performed in the laboratory and in a several-months long field test.

The several-months long field test was performed at the sites listed in Table 1.

Table 1: Description of the test sites

	Teddington (UK) Summer	Cologne Parking lot, Winter	Bornheim, Motorway parking area Summer	Teddington (UK) Winter
Period	07/2008–11/2008	12/2008 – 04/2009	08/2009 – 10/2009	12/2009 – 02/2010
Number of measurement pairs: Test specimens	83	77	60	46
Description	Urban area	Urban area	Rural area + motor-way	Urban area
Classification of am-bient air pollution	low to average	average to high	low to average	average

The following table provides an overview of the equivalence test performed.

Table 2: Equivalence test results (raw data)

PM_x	Slope	Axis in-tercept	All Data sets W_{CM}<25 % Raw data	Calibra-tion yes/no	All Data sets W_{CM}<25% cal. data
$PM_{2,5}$	1.000	0.764	12.7	yes	11.7

* Given the significance of the slope or the axis intercept, a calibration became necessary.

1.1 Summary report on test results

Summary of test results in accordance with standard EN 16450 (July 2017)

Performance criterion	Requirement	Test result	satis-fied	Page
1 Measuring ranges	0 µg/m³ to 1000 µg/m³ as a 24-hour average value 0 µg/m³ to 10,000 µg/m³ as a 1-hour average value, if applicable	The measuring range is set to 0–1,000 µg/m³ by default. Supplementary measuring ranges are possible up to 0–10,000 µg/m³.	yes	50
2 negative signals	Shall not be suppressed	Negative signals are directly displayed and correctly output by the measuring system.	yes	51
3 Zero level and detection limit (7.4.3)	Zero level: ≤ 2.0 µg/m³ Detection limit: ≤ 2.0 µg/m³	On the basis of testing both instruments, the zero level was determined at a maximum of 0.27 µg/m³ and the detection limit at a maximum of 1.75 µg/m³.	yes	52
4 Flow rate accuracy (7.4.4)	≤ 2.0%	The relative difference determined for the mean of the measuring results at +5°C and at +40°C did not exceed -1.93%.	yes	54
5 Constancy of sample flow rate (7.4.5)	≤ 2.0% sampling flow (averaged flow) ≤ 5% rated flow (instantaneous flow)	The 24h-averages deviate from their rated values by less then ± 2.0%, all instantaneous values deviate by less than ± 5%.	yes	56
6 Leak tightness of the sampling system (7.4.6)	≤ 2.0% of sample flow rate	The maximum leak rate was determined at 0.23 l/min and was smaller than 2% of the nominal flow rate 16.67 l/min. The criterion for passing the leak test as specified by the AMS manufacturer – maximum flow rate of 1.0 l/min – proves to be an adequate criterion for monitoring the instrument's leak tightness. The method described reliably detects potential leakages in the system (e.g. contaminations in the area of the inlet nozzle at the filter band caused by filter abrasion.	yes	60

Performance criterion	Requirement	Test result	satis-fied	Page
7 Dependence of measured value on surrounding temperature (7.4.7)	≤ 2.0 µg/m³	The tested temperature range at the site of installation was +5 °C to +40 °C. Taking into account the values displayed by the instrument, we determined a maximum dependence of the zero point on the on surrounding temperature of -1.8 µg/m³.	yes	63
8 Dependence of measured value (span) on surrounding temperature (7.4.7)	≤ 5% from the value at the nominal test temperature	The tested temperature range at the site of installation was +5 °C to +40 °C. At span point, the deviations determined did not exceed 0.3%.	yes	65
9 Dependence of span on supply voltage (7.4.8)	≤ 5% from the value at the nominal test voltage	Voltage variations did not result in deviations > -0.4% compared to the initial value of 230 V.	yes	67
10 Effect of failure of mains voltage	Instrument parameters shall be secured against loss. On return of main voltage the instrument shall automatically resume functioning.	Buffering protects all instrument parameters against loss. On return of mains voltage, the instrument returns to normal operating mode and automatically resumes measuring at the next full hour.	yes	69

Performance criterion	Requirement	Test result	satis-fied	Page
11 Dependence of reading on water vapour concentration (7.4.9)	≤ 2.0 µg/m³ in zero air	Differences between readings determined at relative humidifies of 40% and 90% did not exceed 2.0 µg/m³. Various water vapour concentrations were not observed to cause any significant effect on zero readings.	yes	70
12 Zero checks (7.5.3)	Absolute value ≤ 3.0 µg/m³	The maximum measured value determined for PM2,5 at zero point was 1.8 µg/m³.	yes	72
13 Recording of operational parameters (7.5.4)	Measuring systems shall be able to provide data of operational states for telemetric transmission of – at minimum – the following parameters: Flow rate pressure drop over sample filter (if relevant) Sampling time Sampling volume (if relevant); Mass concentration of relevant PM fraction(s) Ambient temperature Exterior air pressure Air temperature in measuring section temperature of sampling inlet if heated inlet is used	The measuring system allows for comprehensive remote monitoring and control via various connectors (Ethernet, RS232). The instrument provides operating statuses and all relevant parameters.	yes	75
14 Daily averages (7.5.5)	The AMS shall allow for the formation of daily averages or values.	The instrument configuration described and a measurement cycle set to 60 min allow the formation of valid daily averages based on 24 individual measurements.	yes	77

Performance criterion	Requirement	Test result	satis-fied	Page
15 Availability (7.5.6)	At least 90%.	The availability for SN 17010 was 94.8%, for SN 17011 it was 95.9%.	yes	78
16 Between-AMS uncertainty ubs,AMS (7.5.8.4)	≤ 2.5 µg/m³	At no more than 1.57 µg/m³ for $PM_{2.5}$, the between-AMS uncertainty u_{bs} remains well below the permissible maximum of 2.5 µg/m³.	yes	81
17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)	≤ 25% at the level of the relevant limit value related to 24-hour average results (if required, after calibration)	The uncertainty WCM determined without applying correction factors for all observed data sets is below the determined expanded relative uncertainty Wdqo of 25% for fine particulate matter.	yes	87
17 Use of correction factors/terms (7.5.8.5–7.5.8.8)	After the calibration: ≤ 25% at the level of the relevant limit value related to the 24-hour average results	During the test, the test samples met the requirements for data quality of air quality measurements without applying a correction factor. Nevertheless, correction of the axis intercept led to a slight improvement of the expanded uncertainty for the complete data set.	yes	100

Performance criterion	Requirement	Test result	satis-fied	Page
18 Maintenance interval (7.5.7)	At least 14 d	The period of unattended operation is determined by the necessary maintenance works. It is 4 weeks.	yes	106
19 Automatic diagnostic check (7.5.4)	Shall be possible for the AMS	All instrument functions described in the operation manual are available and can be activated. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. it is possible to automatically check and record the zero point and sensitivity.	yes	108
20 Checks of temperature sensors, pressure and/or humidity sensors	Shall be checked for the AMS to be within the following criteria ± 2°C ± 1kPa ± 5 % RH	It is easy to check and adjust the sensors for determining ambient temperature, ambient pressure and relative humidity on-site (filter band area).	yes	110

2. Task Definition

2.1 Nature of the test

TÜV Rheinland Energy GmbH was commissioned by Met One Instruments, Inc. to carry out performance testing of the BAM-1020 with PM2,5 pre-separator.

The BAM-1020 with PM2,5 pre-separator for suspended particulate matter, $PM_{2,5}$, has already been performance-tested and published as such in the Federal Gazette.

The present addendum presents an assessment of the BAM-1020 with PM2,5 pre-separator regarding compliance with the requirements for automated measuring systems defined in the new standard EN 16450 (July 2017). At present, the assessment does not cover the instrument version with touch screen display (BX-970 option), as the necessary adjustments to the firmware have not yet been made for this instrument version.

2.2 Objectives

The measuring system is designed to determine the $PM_{2.5}$ fractions of dust concentrations in the range between 0–1 000 µg/m³.

The existing performance test had been performed in respect of the requirements applicable at the time of testing while at the same time taking into account the latest developments.

The test was performed on the basis of the following standards:

- VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated June 2002 [1]
- VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated August 2004 [2]
- European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005 [3]
- Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods, English version of July 2009 and/or January 2010 [4]

Since July 2017, the European Standard

- Standard EN 16450 "Ambient air — Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2,5}$), German version EN 16450:2017 [8]

has been available. This standard, for the first time, harmonises requirements for the performance testing of automated measuring systems for the determination of dust concentrations (PM_{10} and $PM_{2.5}$) on a European level and will form the basis for the approval of such AMS in the future.

The present addendum presents an assessment of the BAM-1020 measuring system with $PM_{2,5}$ pre-separator regarding compliance with the requirements defined in standard EN 16450 (July 2017). At present, the assessment does not cover the instrument version with touch screen display (BX-970 option), as the necessary adjustments to the firmware have not yet been made for this instrument version.

As most of the performance characteristics and performance criteria defined in chapter 7 of standard EN 16450 (July 2017) have been tested and assessed already in the context of the original performance test, the majority of test results can be taken from and/or re-assessed on the basis of the original test report. It was possible to re-assess some of the original performance data for a number of test criteria. Entirely new tests were performed only for test items 7.4.4 “Flow rate accuracy”, 7.4.8 “Dependence of span on supply voltage” and 7.4.9 “Dependence of reading on water vapour concentration” in Summer 2018. A new test was also performed for test item 7.4.3 “Zero level and detection limit, lower detection limit” in order to submit the GF0.009 filter band used and qualified by Met One Instruments, Inc. since 2013 and manufactured by Whatman to testing. In the meantime, this filter band has completely replaced the type 460130 filter band manufactured by Sibata, which had been used during the original performance test.

On its publication, this addendum will become an integral part of TÜV Rheinland test report no. 936/21209919/A dated 26 March 2010 and will be available online at www.qal1.de.

3. Description of the AMS tested

3.1 Measuring principle

The BAM-1020 ambient air measuring system uses beta-attenuation as its measuring principle.

The principle of the radiometric determination of mass is based on the physical law beta-ray attenuation when passing through a thin layer of material. The following equation holds:

$$c\left(\frac{\mu g}{m^3}\right) = \frac{10^6 A(cm^2)}{Q\left(\frac{l}{min}\right)\Delta t(min)\mu\left(\frac{cm^2}{g}\right)} \ln\left(\frac{I_0}{i}\right)$$

Where:

C is the particle-mass concentration

A is the sampling area for particles (filter spot)

Q is the sampling flow rate

Δt is the sampling time

µ is the mass absorption coefficient

I_0 is the beta count rate at the beginning (clean)

I is the beta count at the end (collect)

The radiometric determination of mass is calibrated in the factory and is checked hourly as part of internal quality assurance at the zero point (clean filter spot) and at the span point (built-in span foil) during operation. Measured values at zero and at span point can easily be derived from the generated data. They can be compared with any stability requirements (drift effects) or with the nominal value for the span foil (factory setting).

3.2 Functioning of the measuring system

The particle sample passes through the $PM_{2.5}$ pre-separator, which consists of a PM_{10} sampling inlet and a $PM_{2.5}$ Sharp Cut Cyclone SCC, at a flow rate of 1 m³/h and reaches the BAM-1020 analyser via the sampling tube.

During performance testing, the measuring system was operated with the BX-830 sample heater (Smart Inlet Heater).

The following process variables were used to control the sample heater:

1. Relative humidity RH at the filter tape (factory setting: 45 %)

The heater switches off as soon as the relative humidity (RH) drops below 1%.

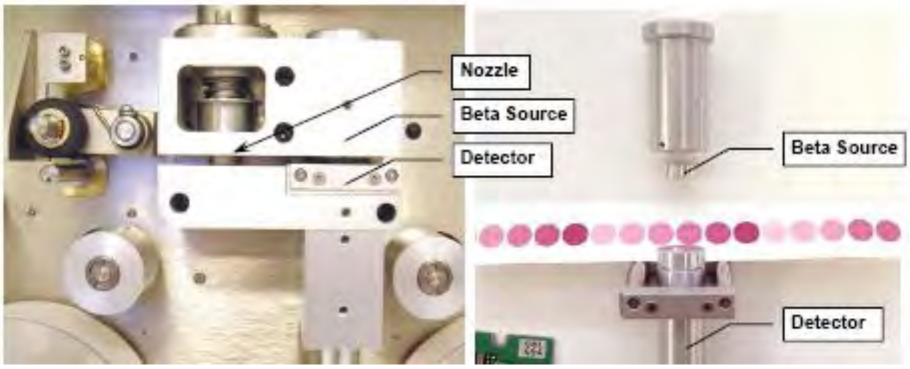
The particles reach the measuring instrument to be loaded onto the glass fibre filter tape for radiometric measurement.

One measurement cycle (incl. automatic check of the radiometric measurement) consists of the following steps (measuring time for $PM_{2,5}$ set to 8 min):

1. Each cycle starts with an initial/blank measurement of a clean filter spot (I_0). It takes 8 minutes.
2. The filter tape is transported forward over a distance of 4 dust spots and pushed under the sampling point. The sample is taken from the filter spot where I_0 was previously determined. For a sampling duration of 42 min. particulate-loaded air is then sucked through that filter spot.
3. At the same time, the spot 4 positions upstream on the filter tape is submitted to radiometric measurement I_1 for a duration of 8 minutes. This measurement is performed to check for potential drift effects caused by changes in external parameters such as temperature or relative moisture. The same spot is subjected to a third radiometric measurement I_2 with an inserted span foil. The same spot of the filter tape is subjected to yet another $I_{1x,}$ eight minutes before the end of the collection time in order to monitor stability of the zero point with the help of I_1 and I_{1x}.

4. Once sampling is completed, the filter tape is reversed back four sampling spots and the sampled filter spot is measured radiometrically (I_3). The calculation of the concentration completes the measurement cycle.
5. The next cycle will start again with step 1.

Figure 1 gives an overview of the sampling and measurement parts of the BAM-1020.



Legende: Nozzle Beta Source = Beta Source
Detector

Figure 1: BAM-1020 – Illustration of sampling and measurement

During the performance test, the cycle time was set to 60 min, radiometric measurement taking 8 min.

Thus, the cycle time consists of 2 x 8 min for the radiometric measurement (I_0 & I_3) as well as approximately 1–2 min for filter tape movements. Consequently, the effective sampling time is around 42 min.

3.3 AMS scope and set-up

The ambient air measuring system BAM-1020 relies on beta attenuation as its measuring principle.

The tested measuring system consists of the PM_{10}-sampling inlet BX-802, the $PM_{2.5}$ Sharp Cut Cyclone SCC BX-807, the sampling tube, the sample heater BX-830, the combined pressure and temperature sensor BX-596 (incl. radiation protection shield, as an alternative the ambient temperature sensor BX-592), the vacuum pump BX-127 (or BX-125), the measuring instrument BAM-1020 (incl. glass fibre filter tape), the required connecting tubes and lines as well as adapters, the roof flange as well as the manual in English language.

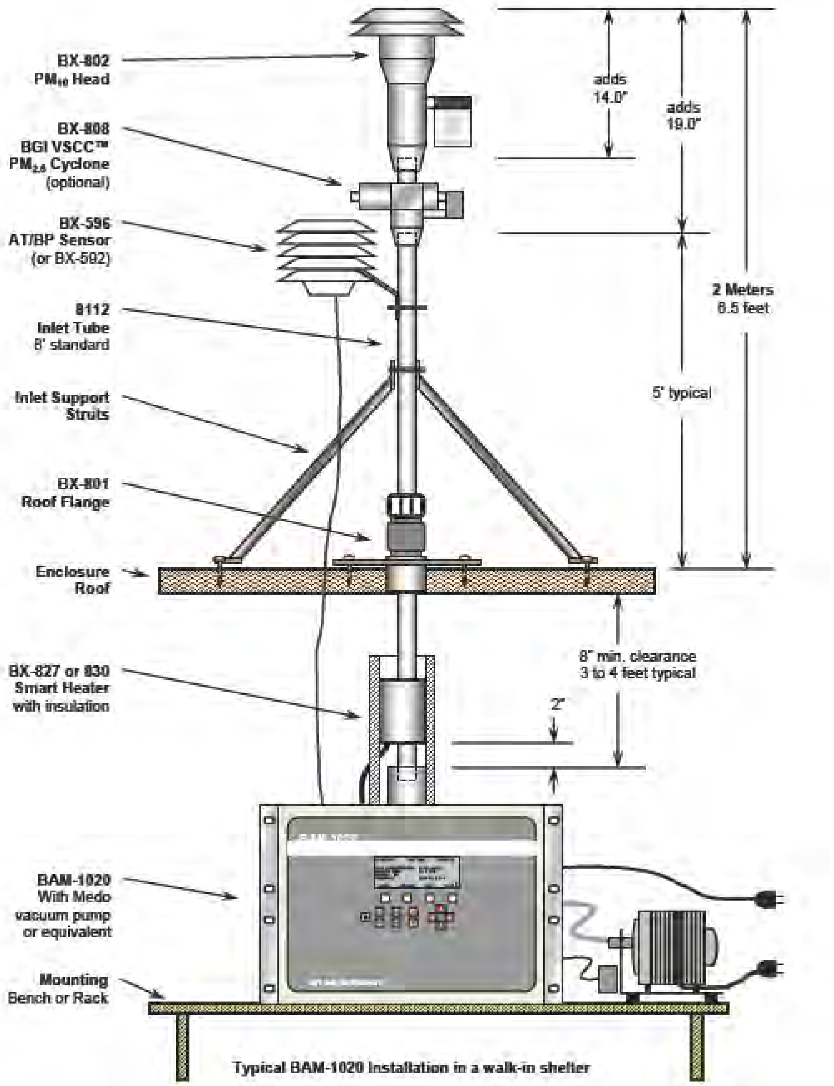


Figure 2: Overview of the BAM-1020 measuring system (instead of $PM_{2.5}$ SCC BX-807 with $PM_{2.5}$ VSCC BX-808 (configuration for US-EPA approval) presented here)

The BAM-1020 measuring system offers the possibility to connect up to 6 different sensors to the available analogue inputs. Thus, besides the combined pressure and temperature sensor BX-596 or the ambient temperature sensor BX-592, it is also possible to connect sensors for air pressure (BX-594), wind direction (BX-590), wind velocity (BX-591), humidity (BX-593) as well as solar radiation (BX-595).

A US-EPA-PM_{10} sampling inlet (type BX-802 used for performance testing) is available. The sampling inlet serves as a pre-separator for the suspended particulate matter, PM_{10} fraction. Directly downstream of the PM_{10} sampling inlet, a Sharp Cut Cyclone SCC (BX-807) is used for the separation of particles in the range of 2.5 µm to 10 µm. The instruments are operated with a constant, regulated flow rate of 16.67 l/min = 1.0 m³/h.

As an alternative option, it is possible to use TSP-sampling inlets or PM_{10} sampling inlets without SCC.

Figure 3: US-EPA PM_{10} sampling head BX-802 for BAM-1020

Figure 4: Sharp Cut Cyclone SCC BX-807 for BAM-1020

Figure 5: Sampling inlet BX-802 + SCC BX-807

The sampling tube connects the sampling inlet to the measuring instrument. The length of the sampling tube was 1.65 m during the test, different lengths can be manufactured with respect to the local conditions.

The BX-830 sample heater is installed at the lower end of the sampling tube (approximately 50 mm above the instrument inlet of BAM-1020). The operation of the heating systems is performed as described in chapter 3.2 Functioning of the measuring system.

Figure 6: BX-830 sample heater

The BX-127 (or BX-125) vacuum pump is connected to the measuring system proper at the end of the sampling path via a hose. The pump is controlled to regulate the operational flow with reference to the ambient conditions (ACTUAL mode).

In addition to the radiometric measuring component, the BAM-1020 measuring system contains the glass fibre filter tape incl. transport system, large parts of the pneumatic system (flow measurement by mass flow sensor), the control unit of the sample heater and all necessary electronic parts and microprocessors for the control and operation of the measuring system and for communication with the system.

Figure 7: BAM-1020 measuring system

Figure 8: BAM-1020 measuring system, installed in measurement cabinet
(2 performance test candidates + 1 candidate for experimental purposes (configuration of heater)

Figure 9: BX-127 vacuum pump

Figure 10: Front view BAM-1020, front cover opened

A soft keypad in combination with a display at the front of the instrument serve to control the measuring system.

The user is can retrieve stored data, change parameters and perform several tests to verify correct operation of the measuring system. The main screen of the user display is found on the top level – here, the current time and date, last 1h-concentration value, the actual flow rate, current software version and the status of the instrument are displayed.

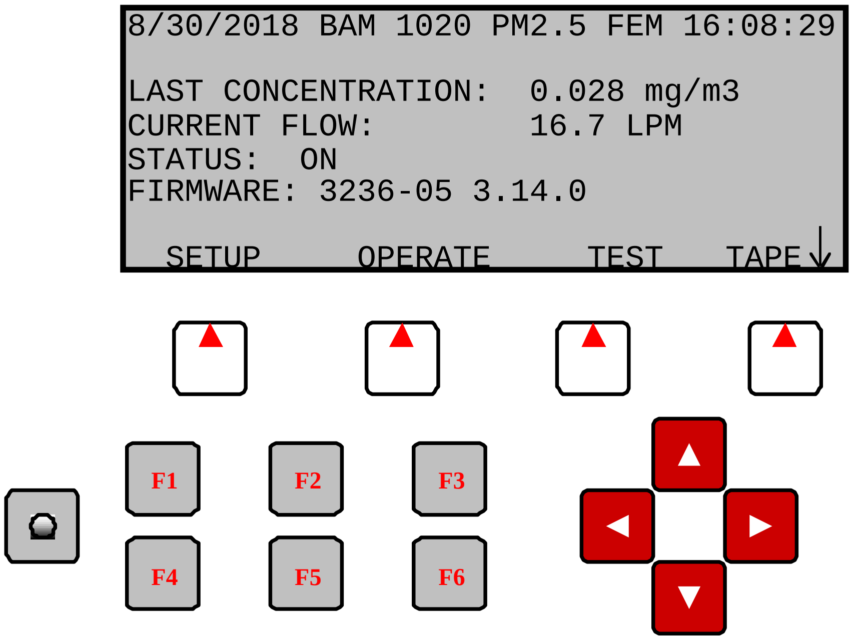


Figure 11: Display (main screen of the user interface) + soft keypad of the BAM-1020

The function keys F1 to F6 allow easy access to various functions from the main screen. For example it is possible, to access information on the last concentration values as well as measured values from other sensors (ambient temperature etc.), error messages and stored data for the measurements of the last ten days.

Starting form the main screen, it is also possible to access sub menus via the soft keys.

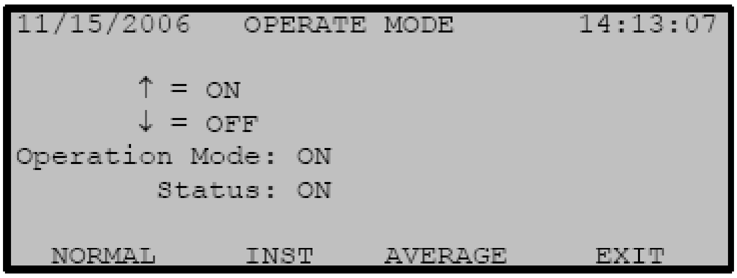
1. Menu „SETUP“ (Press soft key „SETUP“): The “SETUP” menu serves configuration and parameterisation of the measuring system. This menu is used to choose parameter settings such as date/time, sampling duration, measuring range, flow rate, measured value output under operating or standard conditions, or to change the password and choose settings for interfaces, external sensors and sample heater.

```
                     SETUP MODE SELECT

CLOCK     SAMPLE    CALIBRATE EXTRA
ERRORS    PASSWORD  INTERFACE SENSOR
HEATER    QUERY     REPORTS   HJ 653


 SELECT                         EXIT
```

The SETUP Menu

Figure 12: Menu “SETUP”

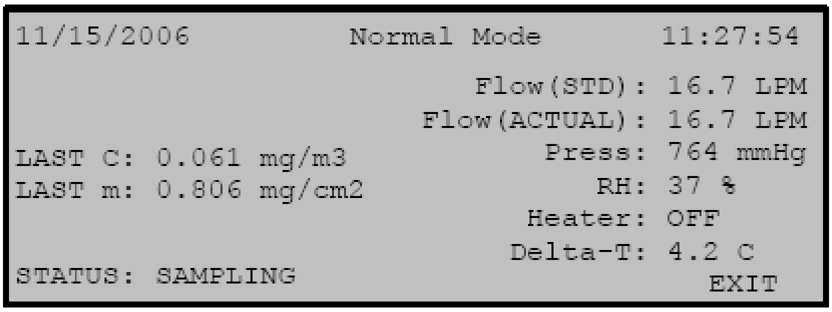
2. Menu “OPERATION” (press soft key “OPERATION”): In the “OPERATION” menu , users can call up information during the operation of the measuring system. As long as the operating mode is switched “ON”, the measuring system operates according to the settings. The on-going measurement will be interrupted by switching “OFF” the operating mode, by calling up the “SETUP”, “TEST”, or “TAPE” menus during on-going operation or as a result of a severe error (e.g. tape fault).



The OPERATE Menu

Figure 13: “OPERATION” menu

Recent measured values are presented in different ways in the NORMAL, INST and AVERAGE submenus. The “NORMAL” screen shows the most common form of presentation. In this screen, the user can check the most important parameters relevant for operation.



The NORMAL Menu

Figure 14: Screen shot “NORMAL”

3. “TEST” menu (press soft key “TEST”): Use the “TEST” menu to perform several tests for checking the hardware and components, e.g. a check of the radiometric measurement (span foil test), a check of the flow rate or a calibration of temperature and pressure sensors as well as of the flow rate.

```
TEST MENU

COUNT       PUMP        TAPE       DAC
CALIBRATE   INTERFACE   FLOW       ALIGN
HEATER      FILTER-T    FILTER-RH


 SELECT                             EXIT
```

The TEST Menu

Figure 15: “TEST” menu

4. Menu „TAPE“ (press soft key “TAPE”): Use the “TAPE” to start an extensive self test of the measuring system at any time (this aborts the ongoing measurement). This self test takes about 4 minutes and checks various mechanic parts (e.g. filter transport system) for correct functioning, the flow rate or the state of the filter tape (tension, tape fault). In case of irregularities or excessive deviations, a “FAIL” error message is displayed which allows to start identifying the problem. “SELF TEST PASSED” will be displayed if the self test does not identify any problems. Measurement operation can be resumed. The performance of this test is generally recommended after each restart of the measurement after any interruption, in any case after a change of the filter tape.

```
02/08/1999              15:29:30
LATCH: OFF              TAPE BREAK: OK
CAPSTAN: OK             TAPE TENSION: OK
NOZZLE DN: OK           SHUTTLE: OK
NOZZLE UP: OK           REF EXTEND: OK
FLOW: OK                REF WITHDRAW: OK
Status:   SELF TEST PASSED
TENSION   SELF TEST                 EXIT
```

Self-Test Status Screen

Figure 16: Screen shot “TAPE/SELF TEST”

In addition to direct communication via keys/display, there are numerous possibilities to communicate via different analogue outputs, relays (status and alarm messages) as well the RS232 interfaces. A printer, PC and modem can be connected to the RS232 interface. The Hyperterminal software can be used for communication with the instrument.

Interface #1 serves the purposes of data transfer and communication of the instrument status. The interface is frequently used for remote control with the help of a modem.

The following system menu is available:

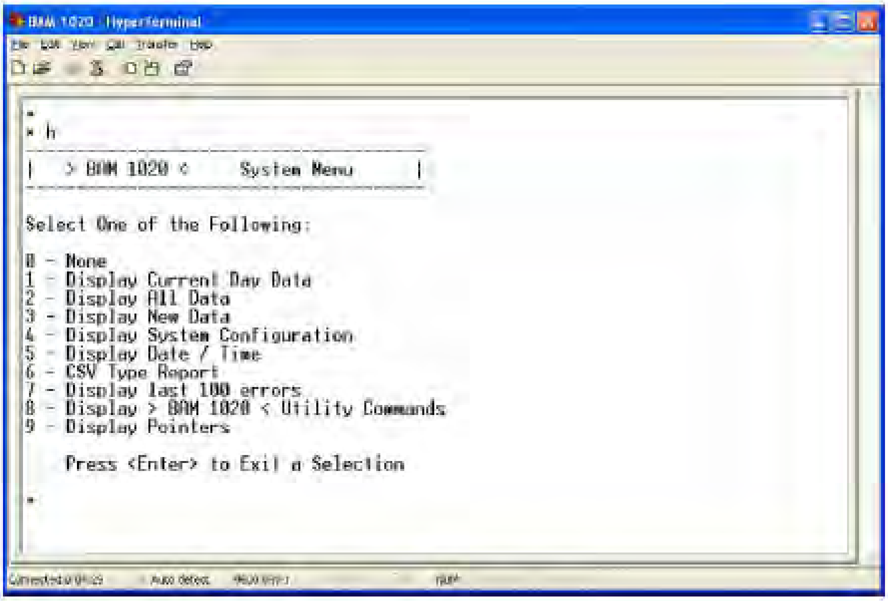


Figure 17: Communication via serial interface #1 - system menu

During the performance test, data were usually retrieved and recorded once a week. The data are suitable to be aggregated in the form of daily averages in an external spreadsheet. The following provides an example of the data thus recorded:

Station	10																					
Time	Conc(ug/m3)	Qtot(m3)	BP(mmH)	WS(MPS)	WS(MPS)	RH(%)	Delta(C)	AT(C)	Stab(ug)	Ref(ug)	E	U	M	I	L	R	N	F	P	D	C	T
2/9/2009 8:00	16	0.701	749.4	5.9	0.7	16	22.3	1.9	-0.8	827.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 9:00	18	0.701	749.7	5.9	0.7	17	21.8	2.5	-1.9	830.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 10:00	9	0.701	749.5	5.9	0.7	18	20.7	3	-3.5	830.2	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 11:00	9	0.701	749.8	5.9	0.7	18	19.4	3.5	-2.9	828	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 12:00	8	0.701	749.9	5.9	0.7	19	17.7	4.5	-0.7	828.9	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 13:00	7	0.701	749.6	5.9	0.7	20	16.3	5.9	-1.2	828.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 14:00	11	0.7	749.5	5.9	0.7	20	16.1	6.3	-3	828.4	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 15:00	12	0.7	749.2	5.9	0.7	20	16.5	5.9	0	826.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 16:00	11	0.7	748.8	5.9	0.7	20	16.5	5.9	-3.8	824.5	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 17:00	13	0.701	748.1	5.8	0.7	20	17.1	4.9	1.9	829.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 18:00	15	0.701	747.3	5.8	0.7	21	17.3	4.2	-0.2	828	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 19:00	20	0.701	746.8	5.8	0.7	22	17	3.9	0.7	831.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 20:00	18	0.7	745.9	5.8	0.7	24	17.1	3.1	-3.2	827.3	0	0	0	0	0	0	0	0	0	0	0	0
2/9/2009 21:00	17	0.701	744.2	5.7	0.7	25	17	2.5	-0.4	828.5	0	0	0	0	0	0	0	0	0	0	0	0

Conc (µg/m³): Dust concentration in µg/m³, ambient conditions

Qtot(m³): Throughput in m³ (here at a 42 min sampling time)

BP(mm-Hg): Air pressure in mm-Hg

WS (MPS): Wind speed, not used in this case

RH(%): relative humidity underneath the filter tape in % - for heating control

Delta(C): Difference ambient temperature – temperature at the filter tape – used to control the heater, in this case deactivated, no longer available from firmware version 3236-05 3.14.0

AT(C): Ambient temperature in °C

Stab(µg): Result of the internal zero measurement in µg from I_1 and I_{1x} (see chapter 3.2 of this report)

Ref(µg): Result of the internal span foil measurement in µg/cm² from I_2 (see chapter 3.2 of this report)

E, U, M, I, L, R, N, F, P, D, C, T: status messages (relay), (see chapter 6.5 of the manual)

For information and diagnosis purposes, menu item 4 (Display System Configuration) allows to display and print the current parameterisation of the BAM-1020 measuring system (see Figure 18).

BAM 1020 Settings Report
07/02/2018 12:38:52

Station ID, 1
Serial Number, X14465

Firmware, 3236-05 V3.14.1

K, 00.979
BKGD, -0.0056
usw, 00.299
ABS, 00.815
Range, 1.000
Offset, -0.015
Clamp, -0.015
Conc Units, mg/m3
Conc Type, ACTUAL
Count Time, 8
Conc Error, FULL SCALE VALUE
Inlet Type, PM2.5

Cv, 00.970
Qo, 00.000
Flow Type, ACTUAL
Flow Setpt, 0016.7
Std Temp, 25

Heat Mode, AUTO
FRH Ctrl, YES
FRH SetPt, 45
Low Power, 6
FRH Log, YES
FT Log, YES

BAM Sample, 42
MET Sample, 60
Cycle Mode, STANDARD
Fault Polarity, NORM
Reset Polarity, NORM
Maintenance, OFF

HJ 653, NO

EUMILRNFPDCT
111111111111

AP, 000150
Baud Rate, 9600
Printer Report, 2
e3, 00,000
e4, 15,000

Channel,	1,	2,	3,	4,	5,	6,
Sensor ID,	4,	2,	2,	255,	255,	35,
Channel ID,	254,	254,	254,	255,	255,	254,
Name,	WS ,	WS ,	WS ,	FRH ,	FT ,	AT ,
Units,	KPH,	MPS,	MPS,	% ,	C ,	C ,
Prec,	1,	1,	1,	0,	1,	1,
FS Volts,	1.000,	1.000,	1.000,	0.500,	2.500,	2.500,
Mult,	160.9,	44.7,	44.7,	32,	-147.1,	95.0,

```
Offset,        0.0,   0.0,   0.0,   -26,   95.8,  -40.0,
Vect/Scalar,   S,     S,     S,     S,     S,     S,
Inv Slope,     N,     N,     N,     N,     N,     N,

Calibration,  Offset,  Slope,
    Flow,   0.384,   0.980,
      AT,   0.391,
      BP,  -1.000,
     FRH,   0.000,
      FT,   0.000,

QUERY,      1,   CONC_A,
Daily Range, 01:00 - 24:00
Dynamic Range, STANDARD
Span Check, 24 HR
Log BP, NONE
Log Membrane, NONE
X3043
```

Figure 18: Typical print-out of a set of parameters for the BAM-1020

The serial interface #2 only serves as a print output and can be connected to a printer or PC. This allows the continues recording of up-to-date information regarding measurement operation.

For external check of the zero point of the measuring system and for determination of the background value BKGD (offset correction for concentration values) according to manual chapter 7.7, a zero filter (BX-302, Zero Filter Calibration Kit) is mounted to the instrument inlet. The use of this filter allows the provision of PM-free air.

Figure 19: BX-302 zero filter during application in the field

With the available shut-off valve, it is also possible to check the leak tightness of the measuring system with the BX-302 zero filter according to the manual chapters 5.4 et seq.

For the purpose of monitoring the inlet flow rate according to the manual chapter 5.7, a BX-305 adapter (Flow Inlet Adapter Kit) is available. As this is largely the same as the BX-302 zero filter kit (apart from the HEPA filter itself), this too allows performing a leak tightness check with the help of the shut-off valve following the manual instructions in chapters 5.4 et seq.

Table 3 lists a number of important instrument characteristics of the BAM-1020 monitor for suspended particulate matter.

Table 3: Instrument-related data BAM-1020 (Manufacturer's specifications)

Dimension/weight	**BAM-1020**
Measuring device	310 x 430 x 400 mm / 24.5 kg (without pump)
Sampling tube	1.65 m (additional lengths available)
Sampling head	BX-802 (US-EPA)
Power supply	100/115/230 V, 50/60 Hz
Power requirement	75 W, main unit
Ambient conditions	
Temperature	-30 - +60 °C (manufacturer specification) +5 - +40 °C during performance testing
Moisture	non-condensing
Sample flow rate	16.67 l/min = 1 m³/h
Radiometry Light source	^{14}C, <2,2 MBq (< 60 µCi)
Detector	Scintillation probe
Checking procedure	Hourly internal zero and span point checks (internal span foil), deviations form the target value are recorded
Parameters of filter replacement	
Measurement cycle (cycle time)	1 min – 200 min Default: 60 min
Measuring time radiometry	4.6 or 8 min selectable for $PM_{2.5}$: 8 min
Sampling time	depending on measuring time radiometry 50, 46 or 42 min for $PM_{2.5}$: 42 min
Parameters BX-830 sample heater	
Target value for relative humidity at filter tape	Default: 45% (active during performance testing)

Date storage capacity (internal)	approx. 180 days for 1h-measured values
Analogue output	0 – 1 (10) V or 0 – 16 mA / 4 – 20 mA – can be set to 0-0.100, 0.200, 0.250, 0.500, 1.000, 2.000, 5.000 or 10.000 mg/m³
Digital output	2 x RS 232 – interface for data transmission and remote control, c/w BX-965 report processor option (not part of the test) additional RS 232 and USB ports
Status signals/error messages	available, for an overview see chapters 7.2 and 9.9 in the manual

4. Test programme

4.1. General

The original performance test [9] was performed using two identical instruments, type BAM-1020, serial numbers S/N 17010 and S/N 17011 in accordance with the minimum requirements specified in [1; 2; 3; 4].

The test was performed with software versions 3236-07 5.01 and 3236-07 5.0.10.

The original test comprised a laboratory test to determine the performance characteristics as well as a field test over a period of several months at various test sites in Germany.

New tests for items 6.1 4 Flow rate accuracy (7.4.4), 6.1 9 Dependence of span on supply voltage (7.4.8), 6.1 11 Dependence of reading on water vapour concentration (7.4.9) and 6.1 3 Zero level and detection limit (7.4.3) were performed with two identical BAM-1020 instruments, serial numbers X14465 and X14499.

The software version most recently announced publically is 3236-07 5.5.0. Software version 3236-05 3.14.1 was installed during the additional tests. The new software version provides new features regarding Chinese requirements, additional features and adaptations of the operational parameters to the requirements of EN 16450 [8].

In the course of the additional tests performed in summer 2018, the software was further updated to reach version 3236-05 3.14.2. Changes related to scaling sensor recording to ambient pressure as well as the data format for “Report Processor Option BX-965”.

In line with the requirements of EN 15267-2, these changes have been documented and classified correctly. No effect on instrument performance was observed. A separate notification is prepared for the relevant body.

Concentrations are indicated as µg/m³ (operating conditions).

The present addendum presents an assessment of the BAM-1020 measuring system with $PM_{2,5}$ pre-separator regarding compliance with the requirements defined in standard EN 16450 [8].

In this report, the heading for each performance criterion cites the requirements according to [8] including its chapter number and wording.

4.2 Laboratory test

A large portion of the laboratory test is taken from the original performance test [9]. For the present report, test results were either taken from the previous report or re-assessed.

For the following test items, additional tests had to be performed in 2018.

- Zero level and detection limit
- Flow rate accuracy
- Influence of mains voltage on measured signal
- Effect of humidity on measured value

The following devices were used to determine the performance characteristics during the laboratory tests.

- Climatic chamber (temperature range –20°C to +50°C, accuracy better than 1°C).
- Isolating transformer,
- 1 mass flow meter Model 4043 (manufacturer: TSI)
- 1 reference flow meter, type BIOS Met Lab 500 (manufacturer: Mesa Lab)
- Zero filter kit BX-302 for external zero point check
- Internal span foils

The measured values were recorded internally. Stored measured values were retrieved using a hyperterminal connected to the RS232 interface.

Chapter 6 summarizes the results of the laboratory tests.

4.3 Field test

The field test was carried out in the context of the existing performance test [9] with 2 identical measuring systems. These were:

Instrument 1: S/N 17010
Instrument 2: S/N 17011

For the present report, test results were either taken from the previous report or re-assessed. No further testing was required.

The following instruments were used during the field test.

- Measurement container provided by TÜV Rheinland, air-conditioned to about 20 °C
- Weather station (WS 500 manufactured by ELV Elektronik AG) for collecting meteorological data such as temperature, air pressure, humidity, wind speed, wind direction and precipitation.
- Two LVS3 reference measuring systems for $PM_{2.5}$ according to item 5
- 1 gas meter, dry version
- 1 mass flow meter Model 4043 (manufacturer: TSI)
- Measuring system for power consumption; Metratester 5 (manufacturer: Gossen Metrawatt)
- Zero filter kit BX-302 for external zero point check
- Internal span foils

Two BAM-1020 systems and two reference measuring systems for $PM_{2.5}$ were simultaneously operated for 24 h each during the field test. The reference system is a discontinuous system: the filter has to be replaced manually after sampling.

Impaction plates of the $PM_{2.5}$ sampling inlets were cleaned approximately every two weeks during the test period and greased with silicone grease in order to ensure reliable separation of particles. The BX-802 PM_{10} sampling inlets and BX-807 $PM_{2,5}$ cyclones of the candidates$_{2.5}$ were cleaned every four weeks The sampling head generally has to be cleaned following the manufacturer's instruction taking into account local concentrations of suspended particulate matter.

The flow rates of the tested and the reference instruments were checked before and after the field test as well as before and after each re-location using a dry gas meter or a mass flow controller in each case connected to the instrument's air inlet via a hose line.

Sites of measurement and instrument installation

Measuring systems in the field test were installed in such a way that only the sampling inlets were outside the measuring cabinet on its roof. The central units of the tested instruments were positioned inside the air-conditioned measurement cabinet. The reference system (LVS3) was installed outdoors on the roof of the measurement cabinet.

The field test was performed at the following measurement sites:

Table 4: Field test sites

No.	Measurement site	Period	Description
1	Teddington (UK), Summer	07/2008–11/2008	Urban area
2	Cologne, parking lot, Winter	12/2008 – 04/2009	Urban area
3	Bornheim, parking lot at motorway, Summer	08/2009 – 10/2009	Rural area + traffic
4	Teddington (UK), Winter	12/2009 – 02/2010	Urban area

Figure 11 to Figure 14 show the $PM_{2,5}$ concentrations measured with the reference systems at the field test sites.

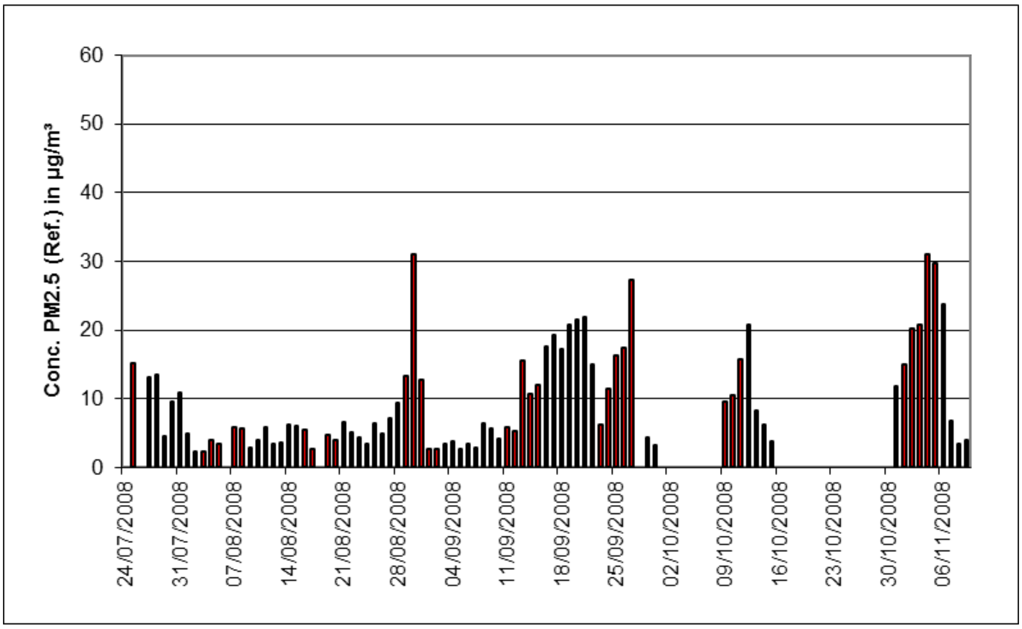


Figure 20: $PM_{2,5}$ concentrations (reference) in Teddington, summer

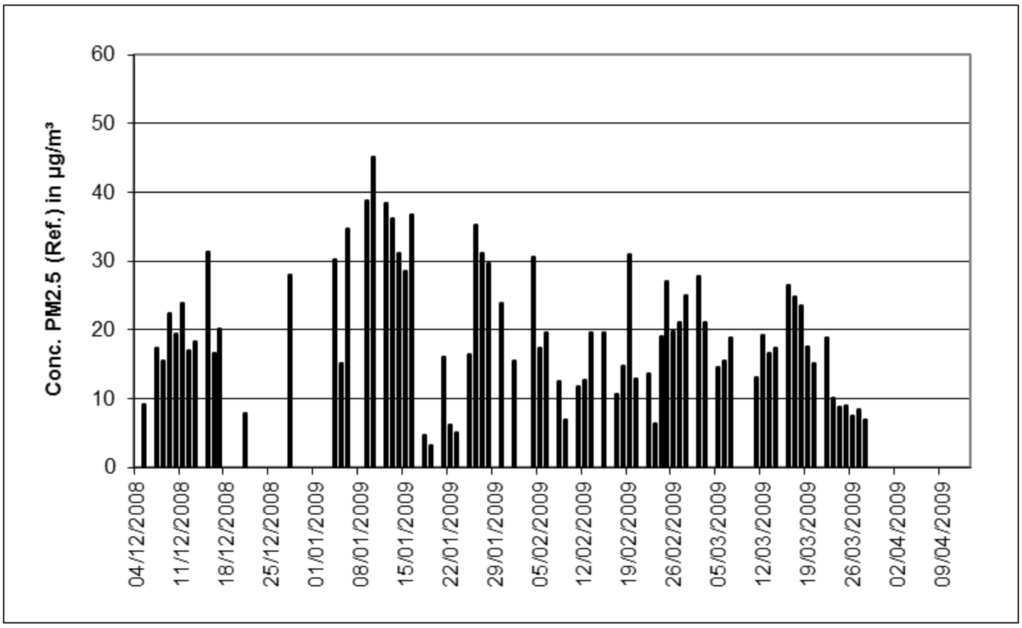


Figure 21: $PM_{2,5}$ concentrations (reference) in Cologne, winter

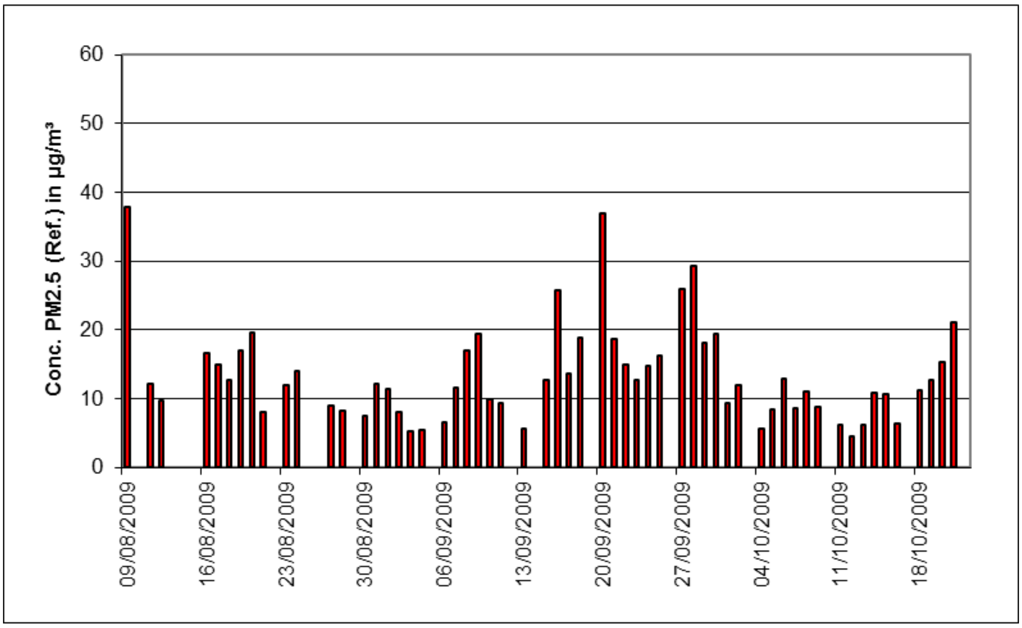


Figure 22: PM$_{2,5}$ concentrations (reference) in Bornheim, summer

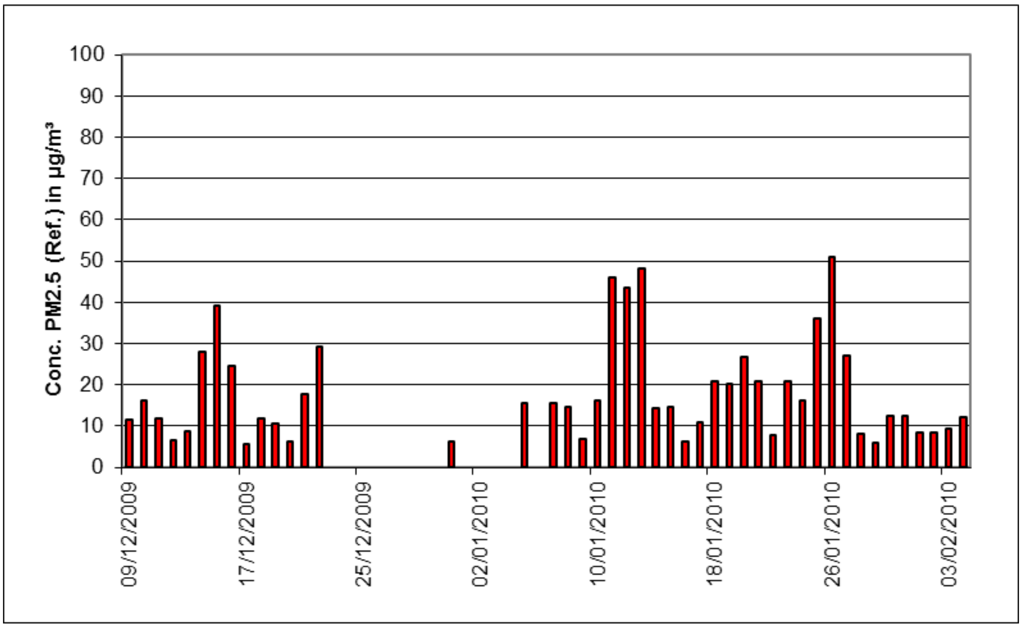


Figure 23: PM$_{2,5}$ concentrations (reference) in Teddington, winter

The following pictures show the measurement container at the field test sites in Teddington, Cologne (parking lot) and Bornheim (parking lot at a motorway).

Figure 24: Field test site in Teddington

Figure 25: Field test site Cologne, parking lot

Figure 26: Field test site Bornheim, motorway parking lot

In addition to the air quality measuring systems for monitoring suspended particulate matter, a data logger for meteorological data was installed at the container/measurement site. Data on air temperature, pressure, humidity, wind speed, wind direction and precipitation were continually measured. 30-minute mean values were recorded.

The following dimensions describe the design of the measurement cabinet as well as the position of the sampling probes.

- Height of cabinet roof. 2.50m
- Height of the sampling system for test/ 1.13 m/0.51m above cabinet roof
- Reference system 3.63 / 3.01 m over ground level
- Height of the wind vane: 4.5 m above ground level

In addition to an overview of the meteorological conditions determined during measurements at the 4 field test sites, the following Table 5 therefore provides information on the concentrations of suspended particulate matter. Meteorological data for the site in Teddington was only available after 17 September 2008. All individual values are presented in appendices 5 and 6.

Table 5: Ambient conditions at the field test sites as daily averages

	Teddington (UK), Summer*	Cologne Parking lot Winter	Bornheim, Motorway parking area Summer	Teddington (UK), Winter
number of measurements Reference	81	75	58	45
Ratio of $PM_{2.5}$ to PM_{10} [%]				
Range	22.3–83.2	42.4 – 92.9	40.3 – 81.8	41.6 – 90.6
Average	53.9	73.8	60.5	70.3
Air temperature [°C]				
Range	4.2–15.4	-14 – 17.8	3.3 – 25.3	-3.7 – 9.8
Average	11.2	3.9	15.4	2.7
Air pressure [hPa]				
Range	984–1016	971 – 1030	995 – 1022	984 – 1037
Average	1000	1008	1010	1008
Rel. humidity [%]				
Range	64–95	48 – 85	44 – 82	77 – 98
Average	81.4	71.4	68.1	89.6
Wind speed [m/s]				
Range	0.0–1.8	0.0 – 6.9	0.0 – 4.4	0.0 – 2.4
Average	0.5	2.0	0.4	0.6
Precipitation rate [mm/d]				
Range	not available	0.0 – 26.9	0.0 – 20.0	0.0 – 11.7
Average		2.5	1.9	1.8

* Weather data only available after 17/09/2008

Sampling duration

Standard EN 14907 [3] fixes the sampling time at 24 h ± 1 h.

During the entire field test, all instruments were set to a sampling time of 24 h (from 10:00 to 10:00 o'clock (Cologne, Teddington) and from 7:00 to 7:00 o'clock (Bornheim)).

Data handling

Prior to their assessment for each field test site, measured value pairs determined from reference values during the field test were submitted to a statistical Grubb's test for outliers (99%) in order to prevent distortions of the measured results from data, which evidently is implausible. Measured values pairs detected as significant outliers may be expunged from the pool of values as long as the test statistic remains above the critical value. The January 2010 version of the guideline [4] requires that no more than 2.5% of the data pairs be detected and removed as outliers.

In principle, no measured value pairs are expunged for the tested AMS, unless there are justifiable technical reasons for implausible values. During the entire test, no measured values were expunged for the tested AMS.

Table 6 presents an overview of the measured value pairs which have been detected and expunged as significant outliers (reference).

Table 6: Results of the Grubb's test for outliers – reference $PM_{2.5}$

Graph Number	Site	Sampler	Number of data-pairs	Maximum Number that can be deleted	Number Identified	Number Deleted	Number of data-pairs remaining
A	Teddington Summer	$PM_{2.5}$ Leckel	83	2	2	2	81
B	Cologne Winter	$PM_{2.5}$ Leckel	77	2	3	2	75
C	Bornheim Summer	$PM_{2.5}$ Leckel	60	2	2	2	58
D	Teddington Winter	$PM_{2.5}$ Leckel	46	1	2	1	45

The following value pairs have been expunged:

Table 7: Value pairs (reference $PM_{2.5}$) discarded from the data set following Grubb's test

Location	Date	Reference 1 [µg/m³]	Reference 2 [µg/m³]
Teddington, Summer	24.07.2008	32.5	27.8
Teddington, Summer	26.07.2008	16.1	13.8
Cologne, Winter	20 January 2009	11.2	8.4
Cologne, Winter	03 February 2009	34.0	37.4
Bornheim, Summer	25 August 2009	13.8	20.3
Bornheim, Summer	22 October 2009	27.0	24.3
Teddington, Winter	06 January 2010	13.5	16.0

Filter handling – Mass measurement

The following filters were used during performance testing:

Table 8: Filter materials used

Measuring device	Filter material, type	Manufacturer
Reference devices LVS3	Emfab™, ∅ 47 mm	Pall

Filter handling was performed in compliance with EN 14907.

The methods used for processing and weighting filters and for weighing are described in detail in appendix 2 to this report.

5. Reference Measurement Method

The following instruments were used during the field test in accordance with EN 14907:

1. as $PM_{2.5}$ reference system:	Low Volume Sampler LVS3 Manufacturer: Engineering office Sven Leckel, Leberstraße 63, Berlin, Germany Date of manufacture: 2007 $PM_{2.5}$ sampling inlet

During the tests, two reference systems for $PM_{2.5}$ were operated in parallel with the flow controlled at 2.3 m³/h. Under normal conditions the accuracy of flow control is < 1% of the nominal flow rate.

For the LVS3 low volume sampler, the rotary vane vacuum pump takes in sample air via the sampling inlet. The volumetric flow is measured between the filter and the vacuum pump with the help of a measuring orifice. The air taken in flows from the pump via a separator for the abrasion of the rotary vane to the air outlet.

After sampling has been completed, the electronics display the sample air volume in standard and operating m³.

The $PM_{2.5}$ concentrations were determined by dividing the quantity of suspended particulate matter on each filter determined in the laboratory with a gravimetric method by the corresponding throughput of sample air flow as operating m³.

6. Test results

6.1 1 Measuring ranges

The measuring ranges shall meet the following requirements:
0 µg/m³ to 1000 µg/m³ as a 24-hour average value
0 µg/m³ to 10,000 µg/m³ as a 1-hour average value, if applicable

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

It was tested whether the measuring system's upper limit of measurement meets the requirements .

6.4 Evaluation

The following measuring ranges can be set at the measuring system: 0 – 0.100, 0 – 0.200, 0 – 0.250, 0 – 0.500, 0 – 1.000, 0 – 2.000, 0 – 5.000 as well as 0 – 10.000 mg/m³.

During the performance test, the measuring range was set to 0–1.000 mg/m³ = 0–1,000 µg/m³.

Measuring range: 0 –1,000 µg/m³ (standard)

6.5 Assessment

The measuring range is set to 0–1,000 µg/m³ by default. Supplementary measuring ranges are possible up to 0–10,000 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 2 negative signals

Negative signals shall not be suppressed.

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

The possibility of displaying negative signals was tested both in the laboratory and in the field test.

6.4 Evaluation

The measuring system is able to output negative signals both via its display and its data outputs.

6.5 Assessment

Negative signals are directly displayed and correctly output by the measuring system.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 3 Zero level and detection limit (7.4.3)

Zero level: ≤ 2.0 µg/m^3
Detection limit: ≤ 2.0 µg/m³

6.2 Equipment

Zero filter for zero checks

6.3 Testing

The zero level and detection limit of the AMS shall be determined by measurement of 15 24-hour average readings obtained by sampling from zero air (no rolling or overlapped averages are permitted). The mean of these 15 24-h averages is used as the zero level. The detection limit is calculated as 3,3 times the standard deviation of the 15 24h-averages.

The zero level and the detection limit were determined with zero filters installed at the AMS inlets of instruments with SN X14465 and SN X14499 during normal operation. Air free of suspended particulate matter is applied over a period of 15 days for a duration of 24h each.

6.4 Evaluation

The detection limit X is calculated from the standard deviation s_{x0} of the measured values sucking air free from suspended particulate matter through both test specimen. It is equal to the standard deviation of the average x_0 of the measured values x_{0i} multiplied by 3.3 for each test specimen.

$$X = 3.3 \cdot s_{x0} \qquad \text{where} \cdot s_{x0} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

6.5 Assessment

On the basis of testing both instruments, the zero level was determined at a maximum of 0.27 µg/m³ and the detection limit at a maximum of 1.75 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 9: Zero level and detection limit $PM_{2.5}$

		Device SN X14465	Device SN X14499
Number of values n		15	15
Average of the zero values (Zero level) $\bar{x}_0$	µg/m³	0.27	0.23
Standard deviation of the values s_{x0}	µg/m³	0.42	0.53
Detection limit x	µg/m³	**1.37**	**1.75**

Schedule 1 in the annex contains the individual measured values for the determination of the zero level and detection limit.

6.1 4 Flow rate accuracy (7.4.4)

The relative difference between the two values determined for the flow rate shall be ≤ 2.0%.

The relative difference between the two values determined for the flow rate shall fulfil the following performance requirements:

≤ 2.0%

- *at 5°C and 40°C for installations in an air-conditioned environment by default*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

Climatic chamber for the temperature range of +5°C to +40°C; a reference flow meter in accordance with item 4 was provided.

6.3 Testing

The BAM-1020 measuring system operates at a flow rate of 16.67 l/min (1 m³/h).

At a temperature of +5 °C and +40 °C the flow rate was measured with the help of a reference flow meter for both measuring systems by taking 10 measurements over a period of 1h at the flow rate specified by the manufacturer for operation. The measurements were performed at equal intervals throughout the measurement period.

6.4 Evaluation

Averages were calculated from the 10 measured values determined at each temperature and deviations from the operating flow rate determined.

6.5 Assessment

The relative difference determined for the mean of the measuring results at +5°C and at +40°C did not exceed -1.93%.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 10 summarises the results of the flow rate measurements.

Table 10: Flow rate accuracy at +5°C and +40°C

		Device SN X14465	Device SN X14499
Nominal value flow rate	l/min	16.67	16.67
Mean value at 5°C	l/min	16.41	16.35
Dev. from nominal value	%	-1.54	-1.93
Mean value at 40°C	l/min	16.87	16.88
Dev. from nominal value	%	1.18	1.24

Schedule 2 in the annex contains the individual measured values for the determination of the flow rate accuracy.

6.1 5 Constancy of sample flow rate (7.4.5)

The instantaneous flow rate and the flow rate averaged over the sampling period shall fulfil the performance requirements below.

≤ 2.0% sample flow (instantaneous flow)
≤ 5% rated flow (instantaneous flow)

6.2 Equipment

For this test, an additional reference flow meter in accordance with item 4 was provided.

6.3 Testing

The BAM-1020 measuring system operates at a flow rate of 16.67 l/min (1 m³/h).

The sample flow rate was calibrated before the first field test and the checked with the help of a mass flow controller at every new field test site and re-adjusted when necessary.

To determine the constancy of the sample flow rate, the flow rate was recorded and evaluated with the help of a mass flow meter over a period of 24h (= 24 measurement cycles, 5-second values for the flow rate).

6.4 Evaluation

The average, standard deviation as well as the maximum and minimum values were determined from the measured values for the flow rate.

6.5 Assessment

Table 11 presents the results of the flow rate checks performed at every field test site.

Table 11: Results of the flow rate checks

Flow rate check before:	SN 17010		SN 17011	
Field test site:	[l/min]	Dev. from target [%]	[l/min]	Dev. from target [%]
Teddington, Summer	16.3	-2.4	16.5	-1.2
Cologne, Winter	16.8	0.6	16.7	0.0
Bornheim, Summer	16.7	0.0	16.9	1.2
Teddington, Winter	16.5	-1.2	16.6	-0.6

The charts illustrating the constancy of the sample flow rate demonstrate that all measured values determined during sampling deviate from their respective rated values by less than ±5%. At 16.67 l/min, the deviation of the 24h-mean for the overall flow rate also remains well below the required maximum of ±2.0% from the rated value.

The 24h-averages deviate from their rated values by less then ± 2.0%, all instantaneous values deviate by less than ± 5%.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table Table 12 lists the characteristics determined for the flow rate. Figure 27 to Figure 28 provide a chart of the flow rate measurement for both instruments - SN 17010 and SN 17011.

Table 12: Characteristics of the overall flow rate measurement (24h mean), SN 17010 and SN 17011

		Device SN 17010	Device SN 17011
Mean value	l/min	16.49	16.63
Dev. from nominal value	%	-1.07	-0.26
Standard deviation	l/min	0.09	0.10
Minimum value	l/min	16.20	16.30
Maximum value	l/min	16.85	16.85

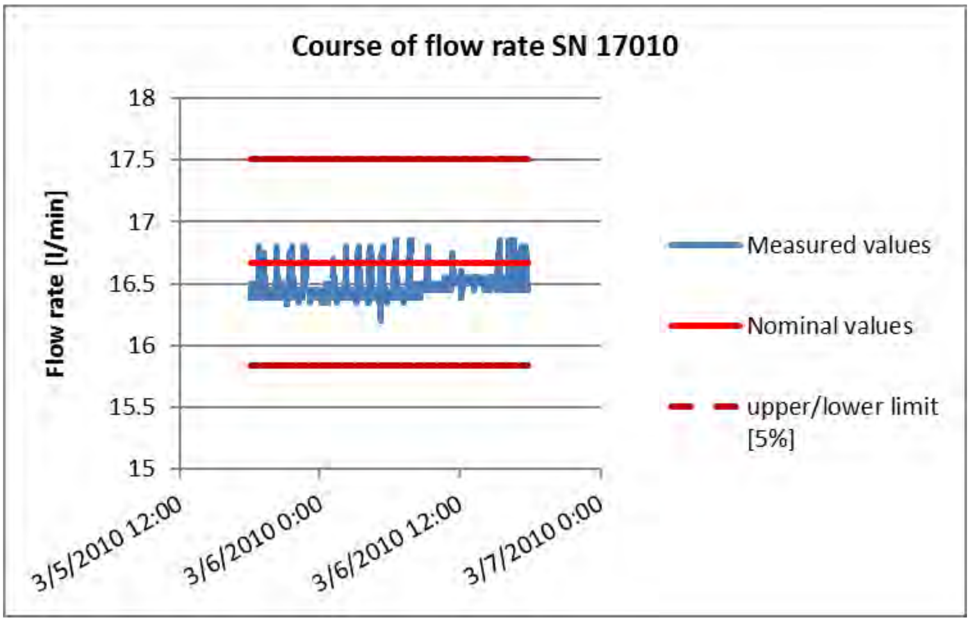


Figure 27: Flow rate of tested instrument SN 17010

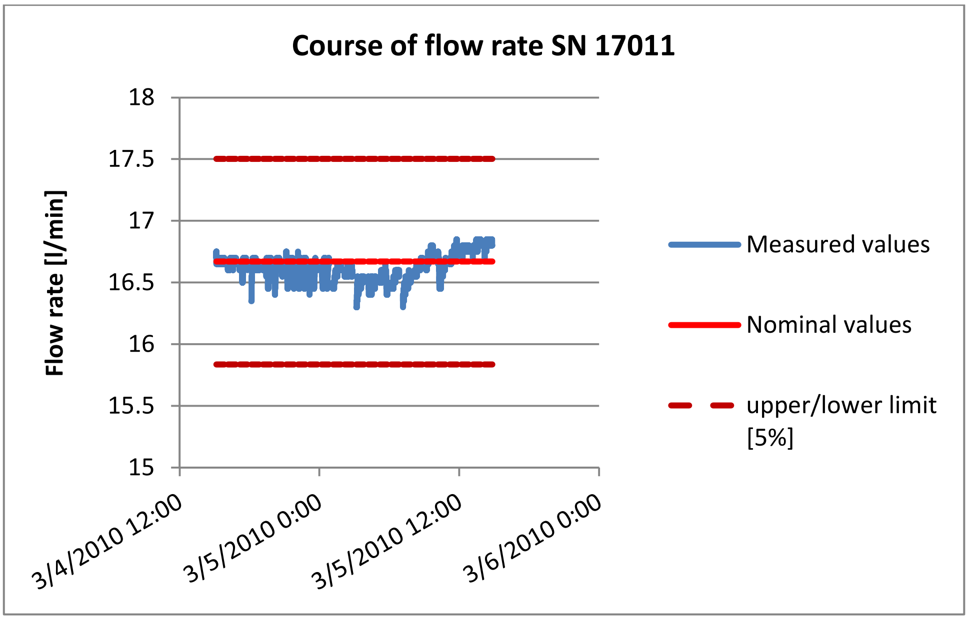


Figure 28: Flow rate of tested instrument SN 17011

6.1 6 Leak tightness of the sampling system (7.4.6)

Leakage shall not exceed 2.0% of the sample flow rate or else meet the AMS manufacturer's specifications in complying with the required data quality objectives (DQO).

6.2 Equipment

BX-302 zero filter kit or BX-305 inlet adapter

6.3 Testing

To determine the leak rate, the BX-305 inlet adapter was attached to the inlet of the sampling tube and the adapter's ball valve was closed slowly. The leak rate was determined from the difference between the flow rate when the pump was switched off (zero point of flow rate measurement) and the measured flow rate with a sealed instrument inlet.

This procedure was performed three times during the field test in Cologne.

It is re recommended to test the instrument's tightness with the procedure described above once a month.

6.4 Evaluation

The leak rate was determined from the difference between the flow rate when the pump was switched off (zero point of flow rate measurement) and the measured flow rate with a sealed instrument inlet.

The maximum of three observed leak rates was determined.

Under the test conditions described, the manufacturer allows a maximum leak rate of 1 l/min as a completely sealed instrument results in a very strong vacuum inside the measuring system which significantly exceeds any vacuum that could be created during normal operation by filter loading.

However, this maximum can be converted to a value which can realistically occur in normal operation. It is recommended to use the determined, converted leak rate for the evaluation of the measuring system.

The Hagen-Poiseuille law applies to laminar flowing liquids and gases in a tube. It describes the quantity of the medium flowing through a tube (with the length l and the radius r) per unit of time as follows:

$$\dot{V} = \frac{dV}{dt} = \frac{\pi r^4}{8\eta} \frac{\Delta p}{l}$$

For the present situation, the following may be derived:

1. The flow length l, the radius r and the dynamic viscosity η (for gases no pressure dependence in the range up to 10 bar) remain constant.

2. Thus, the leak rate $\dot{V}$ is immediately proportional to the differential pressure Δp.

3. During the leak tightness test, the nominal differential pressure is at 438 mbar when using the BX-127 pump (MEDO 230 V, 50 Hz).

4. Differential pressure in normal operation is at around 200–250 mbar. (see exemplary evaluation for SN 17011 from the performance test, Cologne, winter – Figure 29).

5. Accordingly, the displayed leak rate exceeds the actual rate at least by the factor 438/250 = 1.75.

6. Applying this factor to the data obtained results in the following leak rate related to the standard flow rate of 16.67 l/min.

   Gerät1: 1.0%
   System 2 1.4%

6.5 Assessment

The maximum leak rate was determined at 0.23 l/min and was smaller than 2% of the nominal flow rate 16.67 l/min.

The criterion for passing the leak test as specified by the AMS manufacturer – maximum flow rate of 1.0 l/min – proves to be an adequate criterion for monitoring the instrument's leak tightness. The method described reliably detects potential leakages in the system (e.g. contaminations in the area of the inlet nozzle at the filter band caused by filter abrasion.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 13 lists the result from the leak test.

Table 13: Results of the leak test during the field test

	Flow (Pump off)	Flow (Pump on, inlet closed)						
		1 (01.12.08)	2 (26.01.09)	3 (16.02.09)	Max. value	Max.value divided by 1.75	Part target value	Max. acceptable leak rate acc. Manufacturer
	l/min	l/min	l/min	l/min	l/min	l/min	%	l/min
SN 17010	0	0.1	0.3	0	0.3	0.17	1.03	1.0
SN 17011	0	0.1	0.4	0.3	0.4	0.23	1.03	1.0

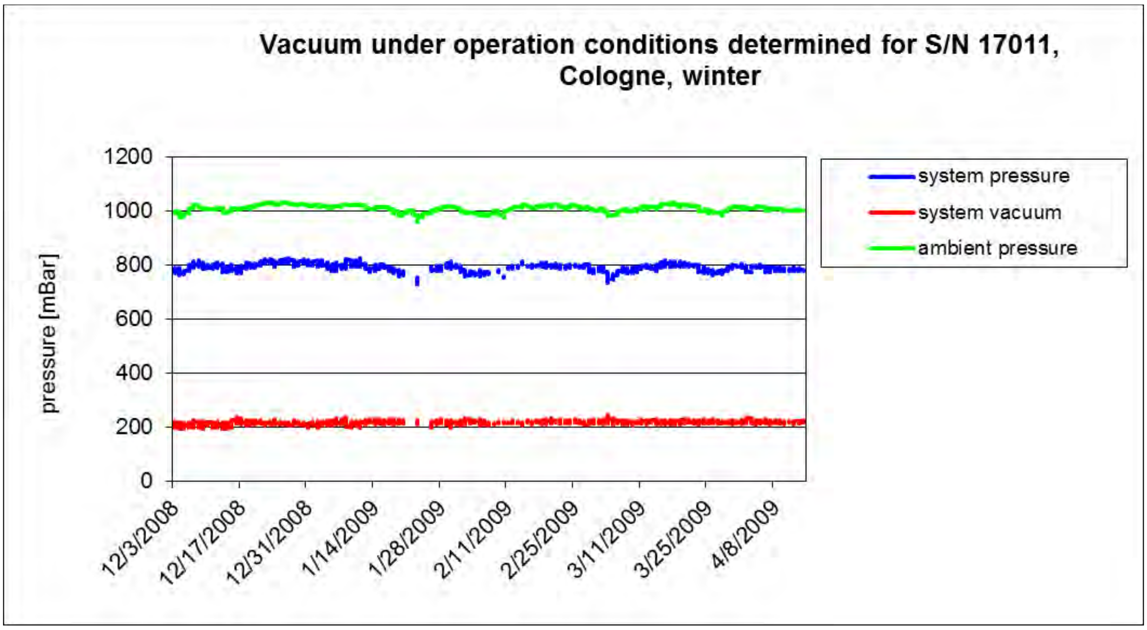


Figure 29: Vacuum under operating conditions determined for S/N 17011, Cologne, Winter

The average vacuum is 218 mbar, the maximum is at 245 mbar and the minimum is at 196 mbar.

6.1 7 Dependence of measured value on surrounding temperature (7.4.7)

The differences found shall comply with the performance criteria given below.
Zero point
≤ 2.0 µg/m3

- *between 5°C and 40°C by default, for installations in an air-conditioned environment.*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

Climatic chamber adjusted to a temperature range of +5 °C to +40 °C, zero filter kit BX-802 for zero point check.

6.3 Testing

The dependence of the zero reading on the surrounding temperature was determined at the following temperatures (within the specifications of the manufacturer):

a) at a nominal temperature $T_{S,n}$ = +20 °C;

b) at a minimum temperature $T_{S,1}$ = +5 °C;

c) at a maximum temperature $T_{S,2}$ = +40 °C.

The complete measuring systems were operated inside a climatic chamber in order to evaluate the influence of ambient temperature on the zero point.

Sample air, free of suspended particles, was supplied to the two candidate systems after fitting two zero filters at the AMS inlet in order to perform zero point checks.

The tests were performed in the temperature sequence $T_{S,n}$ — $T_{S,1}$ — $T_{S,n}$ — $T_{S,2}$ — $T_{S,n}$.

Readings were recorded at zero point after an equilibration period of at least 24h for every temperature step (3 readings each).

6.4 Evaluation

Measured values for the concentrations of the individual readings were read and evaluated.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_{S,n}$ were averaged.

The differences between readings at both extreme temperatures and $T_{S,lab}$ were determined.

6.5 Assessment

The tested temperature range at the site of installation was +5 °C to +40 °C. Taking into account the values displayed by the instrument, we determined a maximum dependence of the zero point on the on surrounding temperature of -1.8 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 14: Dependence of the zero point on surrounding temperature, BAM-1020, Deviation as µg/m³, mean from three measurements S/N 17010 & S/N 17011

Temperature	SN 17010		SN 17011	
	Measured value	Deviation to mean value at 20°C	Measured value	Deviation to mean value at 20°C
°C	µg/m³	µg/m³	µg/m³	µg/m³
20	0.2	-0.9	-1.0	0.1
5	1.6	0.5	-0.3	0.8
20	0.6	-0.5	-1.1	0.0
40	0.3	-0.8	-2.9	-1.8
20	2.5	1.4	-1.3	-0.2
Mean value at 20°C	1.1	-	-1.1	-

Schedule 3 in the annex contains the individual measuring results.

6.1 8 Dependence of measured value (span) on surrounding temperature (7.4.7)

The differences found shall comply with the performance criteria given below.
Sensitivity of the measuring system (span):
≤ 5% from the value at the nominal test temperature

- *between 5°C and 40°C by default, for installations in an air-conditioned environment.*
- *at minimum and maximum temperatures specified by the manufacturer if these deviate from the default temperatures.*

6.2 Equipment

climatic chamber adjusted to +5 °C to +40 °C, internal span foil used to check the span point.

6.3 Testing

The dependence of AMS sensitivity (span) on the surrounding temperature was determined at the following temperatures (within the specifications of the manufacturer):

a) at a nominal temperature $T_{S,n}$ = +20 °C;

b) at a minimum temperature $T_{S,1}$ = +5 °C;

c) at a maximum temperature $T_{S,2}$ = +40 °C.

For the purpose of testing the dependence of the AMS sensitivity on the surrounding temperature, the complete measuring system was operated in the climatic chamber without the outdoor rack.

For the purpose of span checks the sensitivity of the internal span foil was verified for the tested instruments SN 17010 and SN 17011 in order to test the stability of the sensitivity.

The tests were performed in the temperature sequence $T_{S,n}$ — $T_{S,1}$ — $T_{S,n}$ — $T_{S,2}$ — $T_{S,n}$.

Readings were recorded at zero point after an equilibration period of at least 6h for every temperature step (3 readings each).

6.4 Evaluation

Measured values for the internal span foil were recorded at different temperatures and evaluated.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_{S,n}$ were averaged.

The differences between readings at both extreme temperatures and $T_{S,lab}$ were determined.

6.5 Assessment

The tested temperature range at the site of installation was +5 °C to +40 °C. At span point, the deviations determined did not exceed 0.3%.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 15: Dependence on surrounding temperature (internal span foil), BAM-1020, deviation in %, average from 3 readings
S/N 17010 & S/N 17011

Temperature	SN 17010		SN 17011	
	Measured value	Deviation to mean value at 20°C	Measured value	Deviation to mean value at 20°C
°C	[µg/cm²]	%	[µg/cm²]	%
20	829.7	0.0	822.5	-0.1
5	829.3	0.0	822.5	-0.1
20	829.5	0.0	822.8	0.0
40	831.1	0.2	825.2	0.3
20	829.5	0.0	823.6	0.1
Mean value at 20°C	829.6	-	823.0	-

Schedule 3 in the annex contains the results from 3 individual measurements.

6.1 9 Dependence of span on supply voltage (7.4.8)

The differences found shall comply with the performance criteria given below.
Sensitivity of the measuring system (span):
≤ 5% from the value at the nominal test voltage

6.2 Equipment

Isolating transformer, internal span foil for span checks

6.3 Testing

In order to test the dependence of span on supply voltage, supply voltage was reduced to 195 V starting from 230 V, it was then increased to 253 V via an intermediary step of 230 V.

For the purpose of span checks, the sensitivity of the internal span foil was verified for the tested instruments SN X14465 and SN X14499 in order to test the stability of the sensitivity.

6.4 Evaluation

At span point, the percentage change of the measured value determined for every step related to the starting point at 230 V was considered.

6.5 Assessment

Voltage variations did not result in deviations > -0.4% compared to the initial value of 230 V.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 16 shows a summary of the test results.

Table 16: Influence of mains voltage on measured value, deviation in %
SN X14465 & SN X14499

Supply voltage	SN X14465		SN X14499	
	Measured value	Deviation to start value at 230 V	Measured value	Deviation to start value at 230 V
V	[mg]	%	[mg]	%
230	0.815	-	0.826	-
195	0.816	0.2	0.828	0.3
230	0.817	0.3	0.822	-0.4
253	0.816	0.2	0.827	0.1
230	0.815	0.0	0.824	-0.2

Schedule 4 in the annex contains the individual results.

6.1 10 Effect of failure of mains voltage

Instrument parameters shall be secured against loss.
On return of main voltage the instrument shall automatically resume functioning.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

A simulated failure in the mains voltage served to test whether the instrument remained fully functional and reached operation mode on return of the mains voltage.

6.4 Evaluation

In the event of a failure in mains voltage, the measuring system automatically starts a new measuring cycle at the next full hour and thus resumes normal operation.

6.5 Assessment

Buffering protects all instrument parameters against loss. On return of mains voltage, the instrument returns to normal operating mode and automatically resumes measuring at the next full hour.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 11 Dependence of reading on water vapour concentration (7.4.9)

The largest difference in readings between 40% and 90% relative humidity shall fulfil the performance criterion stated below:
≤ 2.0 µg/m³ in zero air when cycling relative humidity from 40% to 90% and back.

.

6.2 Equipment

Climatic chamber c/w humidity control for the range between 40% and 90% relative humidity, zero filter for zero checks

6.3 Testing

The dependence of reading on water vapour concentration in the sample air was determined by feeding humidified zero air in the range between 40% and 90% relative humidity. To this effect, the measuring system was operated in the climatic chamber and the relative humidity of the entire surrounding atmosphere was controlled. Sample air, free of suspended particles was supplied to the instruments SN X14465 and SN X14499 after fitting two zero filters at either AMS inlet in order to perform zero point checks.

After stabilisation of relative humidity and the concentration values, a reading over an 24h-averaging period at 40% relative humidity was recorded. Relative humidity was then increased to 90% at a constant pace. The time needed until an equilibrium was reached (ramp) and the measured value over an averaging time of 24h at 90% relative humidity were recorded. Subsequently, humidity was decreased to 40% at a constant pace. Again, the time needed until an equilibrium was reached (ramp) and the reading over an averaging time of 24h at 40% relative humidity were recorded.

6.4 Evaluation

The measured value for the zero level of 24-hour individual measurements at stable humidity levels were obtained and assessed. The characteristic concerned is the largest difference in µg/m³ between values in the range of 40% to 90% relative humidity.

6.5 Assessment

Differences between readings determined at relative humidifies of 40% and 90% did not exceed 2.0 µg/m³. Various water vapour concentrations were not observed to cause any significant effect on zero readings.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 17: Dependence of reading on water vapour concentration. dev. in µg/m³. $PM_{2.5}$. SN X14465 & SN X14499

rel. Humidity	SN X14465		SN X14499	
	Measured value	Deviation to previous value	Measured value	Deviation to previous value
%	µg/m³	µg/m³	µg/m³	µg/m³
40	0.4	-	-0.1	-
90	-1.6	-2.0	-1.8	-1.7
40	-0.5	1.2	-1.2	0.6
Maximum deviation	-2.0		-1.7	

6.1 12 Zero checks (7.5.3)

During the tests, the absolute measured value of the AMS shall not exceed the following criterion:

Absolute value ≤ 3.0 µg/m³

6.2 Equipment

Zero filter for zero checks

6.3 Testing

As part of the field test the checks were performed over a total of 20 months.

As part of regular checks about every month (incl. at the beginning and at the end of the tests at each location), the measuring systems were operated with zero filters fitted to the AMS inlets over a period of at least 24h and zero readings were evaluated.

6.4 Evaluation

During the tests, the absolute measured value of the AMS at zero point defined at 3.0 µg/m³ shall not be exceeded.

6.5 Assessment

The maximum measured value determined for $PM_{2,5}$ at zero point was 1.8 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 18 shows the determined measured values for the zero point in µg/m³.

Figure 30 to Figure 31 illustrate the zero drift observed during the test period.

Table 18: Zero point checks SN 17010 & SN 17011, $PM_{2.5}$, with zero filter

Date	SN 17010		Date	SN 17011	
	Measured Value µg/m³	Measured value (absolute) > 3.0 µg/m³		Measured Value µg/m³	Measured value (absolute) > 3.0 µg/m³
7/24/2008	1.4	ok	7/24/2008	-1.3	ok
8/18/2008	-0.8	ok	8/18/2008	-1.1	ok
9/23/2008	1.0	ok	9/23/2008	-0.6	ok
10/16/2008	1.8	ok	10/16/2008	-0.8	ok
11/10/2008	-0.1	ok	11/10/2008	-0.2	ok
12/3/2008	-1.2	ok	12/3/2008	-0.3	ok
1/7/2009	0.4	ok	1/7/2009	0.7	ok
2/2/2009	-0.7	ok	2/2/2009	-0.4	ok
3/4/2009	-1.5	ok	3/4/2009	-1.1	ok
4/2/2009	0.2	ok	4/2/2009	0.4	ok
8/13/2009	0.1	ok	8/13/2009	-1.3	ok
9/14/2009	-0.1	ok	9/14/2009	0.3	ok
10/23/2009	-0.1	ok	10/23/2009	-0.2	ok
12/7/2009	0.9	ok	12/7/2009	0.5	ok
1/4/2010	0.4	ok	1/4/2010	0.8	ok
2/5/2010	-0.3	ok	2/5/2010	1.6	ok

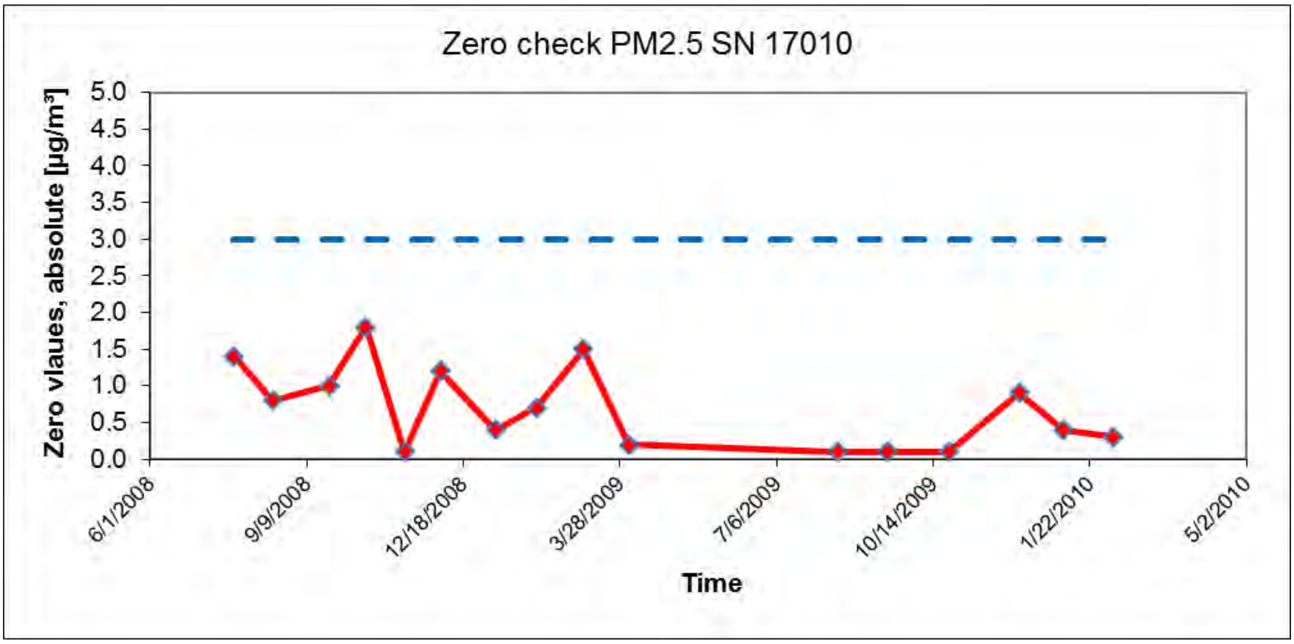


Figure 30: Zero drift SN 17010, measured component $PM_{2.5}$

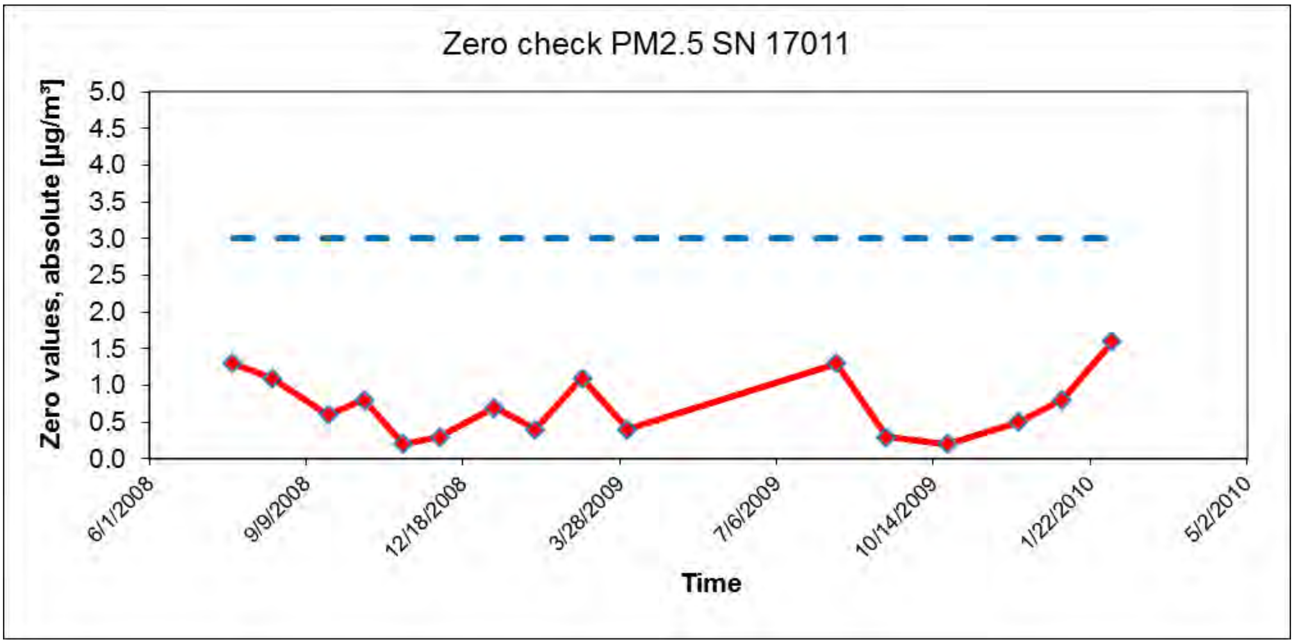


Figure 31: Zero drift SN 17011, measured component $PM_{2.5}$

6.1 13 Recording of operational parameters (7.5.4)

Measuring systems shall be able to provide data of operational states for telemetric transmission of – at minimum – the following parameters:

- *Flow rate;*
- *Pressure drop over sample filter (if relevant);*
- *Sampling time;*
- *Sampling volume (if relevant);*
- *Mass concentration of relevant PM fraction(s);*
- *Ambient temperature,*
- *Exterior air pressure,*
- *Air temperature in measuring section,*
- *Temperature of the sampling inlet if a heated inlet is used;*

Results of automated/functional checks, where available, shall be recorded.

6.2 Equipment

Modem, PC for data acquisition (RS 232-host-device)

6.3 Testing

The measuring system allows for comprehensive remote monitoring and control e.g. via an RS232 interface. It can communicate measured values and status information via the Bavaria-Hesse protocol.

It is possible to communicate the operating statuses and relevant parameters including:

- Concentration measured values from the previous test cycle,
- Sampled volume,
- Sample flow rate
- Ambient temperature and pressure,
- Internal measurement of zero point (STAB) and span point (REF)
- Pressure drop across the filter band (5min flow file),
- It is also possible to configure relative humidity in the area of filter band (monitoring / control of heating) or other meteorological parameters.
-

The parameters “sampling duration” (set via the cycle time) and “temperature of the sample inlet” are irrelevant to the measuring system.

Remote monitoring and control is easily possible via routers or modems.

Access to the instrument and the data during the performance test was ensured by terminal software.

6.4 Evaluation

The measuring system allows for comprehensive remote monitoring and control via various connectors (Ethernet, RS232). The instrument provides operating statuses and all relevant parameters.

6.5 Assessment

The measuring system allows for comprehensive remote monitoring and control via various connectors (Ethernet, RS232). The instrument provides operating statuses and all relevant parameters.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 14 Daily averages (7.5.5)

The AMS shall allow for the formation of daily averages or values.

6.2 Equipment

For this test, a clock was additionally provided.

6.3 Testing

We verified whether the measuring system allows for the formation of daily averages.

6.4 Evaluation

By default, the measuring system operates with a measurement cycle of 60 min. After each measurement cycle, the filter tape is moved forward by one position. The data of each measurement cycle are stored and are available to the user for further processing. Furthermore, the measuring system allows the formation of a 24 h average, which is output in the daily protocol via the serial interface.

During the performance test, the cycle time was set to 60 min, radiometric measurements taking 8 min each.

Thus, the cycle time consists of 2 x 8 min for the radiometric measurement (I_0 & I_3) as well as approximately 1–2 min for filter tape movements. Accordingly, the sampling time per hour is 42 min.

Thus, the available sampling time per measurement cycle corresponds to approx. 70 % of the total cycle time. The results of the field test in accordance with item 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8) in this report show that reproducibility of the test specimen compared to the reference method for this instrument configuration was clearly demonstrated and thus daily averages can reliably be formed.

6.5 Assessment

The instrument configuration described and a measurement cycle set to 60 min allow the formation of valid daily averages based on 24 individual measurements.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 15 Availability (7.5.6)

The availability of the measuring system shall be at least 90%.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The start and end times at each of the four field test sites from the initial test marked the start and end time for the availability test. Proper operation of the measuring system was verified during every on-site visit (usually every working day). This daily check consisted of plausibility checks on the measured values, status signals and other relevant parameters. Time, duration and nature of any error in functioning are recorded.

The total time during the field test in which valid measurement data of ambient air concentrations were obtained was used for calculating availability. Time needed for scheduled calibrations and maintenance (cleaning; change of consumables) should not be included.

Availability is calculated as

$$A = \frac{t_{valid} + t_{cal,maint}}{t_{field}}$$

Where:

t_{valid} is the time during which valid data have been collected;

$t_{cal,maint}$ is the time spent for scheduled calibrations and maintenance;

t_{field} is the total duration of the field test.

6.4 Evaluation

Table 19 establishes the operation, maintenance and outage times. During the field test, the measuring systems were operated for a total of 373 measuring days (see annex 5). This period includes a total of 12 days in zero filter operation, audits as well as days which had to be disregarded because of changing to the zero filter (again, see annex 5).

Outages caused by external events not attributed to the measuring system occurred on 06 August 2008 and 07 August 2008 (48h due to power failure). Furthermore, all measuring systems were out of operation between 17/10/2008 and 20/10/2008 (for SN 17011 additionally 12/08/2009 (repair of SN 17010)). This reduces the total time of operation to 367 (SN 17010) and 366 measuring days (SN 17011).

The following errors in functioning were observed:

A tape fault caused 3 days of outage for S/N 17010. Moreover irregularities (spikes) in the concentration and in the stability values (internal zero check) were recorded at the beginning of tests in Bornheim. It turned out that the detector (PMT) of the measuring system caused these spikes although the reason remains unknown. The detector was replaced on site on 12 August 2009. The parameters for instrument calibration implemented in the system remained unaffected. In sum, the issues with the detector resulted in a total outage of 4 days.

System no. 17011 experienced one day of outage because the filter tape got stuck. Two additional days of outage were the result of a filter fault.

No further errors in functioning were observed:

Regular cleaning of the sampling inlets in the maintenance interval, filter tape replacement (approx. every 2 months) and regular checks of the flow rate and the leak tightness each resulted in outages of less than 1 h per instrument (outage time = 1 cycle). These tasks cause down times of less than 1h per check (16 times during testing) and did not require daily averages to be discarded.

6.5 Assessment

The availability for SN 17010 was 94.8%, for SN 17011 it was 95.9%.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 19: Determination of the availability

		System 1 (SN 17010)	System 2 (SN 17011)
Operation time (t_{field})	d	367	366
Outage time	d	7	3
Maintenance time incl. zero filter ($t_{cal,maint}$)	d	12	12
Actual operating time (t_{valid})	d	348	351
Availability	%	94.8	95.9

6.1 Method used for equivalence testing (7.5.8.4 & 7.5.8.8)

The January 2010 Guide [4] requires compliance with the following five criteria in order to recognise equivalence:

1. Of the full data set, at least 20% of the concentration values (determined with the reference method) shall be greater than the upper assessment threshold specified in 2008/50/EC [7], i.e. 28 µg/m³ for PM_{10} and 17 µg/m³ for $PM_{2.5}$. Should this not be assured because of low concentration levels, a minimum of 32 value pairs is considered sufficient.
2. Between-AMS uncertainty shall remain below 2.5 µg/m³ for the overall data and for data sets with data larger than/equal to 30 µg/m³ PM_{10} and 18 µg/m³ $PM_{2.5}$.
3. The uncertainty between reference systems shall not exceed 2.0 µg/m³.
4. The expanded uncertainty (W_{CM}) is calculated at 50 µg/m³ for PM_{10} and at 30 µg/m³ for $PM_{2.5}$ for every individual test specimen and checked against the average of the reference method. For each of the following cases, the expanded uncertainty shall not exceed 25%:
   - Full data set:
   - datasets representing PM concentrations greater than/equal to 30 µg/m³ for PM_{10}, or concentrations greater than/equal to 18 µg/m³ for $PM_{2.5}$, provided that the set contains 40 or more valid data pairs
   - Datasets for each individual site
5. Preconditions for acceptance of the full dataset are that the slope b is insignificantly different from $|b-1| \le 2 \cdot u(b)$ and the intercept a is insignificantly different from 0: $|a| \le 2 \cdot u(a)$. If these preconditions are not met, the candidate method may be calibrated using the values obtained for slope and/or intercept.

The following chapter address the issue of verifying compliance with the five criteria.

Chapter 6.1 16 Between-AMS uncertainty $u_{bs,AMS}$ (7.5.8.4) addresses verification of criteria 1 and 2.

Verification of criteria 3, 4 and 5 is reported on in chapter 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

Chapter 6.1 17 Use of correction factors/terms (7.5.8.5–7.5.8.8) contains an assessment for the case that criterion 5 is not complied with without applying correction factors.

6.1 16 Between-AMS uncertainty $u_{bs,AMS}$ (7.5.8.4)

The between-AMS uncertainty u_{bs} shall be ≤ 2.5 µg/m³.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The test was performed as part of the field test with four separate comparison campaigns. Different seasons as well as different concentrations of $PM_{2.5}$ were taken into consideration.

In the full dataset, at least 20% of the results obtained using the reference method should be greater than the upper assessment threshold of the annual limit value specified in 2008/50/EC [7]. The assessment threshold for $PM_{2.5}$ is 17 µg/m³.

For each comparison campaign, at least 40 valid value pairs were determined. Of the full dataset, (4 locations, 251 valid pairs of measured values for SN 17010, 253 valid pairs for SN 17011) a total of 33.1% of the measured values exceed the upper assessment threshold of 17 µg/m³ for $PM_{2,5}$. The concentrations measured were related to the ambient conditions.

6.4 Evaluation

Chapter 7.5.8.4 of standard EN 16450 specifies that:

The between-AMS uncertainty u_{bs} shall be ≤ 2.5 µg/m³. A between-AMS uncertainty > 2.5 µg/m³ is an indication of unsuitable performance of one or both instruments, and equivalence should not be stated.

Uncertainty is determined for:

- All locations or comparisons together (full data set)
- 1 data set with measured values ≥ 18 µg/m³ for $PM_{2.5}$ (basis: averages reference measurement)

Furthermore, this report also covers an evaluation of the following data sets:

- Every location or comparison separately
- 1 data set with measured values < 18 µg/m³ for $PM_{2.5}$ (basis: averages reference measurement)

The between-AMS uncertainty u_{bs} is calculated from the differences of all daily averages (24h-values) of the AMS which are operated simultaneously as:

$$u_{bs,AMS}^2 = \frac{\sum_{i=1}^{n}(y_{i,1} - y_{i,2})^2}{2n}$$

Where: $y_{i,1}$ and $y_{i,2}$ = Results of the parallel measurements of individual 24h-values i

n = Number of 24h-values

6.5 Assessment

At no more than 1.57 µg/m³ for $PM_{2.5}$, the between-AMS uncertainty u_{bs} remains well below the permissible maximum of 2.5 µg/m³.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 20 lists the calculated values for the between-AMS uncertainties u_{bs}. A corresponding chart is provided in Figure 32 to Figure 38.

Table 20: In-between-instrument uncertainty u_{bs} for the instruments SN 17010 and S/N 17011, measured component $PM_{2,5}$

Tested instruments	Location	Number of measurements	Uncertainty u_{bs}
SN			µg/m³
17010 / 17011	**All locations**	**345**	**1.38**
Individual locations			
17010 / 17011	Teddington, Summer	97	1.13
17010 / 17011	Cologne, Winter	127	1.76
17010 / 17011	Bornheim, Summer	66	1.13
17010 / 17011	Teddington, Winter	55	1.01
Classing over reference values			
17010 / 17011	**Values ≥ 18 µg/m³**	**174**	**1.57**
17010 / 17011	Values < 18 µg/m³	74	1.05

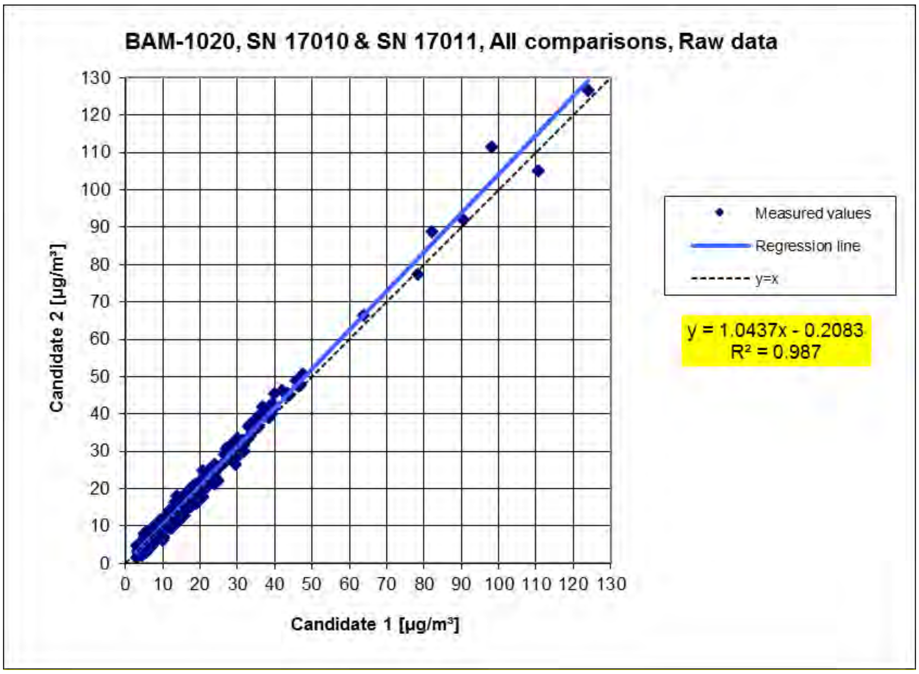


Figure 32: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, all locations

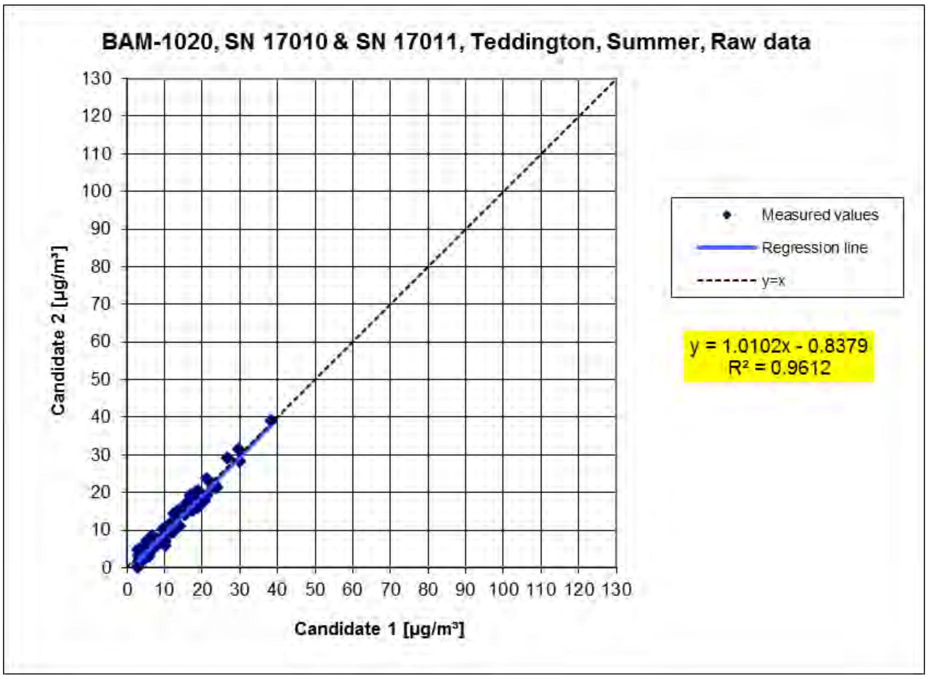


Figure 33: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, Teddington, summer

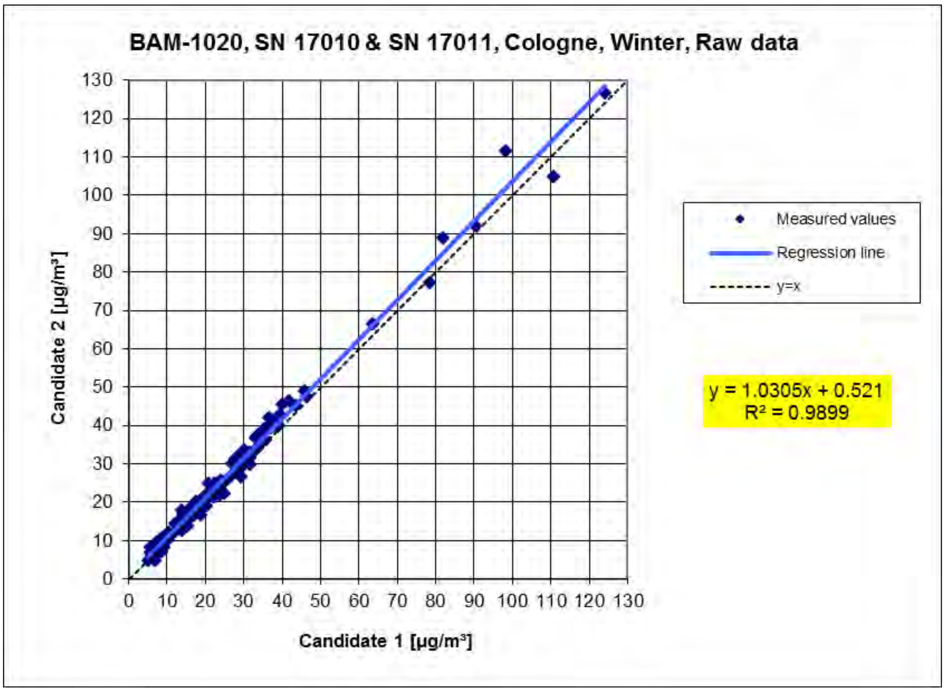


Figure 34: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, location: Cologne, Winter

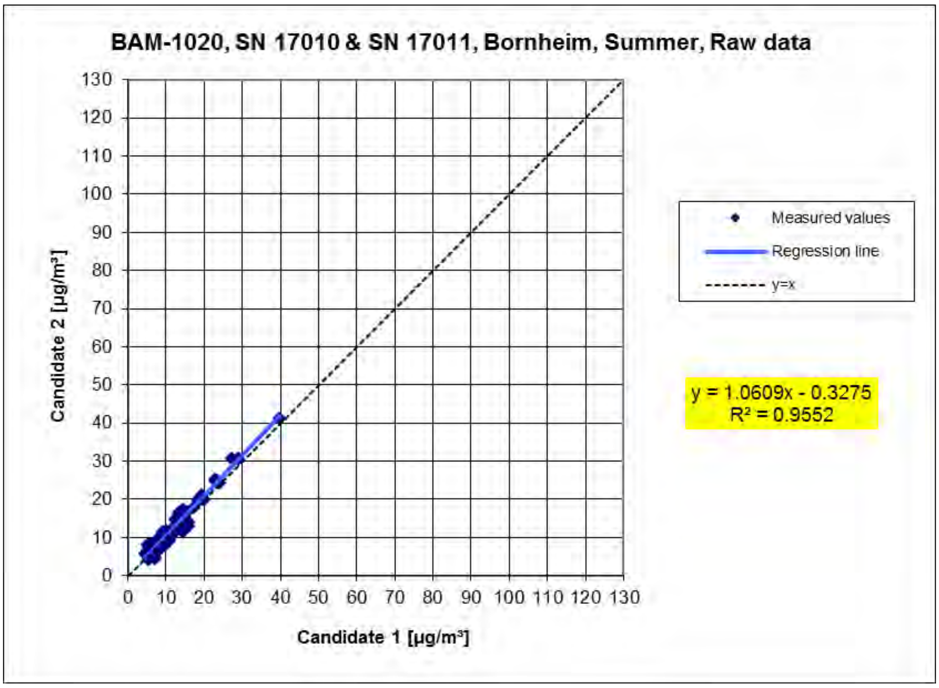


Figure 35: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, location: Bornheim, Summer

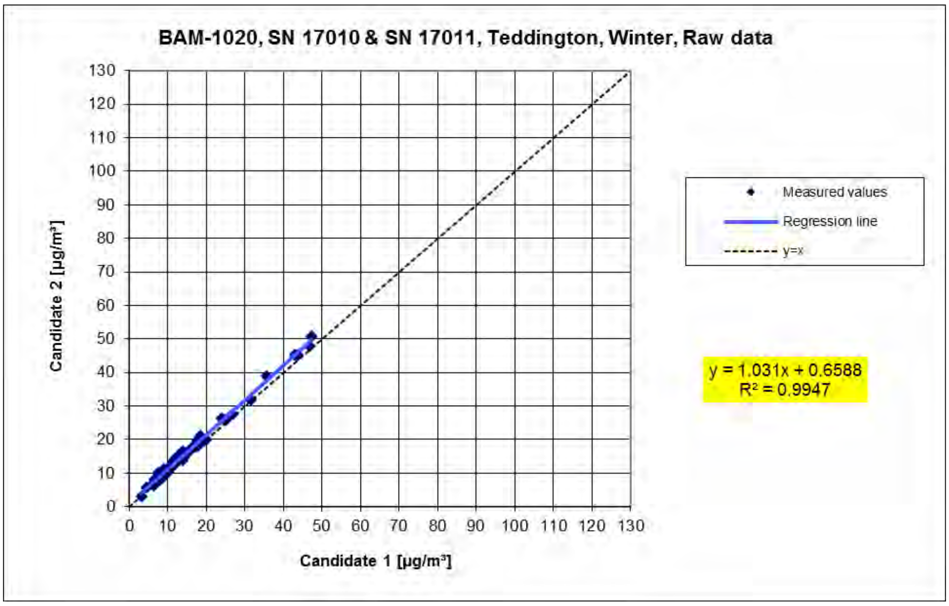


Figure 36: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, Teddington, winter

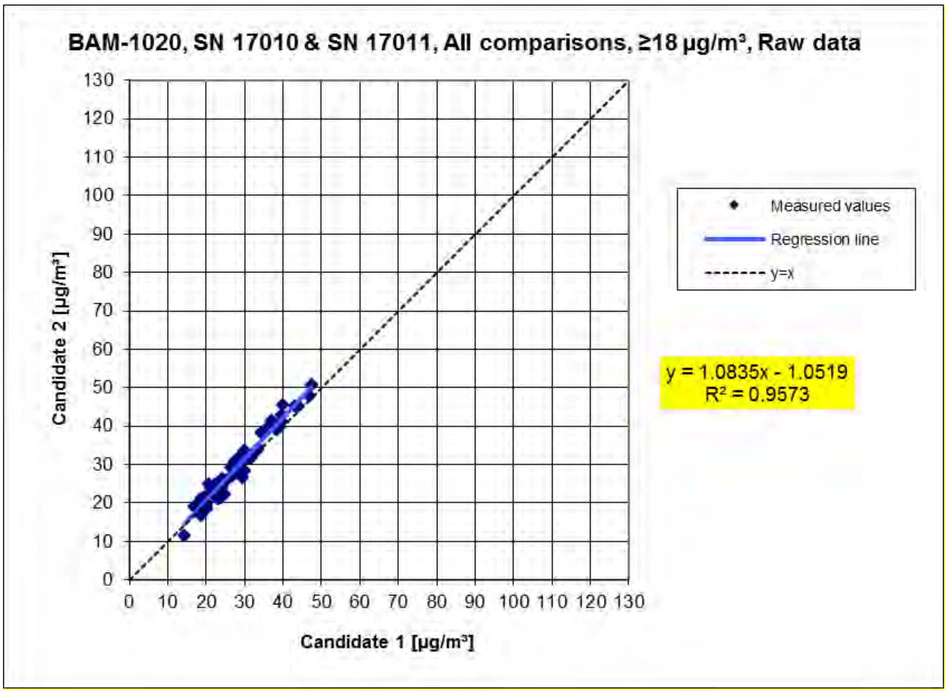


Figure 37: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, all locations, values ≥ 18 µg/m³

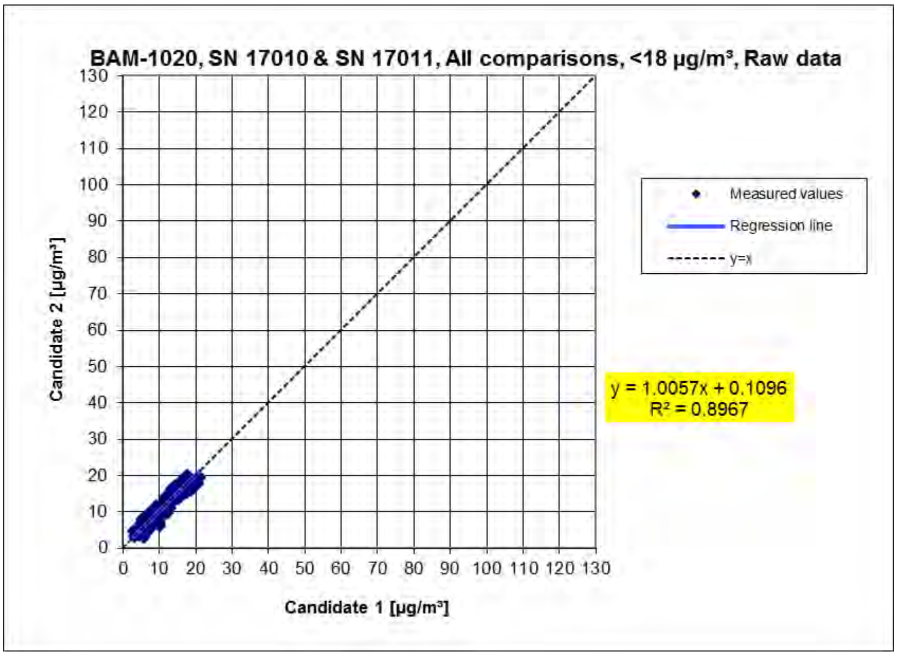


Figure 38: Results of the parallel measurements for instruments SN 17010 / SN 17011, Measured component $PM_{2.5}$, all locations, values < 18 µg/m³

6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

The expanded uncertainty shall be ≤ 25% at the level of the relevant limit value related to the 24-hour average results – after a calibration where necessary.

6.2 Equipment

Additional equipment as described in chapter 5 of this report was used for this test.

6.3 Testing

The test was performed as part of the field test with four separate comparison campaigns. Different seasons as well as different concentrations of $PM_{2.5}$ were taken into consideration.

In the full dataset, at least 20% of the results obtained using the reference method should be greater than the upper assessment threshold of the annual limit value specified in 2008/50/EC [7]. The assessment threshold for $PM_{2.5}$ is 17 µg/m³.

For each comparison campaign, at least 40 valid value pairs were determined. Of the full dataset, (4 locations, 251 valid pairs of measured values for SN 17010, 253 valid pairs for SN 17011) a total of 33.1% of the measured values exceed the upper assessment threshold of 17 µg/m³ for $PM_{2,5}$. The concentrations measured were related to the ambient conditions.

6.4 Evaluation

[EN 16450, 7.5.8.3]

Before calculating the expanded uncertainty of the test specimens, uncertainties were established between the simultaneously operated reference measuring systems (u_{ref})

Uncertainties between the simultaneously operated reference measuring systems $u_{bs,RM}$ were established similar to the between-AMS uncertainties and shall be ≤ 2.0 µg/m³.

Results of the evaluation are summarised in section 6.6.

[EN 16450, 7.5.8.5 & 7.5.8.6]

In order to assess comparability of the tested instruments y with the reference method x, a linear relationship $y_i = a + bx_i$ between the measured values of both methods is assumed. The association between the means of the reference systems and each individual test specimen to be assessed is established by means of orthogonal regression.

The regression is calculated for:

- all sites or comparisons respectively together
- Every location or comparison separately
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ (basis: averages of reference measurement)

For further assessment, the uncertainty u_{c_s} resulting from a comparison of the test specimens with the reference method is described in the following equation which defines u_{CR} as a function of the fine dust concentration x_i.

$$u_{yi}^2 = \frac{RSS}{(n-2)} - u_{RM}{}^2 + \left[a + (b-1)L\right]^2$$

Where RSS is the sum of the (relative) residuals from orthogonal regression

u_{RM} = is the random uncertainty of the reference method; u_{RM} is calculated as $u_{bs,RM}/\sqrt{2}$, with $u_{bs,RM}$ as the betwenn-RM uncertainty.

The algorithms for calculating axis intercept a and slope b as well as their variance by means of orthogonal regression are described in detail in the annex to [8].

The sum of (relative) residuals RSS is calculated according to the following equation:

$$RSS = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

Uncertainty u_{CR} is calculated for:

- all sites or comparisons respectively together
- Every location or comparison separately
- 1 data set with measured values $PM_{2.5}$ ≥ 18 µg/m³ (basis: averages of reference measurement)

The Guideline states the following prerequisite for accepting the full data set:

- The slope be is insignificantly different from 1: $|b-1| \le 2 \cdot u(b)$

and

- The axis intercept a is insignificantly different from 0: $|a| \le 2 \cdot u(a)$, where u(a) and u(b) describe the standard uncertainty of the slope and the axis intercept calculated as the square root of the variance. If the prerequisites are not met, it is possible to calibrate the measuring systems in accordance with section 9.7 of the Guideline (also see 6.1 17 Use of correction factors/terms). The calibration may only be performed for the full data set.

[EN 16450, 7.5.8.7] For all datasets the combined relative uncertainty of the AMS $w_{c,CM}$ is calculated from a combination of contributions from 9.5.3.1 and 9.5.3.2 in accordance with the following equation:

$$w_{AMS}^2 = \frac{u_{yi=L}^2}{L^2}$$

For each data set the uncertainty w_{AMS} is calculated at a level of L = 30 µg/m³ for $PM_{2.5}$.

[EN 16450 7.5.8.8] For each data set the expanded relative uncertainty of the results measured with the test specimen is calculated by multiplying w_{AMS} by an coverage factor k according to the following equation:

$$W_{AMS} = k \cdot w_{AMS}$$

In practice, k is specified at k=2 for large n.

[Item 9.6]

The largest resulting uncertainty W_{AMS} is compared and assessed against the criteria for data quality of air quality measurements in accordance with EU Directive [7]. Two situations are conceivable:

1. $W_{AMS} \leq W_{dqo}$ → The test is deemed equivalent to the reference method.
2. $W_{AMS} > W_{dqo}$ → The tested instrument is not deemed equivalent to the reference method.

The expanded relative uncertainty W_{dqo} specified is 25% [7].

7.5 Assessment

The uncertainty W_{CM} determined without applying correction factors for all observed data sets is below the determined expanded relative uncertainty W_{dqo} of 25% for fine particulate matter.

Criterion satisfied? yes

Given the significance of the axis intercept for the total set of data, a correction facotr is applied according to chapter 6.1 17 Use of correction factors/terms . In spite of the significant slope identified for the complete data set, a correction does not appear to make sense as the slope of the complete data set to be used for correction is 1.000.

The following Table 21 shows an overview on all results of the equivalence test for the BAM-1020 for $PM_{2.5}$. Where a criterion was not satisfied, the corresponding line is marked in red.

Table 21: Overview of the equivalence test for the BAM-1020 for $PM_{2,5}$

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	BAM-1020		SN	SN 17010 & SN 17011	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.33**	**µg/m³**			
Uncertainty between Candidates	**1.38**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**248**				
Slope b	**1.000**	**not significant**			
Uncertainty of b	**0.012**				
Ordinate intercept a	**0.764**	**significant**			
Uncertainty of a	**0.204**				
Expanded meas. uncertainty W_{CM}	**12.70**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.30**	**µg/m³**			
Uncertainty between Candidates	**1.57**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**74**				
Slope b	**1.031**				
Uncertainty of b	**0.033**				
Ordinate intercept a	**-0.068**				
Uncertainty of a	**0.919**				
Expanded meas. uncertainty W_{CM}	**15.96**	**%**			
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.34**	**µg/m³**			
Uncertainty between Candidates	**1.05**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**174**				
Slope b	**0.971**				
Uncertainty of b	**0.025**				
Ordinate intercept a	**1.066**				
Uncertainty of a	**0.267**				
Expanded meas. uncertainty W_{CM}	**9.93**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	BAM-1020		SN	SN 17010 & SN 17011	
			Limit value	30	µg/m³
Status of measured values	Raw data		Allowed uncertainty	25	%
Teddington, Summer					
Uncertainty between Reference	**0.33**	**µg/m³**			
Uncertainty between Candidates	**1.13**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**78**			**78**	
Slope b	**0.994**			**1.016**	
Uncertainty of b	**0.030**			**0.025**	
Ordinate intercept a	**1.822**			**1.018**	
Uncertainty of a	**0.372**			**0.308**	
Expanded meas. uncertainty W_{CM}	**17.18**	**%**		**14.74**	**%**
Cologne, Winter					
Uncertainty between Reference	**0.39**	**µg/m³**			
Uncertainty between Candidates	**1.76**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**75**			**75**	
Slope b	**0.980**			**1.061**	
Uncertainty of b	**0.024**			**0.019**	
Ordinate intercept a	**0.960**			**0.430**	
Uncertainty of a	**0.512**			**0.405**	
Expanded meas. uncertainty W_{CM}	**12.92**	**%**		**18.01**	**%**
Bornheim, Summer					
Uncertainty between Reference	**0.30**	**µg/m³**			
Uncertainty between Candidates	**1.13**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**53**			**57**	
Slope b	**1.052**			**1.134**	
Uncertainty of b	**0.036**			**0.048**	
Ordinate intercept a	**-0.962**			**-1.498**	
Uncertainty of a	**0.527**			**0.727**	
Expanded meas. uncertainty W_{CM}	**11.69**	**%**		**23.95**	**%**
Teddington, Winter					
Uncertainty between Reference	**0.27**	**µg/m³**			
Uncertainty between Candidates	**1.01**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**45**			**43**	
Slope b	**0.970**			**0.991**	
Uncertainty of b	**0.014**			**0.014**	
Ordinate intercept a	**-0.182**			**0.630**	
Uncertainty of a	**0.300**			**0.293**	
Expanded meas. uncertainty W_{CM}	**10.35**	**%**		**7.51**	**%**
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.30**	**µg/m³**			
Uncertainty between Candidates	**1.57**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**76**			**75**	
Slope b	**0.984**			**1.092**	
Uncertainty of b	**0.035**			**0.034**	
Ordinate intercept a	**0.584**			**-1.108**	
Uncertainty of a	**0.975**			**0.95**	
Expanded meas. uncertainty W_{CM}	**16.08**	**%**		**19.09**	**%**
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.34**	**µg/m³**			
Uncertainty between Candidates	**1.05**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**175**			**178**	
Slope b	**0.955**			**1.021**	
Uncertainty of b	**0.028**			**0.026**	
Ordinate intercept a	**1.137**			**0.634**	
Uncertainty of a	**0.306**			**0.286**	
Expanded meas. uncertainty W_{CM}	**11.57**	**%**		**13.54**	**%**
All comparisons					
Uncertainty between Reference	**0.33**	**µg/m³**			
Uncertainty between Candidates	**1.38**	**µg/m³**			
	SN 17010			**SN 17011**	
Number of data pairs	**251**			**253**	
Slope b	**0.969**	**significant**		**1.041**	**significant**
Uncertainty of b	**0.013**			**0.012**	
Ordinate intercept a	**0.989**	**significant**		**0.377**	**not significant**
Uncertainty of a	**0.226**			**0.214**	
Expanded meas. uncertainty W_{CM}	**12.99**	**%**		**16.35**	**%**

Results for testing the five criteria from chapter 6.1 Method used for equivalence testing were as follows:

Criterion 1: More than 20% of the data exceed 17 µg/m³.

Criterion 2: Between-AMS uncertainty of the AMS tested did not exceed 2.5 µg/m³.

Criterion 3: Uncertainty between reference instruments did not exceed 2.0 µg/m³.

Criterion 4: All expanded uncertainties remained below 25%.

Criterion 5) The intercept and slope of the 'All Data' comparison for S/N 17010 are signifi cant. The slope of the 'All Data' comparison for S/N 17011 is significant.

The evaluation of the full data set for both test specimen shows that the measuring system provides good correlation with the reference method: the slope is 1.000 and the intercept is 0.764 at an expanded total uncertainty of 12.70%.

The January 2010 version of the Guideline does not specify clearly which axis intercept and which slope to use for correcting test specimens if a test specimen does not meet the requirements for equivalence testing. After double-checking with the chair of the EU working group responsible for issuing the Guideline (Mr Theo Hafkenscheid), we decided to apply the requirements of the November 2005 version of the Guideline and to use the slope and the intercept determined by means of orthogonal regression for the full data set. These are listed for each criterion under "Additional"

As a result of the significance determined for $PM_{2,5}$, the axis intercept has to be corrected according to Table 21. In spite of the significant slope identified for the complete data set, a correction does not appear to make sense as the slope of the complete data set to be used for correction is 1.000.

It should be noted here that the uncertainty W_{CM} determined without applying correction factors for all observed data sets is below the determined expanded relative uncertainty W_{dqo} of 25% for $PM_{2.5}$.

For compliant monitoring, the revised version of the January 2010 Guideline and standard EN 16450 require continuous random checks of a certain number of instruments in a measurement grid and specify the number of measurement sites to be checked as a function of the expanded uncertainty of a measuring system. The operator of the measurement grid or the competent authority of a member state is responsible for compliant implementation. However, TÜV Rheinland recommends that the expanded uncertainty of the entire data set (in the present case, the uncorrected raw data) be used for this purpose: 12.7% for $PM_{2.5}$, implying annual checks at three measurement sites (Guideline [4], Chapter 9.9.2, Table 6 or EN 16450 [8], Chapter 8.6.2, Table 5). As a result of the necessary use of calibration factors, this assessment should be based on the evaluation of the corrected data sets (see chapter 6.1 17 Use of correction factors/terms).

6.6 Detailed presentation of test results

Table 22 provides an overview of the between-RM uncertainties $u_{bs,RM}$ determined during the field tests.

Table 22: Between RM uncertainty $u_{bs,RM}$ for $PM_{2.5}$

Reference instruments	Location	Number of measurements	Uncertainty $u_{bs,RM}$
No.			µg/m³
1 / 2	Teddington, Summer	77	0.33
1 / 2	Cologne, Winter	75	0.39
1 / 2	Bornheim, Summer	53	0.30
1 / 2	Teddington, Winter	43	0.27
1 / 2	All locations	248	0.33

At all sites, between-RM uncertainty $u_{bs,RM}$ was < 2.0 µg/m³.

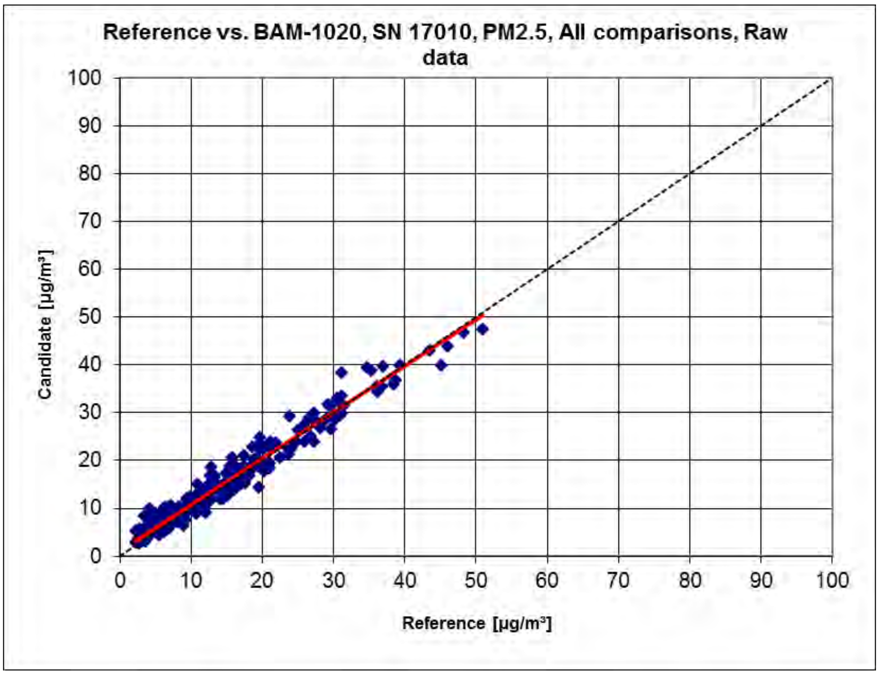


Figure 39: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, all sites

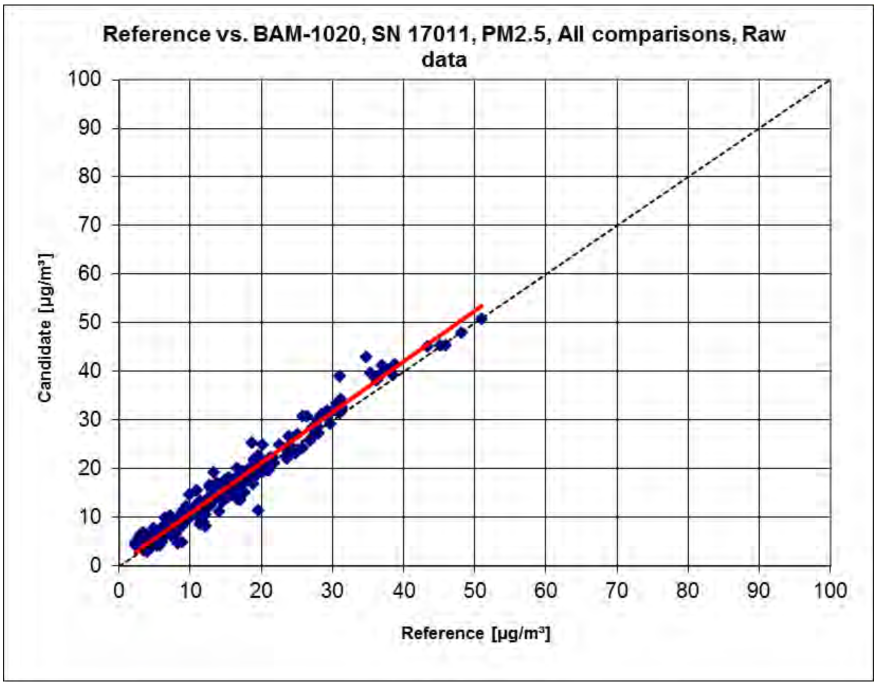


Figure 40: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, all sites

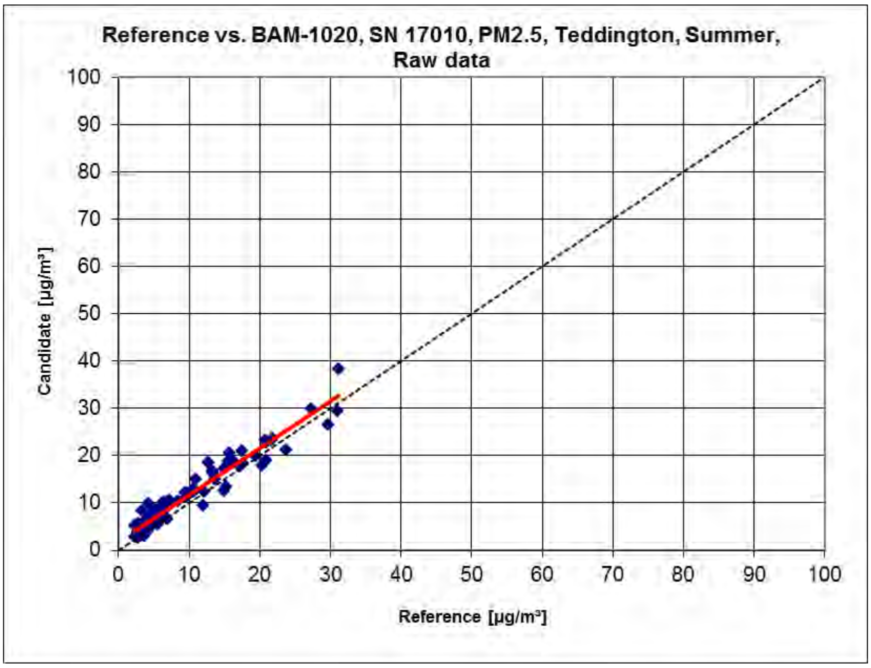


Figure 41: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, Teddington, summer

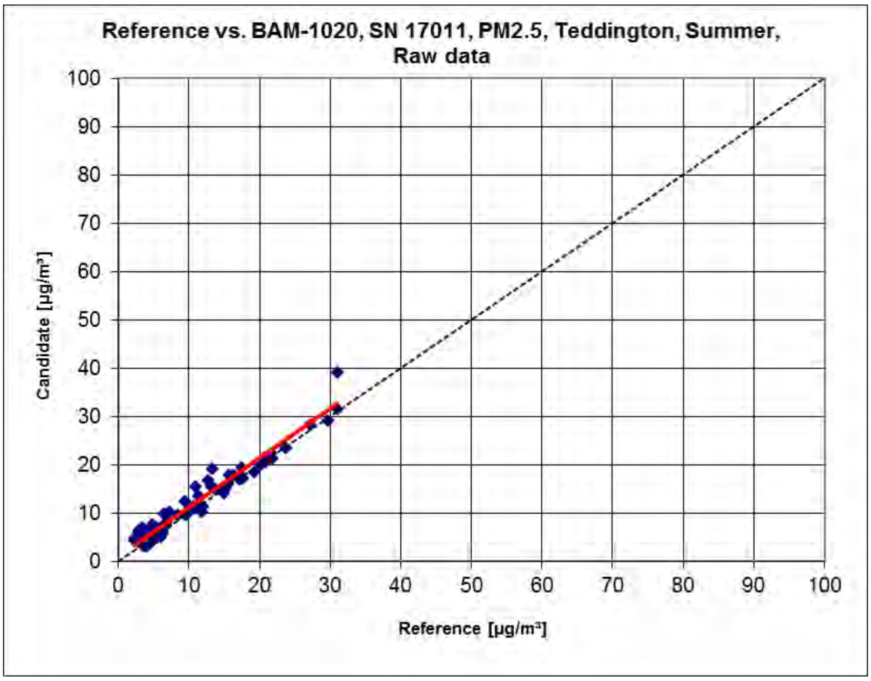


Figure 42: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, Teddington, summer

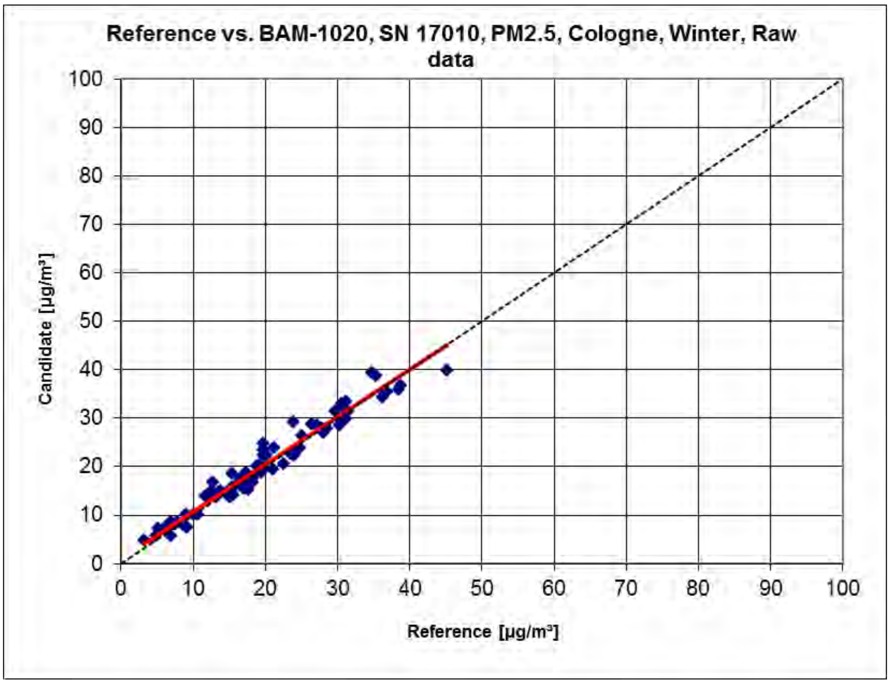


Figure 43: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, Cologne, winter

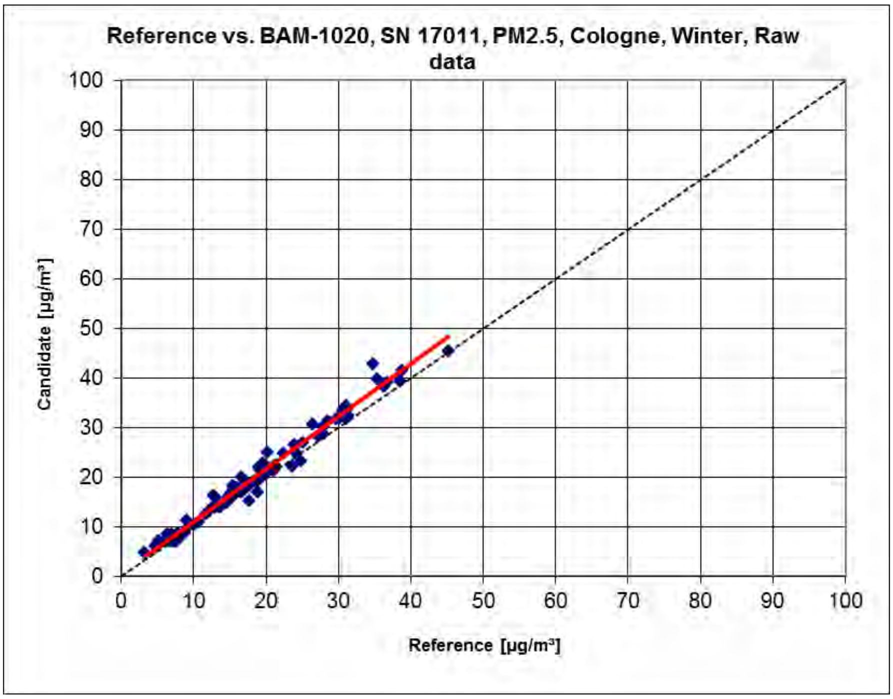


Figure 44: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, Cologne, winter

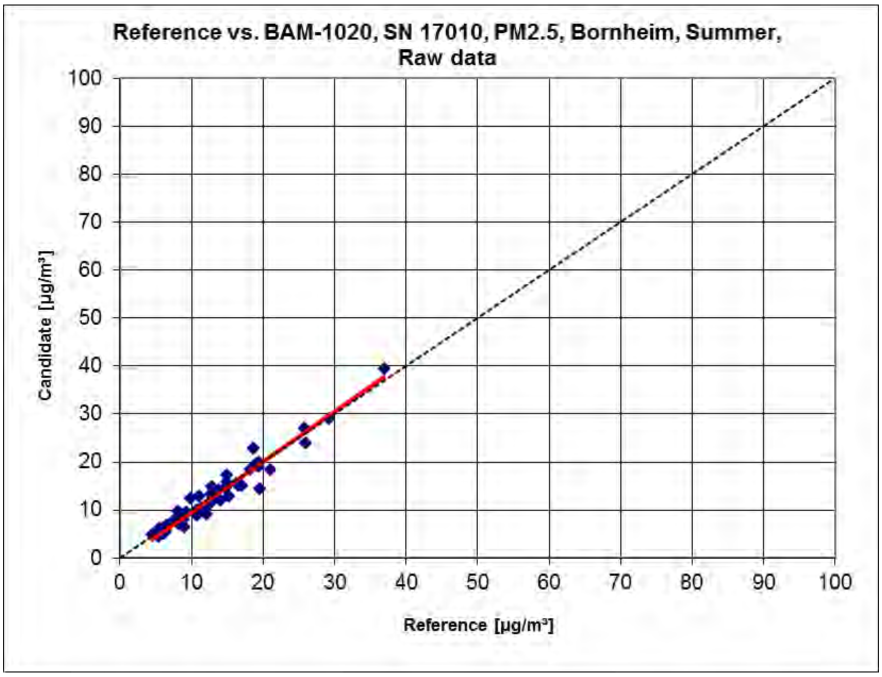


Figure 45: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, Bornheim, summer,

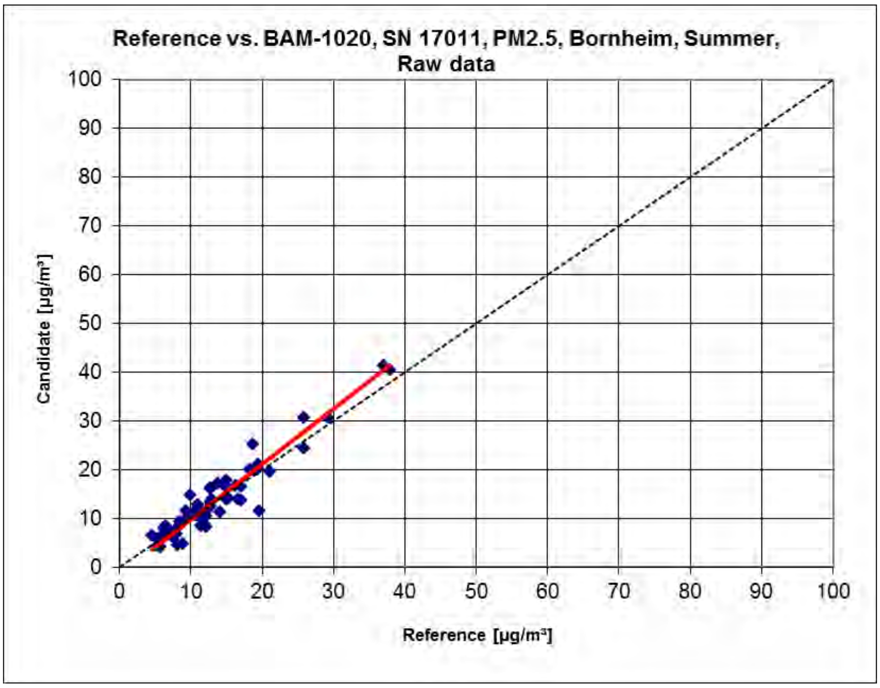


Figure 46: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, Bornheim, summer,

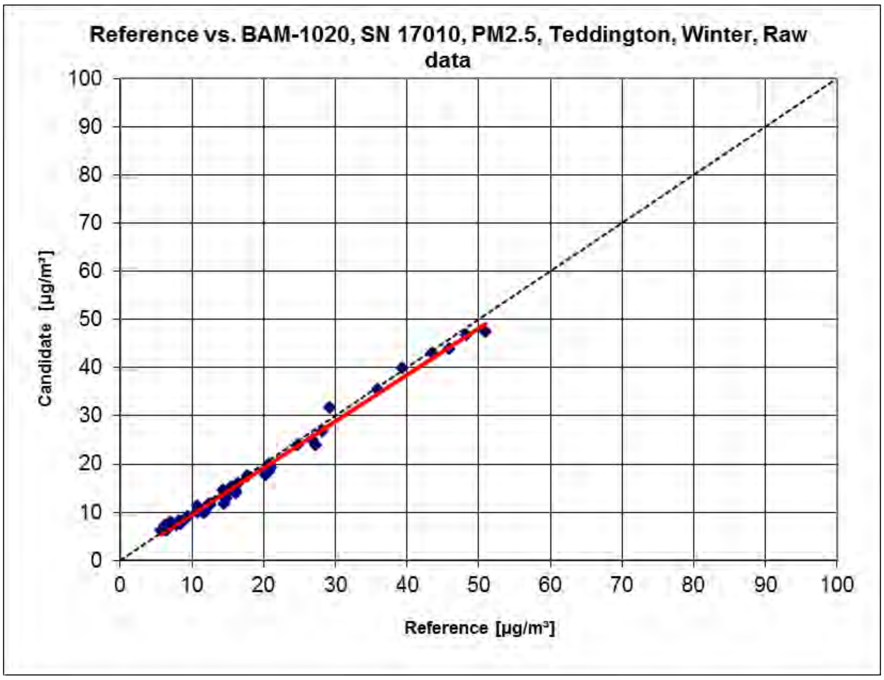


Figure 47: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, Teddington, winter

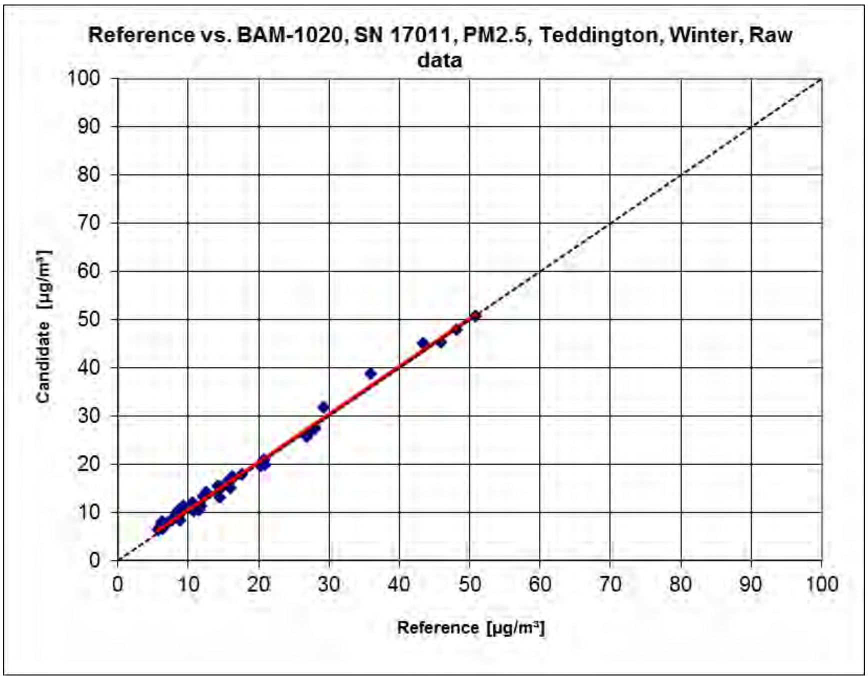


Figure 48: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, Teddington, winter

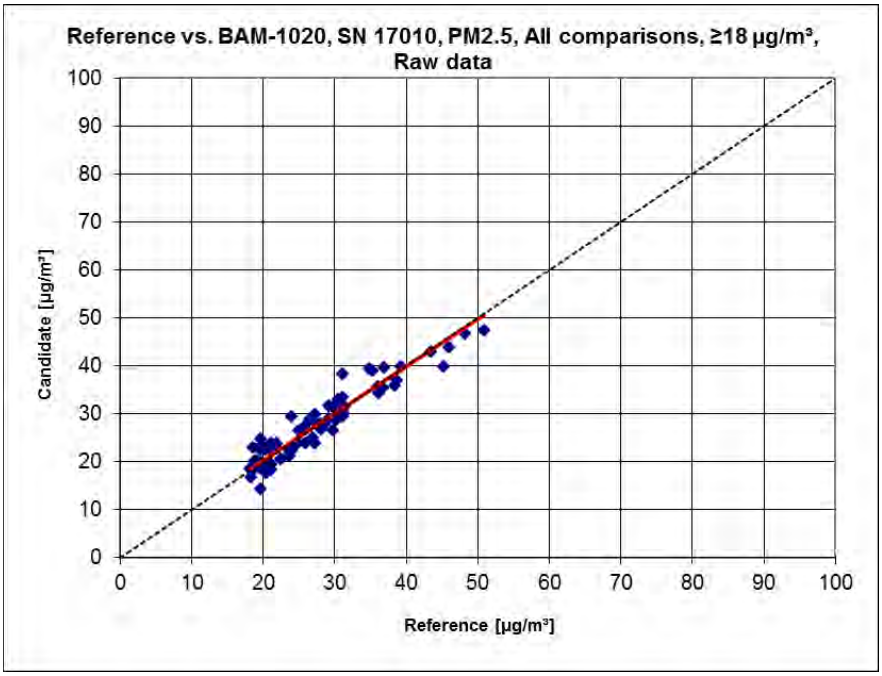


Figure 49: Reference vs. tested instrument, SN 17010, component $PM_{2.5}$, values ≥ 18 µg/m³

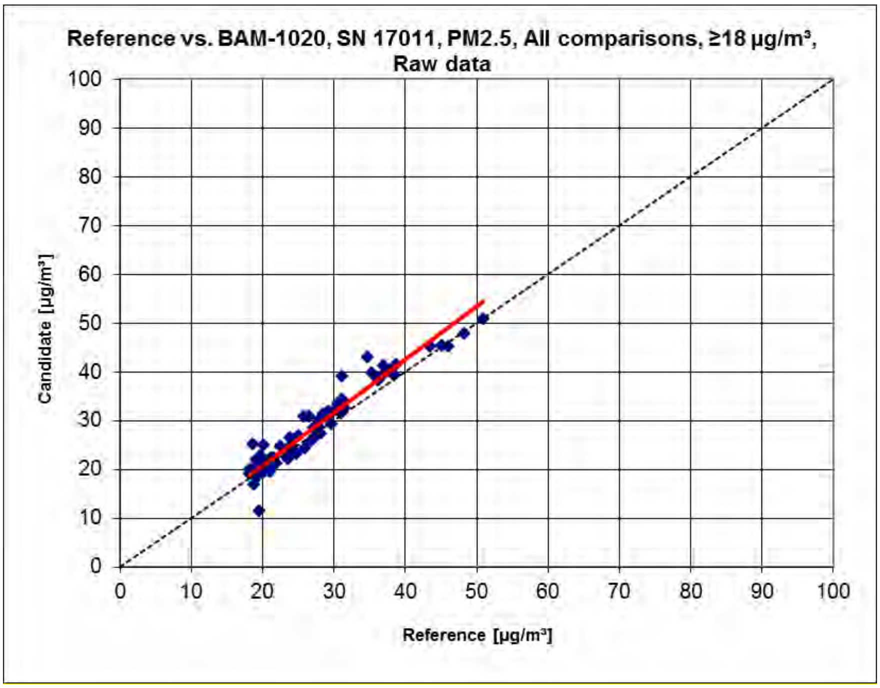


Figure 50: Reference vs. tested instrument, SN 17011, component $PM_{2.5}$, values ≥ 18 µg/m³

6.1 17 Use of correction factors/terms (7.5.8.5–7.5.8.8)

Correction factors/terms (=calibration) shall be applied in the event

the highest expanded uncertainty calculated for the tested instruments exceeds the relative expanded uncertainty specified under requirements for data quality or the test demonstrates that the slope is significantly different from 1 and/or the ordinate intercept is significantly different from 0.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

See item 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8)

6.4 Evaluation

If it emerges from the evaluation of raw data in accordance with 6.1 17 Expanded uncertainty of AMS results (7.5.8.5–7.5.8.8) that $W_{AMS} > W_{dqo}$, i.e. the tested instrument is not found to be equivalent with the reference method, then it is permissible to use a correction factor or term which results from the regression equation for <u>the full data set</u>. The corrected values have to meet the requirements for all data sets or sub data sets. Moreover, a correction may also be used for the case that $W_{AMS} \leq W_{dqo}$ in order to improve the accuracy of the tested instruments.

Three different situations may occur:

a) Slope b is not significantly different from 1: $|b-1| \leq 2u(b)$
   Axis intercept a is significantly different from 0: $|a| > 2u(a)$

b) Slope b is significantly different from 1: $|b-1| > 2u(b)$
   axis intercept a is not significantly different from 0: $|a| \leq 2u(a)$

b) Slope b is significantly different from 1: $|b-1| > 2u(b)$
   Axis intercept a is significantly different from 0: $|a| > 2u(a)$

concerning a)

The value of the axis intercept a may be used as a correction term to correct all input values y_i according to the following equation:

$$y_{i,corr} = y_i - a$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{yi,corr}^2 = \frac{RSS}{(n-2)} - u_{RM}{}^2 + [c + (d-1)L]^2 + u^2(a)$$

where u(a) = uncertainty of the axis intercept a, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [8].

concerning b)

The value of the slope b may be used as a correction term to correct all input values y_i according to the following equation:

$$y_{i,corr} = \frac{y_i}{b}$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using a new linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u_{yi,corr}^2 = \frac{RSS}{(n-2)} - u_{RM}{}^2 + [c + (d-1)L]^2 + L^2u^2(b)$$

where u(b) = uncertainty of the original slope b, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [8].

concerning c)

The values of the slope b and the axis intercept a may be used as a correction terms to correct all input values y_i according to the following equation:

$$y_{i,corr} = \frac{y_i - a}{b}$$

The corrected values $y_{i,corr}$ may then serve to calculate the following new terms using a new linear regression:

$$y_{i,corr} = c + dx_i$$

and

$$u^2_{yi,corr} = \frac{RSS}{(n-2)} - u_{RM}{}^2 + \left[c + (d-1)L\right]^2 + L^2 u^2(b) + u^2(a)$$

where u(b) = uncertainty of the original slope b, whose value was used to determine $y_{i,corr}$ and u(a) = uncertainty of the original axis intercept a, whose value was used to determine $y_{i,corr}$.

The algorithms for calculating axis intercepts and slopes as well as their variance by means of orthogonal regression are described in detail in the annex to [8].

The values for $u_{c\_s,corr}$ are then used to calculate the combined relative uncertainty of the AMS after correction in accordance with the following equation:

$$w^2_{AMS,corr} = \frac{u^2_{corr,yi=L}}{L^2}$$

The uncertainty $w_{AMS,corr}$ for the corrected data set is calculated at the 24h limit value using y_i as concentration at the limit value.

The relative expanded uncertainty $W_{AMS,corr}$ is calculated using the following equation:

$$W_{AMS´,corr} = k \cdot w_{AMS,corr}$$

In practice, k is specified at k=2 for large n.

The largest resulting uncertainty $W_{AMS,corr}$ is compared and assessed against the criteria for data quality of air quality measurements in accordance with EU Directive [7]. Two situations are conceivable:

1. $W_{AMS,corr} \leq W_{dqo}$ → The tested instrument is deemed equivalent to the reference method.

2. $W_{AMS,corr} > W_{dqo}$ → The tested instrument is not deemed equivalent to the reference method.

The expanded relative uncertainty W_{dqo} specified is 25% [7].

6.5 Assessment

During the test, the test samples met the requirements for data quality of air quality measurements without applying a correction factor. Nevertheless, correction of the axis intercept led to a slight improvement of the expanded uncertainty for the complete data set.

Criterion satisfied? yes

The evaluation of the full data set for both test specimen results in a significantly different intercept for the compoent $PM_{2,5}$.

The slope for the entire data set is 1.000. The intercept for the full data set is 0.764 (see Table 21)

In spite of the significant slope identified for the complete data set, a correction does not appear to make sense as the slope of the complete data set to be used for correction is 1.000.

This is why, for the component $PM_{2,5}$, the full data set was only corrected in terms of the slope. All data sets were re-evaluated using the corrected values.

After the correction, all data sets meet the requirements for data quality. The use of a correction factor for the BAM-1020 for $PM_{2.5}$ improves the expanded measurement uncertainties only slightly, but does not bring any decisive advantage.

When a measuring system is operated in the context of a measurement grid, the January 2010 version of the Guideline and standard EN 16450 require that the instruments are tested annually at a number of sites which in turn depends on the highest's expanded uncertainty determined during equivalence testing. The criterion used for specifying the number of sites for annual testing is grouped into 5% steps (Guideline [4], Chapter 9.9.2, Table 6 and/or EN 16450 [8], Chapter 8.6.2, Table 5). It should be noted that the highest expanded uncertainty determined for $PM_{2.5}$ after applying the correction was in the range 20–25%.

The operator of the measurement grid or the competent authority of a member state is responsible for compliant implementation of the requirements for regular tests as described above. TÜV Rheinland recommends the use of the expanded uncertainty of the full data set for this purpose: 12.7% ($PM_{2.5}$ uncorrected data set) and 11.7% ($PM_{2.5}$ data set after correcting intercept). This would require annual tests at 3 sites (uncorrected and corrected).

6.6 Detailed presentation of test results

Table 23 shows the evaluation results of the equivalence test after applying the correction factor to the full data set.

Table 23: Overview of results of the equivalence test, SN 17010 S/N 17011, component $PM_{2,5}$ after correcting the intercept

Comparison candidate with reference according to Standard EN 16450:2017					
Candidate	BAM-1020		SN	SN 17010 & SN 17011	
			Limit value	30	µg/m³
Status of measured values	Offset corrected		Allowed uncertainty	25	%
All comparisons					
Uncertainty between Reference	**0.33**	**µg/m³**			
Uncertainty between Candidates	**1.38**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**248**				
Slope b	**1.000**	**not significant**			
Uncertainty of b	**0.012**				
Ordinate intercept a	**0.000**	**not significant**			
Uncertainty of a	**0.204**				
Expanded meas. uncertainty W_{CM}	**11.67**	**%**			
All comparisons, ≥18 µg/m³					
Uncertainty between Reference	**0.30**	**µg/m³**			
Uncertainty between Candidates	**1.57**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**74**				
Slope b	**1.031**				
Uncertainty of b	**0.033**				
Ordinate intercept a	**-0.832**				
Uncertainty of a	**0.919**				
Expanded meas. uncertainty W_{CM}	**15.00**	**%**			
All comparisons, <18 µg/m³					
Uncertainty between Reference	**0.34**	**µg/m³**			
Uncertainty between Candidates	**1.05**	**µg/m³**			
	SN 17010 & SN 17011				
Number of data pairs	**174**				
Slope b	**0.971**				
Uncertainty of b	**0.025**				
Ordinate intercept a	**0.302**				
Uncertainty of a	**0.267**				
Expanded meas. uncertainty W_{CM}	**10.64**	**%**			

Comparison candidate with reference according to Standard EN 16450:2017				
Candidate	BAM-1020	SN	SN 17010 & SN 17011	
		Limit value	30	µg/m³
Status of measured values	Offset corrected	Allowed uncertainty	25	%
Teddington, Summer				
Uncertainty between Reference	**0.33**	**µg/m³**		
Uncertainty between Candidates	**1.13**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**78**		**78**	
Slope b	**0.994**		**1.016**	
Uncertainty of b	**0.030**		**0.025**	
Ordinate intercept a	**1.058**		**0.254**	
Uncertainty of a	**0.372**		**0.308**	
Expanded meas. uncertainty W_{CM}	**14.54**	**%**	**11.95**	**%**
Cologne, Winter				
Uncertainty between Reference	**0.39**	**µg/m³**		
Uncertainty between Candidates	**1.76**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**75**		**75**	
Slope b	**0.980**		**1.061**	
Uncertainty of b	**0.024**		**0.019**	
Ordinate intercept a	**0.196**		**-0.334**	
Uncertainty of a	**0.512**		**0.405**	
Expanded meas. uncertainty W_{CM}	**13.08**	**%**	**14.12**	**%**
Bornheim, Summer				
Uncertainty between Reference	**0.30**	**µg/m³**		
Uncertainty between Candidates	**1.13**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**53**		**57**	
Slope b	**1.052**		**1.134**	
Uncertainty of b	**0.036**		**0.048**	
Ordinate intercept a	**-1.726**		**-2.262**	
Uncertainty of a	**0.527**		**0.727**	
Expanded meas. uncertainty W_{CM}	**11.17**	**%**	**20.77**	**%**
Teddington, Winter				
Uncertainty between Reference	**0.27**	**µg/m³**		
Uncertainty between Candidates	**1.01**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**45**		**43**	
Slope b	**0.970**		**0.991**	
Uncertainty of b	**0.014**		**0.014**	
Ordinate intercept a	**-0.946**		**-0.134**	
Uncertainty of a	**0.300**		**0.293**	
Expanded meas. uncertainty W_{CM}	**14.46**	**%**	**7.70**	**%**
All comparisons, ≥18 µg/m³				
Uncertainty between Reference	**0.30**	**µg/m³**		
Uncertainty between Candidates	**1.57**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**76**		**75**	
Slope b	**0.984**		**1.092**	
Uncertainty of b	**0.035**		**0.034**	
Ordinate intercept a	**-0.180**		**-1.872**	
Uncertainty of a	**0.975**		**0.95**	
Expanded meas. uncertainty W_{CM}	**16.73**	**%**	**16.73**	**%**
All comparisons, <18 µg/m³				
Uncertainty between Reference	**0.34**	**µg/m³**		
Uncertainty between Candidates	**1.05**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**175**		**178**	
Slope b	**0.955**		**1.021**	
Uncertainty of b	**0.028**		**0.026**	
Ordinate intercept a	**0.373**		**-0.130**	
Uncertainty of a	**0.306**		**0.286**	
Expanded meas. uncertainty W_{CM}	**13.31**	**%**	**11.22**	**%**
All comparisons				
Uncertainty between Reference	**0.33**	**µg/m³**		
Uncertainty between Candidates	**1.38**	**µg/m³**		
	SN 17010		**SN 17011**	
Number of data pairs	**251**		**253**	
Slope b	**0.969**	**significant**	**1.041**	**significant**
Uncertainty of b	**0.013**		**0.012**	
Ordinate intercept a	**0.225**	**not significant**	**-0.387**	**not significant**
Uncertainty of a	**0.226**		**0.214**	
Expanded meas. uncertainty W_{CM}	**13.87**	**%**	**13.61**	**%**

6.1 18 Maintenance interval (7.5.7)

The maintenance interval shall be at least 2 weeks.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

With regard to this minimum requirement, the maintenance tasks required in a specific period and the length of that period for the correct functioning of the measuring system were identified.

Moreover, the results of the zero drift tests in accordance with 6.1 12 Zero checks (7.5.3) were taken into account when determining the maintenance interval .

6.4 Evaluation

Over the entire period of the field test, no unacceptable drift was observed.

The maintenance interval is thus determined by the necessary maintenance works.

1. Checking the operational status
   The instrument status can be verified by checking the AMS; alternatively it can be monitored online.
2. The sampling inlet must in principle be cleaned in accordance with the manufacturer's instructions, taking into account the local suspended particulate concentrations (every 4 weeks in the performance test).
3. Clean the instrument every month This also applies to cleaning the area of the inlet nozzle above the filter tape. In any case, the measuring system must be cleaned after every measurement application.
4. Check of the filter tape stock – a 21 m-filter tape is usually sufficient for approximately 60 days for a measurement cycle set to 60 min. It is recommended to check the filter tape stock routinely at every visit of the measurement site.
5. According to the manufacturer, a flow rate check and a leak check should be carried out every 4 weeks. Furthermore, a plausibility check of the ambient temperature and air pressure measurement is recommended. This can be done together with the other work carried out according to number 4.
6. Replace the filter tape after approx. 2 months (measurement cycle: 60 min). After the replacement, it is strongly recommended to perform a selt test as described in chapter 3.5 of the manual.
7. According to the manufacturer, the calibration of the flow rate should be performed every 3 months.
8. The muffler at the pump should be replaced semi-annually.
9. The sensors for ambient temperature, air pressure, filter temperature and filter rH must be checked every 6 months according to the operating manual.
10. The sample heater must be checked every 6 months according to the operating manual.
11. A 72-hour BKGD test should be performed annually using the BX-302 Zero Filter Kit as described in section 7.7 of the manual.
12. Once a year, the carbon vanes of the vacuum pump (only rotary vane pump) have to be checked and replaced if necessary during an annual maintenance.

13. During the annual basic maintenance, care must also be taken to clean the sampling tube.

The instructions in the manual (chapter 7) must be observed when carrying out maintenance work. All work can generally be carried out with standard tools. During operation times, maintenance may be limited to contamination and plausibility checks and potential status/error messages.

6.5 Assessment

The period of unattended operation is determined by the necessary maintenance works. It is 4 weeks.

Criterion satisfied? yes

6.6 Detailed presentation of test results

The necessary maintenance works are listed in chapter 7 of the operation manual.

6.1 19 Automatic diagnostic check (7.5.4)

Results of automated/functional checks, where available, shall be recorded.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The current operating status of the measuring system is continuously monitored and any issues will be flagged via a series of different error messages. The current state of monitored parameters can be displayed on the instrument itself and is recorded as part of data logging. When a monitored parameter falls outside the permissible ranges of tolerance, an error bit appears.

The measuring system offers the possibility of an internal check of the zero point and the sensitivity:

The count rates I_1 and I_{1x}, which were determined on a clean filter tape spot at every measurement cycle were used to check the zero point of the radiometric measurement (see chapter 3.2 Functioning of the measuring system). The zero point of the radiometric measurement is determined according to the following equation:

$$C_0\left[mg/m^3\right] = \frac{A}{Q} * \frac{K}{mu2} * \ln\left(\frac{I_1}{I_{1X}}\right)$$

C_0 is the particle mass concentration at ZP
A is the particle collection area (filter spot)
Q is the sampling flow rate
K, mu2 are coefficients for beta measurement
I_1 is the initial beta count rate
I_{1X} is the final beta count rate

To check the stability of the sensitivity of the radiometric measurement, the count rates I_1 (clean filter spot) or I_2 (clean filter spot + retracted reference foil) determined during each measurement cycle are used (see chapter 3.2 Functioning of the measuring system). The mass density m [µg/cm²] of the span foil is calculated internally from the count rates determined. The value is continuously compared with the target value ABS determined in the factory and an error message is generated in the event of a deviation exceeding 5 %.

The instrument thus offers the possibility to determine the zero point as well as the reference value for each measuring cycle (here once an hour) within the instrument. The obtained hourly values at the zero point and span point are output via the serial interface and are easily available for evaluation with a spreadsheet programme.

6.4 Evaluation

All instrument functions described in the operation manual are available and can be activated. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. it is possible to automatically check and record the zero point and sensitivity.

6.5 Assessment

All instrument functions described in the operation manual are available and can be activated. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages. it is possible to automatically check and record the zero point and sensitivity.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Available status signals are listed in chapter 6 of the operation manual.

6.1 20 Checks of temperature sensors, pressure and/or humidity sensors

The verifiability of temperature sensors, pressure and/or humidity sensors shall be checked for the AMS. Deviations determined shall be within the following criteria:

T ±2 °C
p ±1 kPa
rF ± 5 %

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

This minimum requirement serves to verify whether AMS sensors for temperature, pressure and humidity, which are necessary for correct AMS performance, are accessible and can be checked at the field test site location. In the event, checks cannot be performed on-site, this has to be documented.

6.4 Evaluation

The BAM-1020 measuring systems use meteorological sensors to measure ambient temperature and air pressure (BX-596 or BX-592) for mass flow control, among other things. In addition, the relative humidity is measured in the area of the filter tape (control of the sample heating).

The manufacturer of the weather station indicates the sensors’ accuracy as follows: ±1.5°K (ambient temperature), ±4% (relative humidity) ±0.25 mmHg, which corresponds to 0.03 kPa, (air pressure).

Relying on transfer standards, it is easily possible to perform comparison measurements on-site at any time and to adjust the sensors in the event of any deviation.

6.5 Assessment

It is easy to check and adjust the sensors for determining ambient temperature, ambient pressure and relative humidity on-site (filter band area).

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

7. Recommendations for use in practice

7.1 Tasks to be performed in the maintenance interval (4 weeks)

The tested measuring systems require regular performance of the following tasks:

- Regular visual inspections/telemetric inspections
- Instrument status ok
- No error messages
- No contaminations
- Check of the instrument functions according to the instructions of the manufacturer
- Check of filter tape stock
- Maintenance of the sampling inlet according to the manufacturer's instructions
- Every 4 weeks Plausibility checks of temperature, pressure sensors and, where necessary, readjustment
- Every 4 weeks Leak check and check of the flow rate

Apart from that please consider the manufacturer's instructions.

By default, the measuring system carries out an internal check of the zero point (zero measurement) and the sensitivity (measurement with span foil) for each measuring cycle. The results of these checks can be used for the continuous check of the stability of the radiometric measurement.

7.2 Additional maintenance tasks

In addition to the regular tasks to be performed during the maintenance interval, the following tasks need to be performed.

- Replace the filter tape after approx. 2 months (measurement cycle: 60 min). After the replacement, it is strongly recommended to perform a selt test as described in chapter 3.5 of the manual.
- According to the manufacturer, the calibration of the flow rate should be performed every 3 months.
- The muffler at the pump should be replaced semi-annually.
- The sensors for ambient temperature, air pressure, filter temperature and filter rH must be checked every 6 months according to the operating manual.
- The sample heater must be checked every 6 months according to the operating manual.
- A 72-hour BKGD test should be performed annually using the BX-302 Zero Filter Kit as described in section 7.7 of the manual.
- Once a year, the carbon vanes of the vacuum pump (only rotary vane pump) have to be checked and replaced if necessary during an annual maintenance.
- During the annual basic maintenance, care must also be taken to clean the sampling tube.

Further details are provided in the operation manual.

Environmental Protection/Air Pollution Control

Guido Baum

Dipl.-Ing. Guido Baum | Dipl.-Ing. Karsten Pletscher

Cologne, 21 September 2018
936/21243375/A

8. Bibliography

[1] VDI Guideline 4202, Part 1 – "Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants," dated June 2002.

[2] VDI Guideline 4203, part 3 – "Testing of automated measuring systems – Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants", dated August 2004

[3] European standard EN 14907, "Ambient air quality – Standard gravimetric measurement method for the determination of $PM_{2.5}$ mass fraction of suspended particulate matter", German version EN 14907: 2005

[4] Guideline "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version of January 2009 or of January 2010

[5] BAM-1020 operation manual version W

[6] Operation manual LVS3 of 2000

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

[8] European standard EN 16450 "Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM10; PM2.5, German version dated July 2017)

[9] TÜV Rheinland Report No. 936/21209919/A dated 26 March 2010; Report on the performance test of the BAM-1020 measuring system with $PM_{2.5}$ pre-separator for suspended particulate matter $PM_{2.5}$ manufactured by Met One Instruments, Inc.

[10] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 25 September 2010

[11] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 24 March 2011

[12] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 21 March 2012

[13] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 18 March 2013

[14] Statement issued by TÜV Rheinland Energie und Umwelt GmbH dated 20 September 2014

[15] Statement issued by TÜV Rheinland Energy GmbH dated 18 August 2017

Hersteller:
Met One Instruments, Inc., Grants Pass, USA

Eignung:
Zur kontinuierlichen Immissionsmessung der PM2,5-Fraktion im Schwebstaub im stationären Einsatz

Messbereich in der Eignungsprüfung:

Komponente	Zertifizierungs-bereich	zusätzlicher Messbereich	Einheit
PM 2,5	0 - 1000	-	µg/m3

Softwareversion: Version 3236-07 5.0.10

Einschränkung:
Bei der Überprüfung der Dichtheit des Probenahmesystems wurden in der Eignungsprüfung die Werte 1,8% und 2,4% ermittelt. In der Mindestanforderung darf die Undichtigkeit nicht mehr als 1% vom durchgesaugten Probevolumen betragen.

Hinweise:
1. Die Anforderungen gemäß des Leitfadens Demonstration of Equivalence of Ambient Air Monitoring Methodsd werden für die Messkomponente PM2,5 eingehalten.
2. Das Gerät ist zur Erfassung von PM2,5 mit folgenden Optionen auszustatten:
Probenahmeheizung (BX-830), PM10-Probenahmekopf (BX-802), PM2,5 Sharp Cut Cyclone SCC (BX-807), kombinierter Druck- und Temperatursensor (BX-596) bzw. alternativ Umgebungstemperatursensor (BX-592).
3. Die Zykluszeit während der Eignungsprüfung betrug 1 h, d.h. jede Stunde wurde ein automatischer Filterwechsel durchgeführt. Jeder Filterfleck wurde nur einmal beprobt.
4. Die Probenahmezeit innerhalb der Zykluszeit beträgt 42 min.
5. Die Messeinrichtung ist in einem verschließbaren Messcontainer zu betreiben.
6. Die Messeinrichtung ist mit dem gravimetrischen PM2,5-Referenzverfahren nach DIN EN 14907 regelmäßig am Standort zu kalibrieren.
7. Die Messeinrichtung wird baugleich von der Firma Horiba -Europe GmbH, 61440 Oberursel unter dem Namen APDA-371 mit PM2,5-Vorabscheider vertrieben.

Prüfinstitut:
TÜV Rheinland Immissionsschutz und Energiesysteme GmbH, Köln
Bericht-Nr.: 936/21209919/A vom 26. März 2010

Figure 51: Initial announcement BAnz. of 28 July 2010, p. 2597, Chapter II Number 1.1

18 Mitteilung zur Bekanntmachung des Umweltbundesamtes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1)

Für die Messeinrichtung BAM 1020 mit PM2,5-Vorabscheider der Fa. Met One Instruments werden die Anforderungen an die Dichtheit des Probenahmesystems nach einer Neubewertung eingehalten. Die Messeinrichtung erfüllt ebenfalls die Anforderungen des Leitfadens Demonstration of Equivalence of Ambient Air Monitoring Methodsd in der Version vom Januar 2010.
Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 25. September 2010

Figure 52: UBA announcement BAnz. of 26 January 2011, p. 294, Chapter IV 18th Notification

11. Mitteilung zu Bekanntmachungen des Umweltbundesam-tes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1) und vom 10. Januar 2011 (BAnz. S. 294, Kapitel IV 18. Mitteilung)

Die Messeinrichtung BAM-1020 mit PM2,5-Vorabscheider der Firma Met One Instruments, Inc. für die Messkomponente Schwebstaub PM2,5 kann optional mit der Pumpe BX-125 betrieben werden.
Die Messeinrichtung kann optional mit einem Touch Screen Dis-play (Option BX-970) ausgerüstet werden. Die aktuelle Soft-wareversion lautet:
3236-77 V5.1.0
Die Softwareversion für die Messeinrichtung ohne Option BX-970 Touch Screen Display lautet weiterhin 3236-07 5.0.10.
Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 24. März 2011

Figure 53: UBA announcement BAnz. of 29 July 2011, p. 2725, Chapter III 11th Notification

5 Mitteilung zu Bekanntmachungen des Umweltbundesamtes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1) und vom 15. Juli 2011 (BAnz. S. 2725, Kapitel III 11. Mitteilung)

Die Messeinrichtung BAM-1020 mit $PM_{2,5}$-Vorabscheider der Firma Met One Instruments, Inc. für die Messkomponente Schwebstaub $PM_{2,5}$ erhält eine neu designte Rückplatte um die erweiterten Schnittstellen u. a. des optionalen Reportprozessors BX-965 unterzubringen.

Die aktuelle Softwareversion der Messeinrichtung lautet:

3236-07 5.0.15

Die aktuelle Softwareversion der Messeinrichtung mit Touch Screen Display (Option BX-970) lautet:

3236-77 V5.1.2

Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 21. März 2012

Figure 54: UBA announcement BAnz AT 20.07.2012 B11 chapter IV 5th Notification

4 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1) und vom 6. Juli 2012 (BAnz AT 20.07.2012 B11, Kapitel IV 5. Mitteilung)

Die aktuelle Softwareversion der Messeinrichtung BAM-1020 mit $PM_{2,5}$-Vorabscheider der Firma Met One Instruments, Inc. für die Messkomponente Schwebstaub $PM_{2,5}$ lautet:

3236-07 5.1.1

Die aktuelle Softwareversion der Messeinrichtung mit Touch Screen Display (Option BX-970) lautet:

3236-77 V5.2.0

Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 18. März 2013

Figure 55: UBA announcement BAnz AT 23.07.2013 B4 chapter V 4th Notification

12 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1) und vom 3. Juli 2013 (BAnz AT 23.07.2013 B4, Kapitel V 4. Mitteilung)

Der Drucksensor 970603 (MICROSWITCH #185PC15AT) in der Messeinrichtung BAM-1020 mit $PM_{2,5}$-Vorabscheider der Fa. Met One Instruments, Inc. wurde abgekündigt und durch den Drucksensor 970595 (HONEYWELL SSCDANN015PAAA5) ersetzt.

Stellungnahme der TÜV Rheinland Energie und Umwelt GmbH vom 20. September 2014

Figure 56: UBA announcement BAnz AT 02.04.2015 B5 chapter IV 12th Notification

9 Mitteilung zu den Bekanntmachungen des Umweltbundesamtes vom 12. Juli 2010 (BAnz. S. 2597, Kapitel II Nummer 1.1) und vom 25. Februar 2015 (BAnz AT 02.04.2015 B5, Kapitel IV 12. Mitteilung)

Die aktuelle Softwareversion der Messeinrichtung BAM-1020 mit $PM_{2,5}$-Vorabscheider der Firma Met One Instruments, Inc. lautet:

3236-07 5.5.0

Die aktuelle Softwareversion der Messeinrichtung mit Touch Screen Display (Option BX-970) lautet:

3236-77 V5.2.0

Stellungnahme der TÜV Rheinland Energy GmbH vom 18. August 2017

Figure 57: UBA announcement BAnz AT 26.03.2018 B8 chapter V 9th Notification

9. Appendices

Annex 1 **Measured and calculated values**

- Schedule 1: Zero level and detection limit
- Schedule 2: Flow rate accuracy
- Schedule 3: Temperature dependence of the zero point and sensitivity
- Schedule 4: Independence of supply voltage
- Annex 5: Measured values from the field test sites
- Schedule 6: Ambient condition at the field test locations

Annex 2: **Methods used for filter weighing**

Annex 3 **Operation manuals**

Annex 1 **Detection limit** **Page 1 of 1**

Manufacturer	Met One Instruments			
Type	BAM-1020	Standards	ZP	Measured values with zero filter
Serial-No.	SN X14465 / SN X14499			

No.	Date	Measured values [µg/m³] SN X14465	Date	Measured values [µg/m³] SN X14499
1	7/22/2018	-0.2	7/22/2018	0.1
2	7/23/2018	0.0	7/23/2018	-0.4
3	7/24/2018	0.0	7/24/2018	0.0
4	7/25/2018	0.5	7/25/2018	0.0
5	7/26/2018	0.2	7/26/2018	0.1
6	7/27/2018	0.6	7/27/2018	0.0
7	7/28/2018	-0.1	7/28/2018	0.3
8	7/29/2018	-0.3	7/29/2018	-0.4
9	7/30/2018	0.0	7/30/2018	-0.6
10	7/31/2018	0.5	7/31/2018	0.7
11	8/1/2018	0.0	8/1/2018	1.3
12	8/2/2018	1.3	8/2/2018	0.4
13	8/3/2018	0.7	8/3/2018	0.8
14	8/4/2018	0.3	8/4/2018	1.1
15	8/5/2018	0.4	8/5/2018	0.2
	No. of values	15	No. of values	15
	Mean	0.27	Mean	0.23
	Standard deviation s_{x0}	0.42	Standard deviation s_{x0}	0.53
	Detection limit x	1.37	Detection limit x	1.75

$$s_{xo} = \sqrt{\left(\frac{1}{n-1}\right) \cdot \sum_{i=1,n} (x_{0i} - \overline{x_0})^2}$$

Annex 2 **Flow rate accuracy** **Page 1 of 1**

Manufacturer: Met One Instruments

Type: BAM-1020

Serial-No.: SN X14465 / SN X14499

Nominal flow rate [l/min]: 16.67

		SN X14465			SN X14499		
Temperature 1	5°C	No.	Date/Time	Measured value [l/min]	No.	Date/Time	Measured value [l/min]
		1	8/15/2018 6:11	16.46	1	8/15/2018 6:13	16.36
		2	8/15/2018 6:15	16.44	2	8/15/2018 6:17	16.34
		3	8/15/2018 6:19	16.43	3	8/15/2018 6:21	16.36
		4	8/15/2018 6:23	16.42	4	8/15/2018 6:25	16.35
		5	8/15/2018 6:27	16.42	5	8/15/2018 6:29	16.36
		6	8/15/2018 6:31	16.42	6	8/15/2018 6:33	16.35
		7	8/15/2018 6:35	16.39	7	8/15/2018 6:37	16.34
		8	8/15/2018 6:39	16.40	8	8/15/2018 6:41	16.33
		9	8/15/2018 6:43	16.40	9	8/15/2018 6:45	16.35
		10	8/15/2018 6:47	16.33	10	8/15/2018 6:49	16.34
			Mean	**16.41**		**Mean**	**16.35**

		SN X14465			SN X14499		
Temperature 2	40°C	No.	Date/Time	Measured value [l/min]	No.	Date/Time	Measured value [l/min]
		1	8/16/2018 6:12	16.80	1	8/16/2018 6:14	16.84
		2	8/16/2018 6:16	16.86	2	8/16/2018 6:18	16.90
		3	8/16/2018 6:20	16.84	3	8/16/2018 6:22	16.86
		4	8/16/2018 6:24	16.91	4	8/16/2018 6:26	16.91
		5	8/16/2018 6:28	16.87	5	8/16/2018 6:30	16.87
		6	8/16/2018 6:32	16.87	6	8/16/2018 6:34	16.87
		7	8/16/2018 6:36	16.88	7	8/16/2018 6:38	16.86
		8	8/16/2018 6:40	16.86	8	8/16/2018 6:42	16.91
		9	8/16/2018 6:44	16.90	9	8/16/2018 6:46	16.88
		10	8/16/2018 6:48	16.87	10	8/16/2018 6:50	16.86
			Mean	**16.87**		**Mean**	**16.88**

Annex 3 — Dependence of zero point on surrounding temperature — Page 1 of 2

Manufacturer	Met One Instruments
Type	BAM-1020
Serial-No.	SN 17010 / SN 17011
Test period:	30.05.2009 - 17.06.2009

SN 17010	No.	Temperature [°C]	Measurement 1 Measured value [µg/m³]	Measurement 2 Measured value [µg/m³]	Measurement 3 Measured value [µg/m³]	Mean value of 3 measurements [µg/m³]	Mean value at 20°C [µg/m³]
Zero	1	20	1.4	-1.0	0.1	0.2	1.1
	2	5	1.6	1.7	1.5	1.6	
	3	20	0.1	0.7	1.1	0.6	
	4	40	-1.3	2.1	0.2	0.3	
	5	20	2.4	0.7	4.5	2.5	

SN 17011	No.	Temperature [°C]	Measured value [µg/m³]	Measured value [µg/m³]	Measured value [µg/m³]	Mean value of 3 measurements [µg/m³]	Mean value at 20°C [µg/m³]
Zero	1	20	-0.7	-0.7	-1.6	-1.0	-1.1
	2	5	-0.4	-0.5	-0.1	-0.3	
	3	20	-1.6	-1.0	-0.7	-1.1	
	4	40	-2.5	-3.0	-3.2	-2.9	
	5	20	-1.7	-1.0	-1.2	-1.3	

Annex 3 — Dependence of span on surrounding temperature — Page 2 of 2

Manufacturer: Met One Instruments

Used test standard: internal reference foil

Type: BAM-1020

Serial-No.: SN 17010 / SN 17011

Test period: 30.05.2009 - 17.06.2009

SN 17010	No.	Temperature [°C]	Measurement 1 Measured value [µg/cm²]	Measurement 2 Measured value [µg/cm²]	Meaurement 3 Measured value [µg/cm²]	Mean value of 3 measurements [µg/cm²]	Mean value at 20°C [µg/cm²]
Span	1	20	829.8	829.7	829.6	829.7	829.6
	2	5	829.4	829.3	829.3	829.3	
	3	20	829.6	829.7	829.3	829.5	
	4	40	830.8	830.7	831.8	831.1	
	5	20	829.3	829.6	829.6	829.5	

SN 17011	No.	Temperature [°C]	Measured value [µg/cm²]	Measured value [µg/cm²]	Measured value [µg/cm²]	Mean value of 3 measurements [µg/cm²]	Mean value at 20°C [µg/cm²]
Span	1	20	822.9	822.6	821.9	822.5	823.0
	2	5	821.8	822.4	823.3	822.5	
	3	20	821.9	823.3	823.3	822.8	
	4	40	823.8	825.4	826.4	825.2	
	5	20	823.3	823.7	823.8	823.6	

Annex 4 **Dependence of span on supply voltage** **Page 1 of 1**

Manufacturer ABC

Used test standard Internal reference foil

Type XYZ

Serial-No. SN X14465 / SN X14499

			Measurement 1	Measurement 2	Measurement 3	
SN X14465	No.	Mains voltage [V]	Measured value [mg]	Measured value [mg]	Measured value [mg]	Mean value of 3 measurements [mg]
Span	1	230	0.813	0.815	0.816	0.815
	2	195	0.811	0.819	0.818	0.816
	3	230	0.815	0.817	0.819	0.817
	4	253	0.813	0.818	0.818	0.816
	5	230	0.815	0.815	0.815	0.815
SN X14499	No.	Mains voltage [V]	Measured value [mg]	Measured value [mg]	Measured value [mg]	Mean value of 3 measurements [mg]
Span	1	230	0.824	0.827	0.826	0.826
	2	195	0.827	0.827	0.830	0.828
	3	230	0.822	0.820	0.824	0.822
	4	253	0.824	0.830	0.826	0.827
	5	230	0.822	0.824	0.826	0.824

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 1 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
1	7/24/2008			32.9	32.0				Zero filter	Teddington, Summer
2	7/25/2008	15.4	15.1	22.5	23.6	65.9	13.6	15.3		
3	7/26/2008			21.0	21.6		15.5	14.1	Outlier Ref. PM2,5	
4	7/27/2008	13.1	13.2	19.0	19.9	67.8	16.5	15.5		
5	7/28/2008	13.5	13.6	20.3	20.3	66.9	15.0	15.1		
6	7/29/2008	4.2	4.7	11.8	12.1	37.4	7.7	6.0		
7	7/30/2008	9.6	9.5	16.2	16.5	58.4	12.2	9.5		
8	7/31/2008	10.8	11.0	22.2	22.4	49.0	15.2	15.5		
9	8/1/2008	4.2	5.5	16.3	15.5	30.3	9.1	7.7		
10	8/2/2008	2.4	2.2				5.3	4.4	Outlier Ref. PM10	
11	8/3/2008	2.0	2.5	8.2	8.4	26.8	3.0	4.9		
12	8/4/2008	3.4	4.4	9.4	9.6	41.1	5.2	4.7		
13	8/5/2008	3.1	3.6	7.5	7.3	45.1	8.4	7.0		
14	8/6/2008								Power failure	
15	8/7/2008	5.4	6.2	11.9	11.4	50.2			Power failure	
16	8/8/2008	5.2	6.2	9.9	9.6	58.5	7.8	6.7		
17	8/9/2008	2.3	3.3	7.1	7.3	39.3	5.0	6.4		
18	8/10/2008	3.9	4.1	11.7	11.2	34.7	4.0	5.1		
19	8/11/2008	5.6	6.0	13.7	13.5	42.7	6.1	6.4		
20	8/12/2008	3.5	3.5	10.6	10.5	33.2	3.1	3.3		
21	8/13/2008	3.5	3.8	11.8	11.4	31.7	4.2	3.7		
22	8/14/2008	6.1	6.5	11.0	11.1	56.9	7.6	6.0		
23	8/15/2008	5.6	6.3	10.0	11.6	55.4	6.6	5.0		
24	8/16/2008	5.5	5.5				5.7	4.8	Outlier Ref. PM10	
25	8/17/2008	2.7	2.7	8.7	8.5	31.2	3.7	4.3		
26	8/18/2008								Zero filter	
27	8/19/2008	4.6	4.7	12.5	13.0	36.6	5.2	7.0		
28	8/20/2008	3.9	4.1	10.2	10.1	39.6	6.4	6.2		
29	8/21/2008	6.5	6.8	13.2	13.5	50.2	8.9	7.5		
30	8/22/2008	5.2	4.9	9.5	9.3	53.6	6.3	5.0		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 2 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
31	8/23/2008	4.5	4.4	9.2	9.5	47.4	7.0	5.6		Teddington, Summer
32	8/24/2008	3.5	3.5	8.6	8.7	40.3	5.7	4.3		
33	8/25/2008	6.5	6.5	12.9	13.0	50.0	10.2	9.9		
34	8/26/2008	4.8	4.9	10.7	9.5	47.9	8.3	7.0		
35	8/27/2008	7.4	7.0	13.4	13.6	53.2	10.7	10.4		
36	8/28/2008	9.6	9.3	14.1	14.2	66.8	12.1	12.4		
37	8/29/2008	13.7	12.8	20.1	19.1	67.8	16.8	19.3		
38	8/30/2008	31.6	30.5	43.8	43.2	71.4	38.3	39.2		
39	8/31/2008	13.3	12.1	22.0	21.6	58.5	18.7	16.8		
40	9/1/2008	2.9	2.6	8.1	8.1	33.9	5.5	4.6		
41	9/2/2008	3.0	2.4	11.8	12.4	22.3	4.1	5.0		
42	9/3/2008	3.6	3.3	14.2	14.3	24.2	5.5	6.0		
43	9/4/2008	4.1	3.7				6.5	4.4	Outlier Ref. PM10	
44	9/5/2008	2.6	2.7	7.5	7.6	35.0	2.7		Span foil SN 17011 stuck, 4 h loss due to repair	
45	9/6/2008	3.4	3.6	8.0	7.6	44.9	4.1	4.8		
46	9/7/2008	3.1	2.7	8.4	8.2	34.8	5.8	4.9		
47	9/8/2008	6.4	6.6	14.7	14.2	45.0	9.0	7.5		
48	9/9/2008	6.0	5.2	14.4	14.2	39.1	8.3	6.4		
49	9/10/2008	4.3	4.1	11.0	10.6	38.6	10.1	6.1		
50	9/11/2008	6.5	5.4	17.2	17.5	34.2	9.2	7.0		
51	9/12/2008	5.5	5.1	9.4	9.1	57.3	8.0	6.4		
52	9/13/2008	15.5	15.4	20.4	20.7	75.5	18.8	16.2		
53	9/14/2008	10.9	10.3	18.1	17.4	60.0	13.0	11.2		
54	9/15/2008	11.8	12.3	17.5	17.5	68.6	12.5	11.3		
55	9/16/2008	17.7	17.4	24.6	24.2	72.0	18.5	17.1		
56	9/17/2008	19.4	19.2	26.9	28.1	70.3	20.0	18.6		
57	9/18/2008	17.0	17.2	24.5	23.6	71.3	17.9	16.9		
58	9/19/2008	20.7	20.9	29.3	29.4	70.9	22.9	21.3		
59	9/20/2008	21.7	21.4	26.9	26.6	80.6	23.2	22.4		
60	9/21/2008	21.6	22.0	28.6	28.1	76.9	23.8	21.3		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 3 of 13**

Manufacturer: Met One Instruments
Type of instrument: BAM-1020
Serial-No.: SN 17010 / SN 17011

PM2,5
Measured values in µg/m³ (ACT)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
61	9/22/2008	14.8	15.0	22.3	22.6	66.3	17.4	15.3		Teddington, Summer
62	9/23/2008	6.3	6.1	18.0	17.8	34.5			Zero filter	
63	9/24/2008	11.4	11.4	18.8	19.7	59.1		13.5	Filter tape SN 17010 cut	
64	9/25/2008	16.1	16.5	26.7	26.4	61.2	19.0	17.9		
65	9/26/2008	17.5	17.4	29.9	29.7	58.5	21.1	19.4		
66	9/27/2008	27.2	27.2	35.7	35.6	76.4	29.9	28.4		
67	9/28/2008						20.4	17.8		
68	9/29/2008	4.3	4.4	7.4	8.5	54.9	5.3	3.6		
69	9/30/2008	3.2	3.3	6.9	6.7	48.3	3.9	3.7		
70	10/1/2008						3.5	2.4		
71	10/2/2008						5.4	3.9		
72	10/3/2008						7.3	5.7		
73	10/4/2008						3.0	1.4		
74	10/5/2008						5.7	3.7		
75	10/6/2008						7.5	6.4		
76	10/7/2008						5.5	5.4		
77	10/8/2008						14.0	11.3		
78	10/9/2008	8.9	10.1	18.4	18.0	52.2	11.2	9.8		
79	10/10/2008	10.5	10.6	19.5	19.6	54.1	12.4	10.8		
80	10/11/2008	15.6	15.8	22.6	22.6	69.5	20.7	17.8		
81	10/12/2008	20.4	21.1	25.9	25.9	80.1	23.4	21.5		
82	10/13/2008	8.3	8.4	14.6	14.4	57.6	10.5	9.5		
83	10/14/2008	6.1	6.4	11.4	12.2	52.7	10.2	7.1		
84	10/15/2008	3.9	3.8	8.2	8.6	46.0	5.7	3.1		
85	10/16/2008								Zero filter	
86	10/17/2008								Not in operation	
87	10/18/2008								Not in operation	
88	10/19/2008								Not in operation	
89	10/20/2008								Not in operation	
90	10/21/2008						7.5	7.5		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 4 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
91	10/22/2008						8.2	7.7		Teddington, Summer
92	10/23/2008						5.4	4.2		
93	10/24/2008						12.1	10.5		
94	10/25/2008						11.2	9.5		
95	10/26/2008						4.4	2.2		
96	10/27/2008						11.0	9.4		
97	10/28/2008						6.8	8.5		
98	10/29/2008						15.8	17.1		
99	10/30/2008						10.5	11.0		
100	10/31/2008	11.7	12.0	16.9	18.5	66.9	9.5	10.2		
101	11/1/2008	14.8	15.1	18.3	19.2	79.9	12.6	14.2		
102	11/2/2008	20.4	20.0	25.5	25.8	78.7	18.0	20.0		
103	11/3/2008	20.7	20.9	27.0	27.8	76.0	19.0	20.5		
104	11/4/2008	31.1	30.9	37.5	38.4	81.7	29.5	31.6		
105	11/5/2008	29.7	29.6	35.5	36.2	82.8	26.6	29.3		
106	11/6/2008	23.5	23.8	28.2	28.6	83.2	21.2	23.6		
107	11/7/2008	6.8	6.7	15.2	14.7	45.4	6.6	8.0		
108	11/8/2008	3.5	3.5	8.6	9.4	39.1	3.7	4.1		
109	11/9/2008	4.1	4.0	11.5	11.9	34.8	4.5	3.9		
110	12/4/2008						6.2	8.4		Cologne, Winter
111	12/5/2008	9.1	9.2	12.5	13.0	71.6	7.5	9.9		
112	12/6/2008						13.8	18.0		
113	12/7/2008	17.4	17.2	22.6	22.8	76.1	16.7	18.4		
114	12/8/2008	15.2	15.8	18.2	18.3	84.8	14.1	16.7		
115	12/9/2008	22.7	22.2				20.7	24.9	Outlier Ref. PM10	
116	12/10/2008	19.9	18.8	24.1	23.9	80.6	18.8	20.4		
117	12/11/2008	24.0	24.0	28.3	29.3	83.2	22.4	25.1		
118	12/12/2008	17.3	16.6	19.1	19.5	87.8	15.5	18.1		
119	12/13/2008	17.9	18.5				16.9	19.1	Outlier Ref. PM10	
120	12/14/2008						36.6	42.1		

Annex 5 **Measured values from field test sites, related to actual conditions**

Manufacturer	Met One Instruments	PM2,5
Type of instrument	BAM-1020	Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
121	12/15/2008	31.3	31.4	34.9	34.7	90.1	31.5	32.5		Cologne, Winter
122	12/16/2008	16.8	16.4	19.6	20.4	83.1	17.6	20.2		
123	12/17/2008	20.1	20.1	32.3	33.2	61.5	22.5	25.1		
124	12/18/2008						12.1	14.5		
125	12/19/2008			20.3	21.6		10.5	12.1		
126	12/20/2008						7.4	8.9		
127	12/21/2008	7.1	8.5	11.1	11.1	70.5	8.6	8.7		
128	12/22/2008						15.4	15.9		
129	12/23/2008						21.2	22.6		
130	12/24/2008						24.1	25.4		
131	12/25/2008						8.2	7.4		
132	12/26/2008						12.0	12.3		
133	12/27/2008						19.7	20.9		
134	12/28/2008	27.9	27.9	33.7	33.9	82.6	27.0	30.3		
135	12/29/2008						33.5	37.0		
136	12/30/2008						45.7	48.9		
137	12/31/2008						98.2	111.5		
138	1/1/2009						82.0	88.9		
139	1/2/2009						46.3	47.5		
140	1/3/2009						32.9	36.9		
141	1/4/2009	30.0	30.4	35.1	36.7	84.1	28.7	32.1		
142	1/5/2009	14.7	15.4	17.0	16.3	90.3	14.1	16.8		
143	1/6/2009	34.6	34.8	49.7	48.6	70.7	39.4	43.0		
144	1/7/2009								Zero filter	
145	1/8/2009						35.5	36.3		
146	1/9/2009	38.8	38.6	48.6	47.7	80.4	37.0	41.6		
147	1/10/2009	45.7	44.6	48.3	48.8	92.9	39.9	45.4		
148	1/11/2009						41.9	46.5		
149	1/12/2009	38.4	38.4	42.7	42.9	89.7	36.0	39.4		
150	1/13/2009	36.3	36.0	41.7	41.6	86.8	34.3	38.3		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 6 of 13**

Manufacturer: Met One Instruments

Type of instrument: BAM-1020

Serial-No.: SN 17010 / SN 17011

PM2,5
Measured values in µg/m³ (ACT)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
151	1/14/2009	31.1	31.3	38.2	38.2	81.5	30.1	33.7		Cologne, Winter
152	1/15/2009	28.4	28.5	32.2	32.0	88.6	27.9	31.3		
153	1/16/2009	36.6	36.8	39.9	40.2	91.6	35.5	39.3		
154	1/17/2009						16.8	16.5		
155	1/18/2009	5.0	4.4	8.5	7.9	57.3	5.9	6.1		
156	1/19/2009	3.0	3.3	6.7	5.9	50.0	5.0	4.9		
157	1/20/2009			14.2	14.5		9.7	11.0	Outlier Ref. PM2,5	
158	1/21/2009	16.0	16.0	21.2	21.6	74.5	16.3	17.8		
159	1/22/2009	6.2	6.3	9.0	8.6	71.3	7.7	7.2		
160	1/23/2009	5.3	4.9	9.2	9.1	55.5	7.2	7.2		
161	1/24/2009						17.4	18.7		
162	1/25/2009	16.4	16.6	21.0	20.4	79.4	16.4	17.6		
163	1/26/2009	35.1	35.5	44.8	43.8	79.6	38.9	39.9		
164	1/27/2009	31.0	31.2	37.4	37.5	83.0	33.6	34.3		
165	1/28/2009	29.9	29.4	33.5	33.9	87.9	31.5	31.7		
166	1/29/2009						28.4	31.3		
167	1/30/2009	23.6	24.1	29.5	29.2	81.2	29.4	26.6		
168	1/31/2009						7.1	7.9		
169	2/1/2009	15.2	15.6	17.8	18.1	85.9	18.7	18.3		
170	2/2/2009								Zero filter	
171	2/3/2009			41.3	41.0		37.1	39.4	Outlier Ref. PM2,5	
172	2/4/2009	30.9	30.2	34.3	34.2	89.1	33.0	33.5		
173	2/5/2009	17.6	17.1	21.2	21.2	81.9	19.0	19.1		
174	2/6/2009	19.4	19.8	23.5	23.7	83.0	22.5	22.9		
175	2/7/2009						22.9	22.5		
176	2/8/2009	12.4	12.6	16.1	16.1	77.3	15.2	13.8		
177	2/9/2009	7.1	6.7	10.8	10.4	64.9	8.6	7.1		
178	2/10/2009						8.3	8.2		
179	2/11/2009	11.5	11.9	16.8	16.6	70.1	13.9	12.7		
180	2/12/2009	12.2	13.1	21.8	22.7	57.0	16.9	16.4		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 7 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
181	2/13/2009	19.8	19.6	25.9	26.3	75.4	23.6	22.2		Cologne, Winter
182	2/14/2009						28.9	28.7		
183	2/15/2009	19.5	19.9	24.7	25.1	79.0	24.8	22.2		
184	2/16/2009			17.7	18.2		15.8	16.3	Ref. 2 PM2,5 not operational	
185	2/17/2009	10.7	10.5	12.7	13.1	82.0	10.3	11.0		
186	2/18/2009	15.0	14.5	21.0	21.6	69.2	14.9	16.2		
187	2/19/2009	30.9	31.0	38.8	38.8	79.7	30.2	31.7		
188	2/20/2009	12.9	13.1	18.3	18.3	70.8	14.7	16.0		
189	2/21/2009						23.1	24.7		
190	2/22/2009	13.5	13.9	20.2	20.8	66.7	15.0	14.0		
191	2/23/2009	6.6	6.0	14.6	15.0	42.4	6.6	8.5		
192	2/24/2009	19.1	18.9	29.9	30.5	63.0	20.3	21.9		
193	2/25/2009	26.9	27.3	36.3	35.5	75.4	28.6	28.4		
194	2/26/2009	20.0	19.6	30.7	30.7	64.6	19.8	20.4		
195	2/27/2009	21.1	21.2	28.3	28.2	74.9	24.0	22.4		
196	2/28/2009	25.0	25.0	31.4	31.5	79.6	26.5	27.1		
197	3/1/2009						31.5	33.1		
198	3/2/2009	28.0	27.8	36.9	37.1	75.3	28.0	28.7		
199	3/3/2009	20.8	21.2	25.9	25.7	81.4	19.6	21.4		
200	3/4/2009								Zero filter	
201	3/5/2009	15.2	13.7	15.2	16.0	92.8	14.7	14.9		
202	3/6/2009	16.1	14.8	21.4	21.9	71.6	16.0	17.9		
203	3/7/2009	18.7	18.9	26.1	26.1	71.9	18.7	16.9		
204	3/8/2009						5.6	6.9		
205	3/9/2009						8.0	9.2		
206	3/10/2009						8.3	9.7		
207	3/11/2009	13.0	13.2	21.4	21.6	60.7	13.9	14.2		
208	3/12/2009	19.1	19.2	24.1	24.5	78.8	19.5	21.5		
209	3/13/2009	16.3	16.9	28.8	28.2	58.4	17.1	17.1		
210	3/14/2009	17.2	17.6	25.7	26.3	66.9	17.4	18.2		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 8 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
211	3/15/2009						8.6	10.5		Cologne, Winter
212	3/16/2009	26.4	26.4	37.0	37.5	70.9	28.9	30.8		
213	3/17/2009	24.5	24.9	36.8	36.7	67.4	24.0	23.3		
214	3/18/2009	23.2	23.8	38.1	38.6	61.3	22.6	22.2		
215	3/19/2009	17.3	17.9	28.5	29.2	61.0	15.4	15.3		
216	3/20/2009	16.0	14.1	26.1	27.0	56.7	13.8	15.8		
217	3/21/2009						43.5	45.4		
218	3/22/2009	19.0	18.5	32.7	32.1	57.8	20.1	19.2		
219	3/23/2009	9.9	10.1	20.8	20.4	48.6	10.2	10.4		
220	3/24/2009	8.5	8.9	15.7	16.0	54.8	8.0	8.7		
221	3/25/2009	9.2	8.8	14.0	14.4	63.2	10.1	11.4		
222	3/26/2009	7.2	7.8	10.9	11.5	67.0	8.2	7.1		
223	3/27/2009	8.4	8.4	12.9	12.3	67.0	8.5	8.4		
224	3/28/2009	7.3	6.5	9.3	8.9	75.6	5.7	8.4		
225	3/29/2009						14.2	17.5		
226	3/30/2009						24.2	24.7		
227	3/31/2009						24.1	25.9		
228	4/1/2009						25.7	26.2		
229	4/2/2009								Zero filter	
230	4/3/2009						63.6	66.4		
231	4/4/2009						90.4	92.0		
232	4/5/2009						78.4	77.4		
233	4/6/2009						31.7	29.9		
234	4/7/2009						22.2	21.4		
235	4/8/2009						7.0	4.8		
236	4/9/2009						9.2	8.3		
237	4/10/2009						17.3	17.4		
238	4/11/2009						35.5	38.5		
239	4/12/2009						124.1	126.7		
240	4/13/2009						110.7	105.1		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 9 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
241	8/9/2009	38.1	37.7					40.5	17010 shows peaks in	Bornheim, Summer
242	8/10/2009							29.4	measured values and	
243	8/11/2009	12.4	11.9					10.6	stability values	
244	8/12/2009	9.6	10.0						Exchange of PMT for 17010	
245	8/13/2009								Zero filter	
246	8/14/2009								Zero filter	
247	8/15/2009						11.5	10.7		
248	8/16/2009	16.5	16.7	22.8	22.8	72.8	15.0	13.9		
249	8/17/2009	15.0	15.0	24.1	23.7	62.7	15.7	14.1		
250	8/18/2009	12.4	13.0	20.1	19.7	63.7	13.3	13.3		
251	8/19/2009	16.8	17.2	24.0	24.3	70.3	15.0	13.7		
252	8/20/2009	19.6	19.4	33.4	32.7	59.1	14.4	11.6		
253	8/21/2009	8.0	8.2	18.9	18.7	43.0	9.7	8.1		
254	8/22/2009						10.8	9.6		
255	8/23/2009	11.7	12.0	17.2	17.6	68.1	10.7	9.1		
256	8/24/2009	14.3	13.8	19.1	20.4	71.3	12.0	11.3		
257	8/25/2009			21.4	21.2		15.9	12.9	Outlier Ref. PM2,5	
258	8/26/2009						9.2	7.6		
259	8/27/2009	8.7	9.1	15.4	16.1	56.3	6.6	4.8		
260	8/28/2009	8.3	8.0	17.0	16.9	48.1	7.0	4.6		
261	8/29/2009						7.5	6.0		
262	8/30/2009	7.3	7.5	16.8	16.8	43.9	7.8	6.3		
263	8/31/2009	12.3	11.9	22.3	21.0	55.9	9.1	8.2		
264	9/1/2009	11.3	11.3	18.1	18.4	62.0	9.9	8.6		
265	9/2/2009	7.9	8.0	13.3	13.7	58.9		6.8	SN 17010, Filter tape cut	
266	9/3/2009	5.3	5.3	8.0	7.2	69.1		4.4	SN 17010, Filter tape cut	
267	9/4/2009	5.4	5.4	8.9	9.2	60.0	4.5	5.6		
268	9/5/2009						7.9	7.2		
269	9/6/2009	6.7	6.5	10.6	10.6	62.3	6.9	7.7		
270	9/7/2009	11.4	11.9	18.5	18.5	62.8	10.5	11.5		

Annex 5 **Measured values from field test sites, related to actual conditions**

Manufacturer: Met One Instruments

Type of instrument: BAM-1020

Serial-No.: SN 17010 / SN 17011

PM2,5
Measured values in µg/m³ (ACT)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
271	9/8/2009	17.0	16.9	25.2	25.0	67.5	15.2	16.5		Bornheim, Summer
272	9/9/2009	19.4	19.2	38.2	37.5	51.0	20.0	20.1		
273	9/10/2009	10.2	9.6	22.3	21.9	44.7	12.4	14.8		
274	9/11/2009	9.1	9.4	21.0	20.7	44.4	9.2	11.6		
275	9/12/2009						11.4	11.6		
276	9/13/2009	5.4	5.6	12.9	13.8	41.5	6.3	6.2		
277	9/14/2009								Zero filter	
278	9/15/2009	12.6	13.0	17.2	16.8	75.0	15.0	16.2		
279	9/16/2009	25.6	25.9	34.5	33.3	76.0	27.2	30.8		
280	9/17/2009	13.6	13.8	20.8	20.2	66.8	14.3	17.2		
281	9/18/2009	18.7	19.0	24.8	25.6	74.8	19.7	19.9		
282	9/19/2009						23.1	24.7		
283	9/20/2009	36.7	37.1	45.0	45.2	81.8	39.6	41.3		
284	9/21/2009	18.2	19.0	28.7	29.1	64.3	23.0	25.3		
285	9/22/2009	14.9	15.0	27.2	28.1	54.1	17.2	17.9		
286	9/23/2009	12.9	12.7	26.8	27.0	47.5	13.2	16.4		
287	9/24/2009	14.9	14.5	23.0	22.8	64.0	14.7	16.7		
288	9/25/2009	16.3	16.1	28.6	27.4	57.9	15.6	16.9		
289	9/26/2009						14.8	15.3		
290	9/27/2009	26.0	25.7	34.9	35.8	73.0	24.0	24.3		
291	9/28/2009	28.8	29.5	44.4	45.3	65.1	29.0	30.8		
292	9/29/2009	18.0	18.3	28.0	27.8	65.1	18.5	20.0		
293	9/30/2009	19.1	19.7	25.1	25.3	77.2	19.2	21.1		
294	10/1/2009	9.6	8.9	18.5	18.8	49.5	9.7	9.8		
295	10/2/2009	12.0	12.0	25.9	26.1	46.0	10.3	11.1		
296	10/3/2009						5.9	7.7		
297	10/4/2009	5.4	6.0	10.6	11.0	52.6	5.5	4.3		
298	10/5/2009	8.2	8.4	12.5	14.0	62.7	7.4	9.3		
299	10/6/2009	12.8	12.9	17.5	18.8	70.7	13.1	13.9		
300	10/7/2009	8.7	8.5	14.0	14.3	60.9	9.1	8.7		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 11 of 13**

Manufacturer	Met One Instruments
Type of instrument	BAM-1020
Serial-No.	SN 17010 / SN 17011

PM2,5
Measured values in µg/m³ (ACT)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
301	10/8/2009	11.2	10.7	16.1	16.7	66.9	12.9	12.8		Bornheim, Summer
302	10/9/2009	9.1	8.5	15.6	15.6	56.4	8.1	9.3		
303	10/10/2009						10.0	10.1		
304	10/11/2009	5.8	6.6	11.6	12.0	52.4	5.1	8.0		
305	10/12/2009	4.8	4.2	9.9	9.9	45.4	5.0	6.6		
306	10/13/2009	6.2	6.3	12.5	12.5	50.0	6.5	6.8		
307	10/14/2009	11.2	10.3	15.4	15.6	69.6	10.1	11.8		
308	10/15/2009	11.2	10.2	18.0	17.8	59.8	8.9	10.7		
309	10/16/2009	6.5	6.3	16.1	15.8	40.3	5.7	8.5		
310	10/17/2009						8.4	8.5		
311	10/18/2009	11.3	11.3	18.4	18.6	60.9	10.4	10.4		
312	10/19/2009	12.8	12.8	19.6	19.6	65.1	11.9	12.5		
313	10/20/2009	15.6	14.9				13.0	14.2	Outlier Ref. PM10	
314	10/21/2009	20.8	21.2	27.6	28.1	75.6	18.4	19.7		
315	10/22/2009			31.7	32.3		23.3	25.0	Outlier Ref. PM2,5	
316	12/9/2009	11.3	11.6	27.5	27.5	41.6	10.1	10.5		Teddington, Winter
317	12/10/2009	16.4	16.2	25.4	25.4	64.2	16.1	17.4		
318	12/11/2009	11.8	11.7	20.3	20.2	57.9	10.4	11.4		
319	12/12/2009	6.4	6.5	13.5	13.6	47.6	6.2	6.9		
320	12/13/2009	8.6	9.1	13.4	13.9	65.1	8.4	8.3		
321	12/14/2009	27.9	28.3	35.3	35.3	79.6	26.9	27.4		
322	12/15/2009	39.8	38.8	47.6	47.4	82.8	39.9		SN 17011 Filter tape error	
323	12/16/2009	24.9	24.5	30.0	30.3	82.0	24.0		SN 17011 Filter tape error	
324	12/17/2009	5.7	5.6	10.2	10.1	55.7	6.3	6.4		
325	12/18/2009	11.6	11.9	16.9	17.0	69.3	10.1	11.3		
326	12/19/2009	10.3	11.0	15.4	14.9	70.4	11.3	12.0		
327	12/20/2009	6.2	6.4	11.1	11.0	56.9	6.6	7.9		
328	12/21/2009	17.7	17.7	20.2	20.4	87.2	17.6	17.9		
329	12/22/2009	29.4	28.9				31.7	31.9	Outlier Ref. PM10	
330	12/23/2009						14.7	15.9		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 12 of 13**

Manufacturer: Met One Instruments
Type of instrument: BAM-1020
Serial-No.: SN 17010 / SN 17011

PM2,5
Measured values in µg/m³ (ACT)

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
331	12/24/2009						16.5	17.5		Teddington, Winter
332	12/25/2009						9.5	9.7		
333	12/26/2009						3.3	3.2		
334	12/27/2009						4.6	5.7		
335	12/28/2009						17.8	19.2		
336	12/29/2009						8.7	9.9		
337	12/30/2009						8.8	9.3		
338	12/31/2009	6.0	6.5				6.5	6.7		
339	1/1/2010						13.8	13.7		
340	1/2/2010						11.6	12.5		
341	1/3/2010						16.4	17.7		
342	1/4/2010								Zero filter	
343	1/5/2010	15.6	15.5				15.5	16.4		
344	1/6/2010			19.2	19.3		13.0	13.9	Outlier Ref. PM2,5	
345	1/7/2010	15.3	15.7	19.4	20.1	78.4	14.6	15.7		
346	1/8/2010	14.6	14.9	18.3	18.4	80.3	12.9	15.2		
347	1/9/2010	7.1	6.9	14.6	14.9	47.4	8.0	7.9		
348	1/10/2010	16.0	16.1	19.5	19.2	82.9	14.4	15.1		
349	1/11/2010	45.7	46.2	51.8	51.3	89.1	43.9	45.3		
350	1/12/2010	43.2	43.6	48.1	48.0	90.4	43.0	45.2		
351	1/13/2010	48.0	48.3	53.4	53.0	90.6	46.8	47.9		
352	1/14/2010	14.1	14.4	16.2	16.3	87.5	14.6	15.6		
353	1/15/2010	14.6	14.4	26.9	27.1	53.6	11.9	13.2		
354	1/16/2010	6.5	6.1	13.5	13.6	46.1	7.5	8.1		
355	1/17/2010	11.0	10.5	20.6	20.6	52.3	10.0	10.4		
356	1/18/2010	21.0	20.4	27.1	26.9	76.7	18.5	21.0		
357	1/19/2010	20.4	20.2	26.5	26.6	76.4	17.7	19.6		
358	1/20/2010	26.6	27.0	32.0	31.9	83.8	25.1	25.8		
359	1/21/2010	20.5	20.9	27.5	27.9	75.0	20.0	20.0		
360	1/22/2010	7.8	7.6	9.7	9.8	78.5	7.3	8.2		

Annex 5 **Measured values from field test sites, related to actual conditions** **Page 13 of 13**

Manufacturer	Met One Instruments	
Type of instrument	BAM-1020	PM2,5 Measured values in µg/m³ (ACT)
Serial-No.	SN 17010 / SN 17011	

No.	Date	Ref. 1 PM2,5 [µg/m³]	Ref. 2 PM2,5 [µg/m³]	Ref. 1 PM10 [µg/m³]	Ref 2. PM10 [µg/m³]	Ratio PM2,5/PM10 [%]	SN 17010 PM2,5 [µg/m³]	SN 17011 PM2,5 [µg/m³]	Remark	Test site
361	1/23/2010	21.0	20.9	25.8	25.1	82.3	19.5	19.8		Teddington, Winter
362	1/24/2010	16.2	15.9	20.7	20.3	78.4	14.0	16.5		
363	1/25/2010	36.1	35.8	42.0	42.4	85.1	35.6	38.9		
364	1/26/2010	50.7	51.1	60.4	60.4	84.2	47.4	50.8		
365	1/27/2010	27.1	27.3	38.9	39.1	69.7	24.0	26.4		
366	1/28/2010	8.3	8.0	13.9	14.1	58.3	8.2	9.2		
367	1/29/2010	5.7	6.0	9.4	9.6	61.5	6.3	6.8		
368	1/30/2010	12.4	12.5	17.6	17.6	70.7	11.5	13.7		
369	1/31/2010	12.2	13.0	17.3	16.9	73.5	11.7	14.2		
370	2/1/2010	8.4	8.3	14.7	14.4	57.5	8.1	9.6		
371	2/2/2010	8.3	8.3	12.0	11.7	70.0	7.7	10.1		
372	2/3/2010	9.4	9.3	19.2	19.2	48.6	9.0	11.3		
373	2/4/2010	12.0	12.4	19.7	19.8	61.7	11.5	13.4		

Annex 6 **Ambient conditions at the field test sites** **Page 1 of 13**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
1	7/24/2008	Teddington, Summer	No weather data available					
2	7/25/2008							
3	7/26/2008							
4	7/27/2008							
5	7/28/2008							
6	7/29/2008							
7	7/30/2008							
8	7/31/2008							
9	8/1/2008							
10	8/2/2008							
11	8/3/2008							
12	8/4/2008							
13	8/5/2008							
14	8/6/2008							
15	8/7/2008							
16	8/8/2008							
17	8/9/2008							
18	8/10/2008							
19	8/11/2008							
20	8/12/2008							
21	8/13/2008							
22	8/14/2008							
23	8/15/2008							
24	8/16/2008							
25	8/17/2008							
26	8/18/2008							
27	8/19/2008							
28	8/20/2008							
29	8/21/2008							
30	8/22/2008							

Annex 6 — Ambient conditions at the field test sites — Page 2 of 13

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
31	8/23/2008	Teddington, Summer						
32	8/24/2008							
34	8/25/2008							
34	8/26/2008							
35	8/27/2008							
36	8/28/2008							
37	8/29/2008							
38	8/30/2008							
39	8/31/2008							
40	9/1/2008							
41	9/2/2008							
42	9/3/2008							
43	9/4/2008		No weather data available					
44	9/5/2008							
45	9/6/2008							
46	9/7/2008							
47	9/8/2008							
48	9/9/2008							
49	9/10/2008							
50	9/11/2008							
51	9/12/2008							
52	9/13/2008							
53	9/14/2008							
54	9/15/2008							
55	9/16/2008							
56	9/17/2008		14.5	1004.7	68.1	0.6	152.9	
57	9/18/2008		11.6	1007.1	72.0	0.5	195.4	
58	9/19/2008		12.8	1012.3	70.1	0.3	169.8	
59	9/20/2008		13.1	1011.1	70.5	0.5	116.4	
60	9/21/2008		13.2	1007.7	70.0	0.6	168.0	

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
61	9/22/2008	Teddington, Summer	14.8	1006.2	76.5	1.1	211.1	
62	9/23/2008		14.4	1005.5	76.0	1.8	228.3	
63	9/24/2008		14.8	1009.9	81.9	0.8	168.0	
64	9/25/2008		13.3	1016.0	74.7	0.7	88.8	
65	9/26/2008		13.4	1015.9	75.6	0.7	146.4	
66	9/27/2008		12.0	1011.2	80.6	0.1	206.1	
67	9/28/2008		13.9	1005.1	70.7	0.2	299.8	
68	9/29/2008		14.0	996.5	71.7	0.3	234.6	
69	9/30/2008		13.7	983.7	83.8	0.4	209.8	
70	10/1/2008		10.4	985.3	71.9	0.4	232.2	
71	10/2/2008		9.5	988.5	69.7	0.7	271.6	
72	10/3/2008		9.3	998.5	64.0	0.6	278.5	
73	10/4/2008		14.1	984.7	87.0	1.1	179.0	
74	10/5/2008		10.1	986.7	88.7	0.6	259.1	
75	10/6/2008		14.8	991.4	87.0	0.9	161.0	
76	10/7/2008		12.7	991.2	89.6	0.6	219.1	
77	10/8/2008		9.6	1007.9	80.6	0.2	276.5	
78	10/9/2008		13.3	1012.5	80.2	0.3	183.9	
79	10/10/2008		12.0	1009.0	84.4	0.4	210.4	
80	10/11/2008		12.8	1006.9	85.9	0.2	197.8	
81	10/12/2008		15.4	1000.7	86.5	0.3	206.3	
82	10/13/2008		12.5	1001.0	90.9	0.1	209.4	
83	10/14/2008		14.4	997.5	90.5	0.3	191.7	
84	10/15/2008		12.1	994.4	86.8	0.3	255.0	
85	10/16/2008		8.2	1001.0	78.7	0.4	240.5	
86	10/17/2008		9.0	1002.0	83.8	0.0	228.9	
87	10/18/2008		10.6	1001.3	83.3	0.1	212.7	
88	10/19/2008		14.0	994.8	76.3	0.8	192.2	
89	10/20/2008		11.2	988.7	90.2	0.4	203.4	
90	10/21/2008		6.7	999.4	80.5	0.2	214.1	

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
91	10/22/2008	Teddington, Summer	9.4	1006.1	80.9	0.2	226.1	
92	10/23/2008		13.6	999.6	79.8	1.0	195.0	
93	10/24/2008		6.5	1010.6	85.1	0.2	250.0	
94	10/25/2008		14.1	1002.3	81.8	0.9	193.8	
95	10/26/2008		9.2	995.1	95.0	0.0	226.6	
96	10/27/2008		4.2	994.2	85.6	0.1	285.3	
97	10/28/2008		4.3	994.2	81.7	0.5	252.7	
98	10/29/2008		4.3	984.0	77.8	0.4	152.8	
99	10/30/2008		5.3	985.1	79.6	1.1	161.5	
100	10/31/2008		5.7	991.6	80.1	0.9	244.7	
101	11/1/2008		8.8	988.8	91.5	1.2	233.2	
102	11/2/2008		10.1	997.2	88.9	0.8	223.8	
103	11/3/2008		10.6	998.1	93.6	0.9	150.9	
104	11/4/2008		11.4	1001.0	86.2	0.8	179.1	
105	11/5/2008		10.5	998.4	92.6	0.5	284.0	
106	11/6/2008		10.5	991.8	90.7	0.4	161.0	
107	11/7/2008		No weather data available					
108	11/8/2008							
109	11/9/2008							
110	12/4/2008	Cologne, Winter	4.4	980.2	77.0	3.7	61.4	4.5
111	12/5/2008		5.6	987.6	76.4	1.7	109.2	12.1
112	12/6/2008		5.1	1007.5	81.1	1.7	150.2	3.6
113	12/7/2008		2.0	1020.6	82.1	0.1	150.4	0.3
114	12/8/2008		0.3	1013.0	80.5	1.1	186.1	0.3
115	12/9/2008		1.3	1006.3	82.4	0.3	124.2	6.5
116	12/10/2008		1.3	1004.8	81.3	0.2	180.1	2.1
117	12/11/2008		0.0	1006.9	81.6	0.5	244.0	0.0
118	12/12/2008		-0.5	1009.1	74.3	4.4	108.3	0.0
119	12/13/2008		0.7	994.1	69.9	5.3	193.9	0.0
120	12/14/2008		-0.4	998.5	78.2	0.4	172.9	0.0

Annex 6 — Ambient conditions at the field test sites — Page 5 of 13

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
121	12/15/2008	Cologne, Winter	1.6	1009.1	80.1	0.1	163.9	0.0
122	12/16/2008		-0.8	1006.2	81.8	0.3	93.4	0.0
123	12/17/2008		0.9	1009.0	84.6	0.4	117.2	4.2
124	12/18/2008		4.5	1011.9	81.3	2.1	107.8	3.9
125	12/19/2008		5.8	1015.8	74.9	3.1	105.9	8.3
126	12/20/2008		7.8	1018.4	81.5	2.2	139.3	17.1
127	12/21/2008		9.1	1023.3	77.9	4.2	136.1	1.5
128	12/22/2008		7.1	1026.1	80.4	1.6	143.9	0.3
129	12/23/2008		4.9	1028.0	82.8	0.1	163.2	0.0
130	12/24/2008		5.4	1023.3	79.4	1.2	175.9	0.0
131	12/25/2008		1.6	1028.1	68.0	0.6	270.6	0.0
132	12/26/2008		-1.3	1029.8	62.5	0.7	265.8	0.0
134	12/27/2008		-3.4	1026.8	69.9	0.7	268.2	0.0
134	12/28/2008		-4.7	1022.7	71.8	0.6	253.1	0.0
135	12/29/2008		-2.7	1024.1	67.3	0.4	257.9	0.0
136	12/30/2008		-3.3	1021.6	68.6	0.6	301.2	0.0
137	12/31/2008		-3.1	1019.5	75.1	0.8	125.8	0.0
138	1/1/2009		-2.9	1021.1	77.5	0.1	159.3	0.0
139	1/2/2009		Down time	1021.5	Down time	Down time	Down time	0.0
140	1/3/2009		-0.4	1017.5	68.8	1.5	187.7	0.0
141	1/4/2009		-0.6	1010.0	75.6	2.4	161.5	0.0
142	1/5/2009		-4.0	1015.4	70.6	0.0	253.5	1.2
143	1/6/2009		-14.0	1016.0	76.0	0.4	187.3	0.0
144	1/7/2009		-6.8	1019.0	76.6	0.3	161.0	0.0
145	1/8/2009		-8.5	1023.0	78.6	0.1	249.4	0.0
146	1/9/2009		-7.7	1021.9	71.6	0.3	209.0	0.3
147	1/10/2009		-5.1	1022.4	65.5	1.0	198.3	0.0
148	1/11/2009		-2.4	1021.0	61.9	2.1	234.1	0.0
149	1/12/2009		2.3	1010.9	58.8	4.7	181.9	0.3
150	1/13/2009		2.4	1006.4	67.3	2.4	73.5	3.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
151	1/14/2009	Cologne, Winter	2.1	1010.8	81.4	0.0	147.0	0.3
152	1/15/2009		1.4	1013.9	69.4	3.0	209.4	0.0
153	1/16/2009		2.1	1012.5	73.2	4.0	170.6	0.0
154	1/17/2009		5.4	1004.0	72.4	4.2	117.3	0.9
155	1/18/2009		3.8	993.4	73.5	3.7	106.3	3.5
156	1/19/2009		5.7	982.8	72.2	5.1	75.6	5.6
157	1/20/2009		0.3	994.1	76.8	0.6	159.6	0.3
158	1/21/2009		2.0	999.7	72.8	2.3	127.5	0.0
159	1/22/2009		4.1	982.6	72.4	6.9	122.9	14.5
160	1/23/2009		3.8	970.9	76.1	4.9	114.9	12.1
161	1/24/2009		1.9	988.2	77.2	0.8	158.4	0.0
162	1/25/2009		1.4	991.3	72.3	2.4	266.9	0.0
163	1/26/2009		0.3	999.1	71.8	0.9	191.8	0.0
164	1/27/2009		1.3	1009.4	65.9	0.4	224.6	0.0
165	1/28/2009		0.1	1012.6	69.6	0.6	226.4	0.0
166	1/29/2009		-0.2	1015.3	67.0	1.8	254.8	0.0
167	1/30/2009		-0.6	1014.4	67.2	2.8	237.0	0.0
168	1/31/2009		0.7	1008.8	56.2	3.3	284.1	0.0
169	2/1/2009		-0.3	998.8	59.4	3.6	289.1	0.0
170	2/2/2009		3.0	991.8	62.3	2.2	269.9	0.0
171	2/3/2009		0.9	992.3	78.8	0.0	73.6	0.6
172	2/4/2009		3.1	988.9	76.5	0.8	137.7	0.0
173	2/5/2009		Down time	986.9	Down time	Down time	Down time	0.0
174	2/6/2009		2.0	983.0	83.1	0.0	250.0	0.3
175	2/7/2009		2.1	988.1	78.4	2.4	156.5	0.6
176	2/8/2009		1.8	998.3	72.0	2.0	130.6	0.0
177	2/9/2009		4.2	987.0	74.6	5.4	130.8	15.3
178	2/10/2009		2.7	993.9	76.1	6.5	138.0	16.8
179	2/11/2009		0.9	1007.2	75.1	1.4	138.8	2.7
180	2/12/2009		0.8	1012.5	77.0	0.4	175.0	0.0

Annex 6 **Ambient conditions at the field test sites** **Page 7 of 13**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
181	2/13/2009	Cologne, Winter	0.2	1013.0	75.7	0.6	208.2	4.1
182	2/14/2009		-1.6	1021.2	71.9	0.8	205.8	0.0
183	2/15/2009		0.6	1016.8	78.2	0.9	136.5	10.6
184	2/16/2009		5.7	1011.2	83.4	3.8	149.9	21.5
185	2/17/2009		0.5	1017.1	71.6	1.8	269.0	0.6
186	2/18/2009		-0.7	1019.4	62.6	0.8	233.1	0.0
187	2/19/2009		3.1	1019.3	68.8	1.2	180.2	3.9
188	2/20/2009		4.5	1021.6	80.9	2.2	156.9	2.4
189	2/21/2009		5.3	1020.0	74.2	1.2	123.9	4.4
190	2/22/2009		5.8	1012.6	78.3	4.5	153.0	3.9
191	2/23/2009		5.1	1013.1	71.9	3.1	173.8	0.6
192	2/24/2009		2.2	1021.0	75.5	0.9	167.8	0.0
193	2/25/2009		6.3	1017.7	71.2	2.9	125.0	0.6
194	2/26/2009		7.1	1011.5	69.8	5.0	141.8	0.6
195	2/27/2009		7.8	1010.7	79.3	2.2	121.5	0.9
196	2/28/2009		7.6	1005.0	76.6	0.7	203.5	0.0
197	3/1/2009		9.5	1002.2	74.3	2.1	119.4	3.0
198	3/2/2009		5.1	1008.9	70.6	1.4	135.2	0.0
199	3/3/2009		6.8	996.3	58.0	5.0	126.5	0.0
200	3/4/2009		6.9	980.1	67.7	3.0	95.7	6.2
201	3/5/2009		4.2	984.5	81.2	4.0	176.4	26.9
202	3/6/2009		3.7	998.0	77.6	4.6	153.8	6.5
203	3/7/2009		8.0	1003.0	69.7	1.3	89.3	0.6
204	3/8/2009		6.2	997.6	68.3	3.7	120.8	5.0
205	3/9/2009		5.9	1004.3	67.8	4.3	118.5	3.3
206	3/10/2009		5.4	1004.3	75.7	4.5	123.9	7.7
207	3/11/2009		5.4	1016.0	69.7	1.7	96.3	2.4
208	3/12/2009		7.7	1012.1	81.9	2.1	157.6	11.0
209	3/13/2009		8.1	1012.2	67.9	1.1	155.3	0.0
210	3/14/2009		9.9	1012.2	70.3	3.9	176.7	1.5

Annex 6 **Ambient conditions at the field test sites** **Page 8 of 13**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
211	3/15/2009	Cologne, Winter	8.0	1022.9	72.8	2.8	153.4	0.0
212	3/16/2009		7.0	1025.4	72.6	0.1	147.8	0.0
213	3/17/2009		6.1	1027.5	66.7	0.4	204.0	0.0
214	3/18/2009		4.6	1021.1	59.6	0.1	218.6	0.0
215	3/19/2009		5.4	1022.0	57.3	0.6	199.4	0.0
216	3/20/2009		4.6	1023.1	50.9	0.8	234.3	0.0
217	3/21/2009		5.6	1019.3	58.1	1.2	139.8	0.0
218	3/22/2009		8.5	1015.0	63.4	5.3	164.1	0.0
219	4/2/2009		5.3	998.8	71.5	6.5	144.3	9.2
220	4/3/2009		3.5	1001.0	67.4	3.2	114.1	9.2
221	4/4/2009		5.4	994.9	75.6	3.8	131.6	8.6
222	4/5/2009		7.3	993.8	74.3	3.6	95.2	14.5
223	4/6/2009		6.9	990.3	66.5	3.9	91.8	1.8
224	4/7/2009		6.5	994.7	70.8	3.3	122.3	3.9
225	4/8/2009		4.8	1007.7	70.0	0.9	185.6	0.3
226	4/9/2009		5.2	1015.9	65.9	0.7	161.6	0.0
227	4/10/2009		10.3	1013.7	50.7	0.9	210.0	0.0
228	4/11/2009		12.9	1011.2	48.2	1.5	247.4	0.0
229	4/2/2009		14.9	1008.3	55.0	1.2	203.4	0.0
230	4/3/2009		17.0	1008.8	58.6	1.5	116.0	0.0
231	4/4/2009		13.6	1014.1	64.4	0.9	170.3	0.0
232	4/5/2009		11.6	1012.5	68.2	0.6	207.5	0.0
234	4/6/2009		16.0	1002.3	54.5	1.5	226.7	0.0
234	4/7/2009		12.7	1004.8	70.5	1.9	94.5	6.5
235	4/8/2009		13.0	1007.1	66.5	2.5	136.7	0.9
236	4/9/2009		15.5	1005.1	62.0	1.5	189.4	0.0
237	4/10/2009		17.7	999.7	53.3	1.4	203.8	0.0
238	4/11/2009		17.8	1001.1	56.5	0.5	148.4	0.0
239	4/12/2009		15.1	1002.6	73.3	0.9	166.7	0.0
240	4/13/2009		12.4	1002.0	76.5	0.1	184.0	0.0

Annex 6 Ambient conditions at the field test sites

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
241	8/9/2009	Bornheim, Summer	20.0	1008.6	72.3	0.0	defective	0.0
242	8/10/2009		19.8	1007.4	66.0	0.2	defective	0.3
243	8/11/2009		19.0	1010.6	70.5	0.5	defective	0.6
244	8/12/2009		18.7	1009.0	73.5	0.0	defective	20.0
245	8/13/2009		17.1	1008.7	77.3	0.1	defective	1.8
246	8/14/2009		17.3	1010.0	70.2	0.0	defective	0.0
247	8/15/2009		22.3	1007.1	56.2	0.0	defective	0.0
248	8/16/2009		22.1	1006.5	64.5	0.0	defective	0.0
249	8/17/2009		20.1	1007.5	64.9	0.4	defective	0.0
250	8/18/2009		20.4	1012.2	57.7	0.0	defective	0.0
251	8/19/2009		24.5	1010.2	53.9	0.2	defective	0.0
252	8/20/2009		25.3	1008.2	61.5	0.5	defective	17.1
253	8/21/2009		17.2	1013.3	65.4	0.0	defective	0.3
254	8/22/2009		17.4	1015.6	60.6	0.0	defective	0.0
255	8/23/2009		19.3	1009.3	55.6	0.4	defective	0.0
256	8/24/2009		23.0	1000.2	55.5	0.8	defective	1.5
257	8/25/2009		19.4	1004.1	74.1	0.1	defective	5.0
258	8/26/2009		16.1	1006.9	74.6	0.0	defective	0.0
259	8/27/2009		23.4	1005.8	56.4	0.0	defective	0.0
260	8/28/2009		17.7	1006.0	57.9	0.6	defective	0.0
261	8/29/2009		14.9	1012.1	57.6	1.1	defective	0.0
262	8/30/2009		15.7	1012.1	59.6	0.3	defective	0.0
263	8/31/2009		23.5	1005.5	44.4	0.8	defective	0.0
264	9/1/2009		14.0	1004.3	80.3	0.0	defective	12.4
265	9/2/2009		17.5	1001.8	65.9	0.0	defective	2.4
266	9/3/2009		15.8	995.9	63.8	1.3	defective	2.4
267	9/4/2009		14.1	1001.3	67.6	1.0	defective	3.9
268	9/5/2009		13.1	1013.4	70.0	0.6	defective	4.4
269	9/6/2009		14.7	1015.2	68.4	0.0	defective	0.0
270	9/7/2009		18.1	1013.4	64.0	0.0	defective	0.0

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
271	9/8/2009	Bornheim, Summer	20.6	1013.2	57.8	0.0	defective	0.0
272	9/9/2009		20.6	1016.5	63.6	0.5	defective	0.0
273	9/10/2009		15.7	1022.1	68.9	0.3	defective	0.0
274	9/11/2009		15.7	1021.5	63.1	0.2	defective	0.0
275	9/12/2009		15.9	1016.8	64.1	0.1	defective	0.0
276	9/13/2009		12.9	1011.7	77.1	0.8	defective	1.2
277	9/14/2009		13.2	1009.2	76.8	0.7	defective	6.8
278	9/15/2009		15.4	1008.4	76.4	0.0	defective	0.0
279	9/16/2009		17.2	1007.2	71.9	0.2	defective	0.0
280	9/17/2009		14.6	1010.2	70.1	0.0	defective	0.0
281	9/18/2009		18.0	1008.2	68.1	0.0	defective	0.0
282	9/19/2009		19.7	1007.3	70.0	0.0	defective	0.0
283	9/20/2009		18.7	1012.3	72.3	0.0	defective	0.0
284	9/21/2009		14.9	1016.8	71.4	0.0	defective	0.0
285	9/22/2009		16.9	1016.5	64.3	0.0	defective	0.0
286	9/23/2009		17.4	1016.4	70.9	0.0	defective	0.0
287	9/24/2009		13.8	1015.9	79.1	0.0	defective	0.6
288	9/25/2009		13.2	1017.9	69.2	0.0	defective	0.0
289	9/26/2009		13.7	1017.5	65.9	0.0	defective	0.0
290	9/27/2009		14.2	1017.1	66.9	0.0	defective	0.0
291	9/28/2009		14.7	1014.5	69.6	0.0	defective	0.0
292	9/29/2009		15.7	1011.3	72.6	0.0	defective	0.3
293	9/30/2009		15.5	1007.7	77.0	0.0	defective	1.2
294	10/1/2009		12.0	1007.4	74.9	0.1	defective	2.1
295	10/2/2009		10.9	1008.6	66.9	0.0	defective	0.0
296	10/3/2009		13.4	1002.1	63.9	0.5	defective	0.0
297	10/4/2009		11.8	1005.3	75.4	0.4	defective	3.3
298	10/5/2009		13.1	1003.9	80.0	0.8	defective	6.5
299	10/6/2009		15.9	1003.5	82.3	0.0	defective	10.3
300	10/7/2009		19.2	1000.6	75.9	0.1	defective	8.6

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
301	10/8/2009	Bornheim, Summer	10.7	1009.6	78.6	0.4	defective	0.0
302	10/9/2009		12.1	1008.9	69.1	0.2	defective	12.4
303	10/10/2009		13.2	1005.2	80.0	0.2	defective	4.2
304	10/11/2009		11.9	1002.7	76.1	0.8	defective	5.9
305	10/12/2009		9.8	1014.3	70.9	1.9	defective	2.1
306	10/13/2009		7.4	1019.5	68.5	0.7	defective	0.0
307	10/14/2009		3.3	1021.8	67.4	0.1	defective	0.0
308	10/15/2009		5.4	1018.6	66.9	0.3	defective	0.3
309	10/16/2009		8.8	1012.5	70.8	4.4	defective	1.5
310	10/17/2009		7.2	1014.4	69.7	1.1	defective	0.0
311	10/18/2009		5.5	1014.0	73.1	0.0	defective	0.0
312	10/19/2009		5.6	1007.6	66.3	0.2	defective	0.0
313	10/20/2009		7.8	998.9	61.4	4.2	defective	0.0
314	10/21/2009		10.0	994.7	57.1	1.5	defective	1.2
315	10/22/2009		8.7	996.5	73.5	0.0	defective	0.0
316	12/9/2009	Teddington, Winter	9.8	1016.5	94.1	0.1	221.3	0.3
317	12/10/2009		3.9	1028.0	90.9	0.2	244.4	0.3
318	12/11/2009		5.7	1028.7	93.8	0.4	231.1	0.0
319	12/12/2009		5.8	1026.3	83.9	0.8	200.2	0.0
320	12/13/2009		4.2	1021.8	87.7	0.5	234.4	0.3
321	12/14/2009		3.4	1016.8	88.8	0.2	201.3	0.0
322	12/15/2009		-0.6	1015.4	87.5	0.2	196.0	0.3
323	12/16/2009		1.5	1006.0	96.9	0.2	244.7	2.8
324	12/17/2009		1.3	1007.7	85.2	2.4	225.4	1.3
325	12/18/2009		-0.8	1012.7	86.6	0.9	281.2	0.0
326	12/19/2009		-0.1	1002.1	85.9	0.2	240.4	1.8
327	12/20/2009		-0.9	995.4	87.3	0.1	206.2	0.0
328	12/21/2009		1.1	983.8	97.3	0.3	187.2	8.6
329	12/22/2009		-2.1	987.9	98.3	0.0	218.1	0.3
330	12/23/2009		2.8	986.8	95.9	0.4	173.5	7.1

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
331	12/24/2009	Teddington, Winter	4.1	985.9	94.1	0.3	217.3	0.5
332	12/25/2009		4.1	998.4	94.5	0.2	209.5	2.3
333	12/26/2009		5.9	995.0	90.2	0.3	199.7	0.8
334	12/27/2009		2.4	1000.0	86.2	0.3	240.5	0.0
335	12/28/2009		3.7	998.2	88.6	1.2	79.9	1.8
336	12/29/2009		4.8	988.0	95.9	1.7	94.0	11.7
337	12/30/2009		4.3	992.3	93.1	1.9	100.8	5.6
338	12/31/2009		2.3	998.1	81.8	1.1	207.4	0.0
339	1/1/2010		-0.1	1007.6	88.3	0.2	242.9	0.0
340	1/2/2010		1.6	1016.3	87.2	0.1	244.7	0.0
341	1/3/2010		-1.6	1021.1	88.3	0.3	205.4	0.0
342	1/4/2010		-3.7	1012.0	97.2	0.0	232.2	0.0
343	1/5/2010		0.8	998.1	89.9	0.7	128.7	4.8
344	1/6/2010		-2.3	1005.1	94.3	0.7	215.4	1.8
345	1/7/2010		-1.2	1013.4	91.1	0.5	240.0	0.0
346	1/8/2010		-1.6	1021.7	91.1	0.8	225.0	0.3
347	1/9/2010		0.9	1018.0	79.3	1.8	160.5	0.0
348	1/10/2010		1.4	1015.1	90.5	0.7	91.6	1.3
349	1/11/2010		1.5	1014.9	86.0	0.3	137.0	0.3
350	1/12/2010		1.4	999.9	85.9	1.5	103.1	0.0
351	1/13/2010		1.5	998.2	94.8	0.1	151.2	8.6
352	1/14/2010		2.5	1008.2	97.0	0.1	228.7	0.3
353	1/15/2010		5.6	1011.4	90.0	1.8	151.4	1.8
354	1/16/2010		5.7	1002.9	96.3	0.4	201.6	9.1
355	1/17/2010		4.1	1018.8	93.9	0.1	218.7	0.0
356	1/18/2010		6.2	1020.8	97.8	0.1	198.8	0.0
357	1/19/2010		6.4	1012.3	83.7	1.4	110.9	1.0
358	1/20/2010		3.0	1011.7	92.1	0.2	227.4	3.8
359	1/21/2010		6.1	1014.9	85.2	1.1	153.8	0.3
360	1/22/2010		7.6	1014.0	95.0	0.5	208.9	7.4

Annex 6 **Ambient conditions at the field test sites**

No.	Date	Test site	Amb. temperature (avg) [°C]	Amb. pressure [hPa]	Rel. humidity [%]	Wind velocity [m/s]	Wind direction [°]	Precipitation [mm]
361	1/23/2010	Teddington, Winter	4.8	1018.4	87.0	0.2	262.2	0.0
362	1/24/2010		4.4	1022.4	91.1	0.1	240.9	1.3
363	1/25/2010		3.2	1032.9	80.0	0.9	161.2	0.5
364	1/26/2010		0.0	1037.1	83.2	0.5	167.1	0.0
365	1/27/2010		4.4	1017.6	85.5	0.3	247.4	1.0
366	1/28/2010		5.5	999.5	86.4	0.5	246.8	8.1
367	1/29/2010		1.3	992.2	76.9	0.9	279.1	0.3
368	1/30/2010		-0.9	1001.4	84.4	0.2	239.9	0.0
369	1/31/2010		0.0	1005.5	91.2	0.1	241.4	0.0
370	2/1/2010		3.1	1010.5	83.9	0.4	221.7	0.3
371	2/2/2010		5.9	1001.8	89.6	0.3	229.2	1.0
372	2/3/2010		6.7	1004.2	91.0	0.2	179.7	2.0
373	2/4/2010		7.6	997.1	86.1	1.3	153.0	2.3

Annex 2:

Methods used for filter weighing

A) Sites located in Germany (Cologne and Bornheim)

A.1 Performance of weighing

Weighing takes place in an air-conditioned weighing chamber. Conditions are as follows: 20 °C ±1 °C and 50% ±5% rel. humidity and thus meet the requirements of EN 14907.

Filters for the field test are weighed manually. For further processing, filters incl. the control filters are placed sieves to avoid cross-loading.
Conditions for initial and back weighing had previously been defined and are in line with the standard.

Before sampling = initial weighing	After sampling = back weighing
Processing 48 hours + 2 hours	Processing 48 hours + 2 hours
Filter weighing	Filter weighing
additional processing 24 hours + 2 hours	additional processing 24 hours + 2 hours
Filter weighing and immediate packaging	Filter weighing

The balance is available ready for operation at all times. The balance is calibrated before every weighing series. If everything turns out to be okay, the reference with is weighed against the calibration weight of 200 mg and peripheral parameters are recorded. Deviations from the previous weighing meet the standard's requirements and do not exceed 20 µg (see Figure 58). The six control filters are weighed this way. For control filters deviating by more than 40 µg a warning is displayed on the evaluation page. This filters are not used for back weighing. The first three flawless control filters are used for back weighing, remaining filters remain safely stored in their can to be used in the event the first three filters are damaged or experience excessive deviations. Figure 59 presents the exemplary trend over a period of four weeks.

Filters, for which there is a difference or more than 40 µg between the first and the second weighing, are not used for initial weighing. For back weighing, filters with differences exceeding 60 µg are removed from the evaluation as required by the standard.

Weighed filters are separately kept in polystyrene boxes for transports to and from the measurement site and for storage. The box is not opened until the filter is inserted in the filter cartridge. Virgin filters can be stored in the weighing chamber up to 28 days until sampling. Should this period be exceeded, initial weighing will be repeated.

Deposited filters can be stored for a maximum of 15 days at temperatures up to 23°C. Filters are stored in a fridge at 7°C.

A2 Evaluation of the filters

Filters are evaluated using a correction term. The purpose of this corrective calculation is to minimise changes in the mass as a result of conditions in the weighing chamber.

Equation:

$$Dust = MF_{rück} - (M_{Tara} \times (MKon_{rück} / MKon_{hin})) \qquad (F1)$$

$MKon_{hin}$ = mean mass of the 3 control filters determined on 48 h and 72h initial weighing

$MKon_{rück}$ = mean mass of the 3 control filters determined on 48 h and 72 h back weighing

M_{Tara} = mean mass of the filter determined on 48 h and 72 h initial weighing

$MF_{rück}$ =mean mass of the filter determined on 48 h and 72 h back weighing

Dust = corrected dust load on the filter

The corrective calculation proved to render the method independent of the conditions in the weighing chamber. This way, the influence of water contents on the filter mass comparing virgin and deposited filters can be controlled and does not influence the dust concentrations deposited on the used filters. This is sufficient to meet the requirements of EN 14907, chapter 9.3.2.5.

The exemplary trend for the calibration weight for Nov 2008 to Feb 2009 shows that the permissible difference of 20 µg compared to the previous measurement is not exceeded.

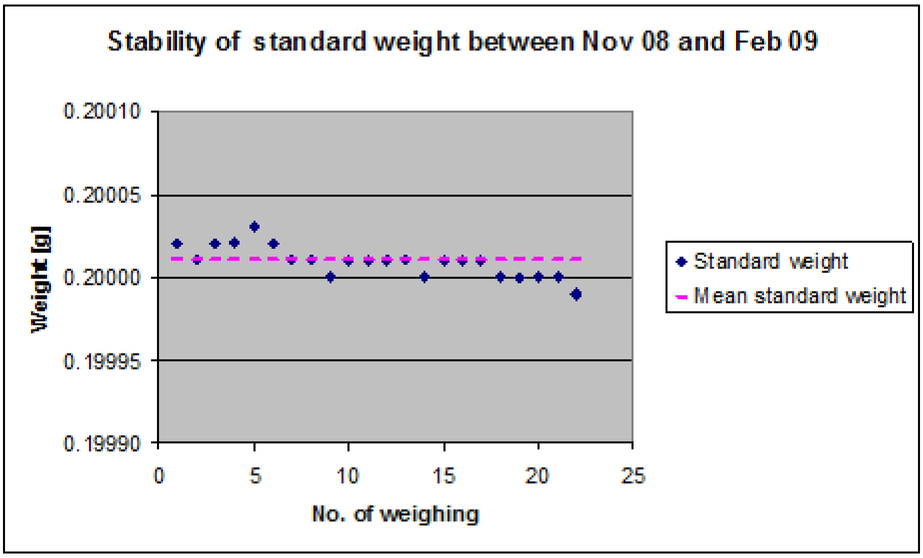


Figure 58: Stability calibration weight

Table 24: Stability calibration weight

Date	Weighing no.	Standard weight	Difference compared to previous weighing
		g	µg
12.11.2008	1	0.20002	
13.11.2008	2	0.20001	-10
10.12.2008	3	0.20002	10
11.12.2008	4	0.20002	0
17.12.2008	5	0.20003	10
18.12.2008	6	0.20002	-10
07.01.2009	7	0.20001	-10
08.01.2009	8	0.20001	0
14.01.2009	9	0.20000	-10
15.01.2009	10	0.20001	10
21.01.2009	11	0.20001	0
22.01.2009	12	0.20001	0
29.01.2009	13	0.20001	0
30.01.2009	14	0.20000	-10
04.02.2008	15	0.20001	10
05.02.2009	16	0.20001	0
11.02.2009	17	0.20001	0
12.02.2009	18	0.20000	-10
18.02.2009	19	0.20000	0
19.02.2009	20	0.20000	0
26.02.2009	21	0.20000	0
27.02.2009	22	0.19999	-10

Marked yellow = mean
Marked green = lowest value
Marked blue = highest value

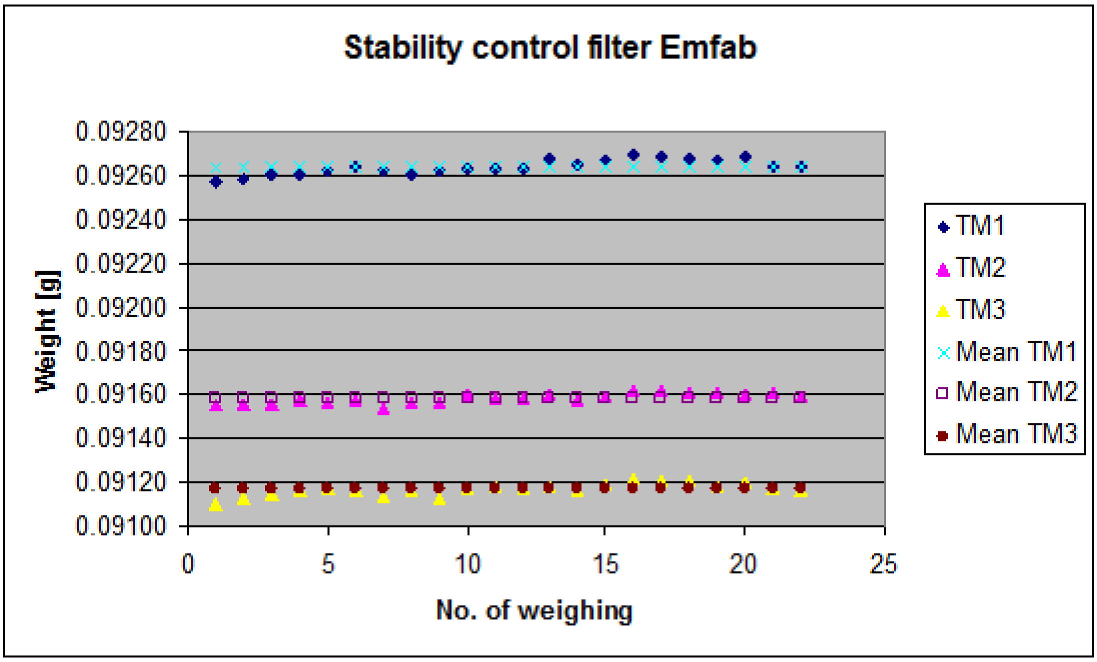


Figure 59: Stability of the control filter

Table 25: Stability of the control filters

	Control filter no.		
Weighing no.	TM1	TM2	TM3
1	0.09257	0.09155	0.09110
2	0.09258	0.09155	0.09113
3	0.09260	0.09155	0.09115
4	0.09260	0.09157	0.09116
5	0.09262	0.09156	0.09117
6	0.09264	0.09157	0.09116
7	0.09262	0.09154	0.09114
8	0.09260	0.09156	0.09116
9	0.09262	0.09156	0.09113
10	0.09263	0.09160	0.09117
11	0.09263	0.09158	0.09118
12	0.09263	0.09158	0.09117
13	0.09267	0.09160	0.09118
14	0.09265	0.09157	0.09116
15	0.09266	0.09159	0.09119
16	0.09269	0.09162	0.09122
17	0.09268	0.09162	0.09121
18	0.09267	0.09161	0.09121
19	0.09266	0.09161	0.09118
20	0.09268	0.09160	0.09120
21	0.09264	0.09161	0.09117
22	0.09264	0.09159	0.09116
Average	0.09264	0.09158	0.09117
Standard dev.	3.2911E-05	2.4937E-05	2.8558E-05
rel. Std. dev.	0.036	0.027	0.031
Median	0.09264	0.09158	0.09117
lowest value	0.09257	0.09154	0.09110
highest value	0.09269	0.09162	0.09122

Marked yellow = mean
Marked green = lowest value
Marked blue = highest value

B) Site in the United Kingdom (Teddington)

B.1 Implementation of weighing protocols

NPL (National Physical Laboratory) was commissioned to weigh filters for the field test manually. In compliance with EN 14907, the filter was stored in the weighing chamber for less than 28 days. The Plexiglas chamber used for weighing was kept at 20 ± 1°C and 50 ± 5 %. Filters were weighed twice each before and after sampling. Table 26 summarises weighing conditions and weighing times.

Table 26: Weighing conditions and weighing times

Pre Sampling	Post Sampling
Condition minimum of 48 hours Weigh Filters Condition 24 hours Weigh Filters	Condition 48 hours Weigh Filters Condition 24 hours Weigh Filters

The beam balance was checked before every weighing series in order to remove mechanical rigidity. Calibration took place after that. At the beginning and the end of every filter lot, a 50 mg and a 200 mg reference weight were weighed. In accordance with the UK PM Equivalence Report [8], the filter was weighed against a 100 mg reference weight rather than against a zero filter since the latter experiences weight loss over time. Four filters each were weighed between the reference weights, since the weighing drift over this period is small.

The **mass of the reference weight (CM)** for the filters was calculated for each weighing series according to equation **E A.1**.

$$CM = \frac{\left(m_{check,Beg} + m_{check,End}\right)}{2}$$ **E A.1**

Where:

$M_{check,Beg}$ = mass of the reference weight, weighed just upstream of the sampling filter.

$M_{check,End}$ = mass of the reference filter, weighed just downstream of the sampling filter.

The **relative mass (RM)** of the filters was determined for every weighing series in accordance with equation **E A.2**. $RM = m_{filter} - CM$ **E A.2**

Where:

m_{filter} = mass of the sampling filter

EN 14907 defines the **particle mass (PM)** as calculated in accordance with the following equation:

$$PM = \left(\frac{RM_{End1} + RM_{End2}}{2}\right) - \left(\frac{RM_{Beg1} + RM_{Beg2}}{2}\right)$$ **E A.3**

Where:

Beg1 marks weighing series 1 before sampling

Beg2 marks weighing series 2 before sampling

End1 marks weighing series 1 after sampling

End2 marks weighing series 2 after sampling

End scattering range (S_{Pre}), Beg scattering range (S_{Post}) and reference weight scattering range (S_{Blank}) were calculated according to the following equation:

$$S_{Pre} = RM_{Anf\,1} - RM_{Anf\,2}$$ **E A.4**

$$S_{Post} = RM_{End1} - RM_{End2}$$ **E A.5**

$$S_{Blank} = \left(\frac{CM_{End2} + CM_{End1}}{2} \right) - \left(\frac{CM_{Anf2} + CM_{Anf1}}{2} \right)$$ **E A.6**

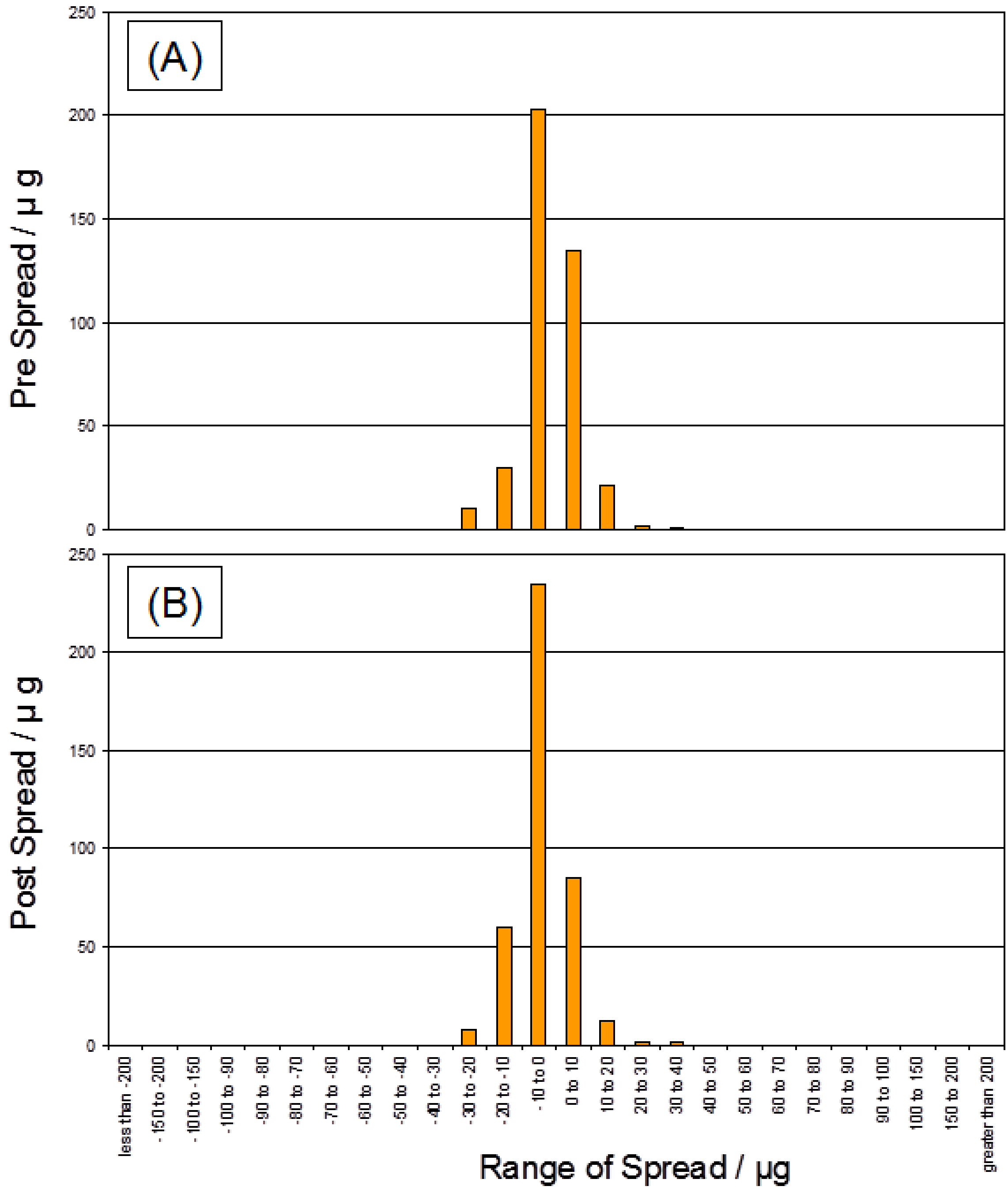
As described in the UK PM Equivalence Report [8], it was not possible to weigh all filters within the 15-day period as required by EN 14907.

However, the filters were immediately taken from the reference sampler to be put in the fridge which is why it was unnecessary to establish whether $T_{Umgebung}$ exceeded 23°C. 15 days appear unfeasible for a relatively small field test scope. The method is unlikely to be copied in national or regional grids. The method used here is representative of the operation of the reference sampler in practice.

A.2 Analysis of the weighing protocol used

Figure 60 presents the scattering behaviour of the initial and back weighing for all EMFAB filters collected referred to the carrying weight and the reference weigt. If all filters lose relative weight, scattering shifts to the right. Conversely, scattering will shift left if the filters increase in mass. Standard EN EN14907 requires undeposited filters to be discarded if the mass difference between the two initial weighings exceeds 40 µg. By the same token, EN 14907 requires filters to be discarded if the difference between the two back weighings exceeds 60 µg. This criterion did not result in any filters being discarded. It is considered unlikely that the defined scattering of repeated mass determinations significantly affect the results.

Figure 60: Scattering of the EMFAB filter for (**A**) initial weighing compared to the reference weight and (**B**) back weighing compared to the reference weight.



Annex 3:

Manual