



The Environment Agency

**2022 UK Report for On-going Particulate Matter (PM₁₀
and PM_{2.5}) Equivalence**

Air Quality

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Executive Summary

The United Kingdom (UK) has a requirement to measure the concentration of particulate matter in air. Two size fractions are measured: PM₁₀ (the concentration of particulate matter below 10 microns in diameter), and PM_{2.5} (the concentration of particulate below 2.5 microns in diameter). The legislation sets out the methods to be followed and the instruments to be used (Reference Methods), but also provides the opportunity for other instruments to be used if they have been shown to be equivalent to the Reference Method.

The Reference Methods for both PM₁₀ and PM_{2.5} require taking 24-hour samples on to filters that are weighed before and after sampling. As such, use of the Reference Method across the UK would result in delays in public information (due to laboratory processes) and data being produced at a resolution of one measurement per 24-hours per site per instrument. To meet the needs for public access to real-time, high-resolution data, the UK uses equivalent instruments that automatically produce hourly data.

During 2022, concentrations of PM₁₀ and PM_{2.5} were almost exclusively measured using Smart Heated BAM 1020s (an instrument that can measure either PM₁₀ or PM_{2.5}) or the Fidas 200 Method 11 (a single instrument that can measure both PM₁₀ and PM_{2.5} at the same time).

Testing and approval of these instruments as being equivalent to the Reference Methods was undertaken several years ago through a series of laboratory and field measurements. There is a requirement to confirm annually that these instruments are still “fit for purpose” due to the continually changing make up of particulate matter across the UK. This process is known as “On-going Equivalence” and this report summarises the findings for the UK for 2022 from this programme.

The legislation and standards governing the process of on-going equivalence are those established by the European Union (EU). Whilst the UK is no longer a Member of the EU, during 2022 the previously established methodologies were continued. The European Standard governing the process of both the initial certification of equivalent instruments and the process of on-going equivalence is EN16450:2017^[1]. With regards to on-going equivalence, each of the approved instruments is tested alongside the Reference Method at a number of sites in order to prove that the instrument is still equivalent to the Reference Method. The requirement is that the Expanded Uncertainty (as calculated using the equations in EN16450:2017) is less than 25 %. For PM₁₀ the calculations are made at a daily

□ _____
[1] CEN Standard EN16450:2017 Ambient air - Automated measuring systems for the measurement of the concentration of particulate matter (PM₁₀; PM_{2.5})

limit value of $50 \mu\text{g m}^{-3}$. For $\text{PM}_{2.5}$ the calculations are made at a pseudo daily limit value of $30 \mu\text{g m}^{-3}$.

During 2022, four sites were used for on-going equivalence testing in the UK:

- London Teddington – An urban background site in the western suburbs of London;
- Manchester Piccadilly – An urban background site in a large pedestrianised square in the centre of Manchester;
- London Marylebone Road – An urban traffic site on a busy London Road;
- Port Talbot Margam – An industrial site close to the Port Talbot Steel Works as well as the Bristol Channel.

A summary of the expanded uncertainties found during 2022 is as follows.

Instrument	Site	Expanded Uncertainty / %	Pass/Fail
PM ₁₀ Smart Heated BAM 1020	London Teddington	9.75	Pass
PM ₁₀ Smart Heated BAM 1020	Manchester Piccadilly	6.33	Pass
PM ₁₀ Smart Heated BAM 1020	London Marylebone	14.34	Pass
PM ₁₀ Smart Heated BAM 1020	Port Talbot Margam	20.54	Pass
PM _{2.5} Smart Heated BAM 1020	London Teddington	10.73	Pass
PM _{2.5} Smart Heated BAM 1020	Manchester Piccadilly	18.31	Pass
PM _{2.5} Smart Heated BAM 1020	London Marylebone	10.19	Pass
PM ₁₀ Fidas 200 Method 11	London Teddington	8.27	Pass
PM ₁₀ Fidas 200 Method 11	Manchester Piccadilly	14.42	Pass
PM ₁₀ Fidas 200 Method 11	London Marylebone	15.17	Pass
PM _{2.5} Fidas 200 Method 11	London Teddington	10.64	Pass
PM _{2.5} Fidas 200 Method 11	Manchester Piccadilly	25.26	Fail
PM _{2.5} Fidas 200 Method 11	London Marylebone	13.12	Pass

For 2022 all but one of the datasets passed the Expanded Uncertainty requirement by being below 25%.

There were no significant issues noted with the specific instruments deployed in this study during 2022.

1 Introduction to the Legislation

The European Ambient Air Quality Directive 2008/50/EC ^[2] was promulgated into UK law in 2010. Whilst the UK has now left the European Union, in 2022, it still followed the requirements set out in 2008/50/EC, in England *via* 'The Air Quality Standards Regulations (AQSR 2010)', and variations of these for the Devolved Administrations in Scottish Government, Welsh Government and The Northern Ireland Assembly). It is noteworthy these are amended by 'The Air Quality (Amendment of Domestic Regulations) (EU Exit) Regulations 2019', and variations of similar EU exit legislation for the aforementioned Devolved Administrations.

2008/50/EC sets out concentration limits and data quality objectives for different pollutants. For Particulate Matter (PM), two size fractions are measured – PM₁₀ (the concentration of particulate matter below 10 microns in diameter), and PM_{2.5} (the concentration of particulate below 2.5 microns in diameter). 2008/50/EC sets out that instruments used for particulate matter monitoring should have a measurement uncertainty below 25 %.

For PM₁₀ and PM_{2.5} 2008/50/EC requires that countries use the reference methods or else prove that the instruments they use are equivalent to the reference method. The reference method is covered by EU Standard EN12341:2014 ^[3].

The process of equivalence testing is covered by EU Standard EN16450:2017 ^[1]. Primarily this relates to setting out laboratory and field test requirements in order to show that candidate instruments can be proven to have an expanded uncertainty below the 25 % defined in 2008/50/EC. For the field testing this requires operating the candidate instruments alongside the reference instruments. Additionally, EN16450:2017 requires that countries continually prove that the instruments they deploy are still equivalent to the reference method accounting for the changing pollution climates since the initial tests were undertaken. As with the initial field testing, this process requires operating the candidate instruments alongside the reference instruments.

□

[2] 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
<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF>

[3] Standard EN12341:2014 Ambient air - Standard gravimetric measurement method for the determination of the PM₁₀ or PM_{2.5} mass concentration of suspended particulate matter.

2 The Instruments Deployed

2.1 Reference Method

The Reference Method is based upon the principle of gravimetry – which is the physical weighing of filters. Several manufacturers make different versions of the European Reference Methods in accordance with the requirements set out in EN12341:2014. Those instruments deployed in the present study are the SEQ47/50 as manufactured by Sven Leckel GMBH based in Berlin, Germany and the Digital DPA14 as manufactured by Digital AG based in Zurich, Switzerland.

Air is drawn at a rate of $2.3 \text{ m}^3 \text{ hr}^{-1}$ through a sampling head that is designed to remove particles greater than either 10 microns in diameter (when measuring PM_{10}) or 2.5 microns in diameter (when measuring $\text{PM}_{2.5}$). Following removal of the larger particles, the air is passed through a filter for 24 hours. The instrument holds multiple filters that are exchanged automatically every 24 hours.

EN12341:2014 defines four permissible filter materials which in turn can be made by multiple manufacturers to multiple specifications. The UK uses Teflon coated glass fibre filters as these have been shown to have limited effects due to absorption of water (as would quartz fibre or to lesser extent glass fibre) or problems with static and overloading the filter at moderate concentrations (as would Teflon). Further, Teflon coated glass fibre is only manufactured by a single manufacturer (Pall under the brand name Emfab), which reduces the potential for variability. Additionally, Teflon coated glass fibre filters were used in the Reference Methods as a part of the initial equivalence testing process.

Filters are weighed twice before sampling and again twice after sampling. Prior to weighing the filters are conditioned at 45 to 50 % Relative Humidity (RH) and 20 to 21 °C. The mass of the particulate matter collected on the filter is calculated as the average mass post sampling minus the average mass prior to sampling. The concentration is calculated as the mass of the particulate matter divided by the volume as measured by the SEQ47/50.

2.2 Met One Smart Heated BAM 1020

BAM is an acronym of Beta Attenuation Monitor – and relates to the use of beta radiation to measure particulate concentrations. The instruments used are Smart Heated versions of the BAM 1020 as manufactured by Met One based in Grants Pass, Oregon, USA.

For the PM_{10} version, air is drawn at a rate of $1 \text{ m}^3 \text{ hr}^{-1}$ through a sampling head that is designed to remove particles greater than 10 microns in diameter on to the tape. This is of a different design to that deployed in the Reference Method. Following this, the air stream is heated slightly to force some of the particle bound water and any water droplets to enter the gaseous phase. The air is then passed

through a glass fibre tape, to which the particles are deposited, but the gaseous phase water that was previously in the particle phase passes through. The instrument works by measuring the beta attenuation through a blank of tape for 4 minutes, then following 1 minute to move the tape, sampling PM₁₀ laden air for 50 minutes through the tape, before moving the tape again and measuring the Beta attenuation for a further 4 minutes. The mass of particulate matter is calculated from the change in the beta attenuation before and after sampling. The concentration is calculated as the mass divided by the volume of air sampled.

The PM_{2.5} version is very similar. After the PM₁₀ inlet it has a PM_{2.5} cyclone that removes particles greater than 2.5 microns. It performs the beta counts for 8 minutes rather than 4 and the sampling for 42 minutes rather than 50. This is to increase the “signal to noise” ratio, and so more accurately measure PM_{2.5} concentrations which are (by definition) lower than PM₁₀ concentrations.

The initial equivalence certification of the instruments is provided in the following references [4,5]. Both had a series of extensive laboratory tests. The PM_{2.5} Smart Heated BAM 1020 had four field tests – two in Germany and two in the UK. To be equivalent, the PM_{2.5} data do not need to be corrected. The PM₁₀ Smart Heated BAM 1020 had seven field tests – three in Germany, two in Austria, one in the Czech Republic, and one in the UK. It was shown that to be equivalent, the PM₁₀ data need to be divided by 1.035.

2.3 Palas Fidas 200 Method 11

The Fidas 200 is manufactured by Palas based in Karlsruhe, Germany. The Fidas 200 utilises optical particle counting and sizing to calculate mass concentrations. Air is drawn at a flow rate of 0.3 m³ hr⁻¹ through a sampling head that is not designed to remove larger particles but is designed to prevent insects entering the instrument. The instrument counts particles of different sizes. The instrument then heats the sample stream slightly to force some of the particle bound water and any water droplets to enter the gaseous phase. Following this the instruments counts particles and puts them in to bins of different size ranges. It then uses an algorithm to calculate PM₁₀ and PM_{2.5} based upon the numbers of particle in each bin combined with a pre-determined particle size density distribution.

[4] UK Report on the Equivalence of the Smart Heated PM_{2.5} BAM-1020. <http://www.csagroupuk.org/wp-content/uploads/2015/05/PM25-Smart-BAM1020-UK-Report-211013.pdf>

[5] UK Report on the Equivalence of the Smart Heated PM₁₀ BAM-1020. <http://www.csagroupuk.org/wp-content/uploads/2015/05/Smart-BAM-1020-PM10-UK-Report-with-manual-Final.pdf>

The initial equivalence certification of the instruments is provided in the following reference [6]. There were six field tests of which four were in Germany and two were in the UK. There were also a series of extensive laboratory tests. The instruments tested were operating with a concentration calculation algorithm known as Method 11. This same algorithm is utilised in those instruments tested at the on-going equivalence sites as well as all other instruments deployed in the UK Network. It was shown that, to be equivalent, the PM₁₀ data did not need correcting, but the PM_{2.5} data needs to be corrected by dividing by 1.06.

□ _____
[6] UK Report on the Equivalence of the Palas Fidas 200 Method 11 for PM₁₀ and PM_{2.5}.
<http://www.csagroupuk.org/wp-content/uploads/2016/04/Palas-UK-Report-Final-with-Manuals-080316.pdf>

3 The Monitoring Sites

During 2022, four sites were used for on-going equivalence testing.

3.1 London Teddington

London Teddington is an urban background site in the western suburbs of London [7]. The instruments deployed were a PM₁₀ SEQ Reference Method, a PM_{2.5} SEQ Reference Method, a PM₁₀ Smart Heated BAM 1020, a PM_{2.5} Smart Heated BAM 1020, a Fidas 200 Method 11. Data from the Fidas 200 Method 11 are available from UK Air [8].

3.2 Manchester Piccadilly

Manchester Piccadilly is an urban background site in a large pedestrianised square in the centre of Manchester [9]. The instruments deployed were a PM₁₀ SEQ Reference Method, a SEQ PM_{2.5} Reference Method, a PM₁₀ Smart Heated BAM 1020, a PM_{2.5} Smart Heated BAM 1020 and a Fidas 200 Method 11. Data from the Fidas 200 Method 11 are available from UK Air [8].

3.3 London Marylebone Road

London Marylebone Road which is a busy urban traffic site in the centre of London [10]. The instruments deployed were a PM₁₀ Digital Reference Method, a Digital PM_{2.5} Reference Method, a PM₁₀ Smart Heated BAM 1020, a PM_{2.5} Smart Heated BAM 1020 and a Fidas 200 Method 11. Data from the Smart Heated BAMs are available from UK Air [8].

3.4 Port Talbot Margam

Port Talbot Margam is an industrial site close to the Port Talbot Steel Works as well as the Bristol Channel [11]. At this site there was deployed a PM₁₀ SEQ Reference Method, and a PM₁₀ Smart Heated BAM 1020. Data from both instruments are available from UK Air [8].

[7] https://uk-air.defra.gov.uk/networks/site-info?site_id=TED2

[8] <https://uk-air.defra.gov.uk/data/>

[9] https://uk-air.defra.gov.uk/networks/site-info?site_id=MAN3

[10] https://uk-air.defra.gov.uk/networks/site-info?site_id=MY1

[11] https://uk-air.defra.gov.uk/networks/site-info?site_id=PT4

4 Calculating the Uncertainty

The equations to calculate the uncertainty are covered in EN16450:2017. The calculations are undertaken with 24-hour average data and using graphs with the reference method on the “x axis” and the continuous monitor on the “y axis”. A straight line of best fit is drawn using orthogonal linear regression and the intercept is not forced through the origin.

The slope and intercept of the lines of best fit are calculated as are the uncertainties associated with the slope and intercept. EN16450:2017 then define the slopes and intercept as being significant based upon whether the slope is within two uncertainties of 1 and the intercept is within two uncertainties of 0.

When undertaking the initial approval of equivalent instruments, there are requirements to check whether slope and/or intercept correction would result in a lower expanded uncertainty. However, for on-going equivalence testing there is no requirement to do so unless there is evidence of a consistent shift in results across many sites and years.

For PM₁₀ the calculations are made at a daily limit value (LV) of 50 µg m⁻³. For PM_{2.5} the calculations are made at a pseudo daily limit value of 30 µg m⁻³.

The uncertainty is made up of two parts – the bias at the LV, which is how far from the line of best fit is from the reference method at the Limit Value, and the random term, which is a measure of how noisy the distribution is. Both the bias and random terms are expressed in µg m⁻³. To calculate the expanded uncertainty, the two uncertainty components are combined by squaring them, adding the two squared uncertainties, and then square rooting the total. The units are still in µg m⁻³. This is then expressed as a percentage by dividing by the limit value (*i.e.* 50 µg m⁻³ for PM₁₀ or 30 µg m⁻³ for PM_{2.5}), and then multiplied by 2 (otherwise known as expanded) in order to express as an uncertainty at the 95 % confidence interval.

As the uncertainty (expressed in µg m⁻³) is divided by the LV to express as a percentage, and the LV is lower for PM_{2.5} than it is for PM₁₀, it is more difficult to meet the 25 % Expanded Uncertainty requirement for PM_{2.5} than it is for PM₁₀. As such, a PM₁₀ instrument may have a significantly higher bias at LV than a PM_{2.5} instrument yet have a lower Expanded Uncertainty overall.

5 Summary of Results

The results are summarised in Table 5.1 and shown in more detail in the Figures in the Appendix. Site names and instrument names have been truncated to fit the Table on to a single page and to improve the legibility of the Graphs. The PM_{2.5} Fidas 200 Method 11 data have been corrected by dividing by 1.06 prior to plotting the graph and performing the calculations. Similarly, the PM₁₀ Smart Heated BAM 1020 data have been corrected by dividing by 1.035 prior to plotting the graph and performing the calculations. It is not necessary to correct any of the other instruments.

The parameters described in the above Section are given in the Table and the Graphs. In addition to these, the number of points is given (n) as is the coefficient of determination (R^2) – this is a measure of how straight the line is, with 1 being a perfect straight line. There are no requirements on n or R^2 in EN16450:2017.

Where a slope is not significantly different from 1 or the intercept is not significantly different from 0 based on two standard deviations, then an **NS** (Not Significant) is given in green. Where a slope is significantly different from 1 or the intercept is significantly different from 0 based on 2 standard deviations, then an **S** (Significant) is given in red.

Where an Expanded Uncertainty is below 25 % then **Pass** is given in green. Where an Expanded Uncertainty is above 25 % then **Fail** is given in red.

Many of the slopes and intercepts were statistically significant. Within EN16450:2017 ^[1], when considering the initial equivalence testing of an instrument there are requirements to test whether improvements to the distribution can be made by applying slope and intercept correction. This is why the PM₁₀ Smart Heated BAM 1020 and PM_{2.5} Fidas Method 11 are both slope corrected. However, when undertaking on going equivalence testing, there is no requirement to consider the slope and intercept unless an expanded uncertainty is above 25 %.

All but one of Expanded Uncertainties were below 25 %. For the PM_{2.5} Fidas the Expanded Uncertainty was marginally higher than 25% (at 25.26 %) at Manchester Piccadilly.

Table 5.1: Summary of Results.

Instrument	Site	Figure	Slope, Uncertainty of Slope	Intercept, Uncertainty of Intercept / $\mu\text{g m}^{-3}$	Expanded Uncertainty / %	n	Bias at LV / $\mu\text{g m}^{-3}$	Random Term / $\mu\text{g m}^{-3}$	R ²
PM ₁₀ BAM	Teddington	A.1	1.011 +/- 0.013 NS	1.334 +/- 0.209 S	9.75 Pass	291	1.877	1.554	0.952
PM ₁₀ BAM	Manchester	A.2	0.980 +/- 0.009 S	-0.027 +/- 0.172 NS	6.33 Pass	316	-1.023	1.206	0.976
PM ₁₀ BAM	Marylebone	A.3	0.909 +/- 0.024 S	2.047 +/- 0.476 S	14.34 Pass	245	-2.525	2.545	0.839
PM ₁₀ BAM	Port Talbot	A.4	1.055 +/- 0.011 S	1.620 +/- 0.293 S	20.54 Pass	326	4.358	2.717	0.964
PM _{2.5} BAM	Teddington	A.5	1.026 +/- 0.014 NS	0.272 +/- 0.136 S	10.73 Pass	284	1.049	1.220	0.948
PM _{2.5} BAM	Manchester	A.6	0.980 +/- 0.020 NS	-0.790 +/- 0.250 S	18.31 Pass	322	-1.381	2.374	0.869
PM _{2.5} BAM	Marylebone	A.7	0.913 +/- 0.017 S	1.985 +/- 0.186 S	10.19 Pass	260	-0.632	1.392	0.911
PM ₁₀ Fidas	Teddington	A.8	1.049 +/- 0.012 S	-1.030 +/- 0.194 S	8.27 Pass	347	1.400	1.521	0.956
PM ₁₀ Fidas	Manchester	A.9	0.948 +/- 0.010 S	-0.719 +/- 0.198 S	14.42 Pass	335	-3.330	1.385	0.964
PM ₁₀ Fidas	Marylebone	A.10	1.006 +/- 0.022 NS	-3.288 +/- 0.437 S	15.17 Pass	256	-2.978	2.348	0.884
PM _{2.5} Fidas	Teddington	A.11	1.031 +/- 0.011 S	0.170 +/- 0.110 NS	10.64 Pass	349	1.114	1.144	0.963
PM _{2.5} Fidas	Manchester	A.12	0.886 +/- 0.015 S	0.089 +/- 0.192 NS	25.26 Fail	338	-3.327	1.813	0.903
PM _{2.5} Fidas	Marylebone	A.13	0.975 +/- 0.020 NS	-0.211 +/- 0.215 NS	13.12 Pass	272	-0.975	1.710	0.892

6 Data Capture

2008/50/EC requires that data capture be at least 90 %. The European Commission have subsequently released Guidance ^[12] that allows for 5 % maintenance time and stipulates that data capture should be at least 85 %. While there are data capture criteria for initial equivalence testing, there are no data capture criteria for on-going equivalence tests. There were no significant problems with any of the instruments, and they all had a data capture rate greater than 85 % after accounting for the London Marylebone Digitels being brought online in March 2022 and a leaking roof at London Teddington requiring the BAMs to be temporarily removed from site.

□ _____
[12] *Guidance on the Commission Implementing Decision laying down rules for Directives 2004/107/EC and 2008/50/EC of the European Parliament and of the Council as regards the reciprocal exchange of information and reporting on ambient air (Decision 2011/850/EU). European Commission. DG ENV 2013.*

7 Conclusions

For 2022 all but one of the datasets passed the Expanded Uncertainty requirement by being below 25 %. For the PM_{2.5} Fidas the Expanded Uncertainty was marginally higher than 25% Manchester Piccadilly.

There were no significant issues noted with the specific instruments deployed in this study during 2022.

Appendix of Figures

Figure A.1: Equivalence calculations for the PM₁₀ Smart Heated BAM1020 at London Teddington.

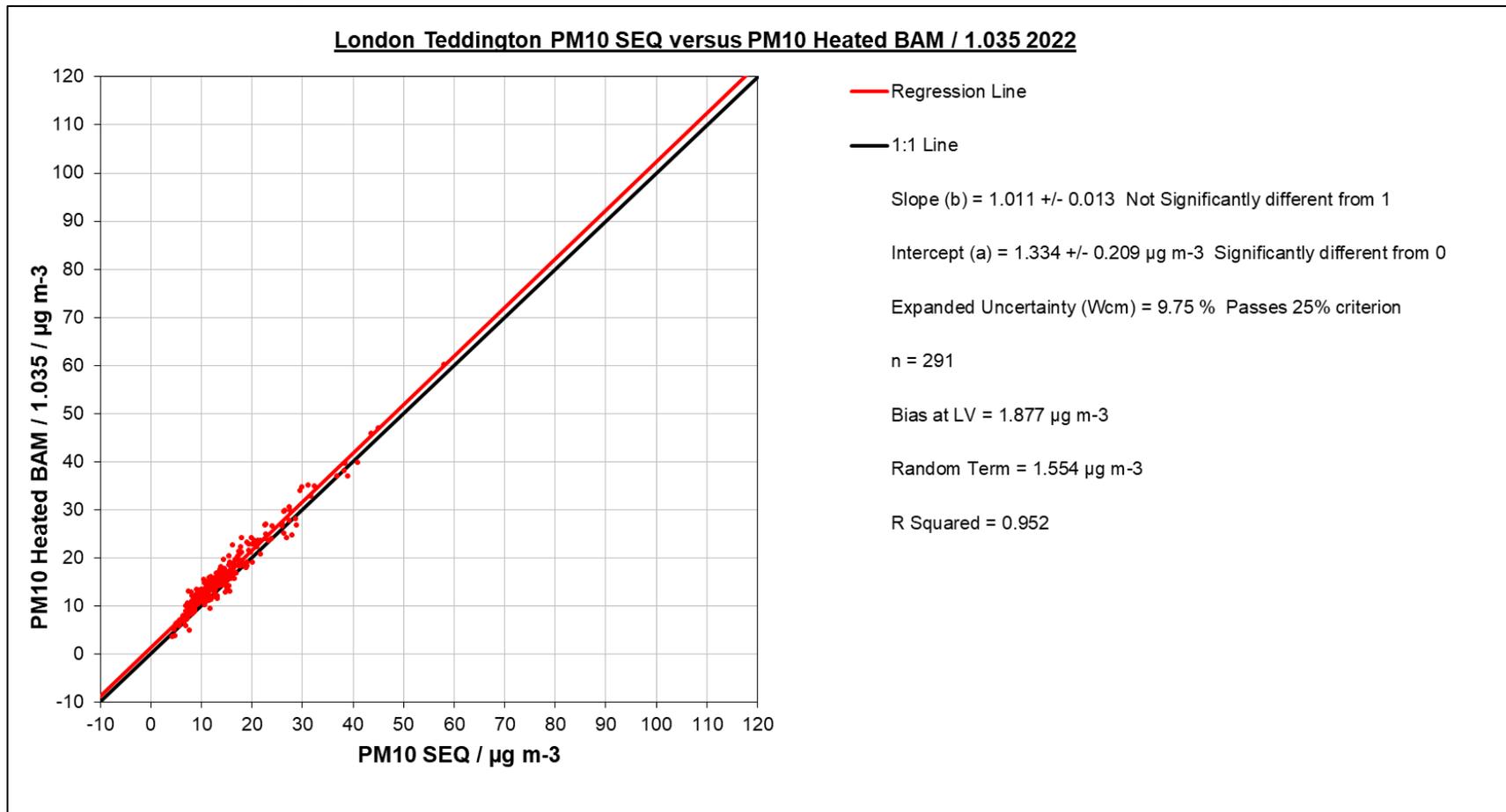


Figure A.2: Equivalence calculations for the PM₁₀ Smart Heated BAM1020 at Manchester Piccadilly.

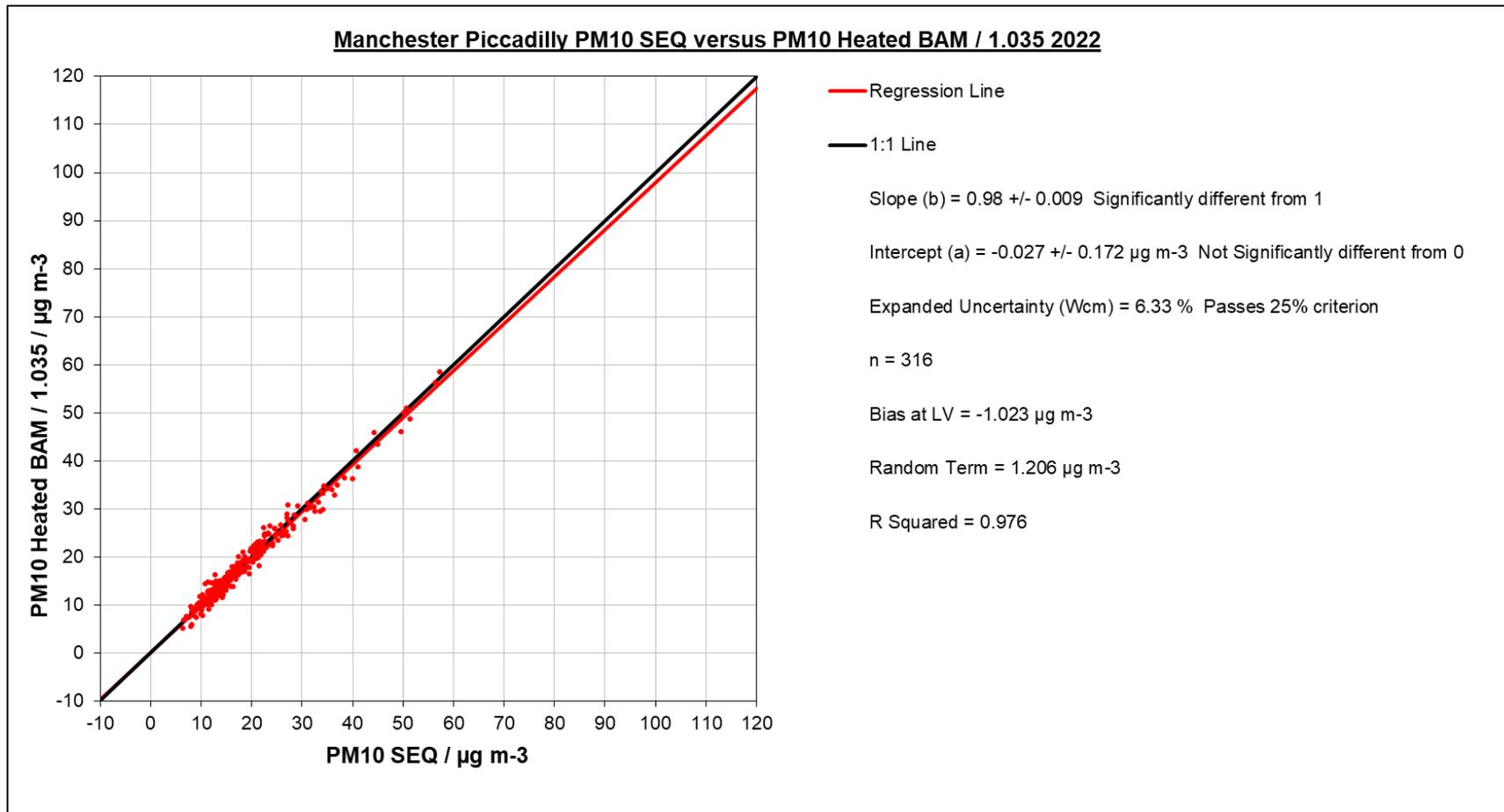


Figure A.3: Equivalence calculations for the PM₁₀ Smart Heated BAM1020 at London Marylebone Road.

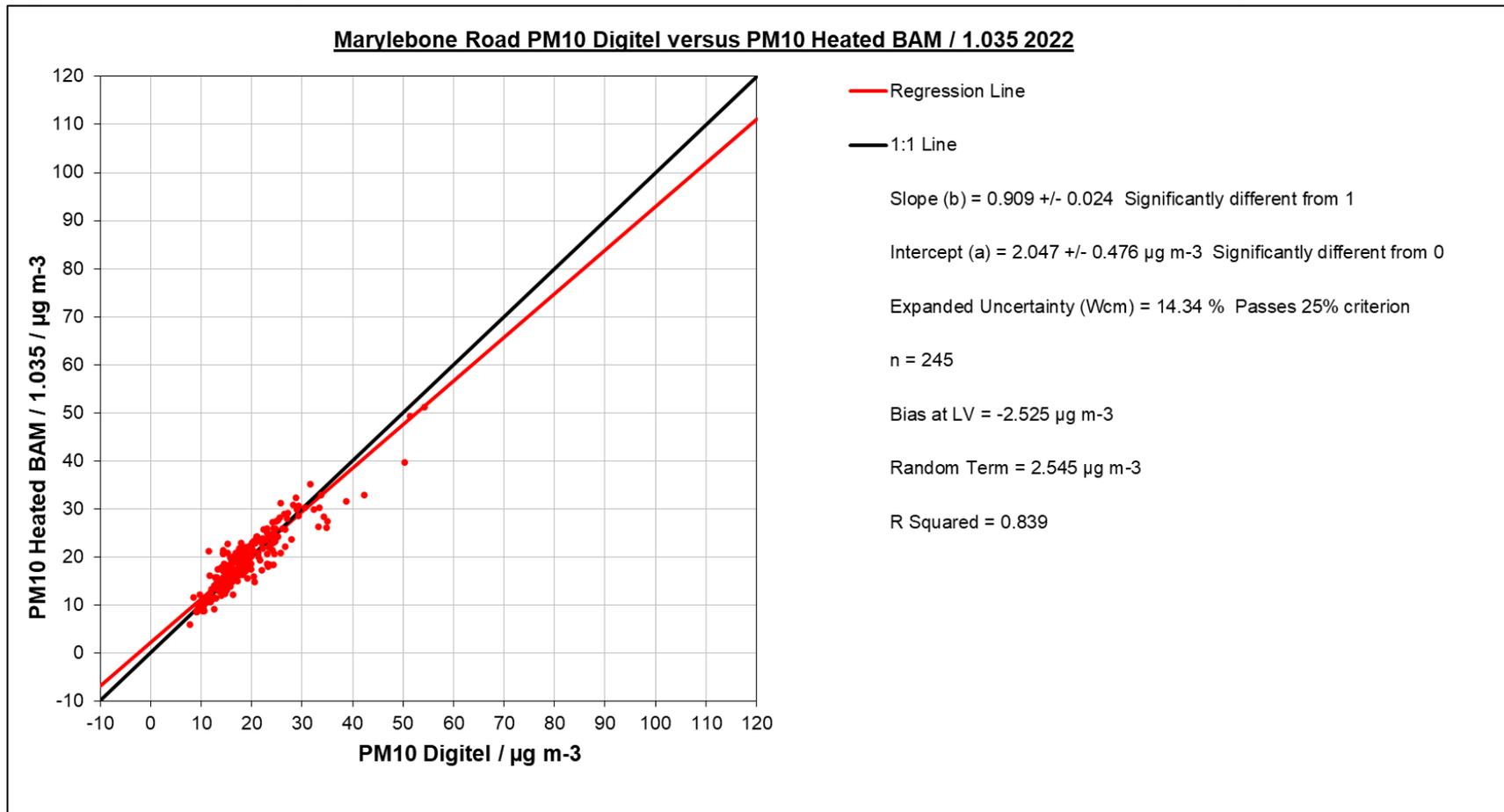


Figure A.4: Equivalence calculations for the PM₁₀ Smart Heated BAM1020 at Port Talbot Margam.

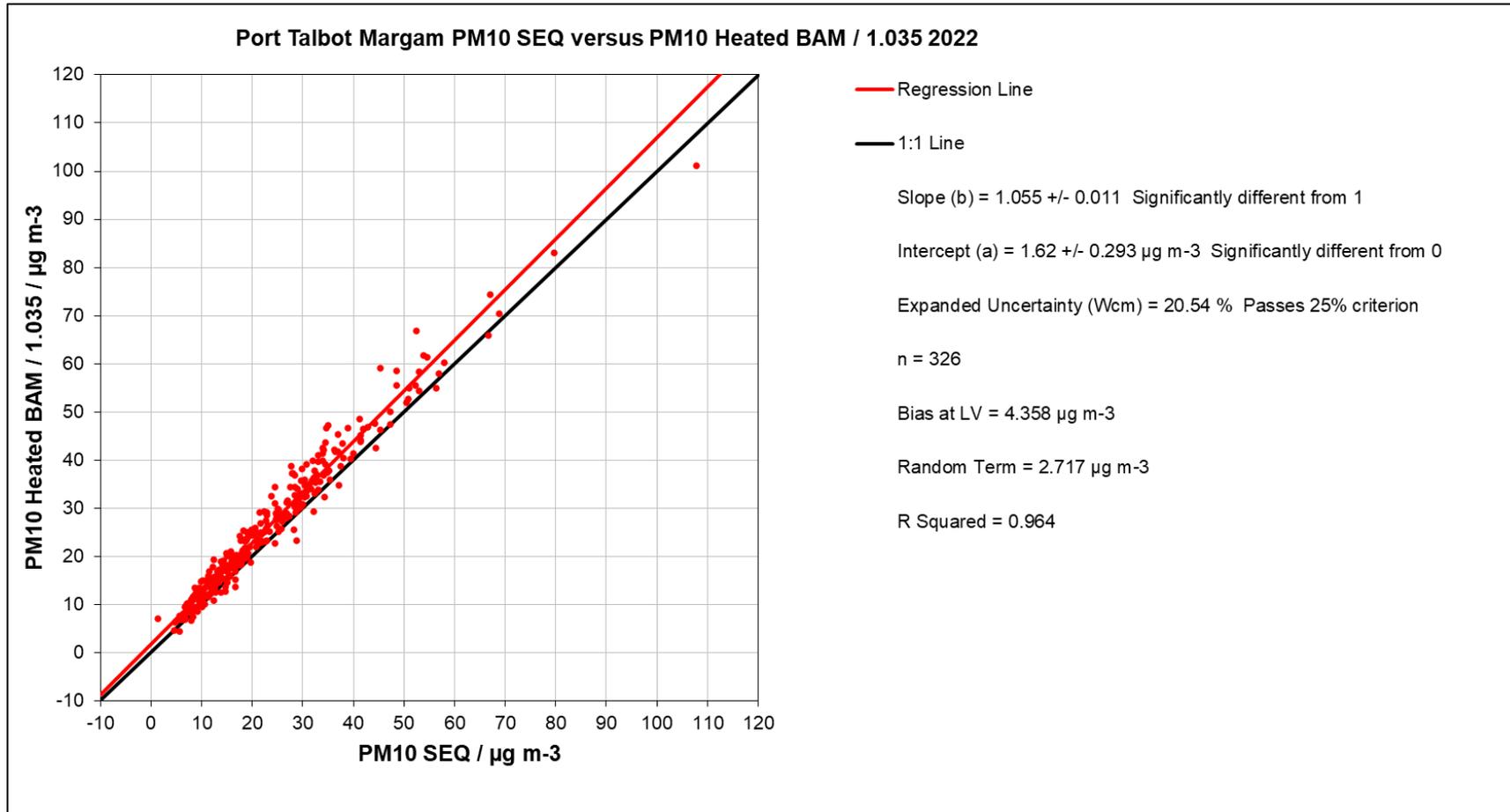


Figure A.5: Equivalence calculations for the PM_{2.5} Smart Heated BAM1020 at London Teddington.

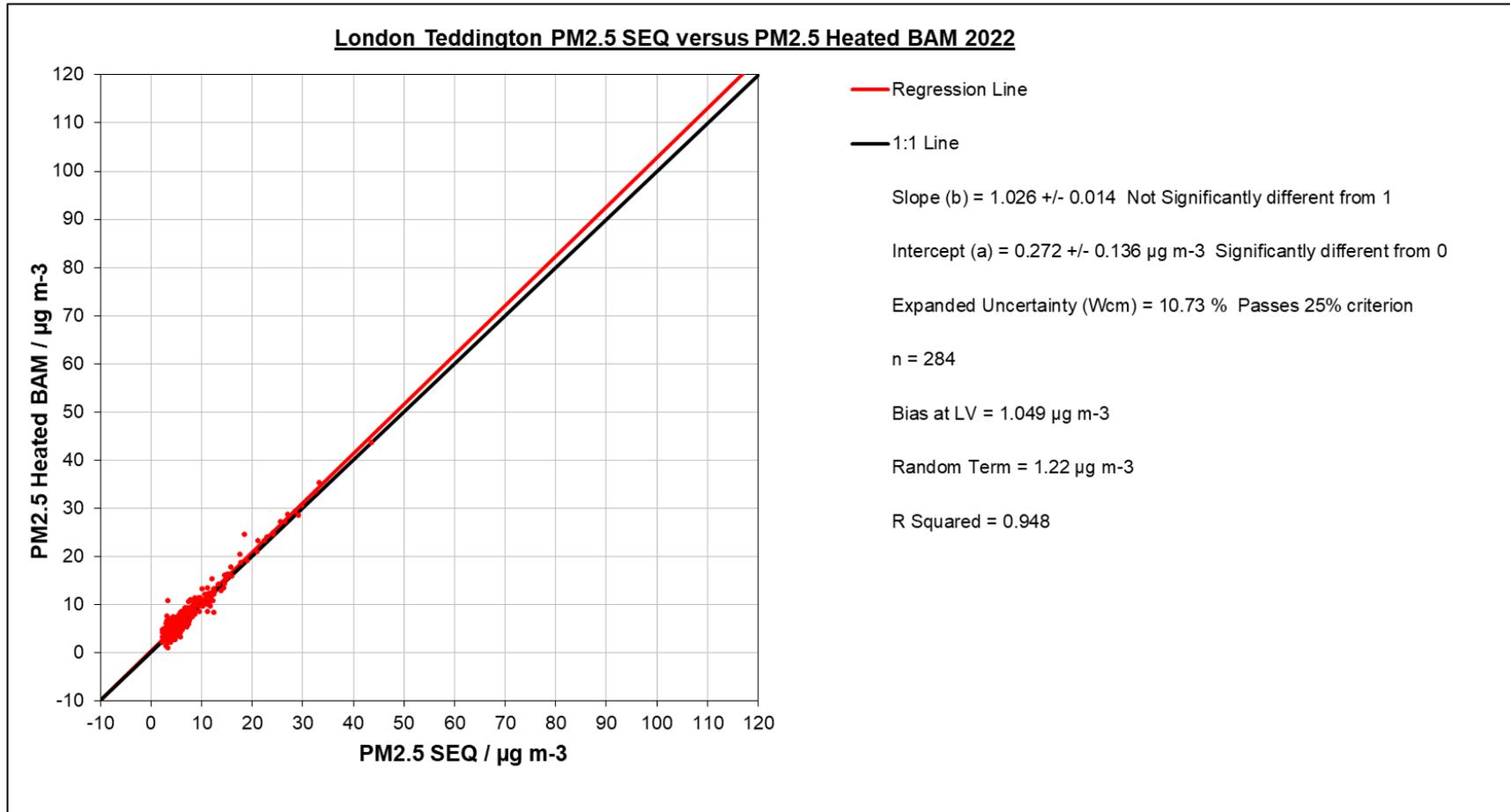


Figure A.6: Equivalence calculations for the PM_{2.5} Smart Heated BAM1020 at Manchester Piccadilly.

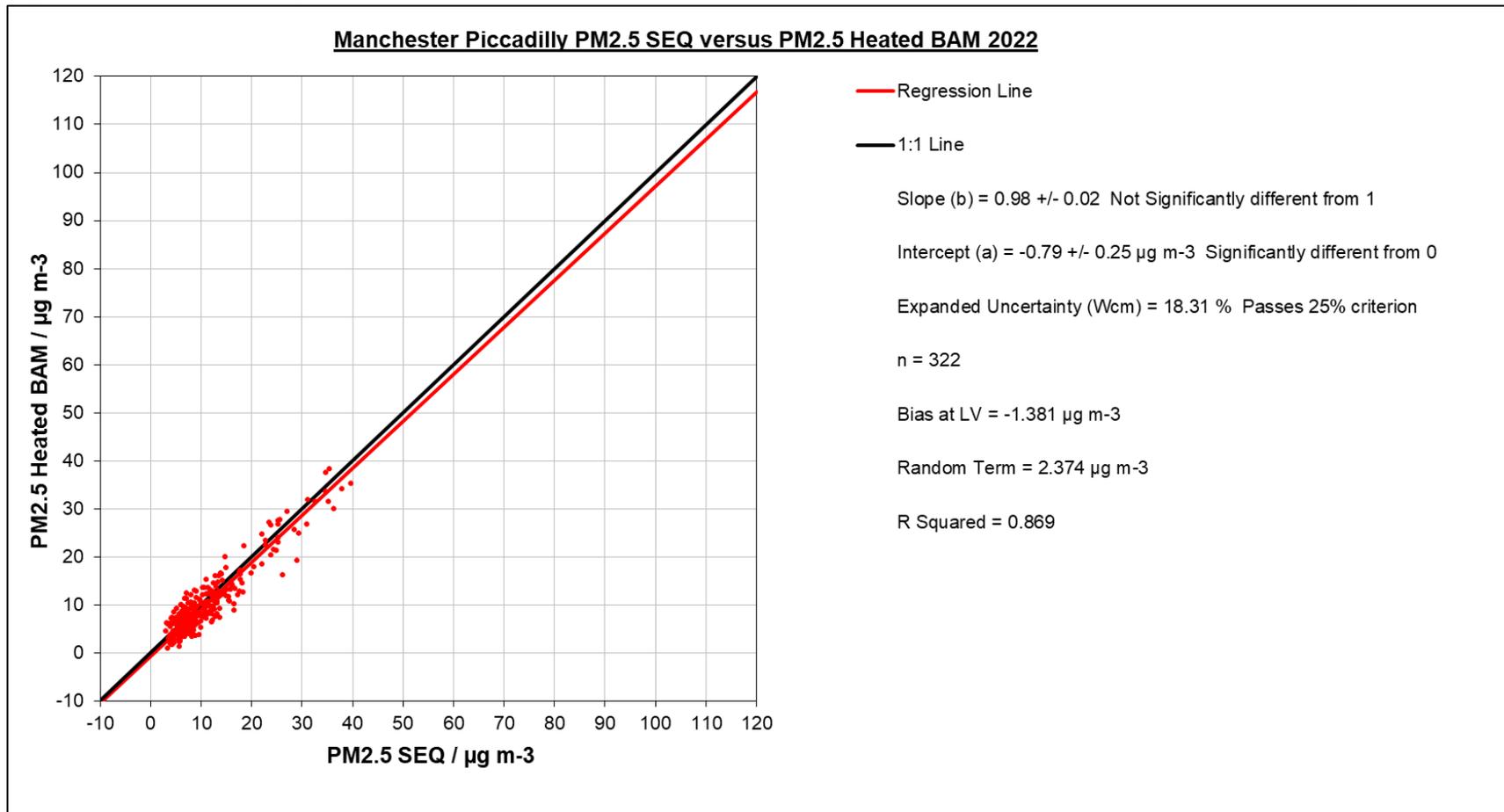


Figure A.7: Equivalence calculations for the PM_{2.5} Smart Heated BAM1020 at London Marylebone Road.

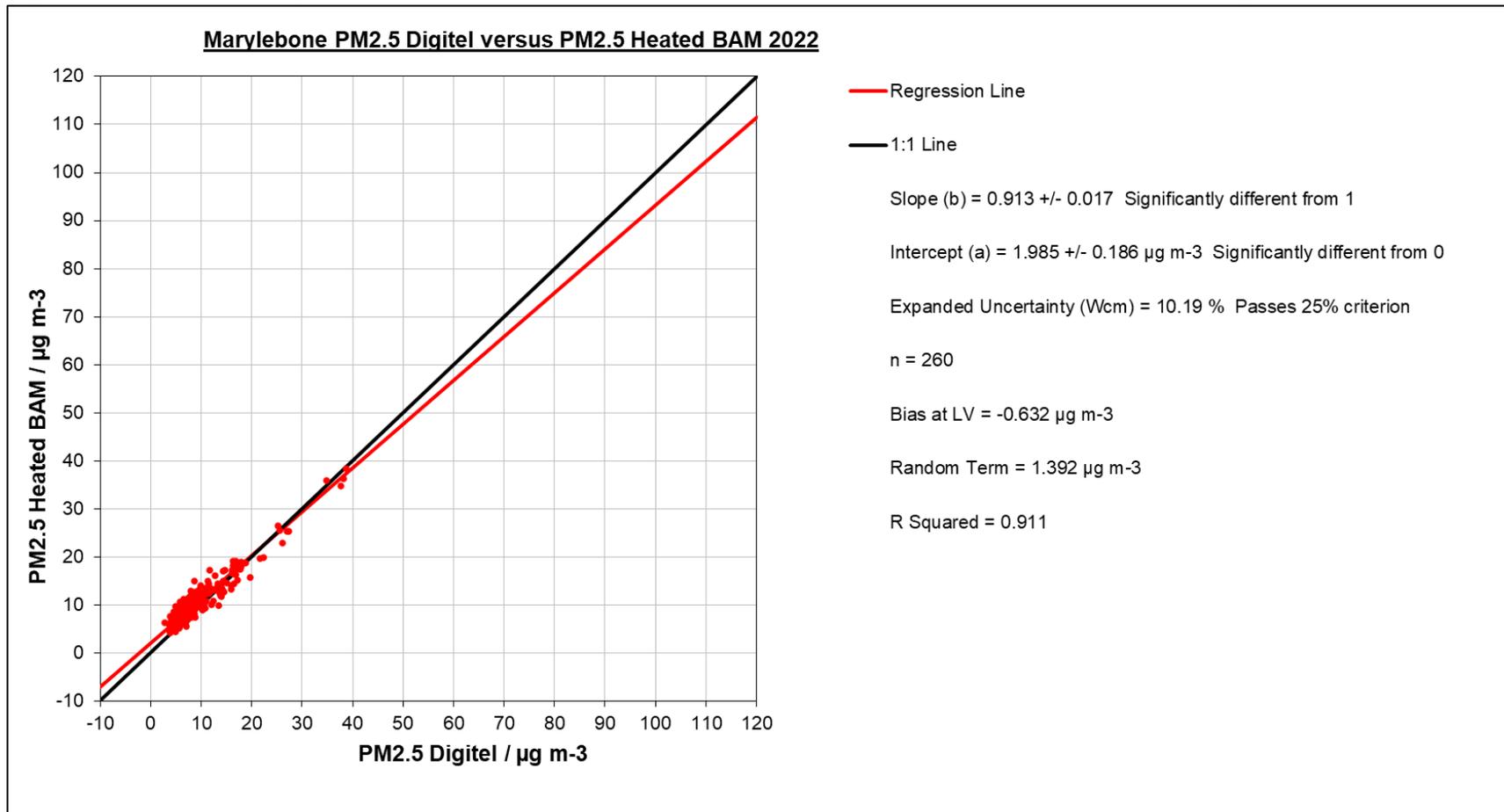


Figure A.8: Equivalence calculations for the PM₁₀ Fidas 200 Method 11 at London Teddington.

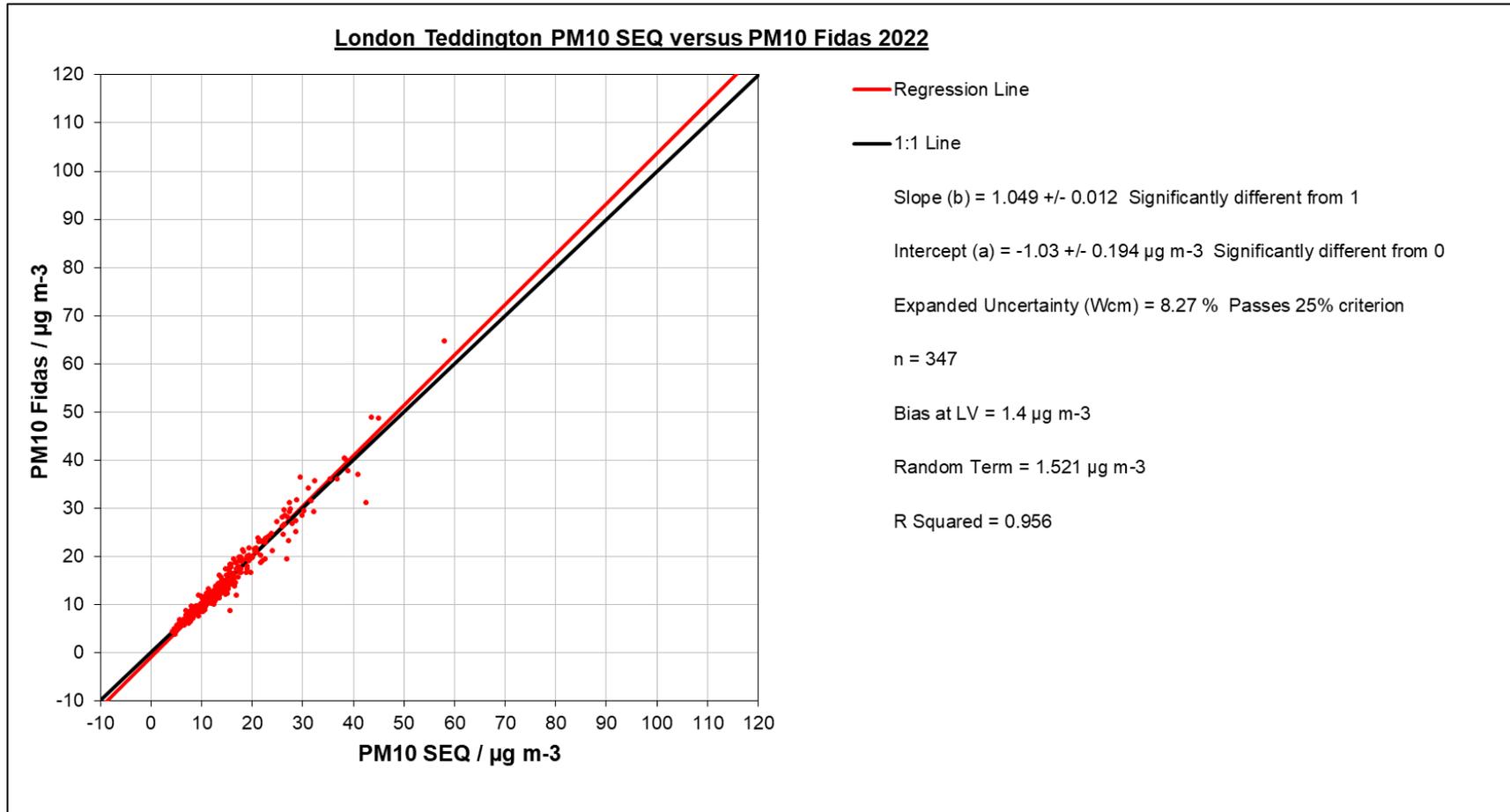


Figure A.9: Equivalence calculations for the PM₁₀ Fidas 200 Method 11 at Manchester Piccadilly.

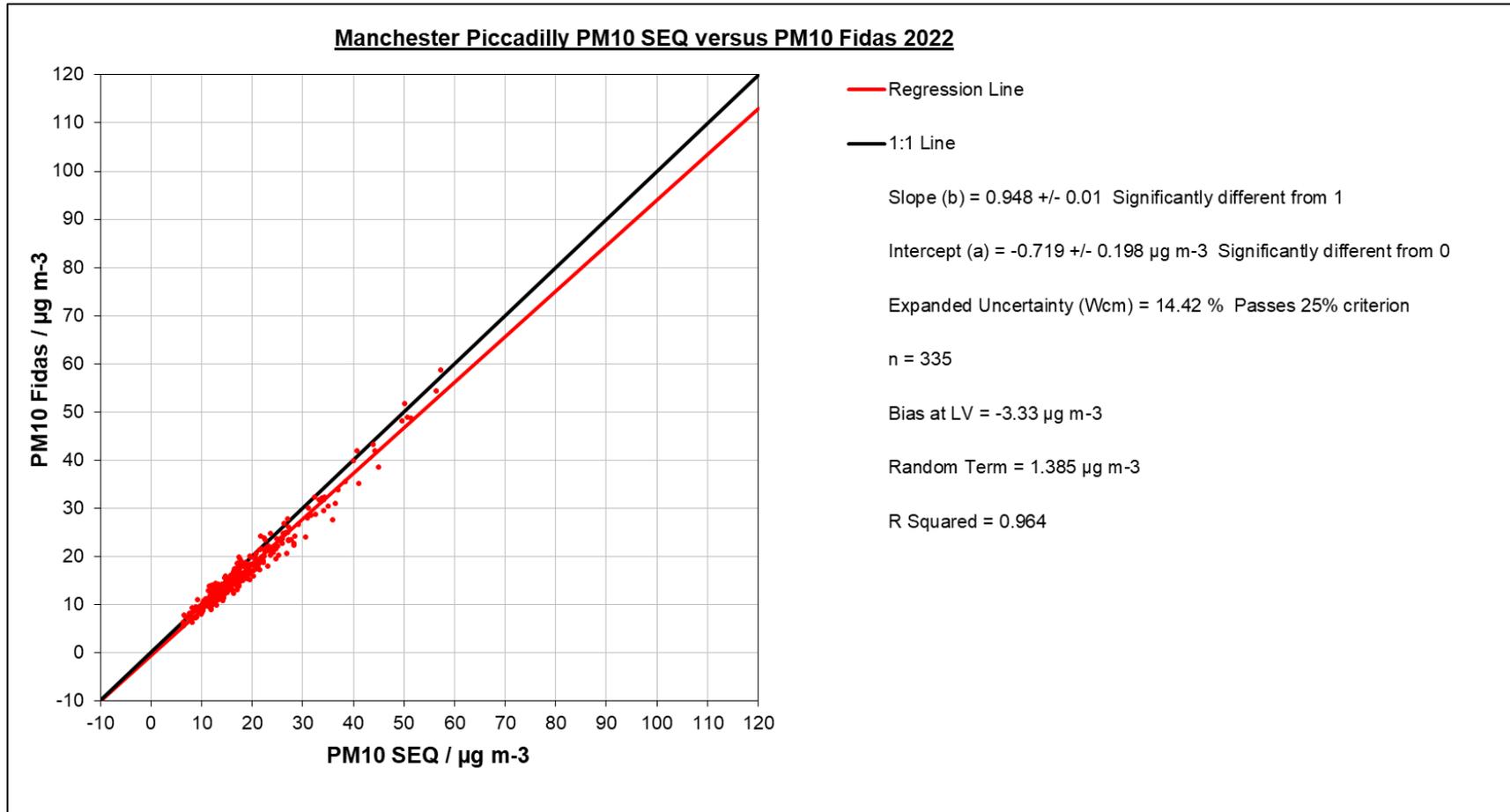


Figure A.10: Equivalence calculations for the PM₁₀ Fidas 200 Method 11 at London Marylebone Road.

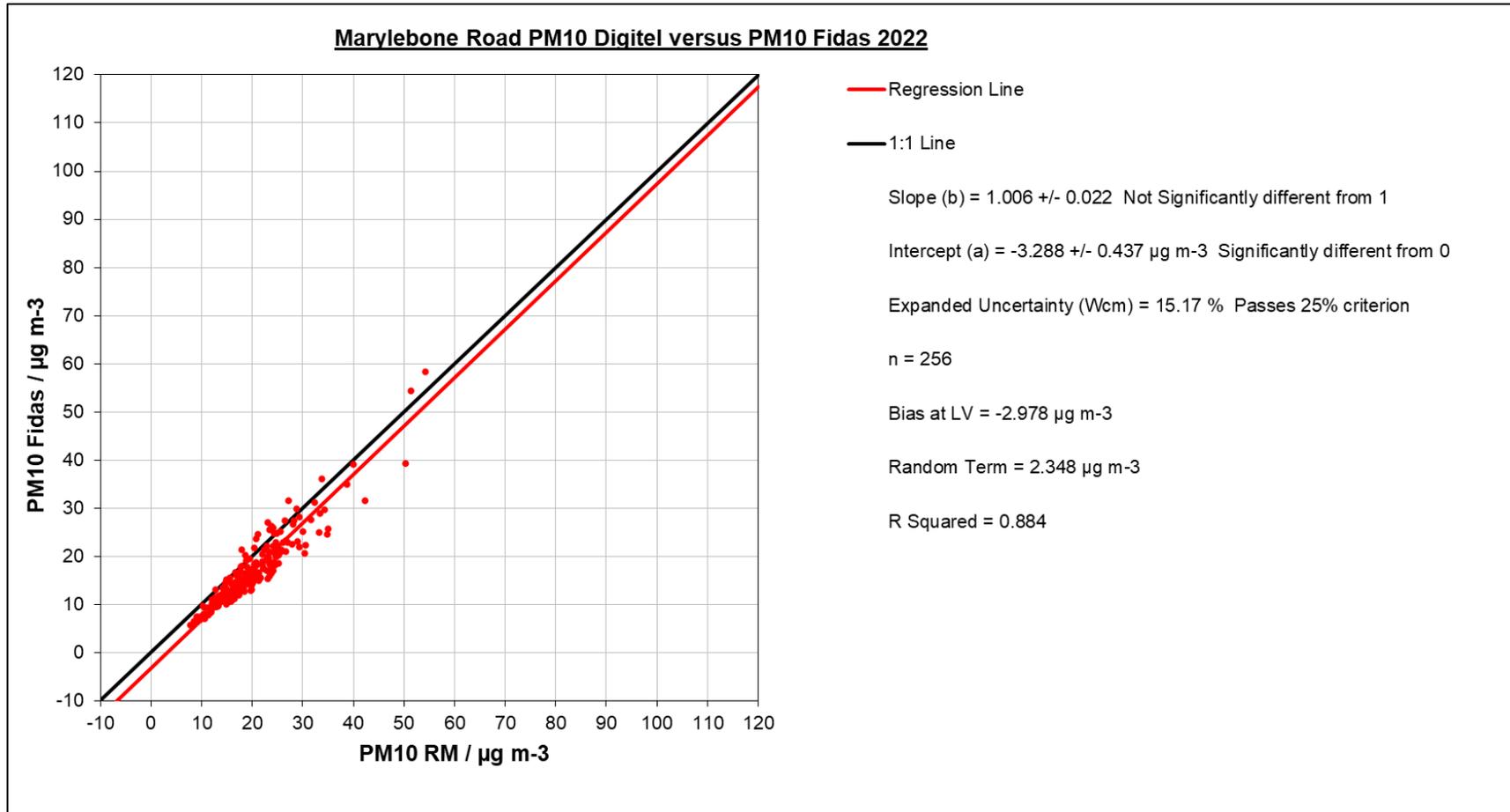


Figure A.11: Equivalence calculations for the PM_{2.5} Fidas 200 Method 11 at London Teddington.

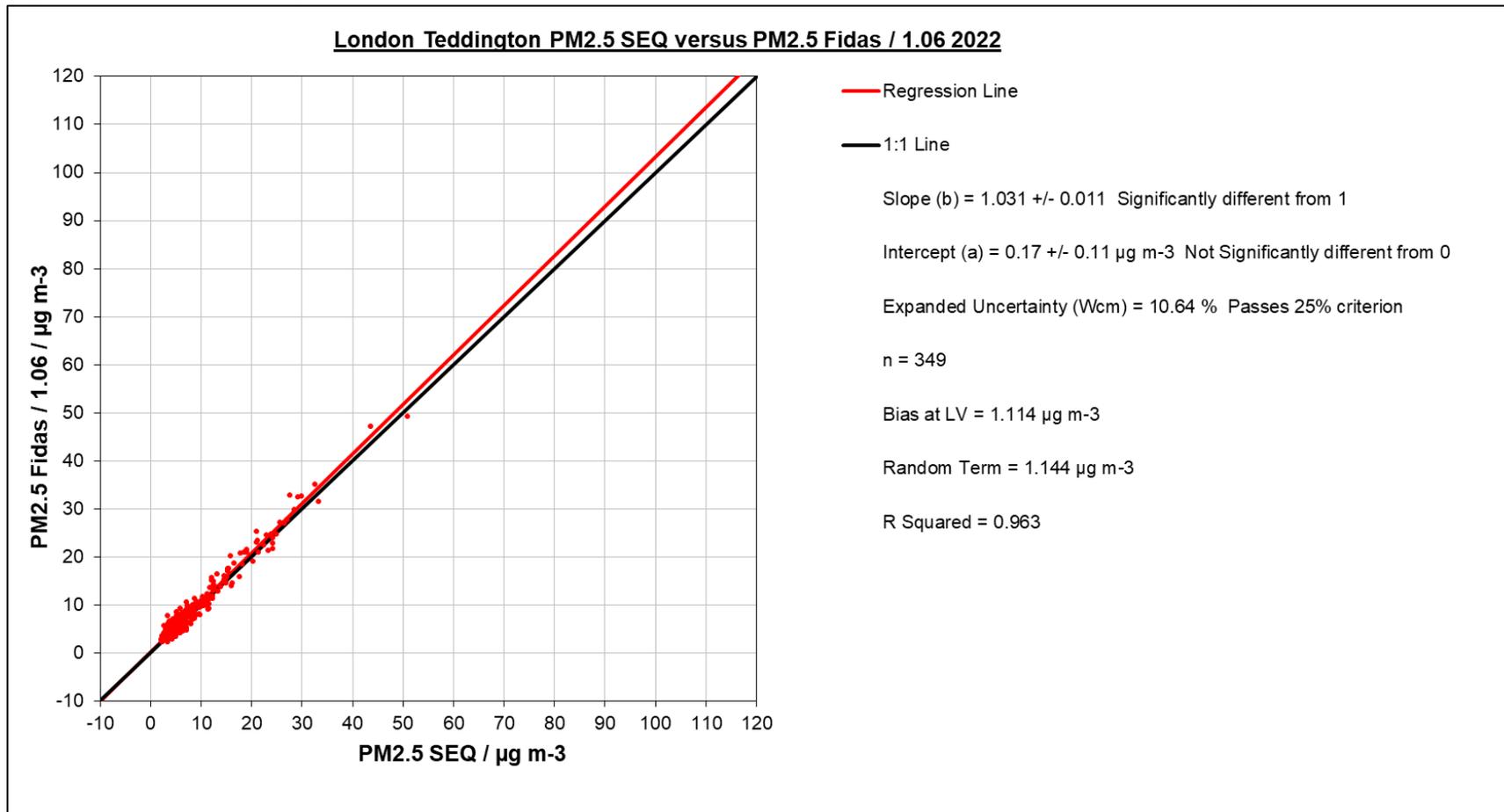


Figure A.12: Equivalence calculations for the PM_{2.5} Fidas 200 Method 11 at Manchester Piccadilly.

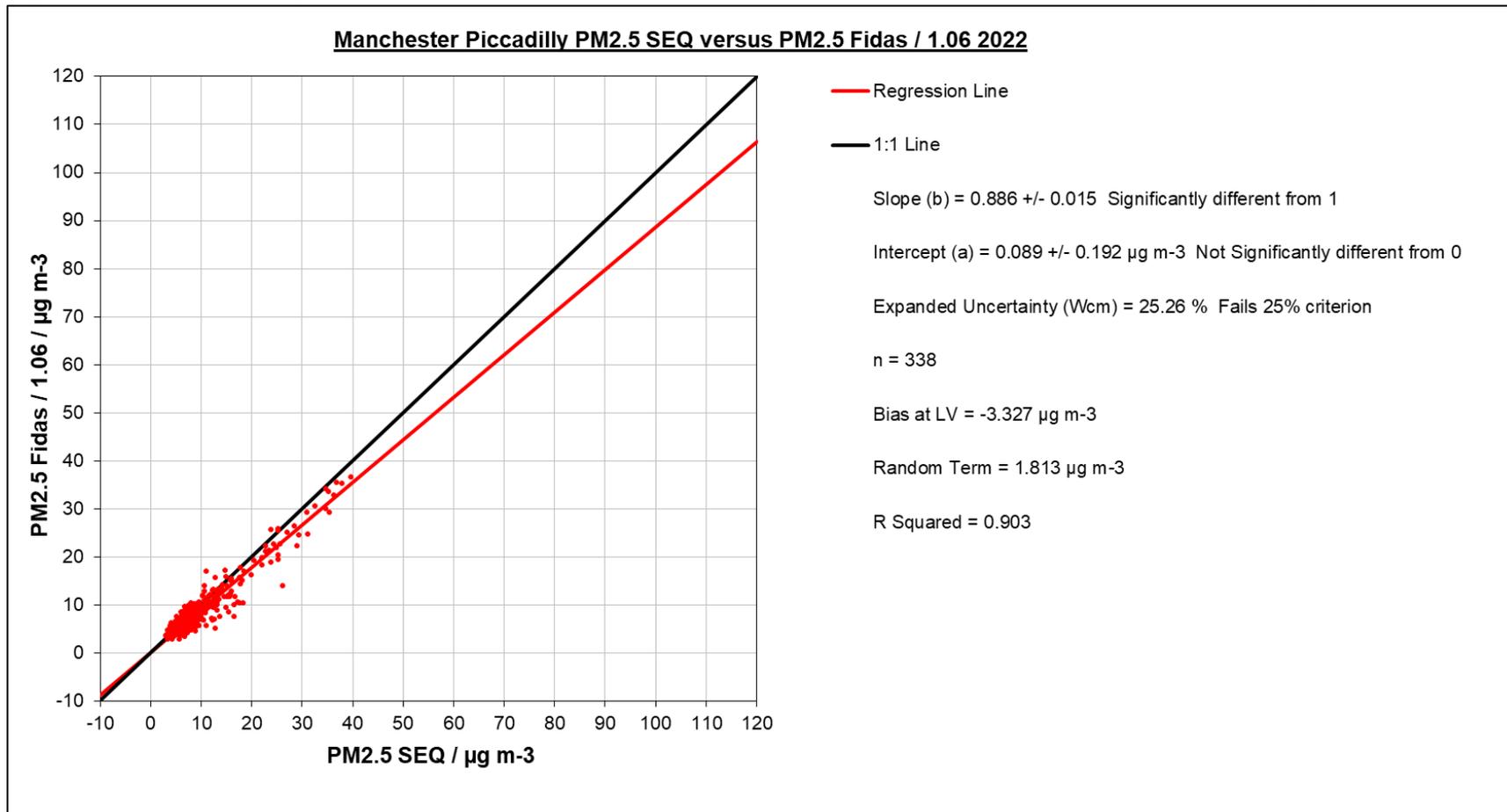


Figure A.13: Equivalence calculations for the PM_{2.5} Fidas 200 Method 11 at London Marylebone Road.

