The Environment Agency

2021 UK Report for On-going Particulate Matter (PM_{10} 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: PM_{10} (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 PM_{10} 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. In order to allow the public access to real time high frequency data, the UK uses equivalent instruments that automatically produce hourly data.

During 2021, concentrations of PM_{10} and $PM_{2.5}$ were almost exclusively measured using Smart Heated BAM 1020s (an instrument that can measure either PM_{10} or $PM_{2.5}$) or the Fidas 200 Method 11 (a single instrument that can measure both PM_{10} and $PM_{2.5}$ at the same time). At the beginning of the year there were four each of PM_{10} and $PM_{2.5}$ FDMS 8500s (an instrument that can measure either PM_{10} or $PM_{2.5}$), though these were all replaced by the end of 2021 as they had reached the end of their operational life and were no longer supported by the manufacturer.

Testing and approval of these instruments as being equivalent to the Reference Methods was undertaken a number of 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 2021 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 2021 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

[1] CEN Standard EN16450:2017 Ambient air - Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2,5}$)

requirement is that the Expanded Uncertainty (as calculated using the equations in EN16450:2017) is less than 25 %. For PM_{10} the calculations are made at a daily limit value of 50 µg m^{-3}. For $PM_{2.5}$ the calculations are made at a pseudo daily limit value of 30 µg m^{-3}.

During 2021, three 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;
- 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 2021 is as follows.

Instrument	Site	Expanded Uncertainty / %	Pass/Fail
PM_{10} Smart Heated BAM 1020	London Teddington	24.94	Pass
PM_{10} Smart Heated BAM 1020	Manchester Piccadilly	8.68	Pass
PM_{10} Smart Heated BAM 1020	Port Talbot Margam	14.96	Pass
$PM_{2.5}$ Smart Heated BAM 1020	London Teddington	14.20	Pass
$PM_{2.5}$ Smart Heated BAM 1020	Manchester Piccadilly	17.14	Pass
PM_{10} Fidas 200 Method 11	London Teddington	8.20	Pass
PM_{10} Fidas 200 Method 11	Manchester Piccadilly	20.94	Pass
$PM_{2.5}$ Fidas 200 Method 11	London Teddington	12.26	Pass
$PM_{2.5}$ Fidas 200 Method 11	Manchester Piccadilly	20.62	Pass
PM_{10} FDMS 8500	London Teddington	20.92	Pass
$PM_{2.5}$ FDMS 8500	London Teddington	27.79	Fail

For 2021 all but one of the instruments passed the expanded uncertainty requirement by being below 25%. The $PM_{2.5}$ FDMS 8500 did not pass the expanded uncertainty requirement as it was shown to overestimate concentrations. Whilst there were four $PM_{2.5}$ FDMS 8500s in the network at the start of 2021, these had been replaced by the end of 2021, and as such this has little impact upon the validity of data in 2021.

There were no significant issues noted with the instruments.

Overall, these results justify the use of the instruments in the UK Network.

For 2022, the following enhancements are being introduced to the equivalence programme:

- The introduction of London Marylebone Road – An urban traffic site on a very busy road in the centre of London. This will provide data relating to traffic sourced particulate pollution;
- Operation of the reference methods every day of the year at London Teddington and Manchester Piccadilly (as opposed to between 150 and 180 days per year in 2021). This will allow us to better understand the behaviour of the instruments throughout the entire year.

1 Introduction to the Legislation

The European Ambient Air Quality Directive2008/50/EC [2] was promulgated into UK law in 2010. Whilst the UK has now left the European Union, in 2021 it still followed the requirements set out in 2008/50/EC.

The Directive sets out concentration limits and data quality objectives for different pollutants. For Particulate Matter (PM), two size fractions are measured – PM_{10} (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 Directive sets out that instruments used for particulate matter monitoring should have a measurement uncertainty below 25 %.

For PM_{10} and $PM_{2.5}$ the Directive 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 the Directive. 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.

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[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 PM_{10} 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. A number of 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.

Air is drawn at a rate of 2.3 $m^3\ hr^{-1}$ 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 $PM_{2.5}$). 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 a number of 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 ºC. 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 in order 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 $m^3\ hr^{-1}$ 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 PM_{10} 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 PM_{10} 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 PM_{10} 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. In order to be equivalent, the $PM_{2.5}$ data do not need to be corrected. The PM_{10} 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 in order to be equivalent, the PM_{10} 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 m^3 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 PM_{10} and $PM_{2.5}$ based upon the numbers of particle in each bin combined with a pre-determined particle size density distribution.

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[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 PM_{10} 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, in order to be equivalent, the PM_{10} data did not need correcting, but the $PM_{2.5}$ data needs to be corrected by dividing by 1.06.

2.4 Thermo FDMS 8500

The 8500 series FDMS (Filter Dynamic Measurement System) instruments were manufactured by Thermo based in Franklin, Massachusetts, USA. They are no longer manufactured. The system uses the principal of frequency of oscillation of a filter in order to calculate small changes in mass.

The instruments operate at 1 m^3 hr^{-1} and the PM_{10} and $PM_{2.5}$ variants differ only in the use of a $PM_{2.5}$ cyclone below the PM_{10} inlet. In the FDMS 8500, excess water is removed from the sample stream by passing it through a membrane drier made of Nafion.

A proportion of the air flow is passed through the oscillating filter whereas the rest is vented. The system alternates every 6 minutes between passing the air stream directly through the oscillating filter (during which time the mass on the oscillating filter increases) and passing the air first through a chilled filter to remove particles (during which time the mass on the oscillating filter may decrease due to volatilisation of particulate matter). The system calculates the mass concentration and additionally reports non-volatile and volatile mass concentration fractions.

The initial equivalence certification of the FDMS 8500 instruments is provided in the following reference [7]. There were eight field tests all of which were in the UK. There were no laboratory tests as the instruments were approved before the laboratory tests were formulated. It was shown that no correction was necessary for either PM_{10} or $PM_{2.5}$.

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[6] UK Report on the Equivalence of the Palas Fidas 200 Method 11 for PM_{10} and $PM_{2.5}$. http://www.csagroupuk.org/wp-content/uploads/2016/04/Palas-UK-Report-Final-with-Manuals-080316.pdf
[7] Assessment of UK AURN Particulate Matter Monitoring Equipment against the January 2010 guide to demonstration of equivalence
http://uk-air.defra.gov.uk/assets/documents/reports/cat14/1101140842_Assessment_of_UK_AURN_PM_Equipment_against_2010_GDE.pdf

3 The Monitoring Sites

During 2021, three 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 [8]. The instruments deployed were a PM_{10} SEQ Reference Method, a $PM_{2.5}$ SEQ Reference Method, a PM_{10} Smart Heated BAM 1020, a $PM_{2.5}$ Smart Heated BAM 1020, a PM_{10} FDMS 8500, a $PM_{2.5}$ FDMS 8500, and a Fidas 200 Method 11. Data from the Fidas 200 Method 11 are available from UK Air [9]. The reference methods were operated for around 150 days in 2021. For 2022, they are being run every day. This will allow us to better understand the behaviour of the instruments throughout the entire year.

3.2 Manchester Piccadilly

Manchester Piccadilly is an urban background site in a large pedestrianised square in the centre of Manchester [10]. The instruments deployed were a PM_{10} SEQ Reference Method, a SEQ $PM_{2.5}$ Reference Method, a PM_{10} 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 [9]. The reference methods were operated for around 180 days in 2022. For 2022, they are being run every day. This will allow us to better understand the behaviour of the instruments throughout the entire year.

3.3 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 PM_{10} SEQ Reference Method, and a PM_{10} Smart Heated BAM 1020. Data from both instruments are available from UK Air [9]. The Reference Method is operated every day of the year.

3.4 Future Developments

Recognising the need for measurements in urban traffic locations, during 2022, a fourth site has been added at London Marylebone Road [12] which is a busy roadside site in the centre of London.

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

[9] https://uk-air.defra.gov.uk/data/

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

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

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

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 PM_{10} 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 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 PM_{10} 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 PM_{10}, it is more difficult to meet the 25 % Expanded Uncertainty requirement for $PM_{2.5}$ than it is for PM_{10}. As such, a PM_{10} 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 in order 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 diving by 1.06 prior to plotting the graph and performing the calculations. Similarly, the PM_{10} 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 PM_{10} 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 was below 25 %. The one instrument where the Expanded Uncertainty was high is the $PM_{2.5}$ FDMS 8500. This was due to the slope and intercept both being high leading to an over estimation of concentrations, combined with it being harder to meet the 25 % Expanded Uncertainty at the lower Limit Value used for the assessment of $PM_{2.5}$. Whilst there were four $PM_{2.5}$ FDMS 8500s in the network at the start of 2021, these had been replaced by the end of 2021, and as such this has little impact upon the validity of data in 2021.

Overall, these results justify the use of the instruments in the UK Network.

Table 5.1: Summary of Results.

Instrument	Site	Figure	Slope, Uncertainty of Slope	Intercept, Uncertainty of Intercept / µg m^{-3}	Expanded Uncertainty / %	n	Bias at LV / µg m^{-3}	Random Term / µg m^{-3}	R^2
PM_{10} BAM	Teddington	A.1	1.089 +/- 0.019 S	1.625 +/- 0.255 S	24.94 Pass	146	6.098	1.304	0.957
PM_{10} BAM	Manchester	A.2	0.940 +/- 0.013 S	1.288 +/- 0.241 S	8.68 Pass	172	-1.700	1.348	0.967
PM_{10} BAM	Port Talbot	A.3	1.000 +/- 0.010 NS	2.193 +/- 0.282 S	14.96 Pass	326	2.183	3.037	0.970
$PM_{2.5}$ BAM	Teddington	A.4	1.033 +/- 0.021 NS	0.825 +/- 0.190 S	14.20 Pass	143	1.820	1.106	0.943
$PM_{2.5}$ BAM	Manchester	A.5	0.955 +/- 0.020 S	-0.769 +/- 0.231 S	17.14 Pass	158	-2.129	1.443	0.935
PM_{10} Fidas	Teddington	A.6	1.048 +/- 0.018 S	-0.718 +/- 0.251 S	8.20 Pass	147	1.664	1.198	0.955
PM_{10} Fidas	Manchester	A.7	0.880 +/- 0.017 S	1.040 +/- 0.299 S	20.94 Pass	182	-4.956	1.688	0.937
$PM_{2.5}$ Fidas	Teddington	A.8	1.042 +/- 0.020 S	0.235 +/- 0.179 NS	12.26 Pass	147	1.505	1.057	0.948
$PM_{2.5}$ Fidas	Manchester	A.9	0.877 +/- 0.018 S	0.927 +/- 0.212 S	20.62 Pass	174	-2.754	1.407	0.927
PM_{10} FDMS	Teddington	A.10	1.107 +/- 0.037 S	-0.864 +/- 0.513 NS	20.92 Pass	140	4.470	2.714	0.841
$PM_{2.5}$ FDMS	Teddington	A.11	1.093 +/- 0.023 S	1.168 +/- 0.211 S	27.79 Fail	143	3.965	1.284	0.936

6 Data Capture

The Directive requires that data capture be at least 90 %. The European Commission have subsequently released Guidance [13] 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 %.

[13] 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 2021 all but one of the instruments passed the expanded uncertainty requirement by being below 25 %. The $PM_{2.5}$ FDMS 8500 did not pass the expanded uncertainty requirement at Teddington as it was shown to marginally overestimate concentrations. Whilst there were a four $PM_{2.5}$ FDMS 8500s in the network at the start of 2021, these had been replaced by the end of 2021, and as such this has little impact upon the validity of data in 2021.

There were no significant issues noted with the instruments.

Overall, these results justify the use of the instruments in the UK Network.

For 2022, the following enhancements are being introduced:

- The introduction of London Marylebone Road – An urban traffic site on a very busy road in the centre of London. This will provide data relating to traffic sourced particulate pollution;
- Operation of the reference methods every day of the year at London Teddington and Manchester Piccadilly (as opposed to between 150 and 180 days per year in 2021). This will allow us to better understand the behaviour of the instruments throughout the entire year.

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Appendix of Figures

Figure A.1: *Equivalence calculations for the PM_{10} Smart Heated BAM1020 at London Teddington.*

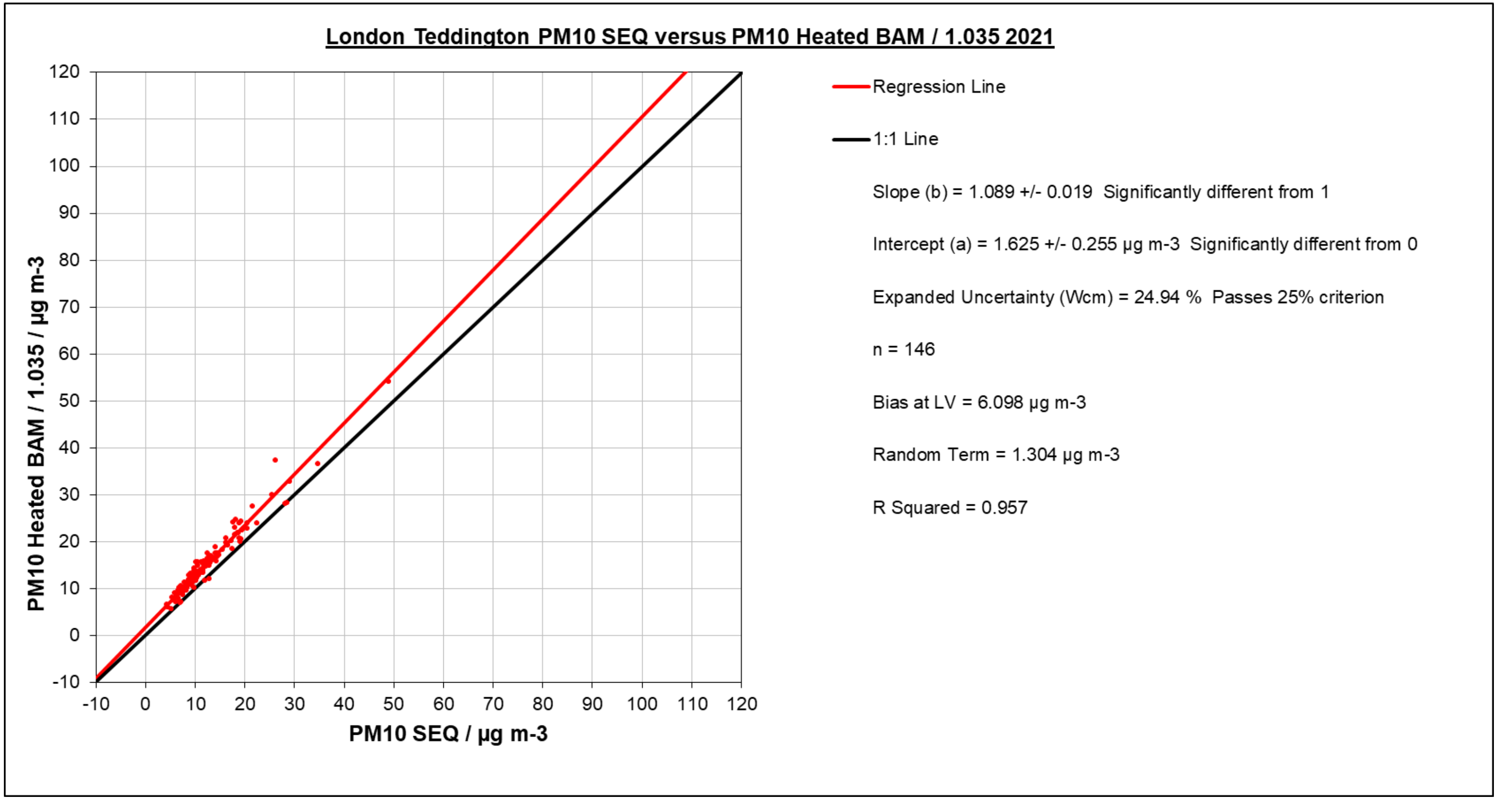

Figure A.2: *Equivalence calculations for the PM_{10} Smart Heated BAM1020 at Manchester Piccadilly.*

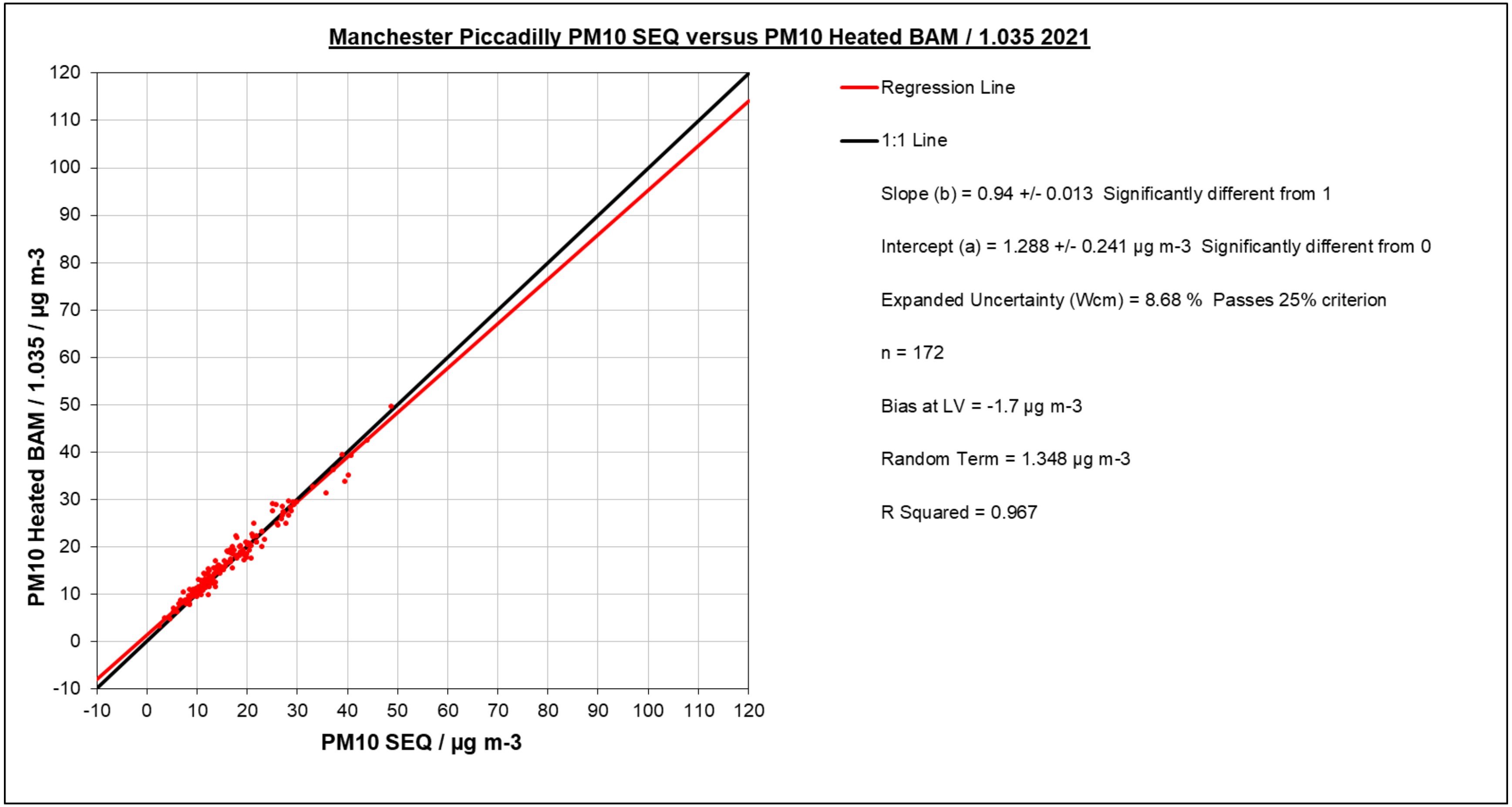

Figure A.3: *Equivalence calculations for the PM_{10} Smart Heated BAM1020 at Port Talbot Margam.*

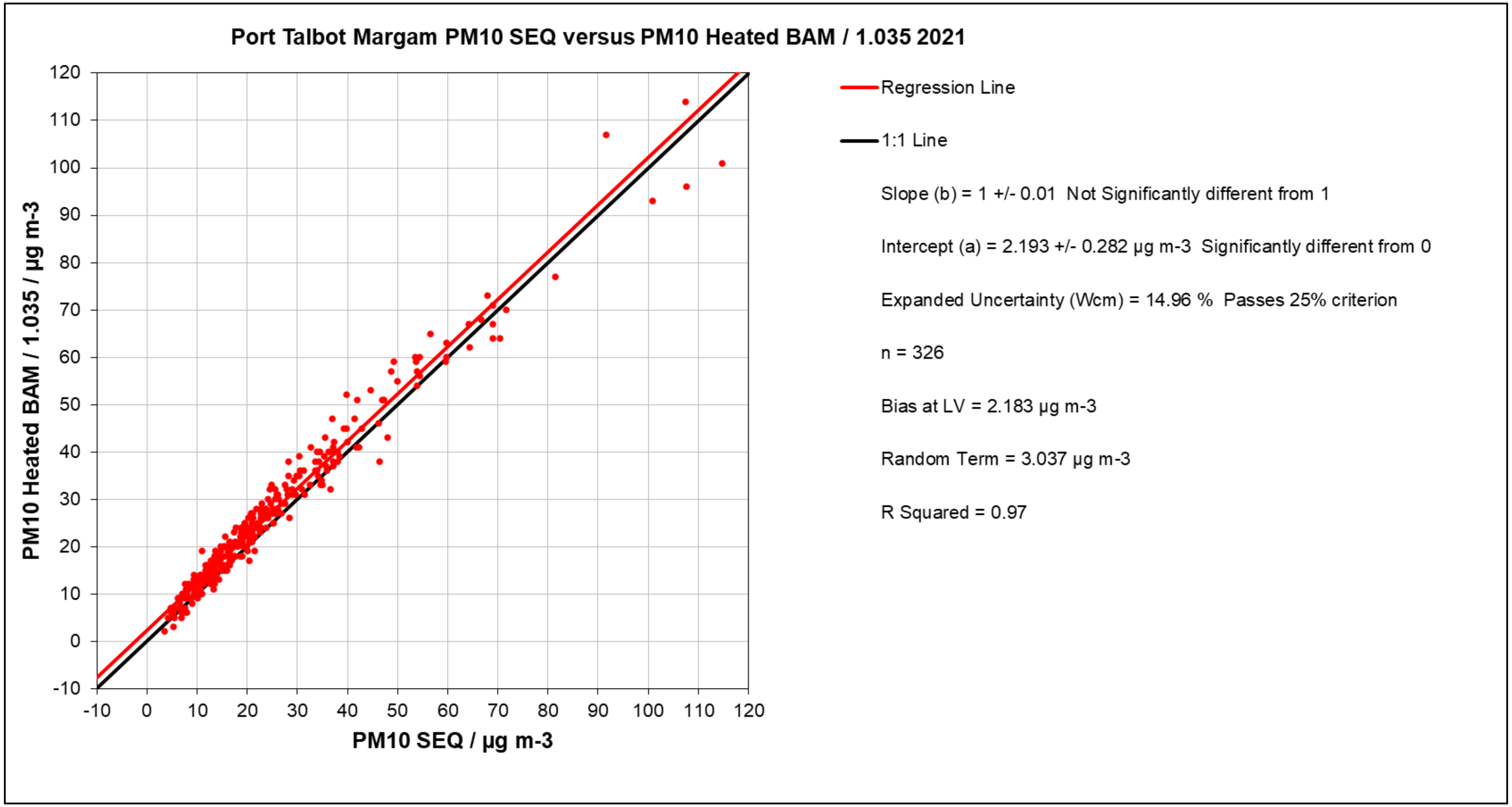

Figure A.4: Equivalence calculations for the $PM_{2.5}$ Smart Heated BAM1020 at London Teddington.

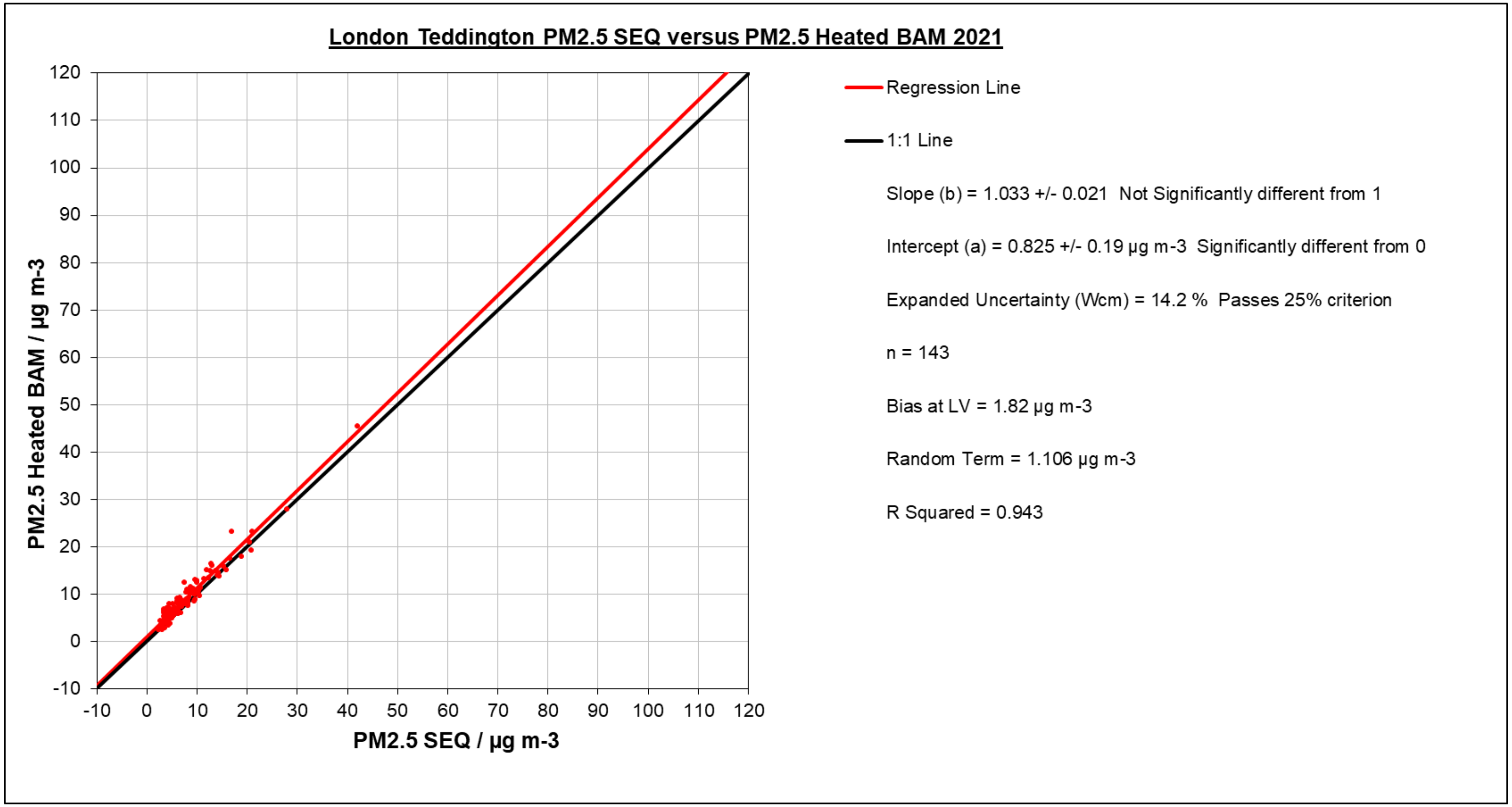

Figure A.5: Equivalence calculations for the $PM_{2.5}$ Smart Heated BAM1020 at Manchester Piccadilly.

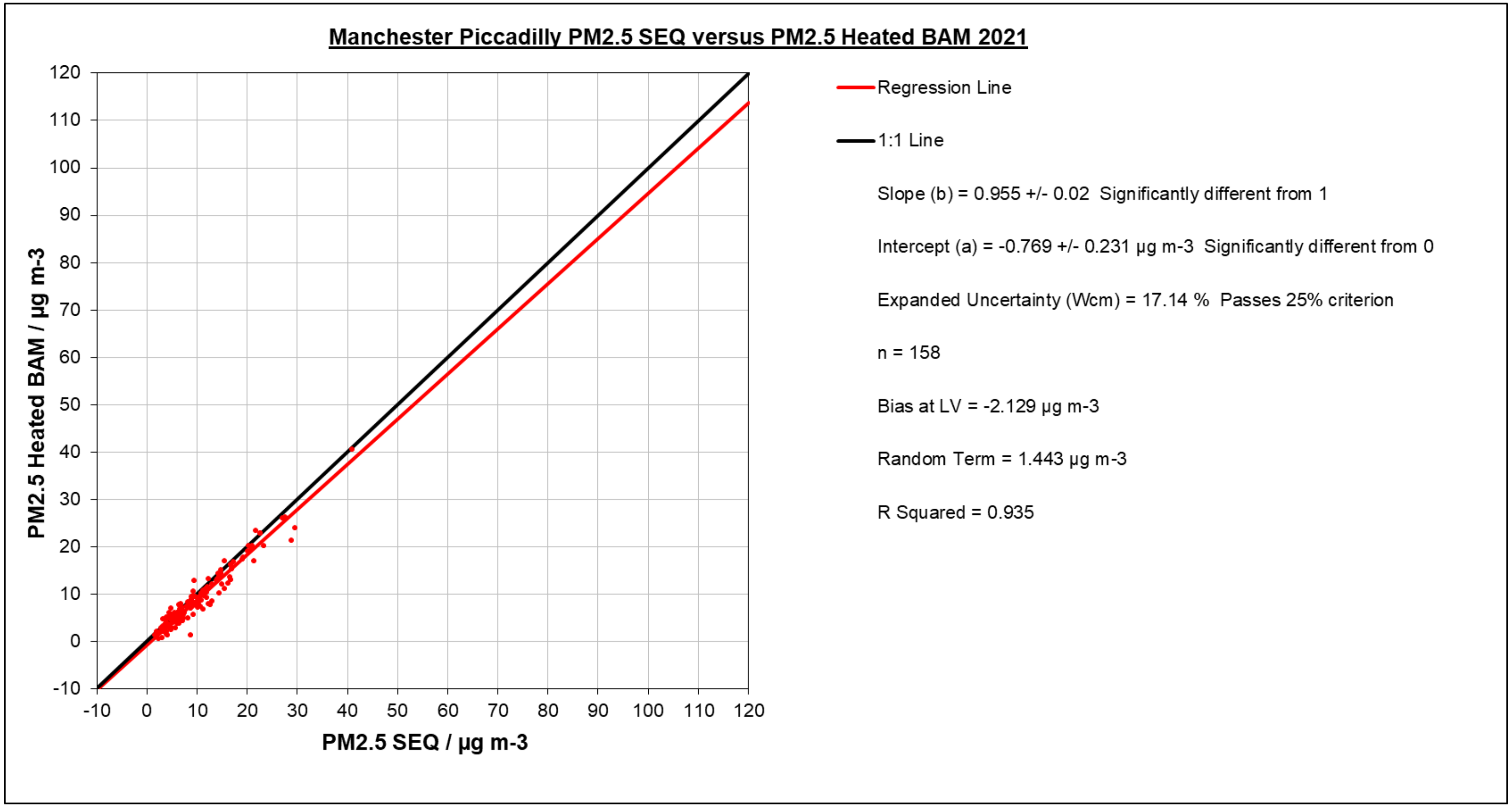

Figure A.6: Equivalence calculations for the PM_{10} Fidas 200 Method 11 at London Teddington.

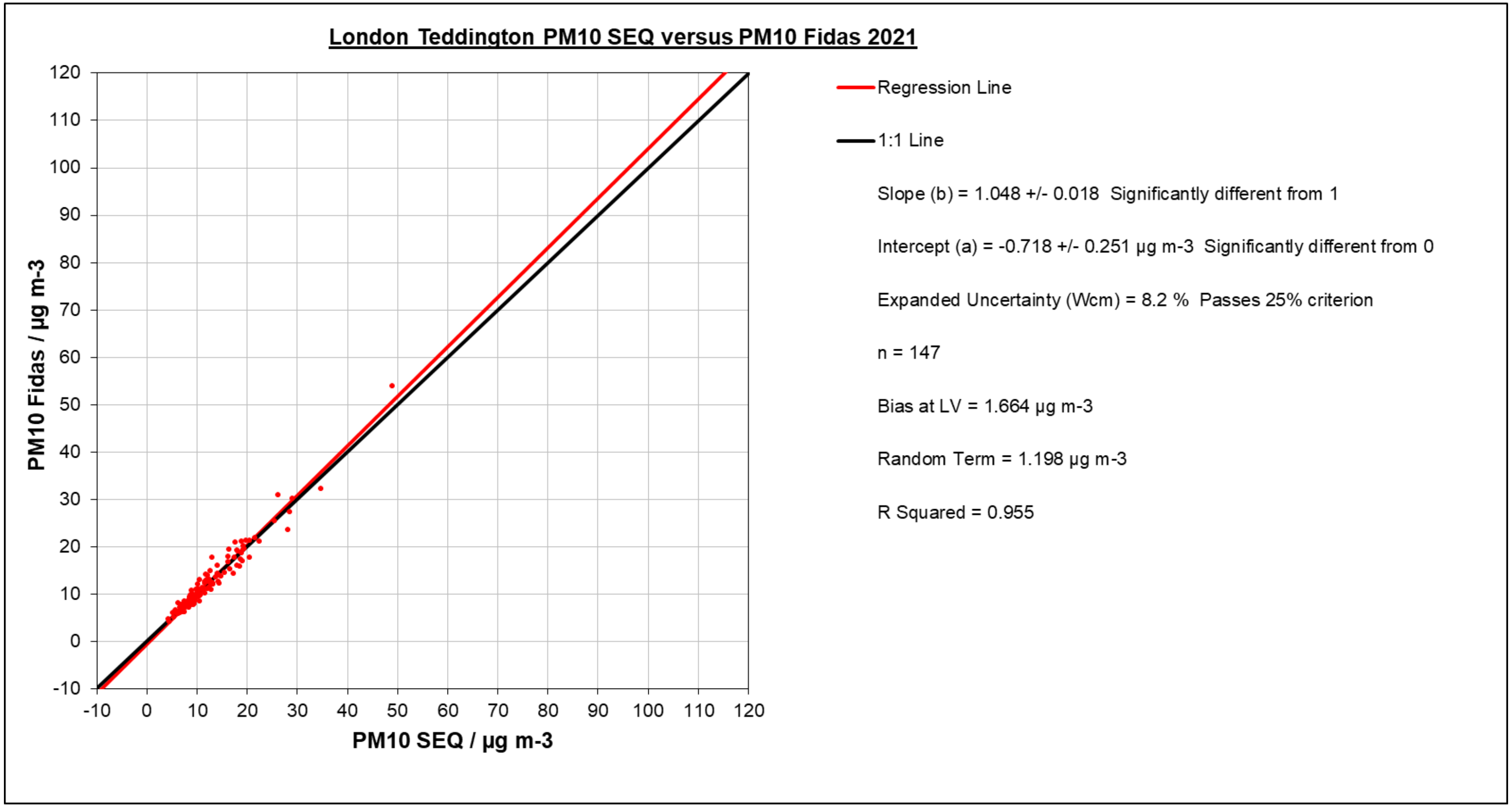

Figure A.7: Equivalence calculations for the PM_{10} Fidas 200 Method 11 at Manchester Piccadilly.

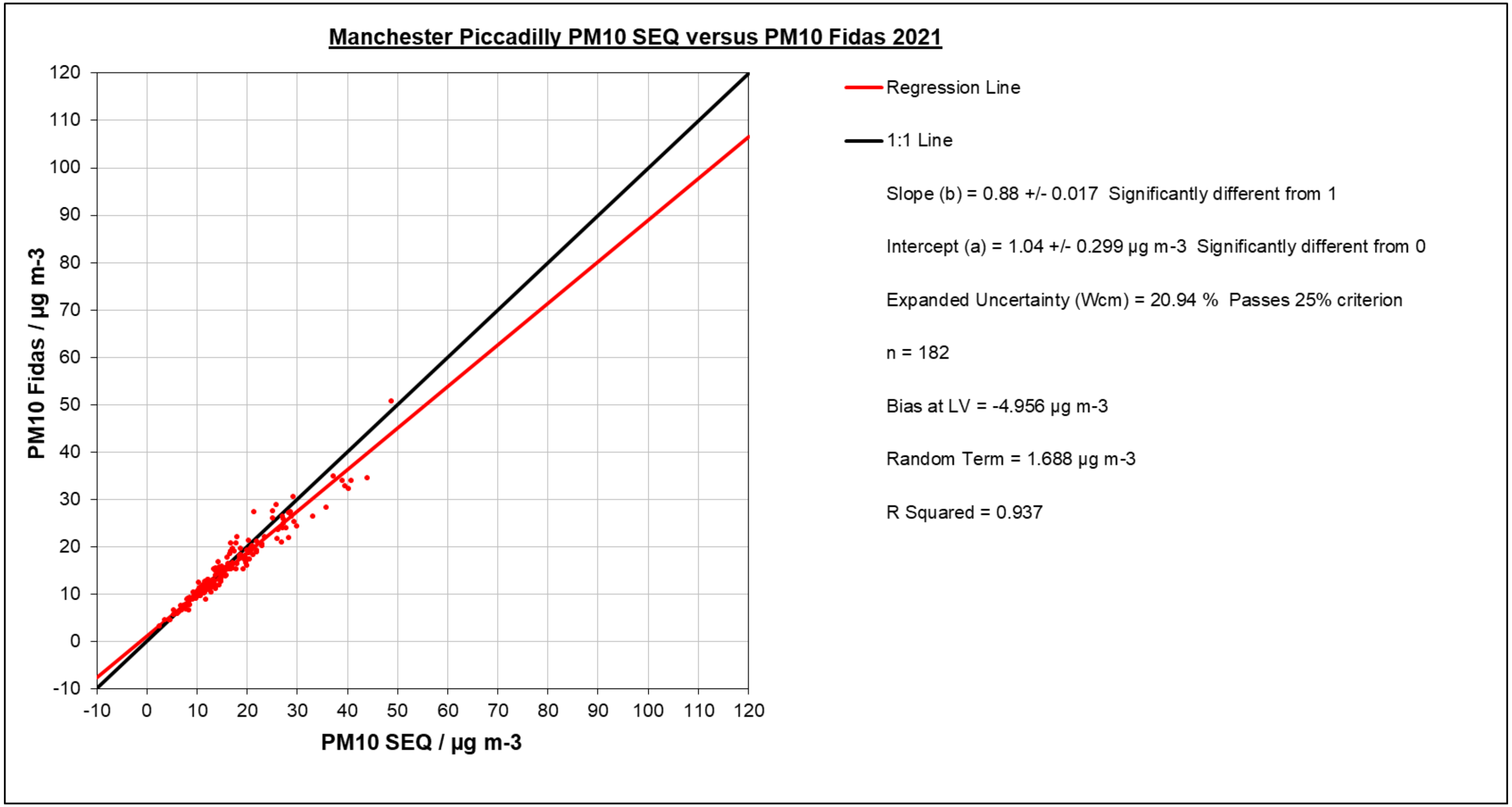

Figure A.8: *Equivalence calculations for the $PM_{2.5}$ Fidas 200 Method 11 at London Teddington.*

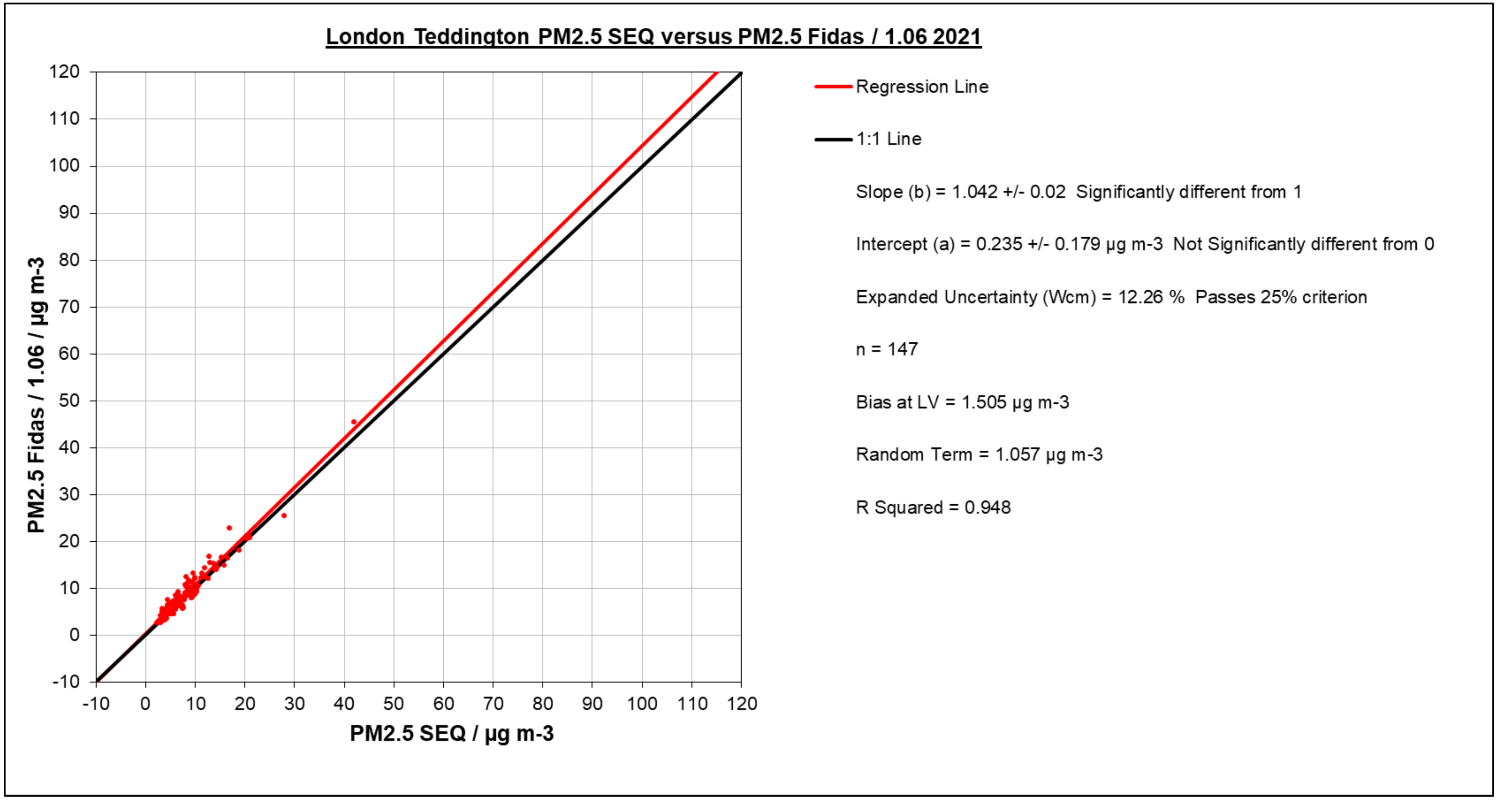

Figure A.9: Equivalence calculations for the $PM_{2.5}$ Fidas 200 Method 11 at Manchester Piccadilly.

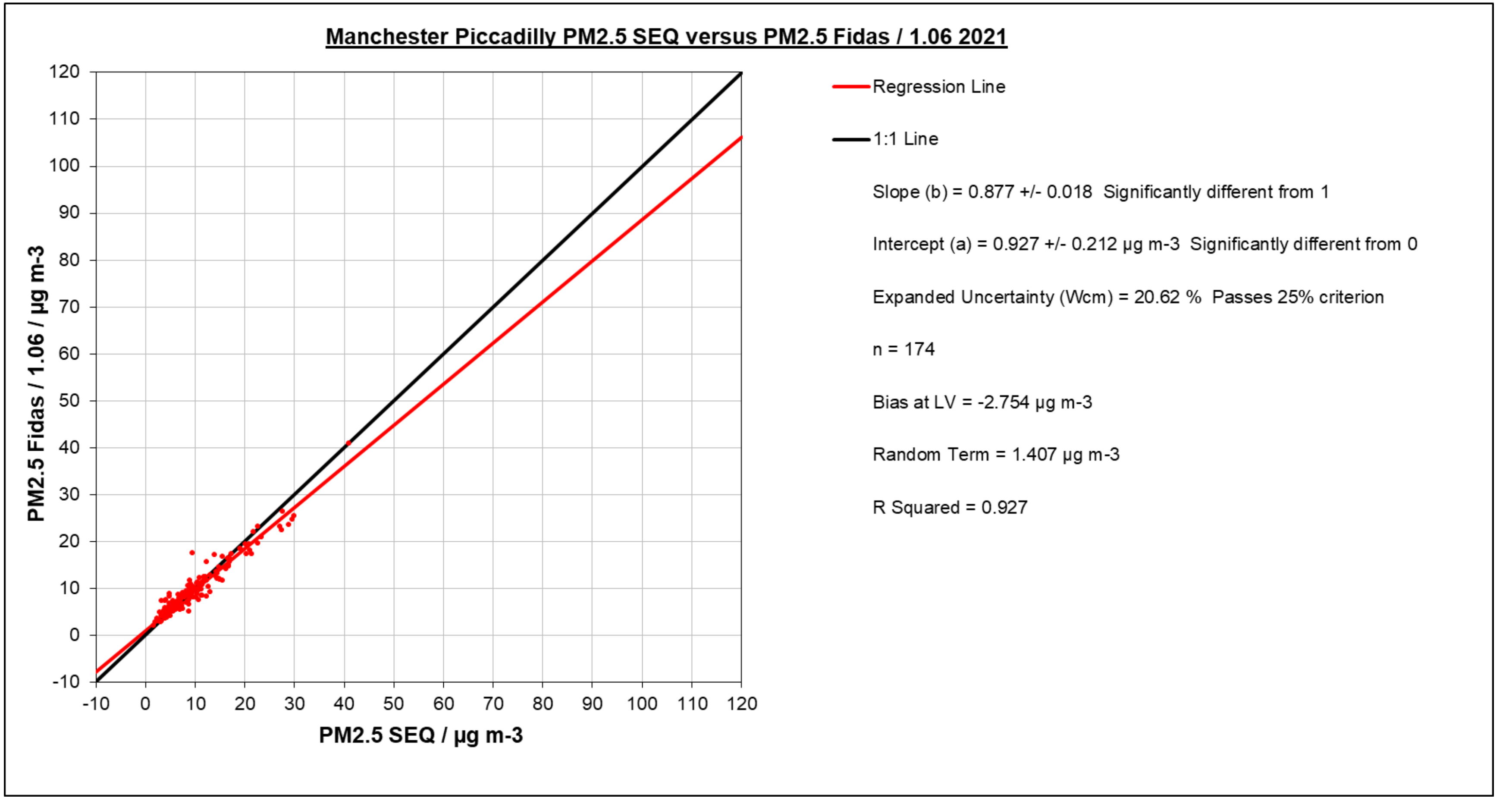

Figure A.10: Equivalence calculations for the PM_{10} FDMS 8500 at London Teddington.

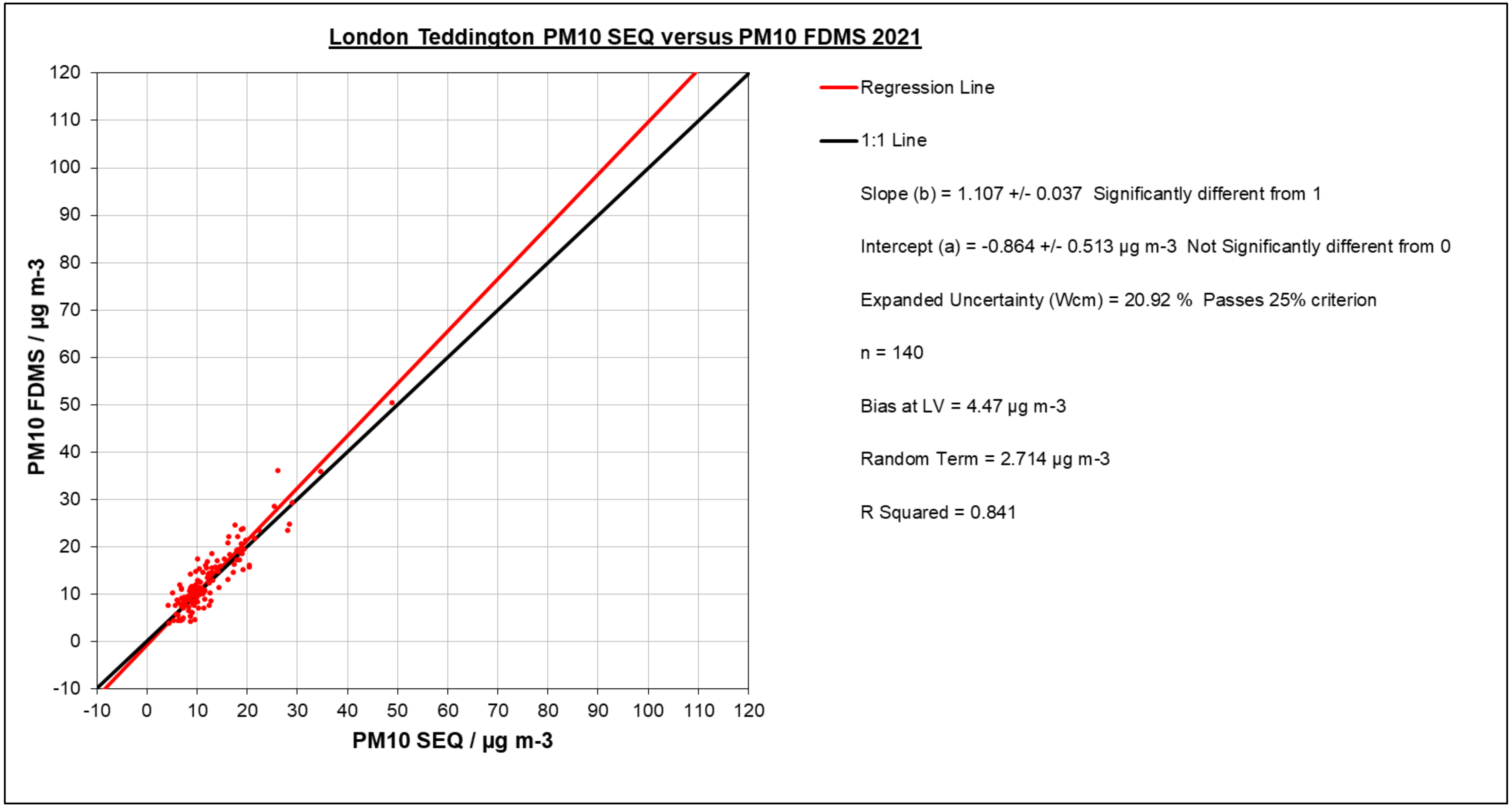

Figure A.11: Equivalence calculations for the $PM_{2.5}$ FDMS 8500 at London Teddington.