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Evaluation of the inter-laboratory comparison exercise for SO_2, CO, O_3, NO and NO_2 (26-29 June 2017, Ispra)

European Commission harmonisation programme for air quality measurements

Barbiere M., Lagler F., Borowiak A.

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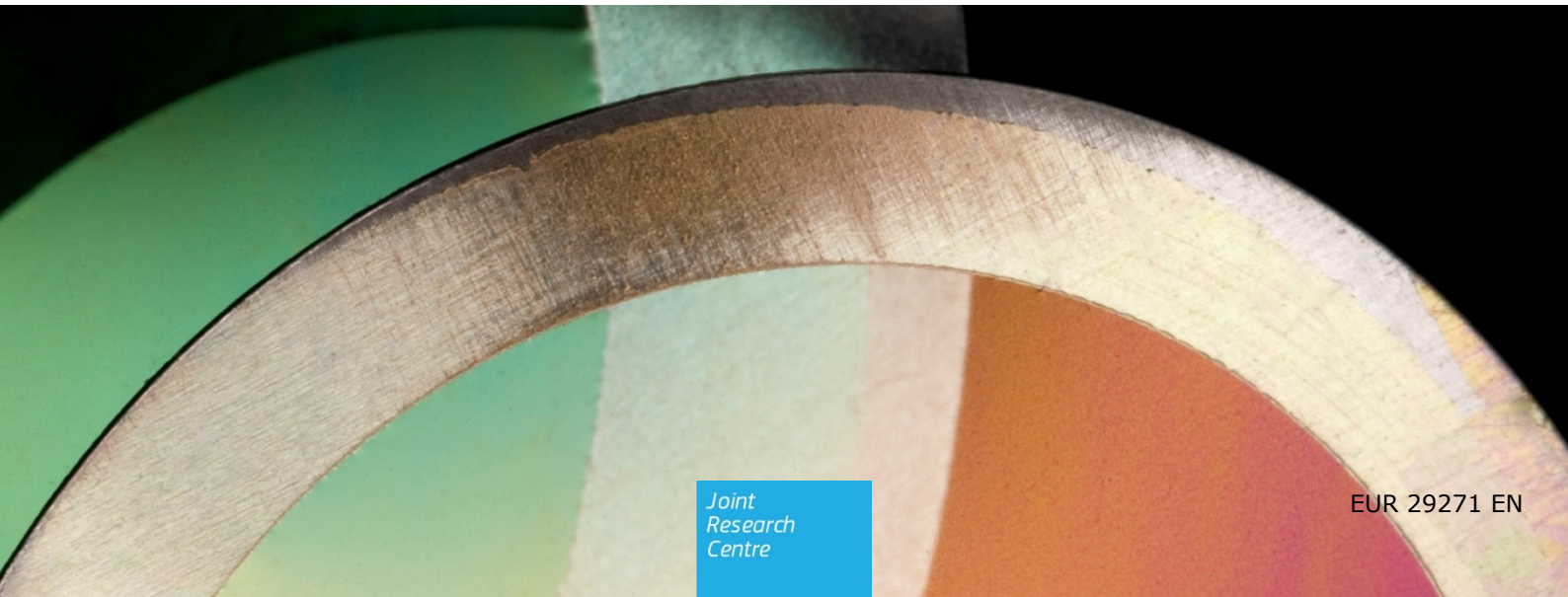

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Abbreviations

AQUILA	Network of National Reference Laboratories for Air Quality
CEN	European Committee for Standardization
CO	Carbon monoxide
CRM	Certified Reference Material
DQO	Data Quality Objective
ERLAP	European Reference Laboratory for Air Pollution
EC	European Commission
GPT	Gas Phase Titration
ILC	Inter-Laboratory Comparison Exercise
ISO	International Organization for Standardization
JRC	Joint Research Centre
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_X	The oxides of nitrogen, the sum of NO and NO_2
NRL	National Reference Laboratory
O_3	Ozone
SO_2	Sulphur dioxide
VDI	Verein Deutscher Ingenieure
WHO-CC	World Health Organization Collaborating Centre for Air Quality Management and Air Pollution Control, Berlin

Mathematical Symbols

symbol	*explanation*
α	converter efficiency (EN 14211)
E_n	E_n – score statistic (ISO 13528)
r	repeatability limit (ISO 5725)
R	reproducibility limit (ISO 5725)
σ_p	standard deviation for proficiency assessment (ISO 13528)
x*	robust average (Annex C ISO 13528)
s*	robust standard deviation (Annex C ISO 13528)
s_r	repeatability standard deviation (ISO 5725)
s_R	reproducibility standard deviation (ISO 5725)
$U_{X'}$	expanded uncertainty of the assigned/reference value (ISO 13528)
U_{xi}	expanded uncertainty of the participant's value
$u_{X'}$	standard uncertainty of the assigned/reference value (ISO 13528)
X	assigned/reference value (ISO 13528)
x_i	average of three values reported by the participant *i* (for particular parameter and concentration level) (ISO 5725)
$x_{i,j}$	j-the reported value of participant i (for particular parameter and concentration level) (ISO 5725)
z'	z'-score statistic (ISO 13528)

Abstract

Within the harmonisation programme of Air Quality monitoring in Europe the European Reference Laboratory of Air Pollution (ERLAP) organises Inter-Laboratory Comparison Exercises (ILC). From the 26th to the 29th of June 2017, eight Laboratories of AQUILA (Network of European Air Quality Reference Laboratories) met for a laboratory comparison exercise in Ispra (IT) to evaluate their proficiency in the analysis of inorganic gaseous air pollutants (NO, NO_2, SO_2, CO and O_3) covered by the European Air Quality Directive 2008/50 EC [1] and its recent amendments 2015/1480/EC [42].

The proficiency evaluation, where each participant's bias was compared to two criteria, provides information on the current situation and capabilities to the European Commission and can be used by participants in their quality control system.

On the basis of adopted criteria, 78.1% of the results reported by AQUILA laboratories were good both in terms of measured values and reported uncertainties. The rest of the results had good measured values, but the reported uncertainties were either too high (11.5%) or too small (6.5%). Only five values (1.9%) were found questionable and 1.9% unsatisfactory. Comparability of results among AQUILA participants at the highest generated concentration levels is satisfactory only for the measurements of some pollutants. The performance of SO2 and NO_2 are above the limits respectively from 15 and 50 nmol/mol.

1. Introduction

The Directive 2008/50/EC [1] on ambient air quality and cleaner air for Europe sets a framework for a harmonised air quality assessment in Europe.

One important objective of the Directive [1] is that the ambient air quality shall be assessed on the basis of common methods and criteria. It deals with the air pollutants sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and monoxide (NO), particulate matter, lead, benzene, carbon monoxide (CO) and ozone (O_3). Among others it specifies the reference methods for measurements and Data Quality Objectives (DQOs) for the accuracy of measurements.

The European Commission (EC) has supported the development and publication of reference measurement methods for CO [2], SO_2 [3], NO-NO_2 [4] and O_3 [5] as European standards. Appropriate calibration methods [6], [7] and [8] have been standardised by the International Organization for Standardization (ISO).

As foreseen in the Air Quality Directive, the European Reference Laboratory of Air Pollution (ERLAP) of the Directorate for Energy, Transport and Climate at the Joint Research Centre (JRC) organises inter-laboratory comparison exercises (ILC) to assess and improve the status of comparability of measurements of National Reference Laboratories (NRL) of the Member States of the European Union.

The World Health Organization Collaborating Centre for Air Quality Management and Air Pollution Control, Berlin (WHO CC) is carrying out similar activities since 1994 [9] [10], [24], [31], [33], [35], [38] and [45] but with a view to obtaining harmonised air quality data for health related studies. Their programme integrates within the WHO EURO region, which includes public health institutes and other national institutes - especially from the Central Eastern Europe, Caucasus and countries from Central Asia.

Starting in 2004, it has been decided to bring together the efforts of both the JRC-ERLAP and WHO CC and to coordinate activities as far as possible, with a view to optimize resources and have better international harmonisation.

The following report deals with the ILC that took place from 26th to the 29nd of June 2017 in Ispra (IT).

Since 1990 ERLAP organises ILC aiming to evaluate the comparability of measurements carried out by NRLs and promoting information exchange among the expert laboratories. Currently, a more systematic approach has been adopted, in accordance with the Network of National Reference Laboratories for Air Quality (AQUILA) [11], aiming both to provide an alert mechanism for the purposes of the EC legislation and to support the implementation of quality schemes by NRLs.

The methodology for the organisation of ILC was developed by ERLAP in collaboration with AQUILA and is described in a paper on the organisation of laboratory comparison exercises for gaseous air pollutants [12].

This evaluation scheme was adopted by AQUILA in December 2008 and is applied to all ILC since then. It contains common criteria to alert the EC on possible performance failures which do not rely solely on the uncertainty claimed by participants. The evaluation scheme implements the z'-score method [13] with the uncertainty requirements for calibration gases stated in the European standards [2], [3], [4] and [5], which are consistent with the DQOs of European Directives.

According to the above-mentioned document, NRLs with an overall unsatisfactory performance in the z'-score evaluation (one unsatisfactory or two questionable results per parameter) ought to repeat their participation in the following ILC in order to

demonstrate remediation measures [12]. In addition, considering that the evaluation scheme should be useful to participants for accreditation according to ISO 17025, they are requested to include their measurement uncertainty. Hence, participants' results (measurement values and uncertainties) are compared to the assigned values applying the E_n – score method [13].

Beside the proficiency of participating laboratories, the repeatability and reproducibility of standardised measurement methods [14], [15] and [16] are evaluated as well. These group evaluations are useful indicators of trends in measurement quality over different ILC.

2. Inter-laboratory organisation

The ILC was announced in February 2017 to the members of the AQUILA network and the WHO CC representative. Registration was opened in April 2017 and closed at the beginning of June 2017.

The participants were required to bring their own measurement instruments, data acquisition equipment and travelling standards (to be used for calibrations or checks during the ILC).

The participants were invited to arrive on Monday, 26th of June 2017, for the installation of their equipment. The calibration of NO_x and O_3 analysers was carried out on Tuesday morning and the generation of NO_x and O_3 gas mixtures started at 11:00.

The calibration of SO_2 and CO analysers was carried out on Wednesday afternoon and the generation of CO and SO_2 gas mixtures started at 20:00.

The test gases generation and measurements finished on Thursday at 9:00.

2.1. Participants

All participants were organisations dealing with the routine ambient air monitoring or institutions involved in environmental or public health protection. The national representatives came from Germany, Italy, Spain, Croatia, France, United Kingdom and Lithuania.

Country	Laboratory	Code
Germany	Umweltbundesamt (UBA)	A
Italy	Istituto Superiore Protezione Ricerca Ambientale (ISPRA)	B
Spain	Instituto De Salud Carlos III (ISCIII)	C
Croatia	Meteorological and Hydrological Service (DHZ-CAL)	D
France	Institut National de l'EnviRonnement Industriel et des RisqueS (INERIS)	E
United Kingdom	National Physical Laboratory (NPL)	F
European Commission	European reference Laboratory for Air Pollution (ERLAP)	G
Croatia	Meteorological and Hydrological Service (DHZ-TES)	H
Lithuania	Environmental Protection Agency (AAA)	I

Table 1: List of participating organisations.

Table 2 reports the manufacturer and model of the instrumentation used by every participant during the inter-laboratory comparison exercise including those used in the calculation of the assigned values.

The instrumentation used to analyse all parameters was manufactured by three different companies.

The list contains the information reported by participants and cannot be considered as an implicit or explicit endorsement by the organisers of any specific instrumentation.

GAS	LAB CODE	**INSTRUMENT**
SO2	A	HORIBA, 2011, APSA 370
	B	Thermo 43i, 2006
	C	TELEDYNE/T100U
	D	Thermo Scientific, 2014, 43i TLE
	E	TEI, 2005, 43i
	F	TE43i, 2013
	G	Thermo 43iTLE, 2009
	H	EAS ENVIMET 100E; 2009
	I	HORIBA, 2010, APSA 370
NO/NO2	A	HORIBA,2009,APNA 370
	B	Thermo 42i, 2006
	C	Horiba, 2011, APNA-370
	D	Horiba, 2011, APNA-370
	E	API 200a, 1997
	F	HORIBA,2009,APNA 370
	G	Thermo, TE42i, 2014
	H	EAS ENVIMET200E; 2009
	I	Horiba APNA 370, 2010
CO	A	HORIBA, 2007,APMA 370
	B	Thermo 48i, 2006
	C	TELEDYNE/T300
	D	Horiba, 2011, APMA 370
	E	API, 2010, 300E
	F	TE48i
	G	Horiba, APMA-370, 2010
	H	EAS ENVIMET 300E; 2009
	I	Horiba APMA 370, 2010
O3	A	MLU,2016, 49i
	B	Thermo 49i, 2006
	C	API T 400 2014
	D	Thermo Scientific, 2012, 49i
	E	TEI, 2005, 49i
	F	TE49c, 1996
	G	Thermo, 49-iPS , 2014
	H	EAS ENVIMET400E; 2009
	I	Horiba APOA 370, 2010

Table 2: List of instruments used by participants.

2.2. Preparation of test mixtures

The ERLAP ILC facility has been described in several reports [17], [18]. During this ILC, gas mixtures were prepared for SO_2, CO, O_3, NO and NO_2 at concentration levels around limit values, critical levels and assessment thresholds set by the European Air Quality Directive [1].
The test mixtures were prepared by the dilution of gases from cylinders containing high concentrations of NO, SO_2 or CO using thermal mass flow controllers [8]. O_3 was added using an ozone generator and NO_2 was produced applying the gas phase titration method [19] in a condition of NO excess.
The participants were required to report three half-hour-mean measurements for each concentration level (run) in order to evaluate the repeatability of standardised measurement methods. Zero concentration levels were generated for one hour and one half-hour-mean measurement was reported. The sequence programme of generated test gases is given in Table 3.

day	start time	duration	parameter	installation	calibration	Zero Air	NO	NO_2	O_3	CO	SO_2
		h				nmol/mol	nmol/mol	nmol/mol	nmol/mol	mmol/mol	nmol/mol
1st	09:00	5	/	X							
2nd	08:00	3	/		X						
2nd	11:00	1	NO-NO_2-O_3			0					
2nd	12:00	2	NO-NO_2				280				
2nd	14:00	2	NO-NO_2				185	95			
2nd	16:00	2	O_3						90		
2nd	18:00	2	NO-NO_2				55				
2nd	20:00	2	NO-NO_2				25	30			
2nd	22:00	2	O_3						30		
3rd	00:00	2	NO-NO_2				480				
3rd	02:00	2	NO-NO_2				360	120			
3rd	04:00	2	O_3						110		
3rd	06:00	2	NO-NO_2				25				
3rd	08:00	2	NO-NO_2				12	22			
3rd	10:00	2	O_3						22		
3rd	12:00	2	NO-NO_2				130				
3rd	14:00	2	NO-NO_2				70	60			
3rd	16:00	2	O_3						60		
3rd	< 18:00	2	calibration		X						
3rd	20:00	1	CO-SO_2			0					
3rd	21:00	2	CO-SO_2							5	12
3rd	23:00	2	CO-SO_2							3	5
4th	01:00	1	CO-SO_2	Zero Air not reported						0	0
4th	02:00	2	CO-SO_2							8	130
4th	04:00	2	CO-SO_2							1	60
4th	06:00	2	CO-SO_2							2	30
4th	08:00	1				0					
4th	09:00	END									

Table 3: Sequence program of generated test gases with indicative pollutant concentrations

3. The evaluation of laboratory's measurement proficiency

To evaluate the participant's measurement proficiency, the methodology described in ISO 13528 [13] was applied. It has been agreed among the AQUILA members to take the measurement results of ERLAP as the assigned/reference values for the whole ILC [12].

The traceability of ERLAP's measurement results and the method applied to validate them are presented in Annex A. In the following proficiency evaluations, the uncertainty of test gas homogeneity (Annex A) was added to the uncertainties of ERLAP's measurement results.

All data reported by participating laboratories are presented in Annex B.

As it is described in the position paper [12], the proficiency of the participants was assessed by calculating two performance indicators.

The first performance indicator (z'-score) tests whether the difference between the participants measured value and the assigned/reference value remains within the limits of a common criterion.

The second performance indicator (E_n-score) tests if the difference between the participants measured values and assigned/reference value remains within the limits of a criterion, that is calculated individually for each participant, from the uncertainty of the participants measurement result and the uncertainty of the assigned/reference value.

3.1. z' – score

The z'- score statistic is calculated according to ISO 13528 [13] as:

$$z' = \frac{x_i - X}{\sqrt{\sigma_p^2 + u_X^2}} = \frac{x_i - X}{\sqrt{(a \cdot X + b)^2 + u_X^2}} \qquad \text{Equation 1}$$

where $\boldsymbol{x_i}$ is a participant's average value for each run, $\boldsymbol{X}$ is the assigned/reference value, $\boldsymbol{\sigma_p}$ is the 'standard deviation for proficiency assessment' and $\boldsymbol{u_X}$ is the standard uncertainty of the assigned value. For ***a*** and ***b*** see Table 4.

In the European standards [2], [3], [4] and [5] the uncertainties for calibration gases used in ongoing quality control are prescribed. In fact, it is stated that the maximum permitted expanded uncertainty for calibration gases is 5% and that 'zero gas' shall not give instrument reading higher than the detection limit. As one of the tasks of NRLs is to supply calibration gas mixtures, the 'standard deviation for proficiency assessment' ($\boldsymbol{\sigma_p}$) [13] is calculated in fitness-for-purpose manner from requirements given in European standards.

Over the whole measurement range σ_p is calculated by linear interpolation between 2.5% at the calibration point (75% of calibration range) and the limit of detection at zero concentration level. The limits of detection of studied measurement methods were evaluated from the data of previous ILC. The linear function parameters of σ_p are given in Table 4:

	$\sigma_p = a \cdot c + b$	
Gas	**a**	**b**
		nmol/mol
SO_2	0.022	1
CO	0.024	100
O_3	0.020	1
NO	0.024	1
NO_2	0.020	1

Table 4: Standard deviation for proficiency assessment (σp).

σ_p is a linear function of concentration (c) with parameters: slope (a) and intercept (b).

The assessment of results in the z`-score evaluation is made according to the following criteria:

- $|z'| < 2$ are considered satisfactory.
- $2 < |z'| < 3$ are considered questionable.
- $|z'| \geq 3$ are considered unsatisfactory. Scores falling in this range are very unusual and are taken as evidence that an anomaly has occurred that should be investigated and corrected.

The results of z'-score evaluation are presented in bar plots (Figure 1 to Figure 5) in which the z'-scores of each participant are grouped together, and assessment criteria are presented as z'=±2 and z'=±3 lines.

Laboratory C didn't report any values for NO and NO_2.

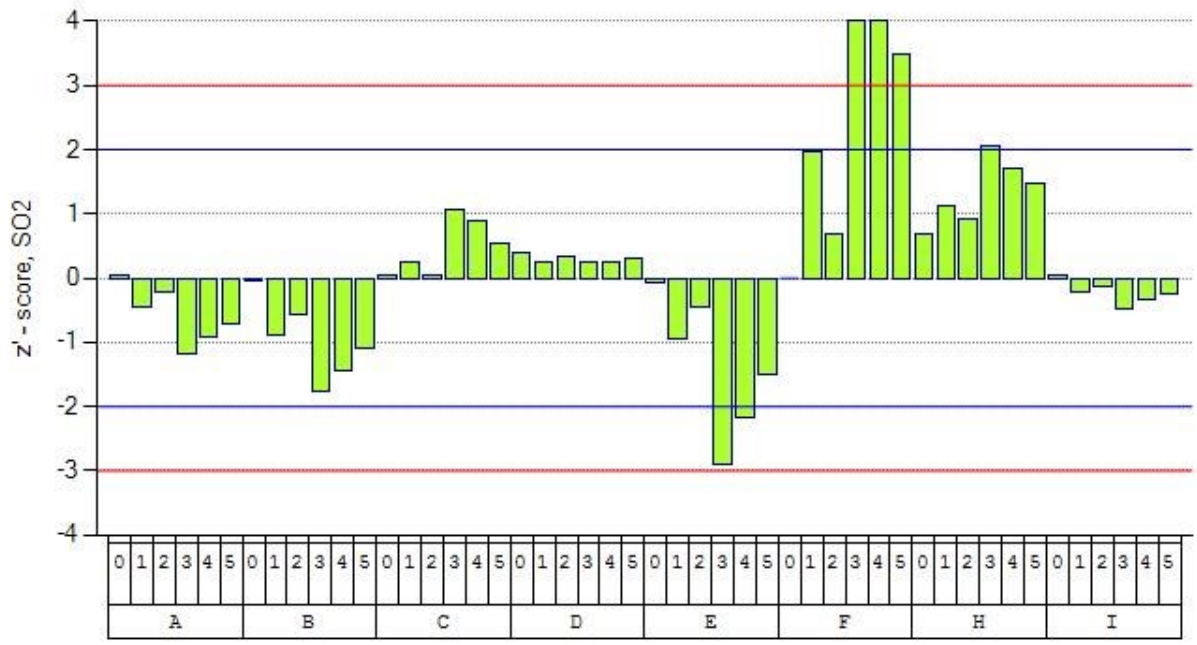

Figure 1: Z'-score evaluations of SO2 measurements

Scores are given for each participant and each tested concentration level (run). Run number order (with nominal concentration) is: 0 (0 nmol/mol), 1 (12 nmol/mol), 2 (5 nmol/mol), 3 (130 nmol/mol), 4 (60 nmol/mol), 5 (30 nmol/mol). The assessment criteria are presented as z'=±2 (blue line) and z'=±3 (red line). They represent the limits for the questionable and unsatisfactory results.

Note from the participant F: "The SO2 results were reported in error. The problem was retrospectively traced to the calibration cylinder taken to Ispra".

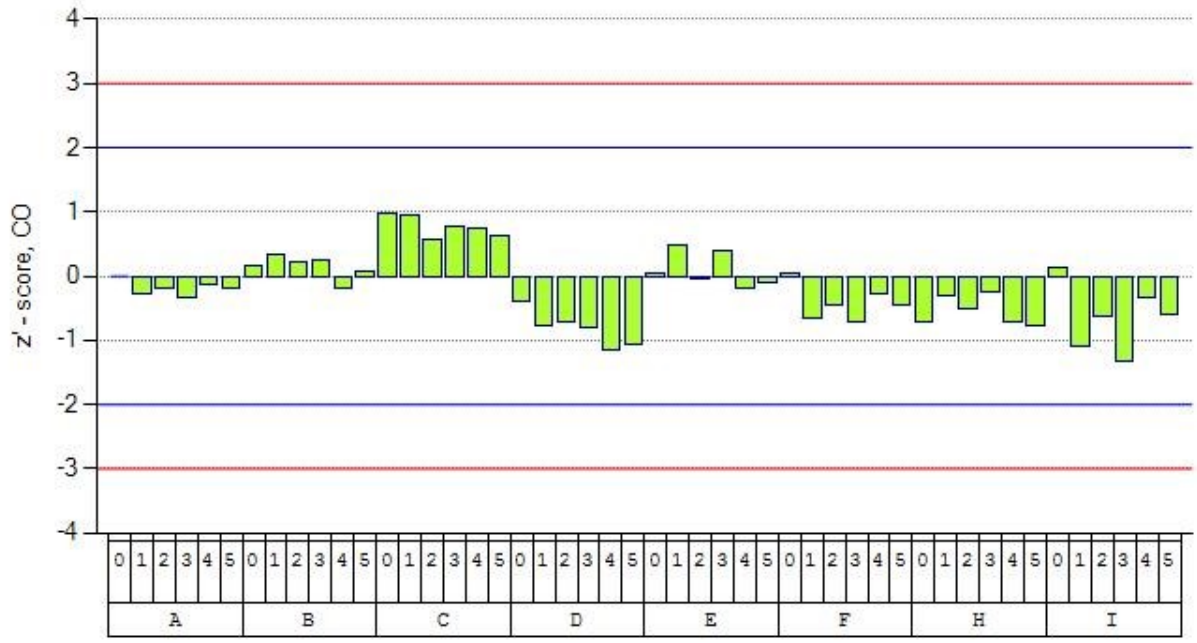

Figure 2: Z'-score evaluations of CO measurements

Scores are given for each participant and each tested concentration level (run). Run number order (with nominal concentration) is: 0 (0 µmol/mol), 1 (5 µmol/mol), 2 (3 µmol/mol), 3 (8 µmol/mol), 4 (1 µmol/mol), 5 (2 µmol/mol). The assessment criteria are presented as z'=±2 (blue line) and z'=±3 (red line). They represent the limits for the questionable and unsatisfactory results.

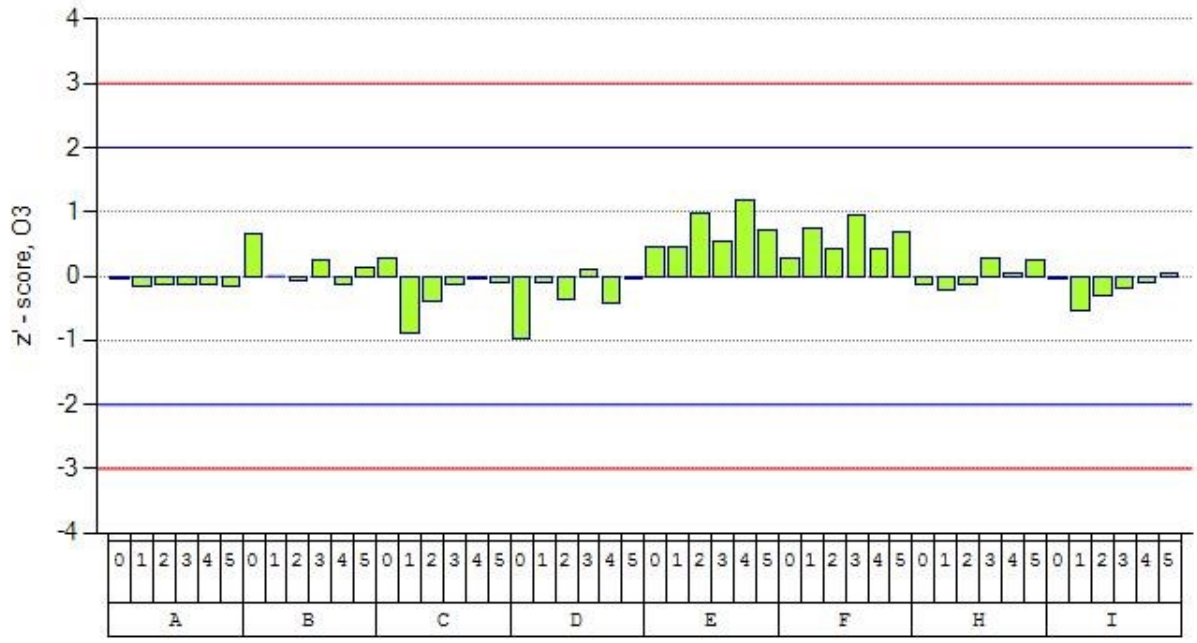

Figure 3: Z'-score evaluations of O3 measurements

Scores are given for each participant and each concentration level (run). Run number order (with nominal concentration) is: 0 (0 nmol/mol), 1 (90 nmol/mol), 2 (30 nmol/mol), 3 (110 nmol/mol), 4 (22 nmol/mol), 5 (60 nmol/mol). The assessment criteria are presented as z'=±2 (blue line) and z'=±3 (red line). They represent the limits for the questionable and unsatisfactory results.

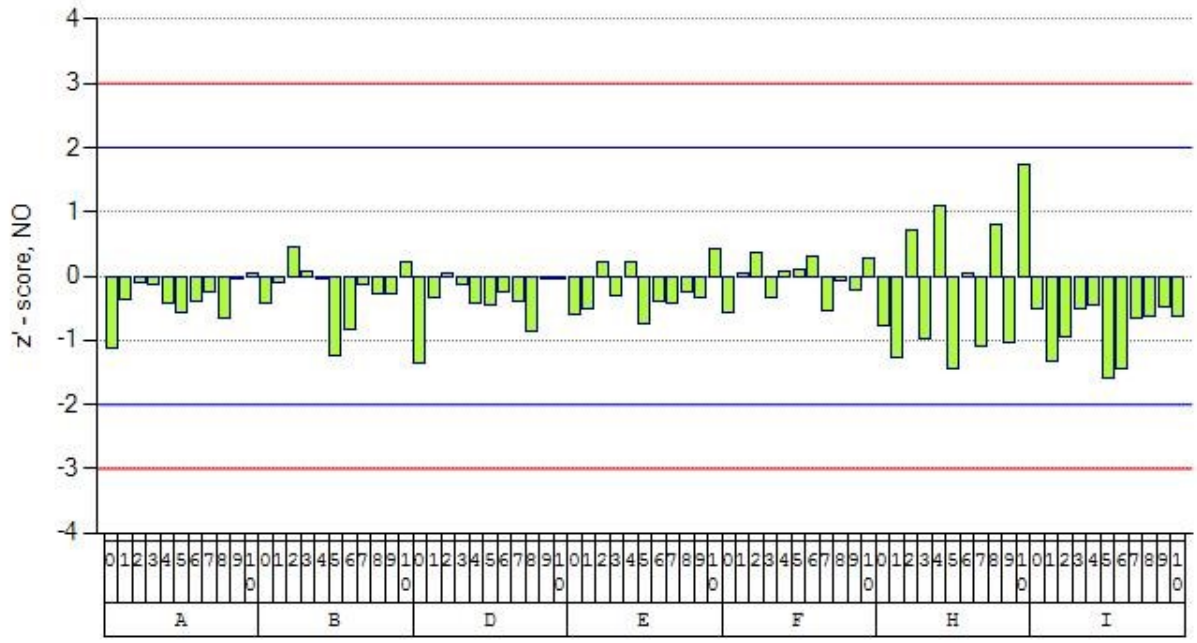

Figure 4: Z'-score evaluations of NO measurements

Scores are given for each participant and each tested concentration level (run). Run number order (with nominal concentration) is: 0 (0 nmol/mol), 1 (280 nmol/mol), 2 (185 nmol/mol), 3 (55 nmol/mol), 4 (25 nmol/mol), 5 (480 nmol/mol), 6 (360 nmol/mol), 7 (25 nmol/mol), 8 (12 nmol/mol), 9 (130 nmol/mol), 10 (70 nmol/mol). The assessment criteria are presented as z'=±2 (blue line) and z'=±3 (red line). They represent the limits for the questionable and unsatisfactory results.

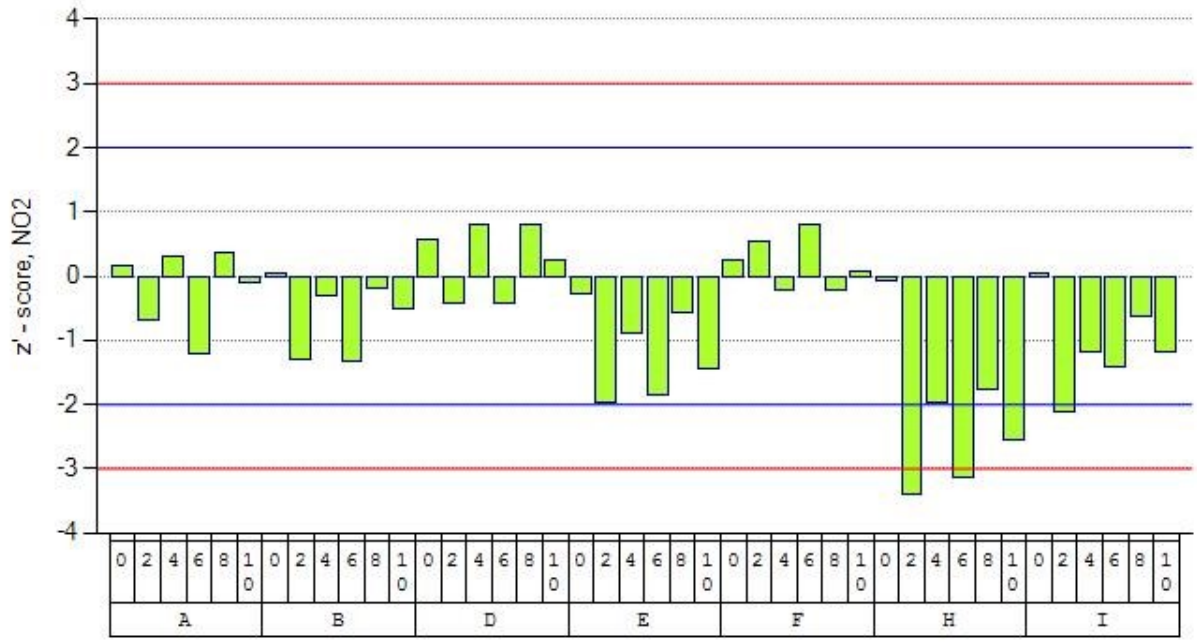

Figure 5: Z'-score evaluations of NO2 measurements

Scores are given for each participant and each concentration level (run). Run number order (with nominal concentration) is: 0 (0 nmol/mol), 1 (95 nmol/mol), 2 (30 nmol/mol), 3 (120 nmol/mol), 4 (22 nmol/mol), 5 (60 nmol/mol). The assessment criteria are presented as z'=±2 (blue line) and z'=±3 (red line). They represent the limits for the questionable and unsatisfactory results.

3.2. En - score

The normalised deviations [13] (E_n) were calculated according to:

$$E_n = \frac{x_i - X}{\sqrt{U_{x_i}^2 + U_X^2}} \qquad \text{Equation 2}$$

where ***X*** is the assigned/reference value with an expanded uncertainty $\boldsymbol{U_X}$ and $\boldsymbol{x_i}$ is the participant's average value with an expanded uncertainty $\boldsymbol{U_{Xi}}$. Satisfactory results are the ones for which $|E_n| < 1$. In Figure 6 to Figure 10 the bias of each participant (x_i-X) is plotted and error bars are used to show the value of denominator of equation 2. These plots represent also the E_n-score evaluations where, considering the E_n criterion $|E_n| < 1$ all results with error bars touching or crossing the x-axis are satisfactory. Reported standard uncertainties (Annex B) that are larger than the "standard deviation for proficiency assessments" (σ_p, Table 4) are considered not fit-for-purpose and are denoted with "*" in the x-axis of each figure. The E_n evaluation showed many unsatisfactory results for different parameters and concentrations, as reported in table 5. The calculation of uncertainty is an issue that shouldn't be underestimated.

Parameter	Lab Code	Value	Run	En	En evaluation
SO2	A	126,56	SO2 _3	-1,03	unsatisfactory
O3	B	0,78	O3_0	1,05	unsatisfactory
CO	C	1,118	CO _4	1,59	unsatisfactory
NO	E	488,68	NO _5	-1,01	unsatisfactory
NO2	E	91,59	NO2 _2	-1,55	unsatisfactory
NO2	E	114,6	NO2 _6	-1,34	unsatisfactory
O3	E	33,74	O3 _2	2,46	unsatisfactory
O3	E	23,41	O3 _4	3,25	unsatisfactory
O3	E	61,63	O3 _5	1,5	unsatisfactory
SO2	E	119,76	SO2 _3	-3,76	unsatisfactory
SO2	E	55,06	SO2 _4	-2,29	unsatisfactory
SO2	E	28,2	SO2 _5	-1,14	unsatisfactory
CO	F	4,85	CO _1	-1,04	unsatisfactory
CO	F	7,78	CO _3	-1,13	unsatisfactory
SO2	F	17,52	SO2 _1	1,34	unsatisfactory
SO2	F	157,26	SO2 _3	3,36	unsatisfactory
SO2	F	72,15	SO2 _4	3,02	unsatisfactory
SO2	F	36,99	SO2 _5	2,37	unsatisfactory
NO2	H	86,9	NO2 _2	-1,69	unsatisfactory
NO2	H	26,37	NO2 _4	-1,3	unsatisfactory
NO2	H	7,58	NO2 _5	1,16	unsatisfactory
NO2	H	109,48	NO2 _6	-1,48	unsatisfactory
NO2	H	18,45	NO2 _8	-1,23	unsatisfactory
NO2	H	54,53	NO2 _10	-1,43	unsatisfactory
SO2	H	139,47	SO2 _3	1,35	unsatisfactory
SO2	H	64,38	SO2 _4	1,32	unsatisfactory
SO2	H	33,46	SO2 _5	1,24	unsatisfactory
NO2	I	91,07	NO2 _2	-1,08	unsatisfactory

Table 5: Unsatisfactory results according to En - score.

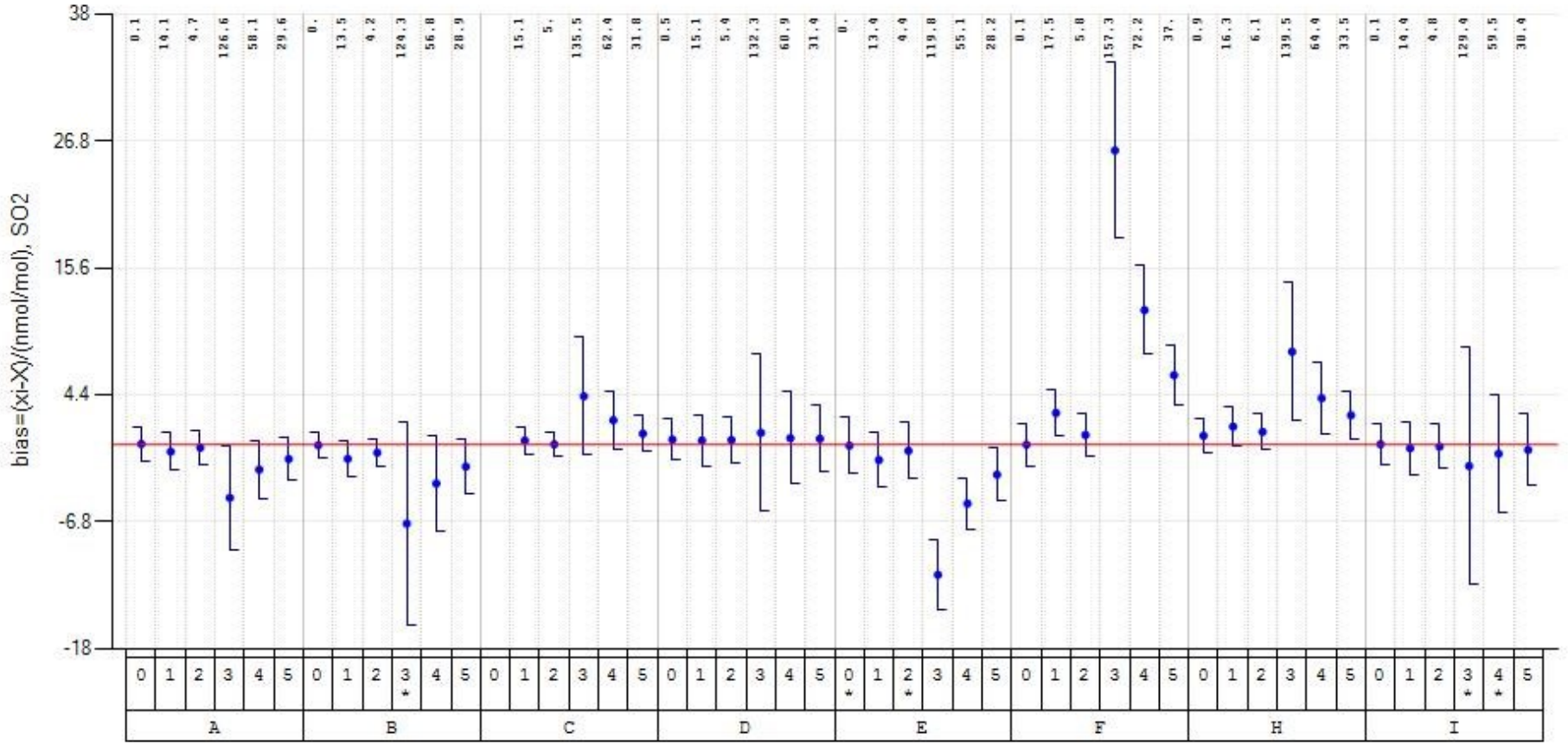

Figure 6: Bias of participant's SO2 measurement results

Expanded uncertainty of bias for each run is presented as error bar. The results with error bars touching or crossing the x-axis are satisfactory. For each evaluation the run number (numbers 0 to 5) together with the participants rounded run average (nmol/mol) is given. The '*' mark indicates reported standard uncertainties bigger than σ_p. Participant C didn't report the uncertainty for run 0.

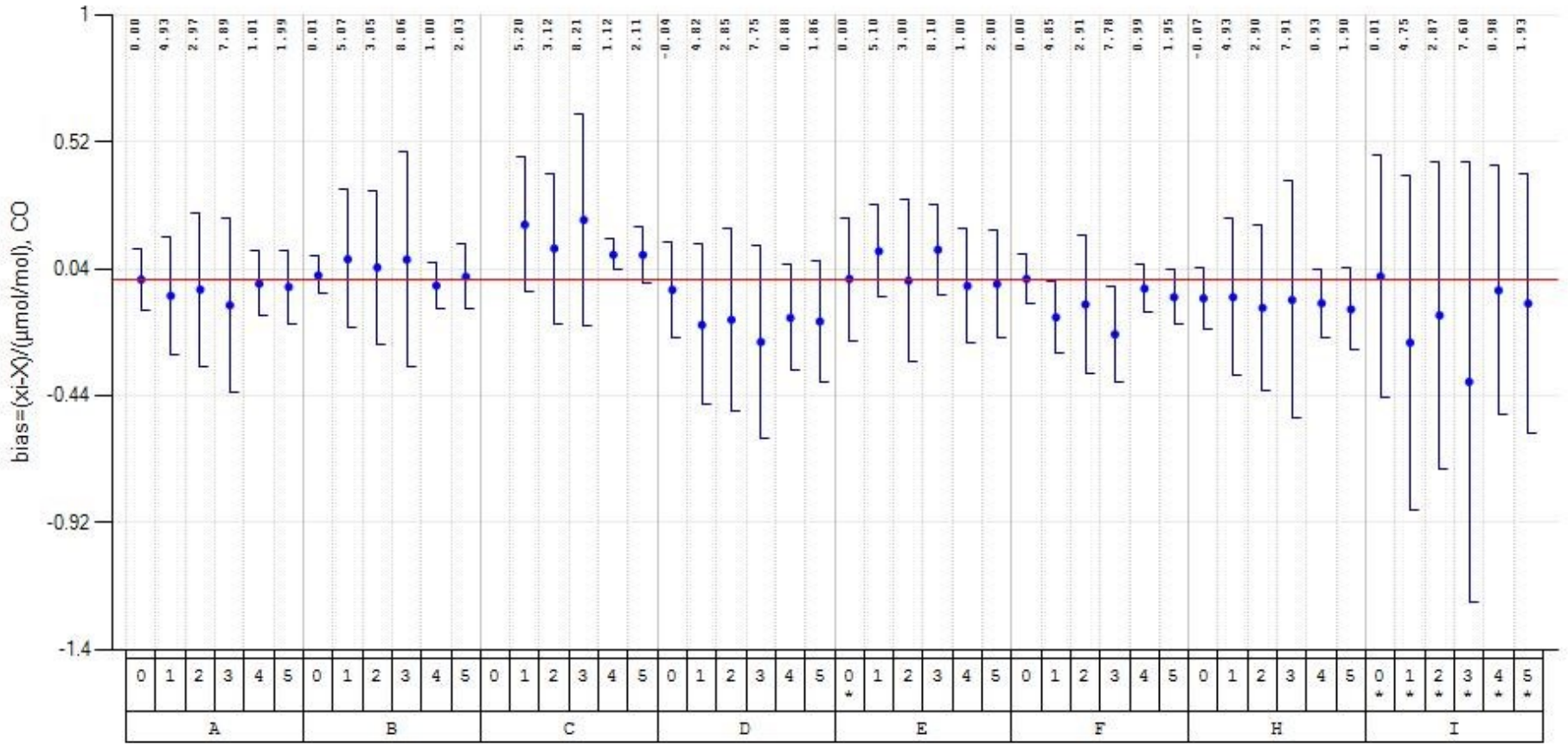

Figure 7: Bias of participant's CO measurement results

Expanded uncertainty of bias for each run is presented as error bar. Results with error bars touching or crossing the x-axis are satisfactory. For each evaluation the run number (numbers 0 to 5) together with the participants rounded run average (µmol/mol) is given. The '*' mark indicates reported standard uncertainties bigger than σ_p. Participant C didn't report the uncertainty for run 0.

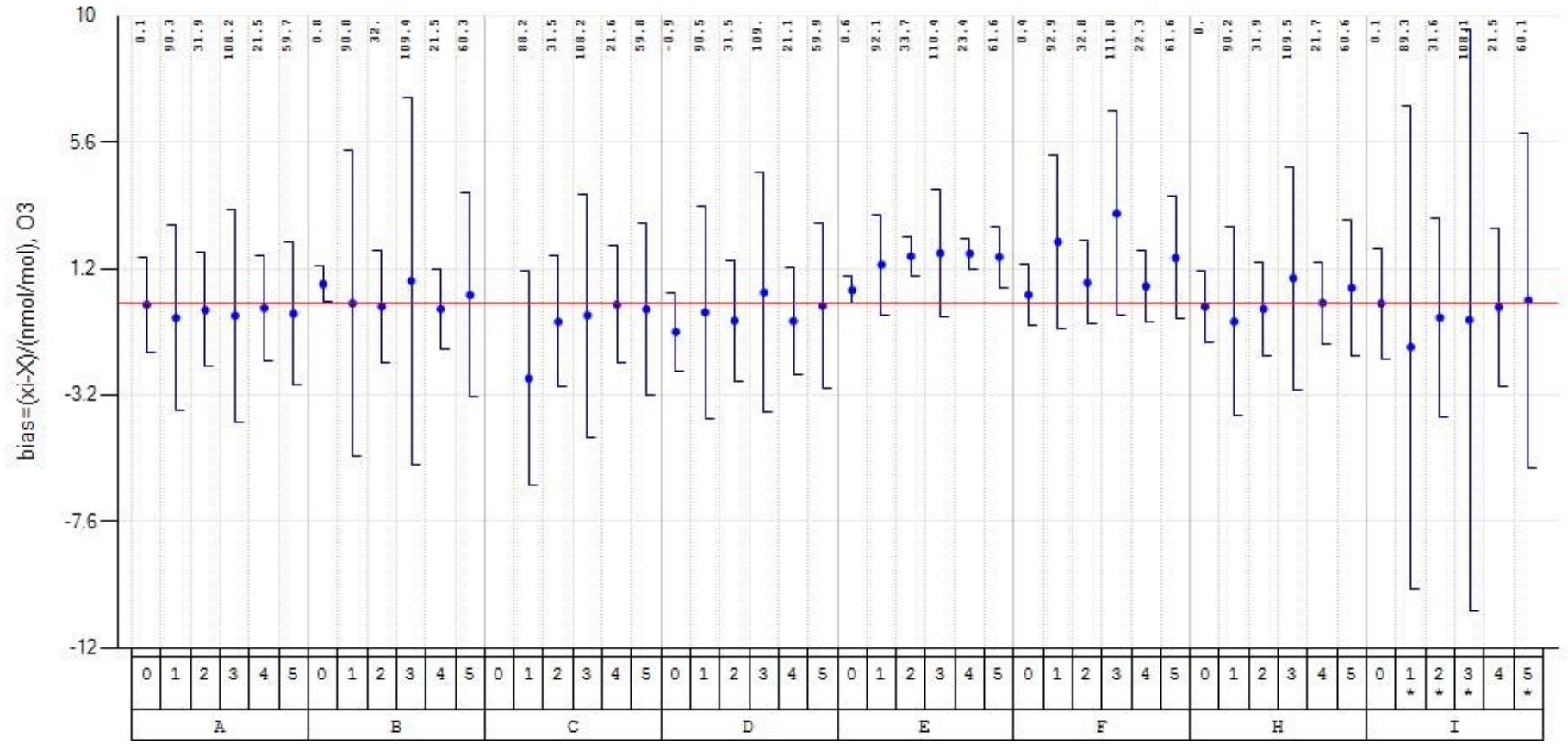

Figure 8: Bias of participant's O3 measurement results

Expanded uncertainty of bias for each run is presented as error bar. Results with error bars touching or crossing the x-axis are satisfactory. For each evaluation the run number (numbers 0 to 5) together with the participants rounded run average (nmol/mol) is given. The '*' mark indicates reported standard uncertainties bigger than σ_p. Participant C didn't report the uncertainty for run 0.

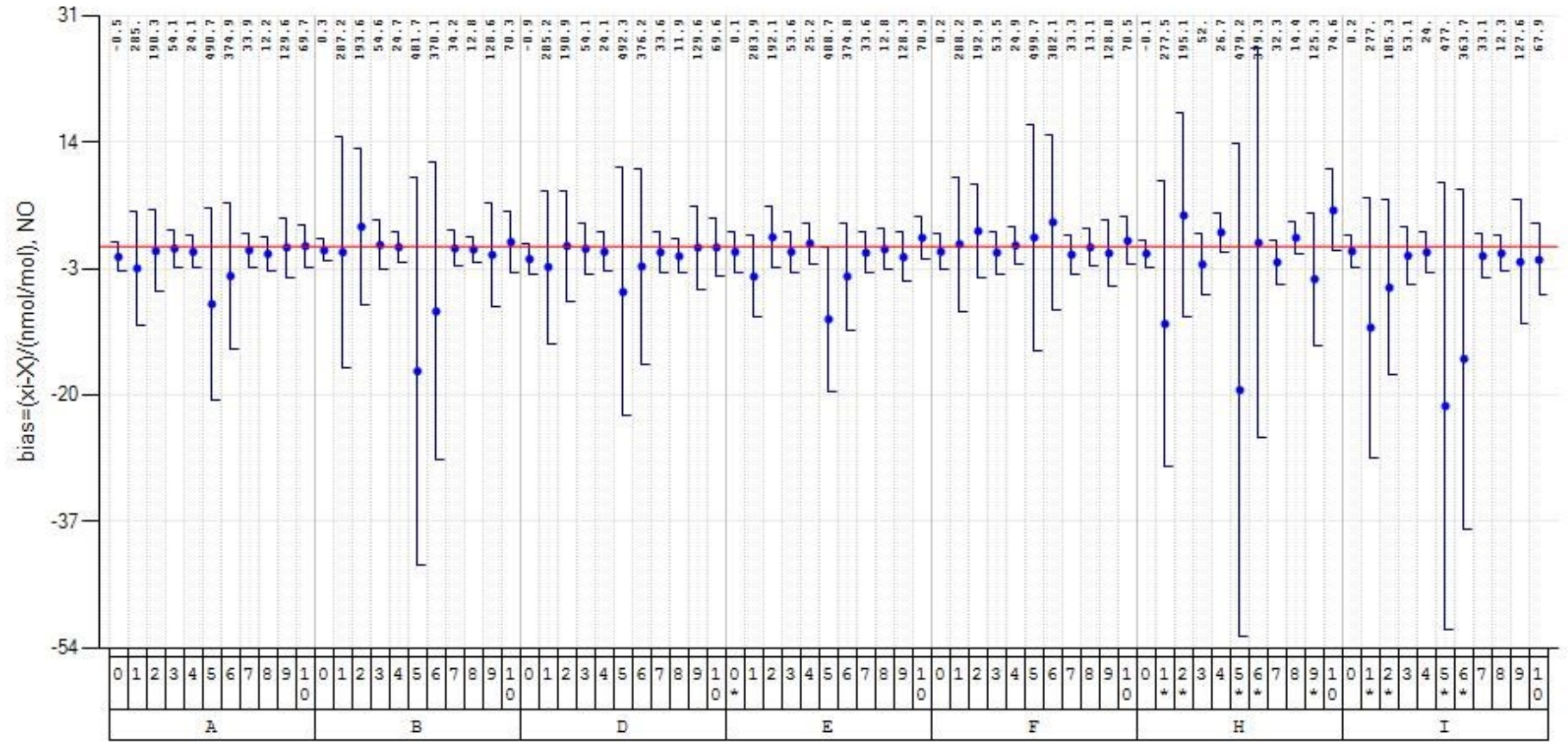

Figure 9: Bias of participant's NO measurement results

Expanded uncertainty of bias for each run is presented as error bar. Results with error bars touching or crossing the x-axis are satisfactory. For each evaluation the run number (numbers 0 to 10) together with the participants rounded run average (nmol/mol) is given. The '*' mark indicates reported standard uncertainties bigger than σ_p. Participant C didn't report any values for this pollutant.

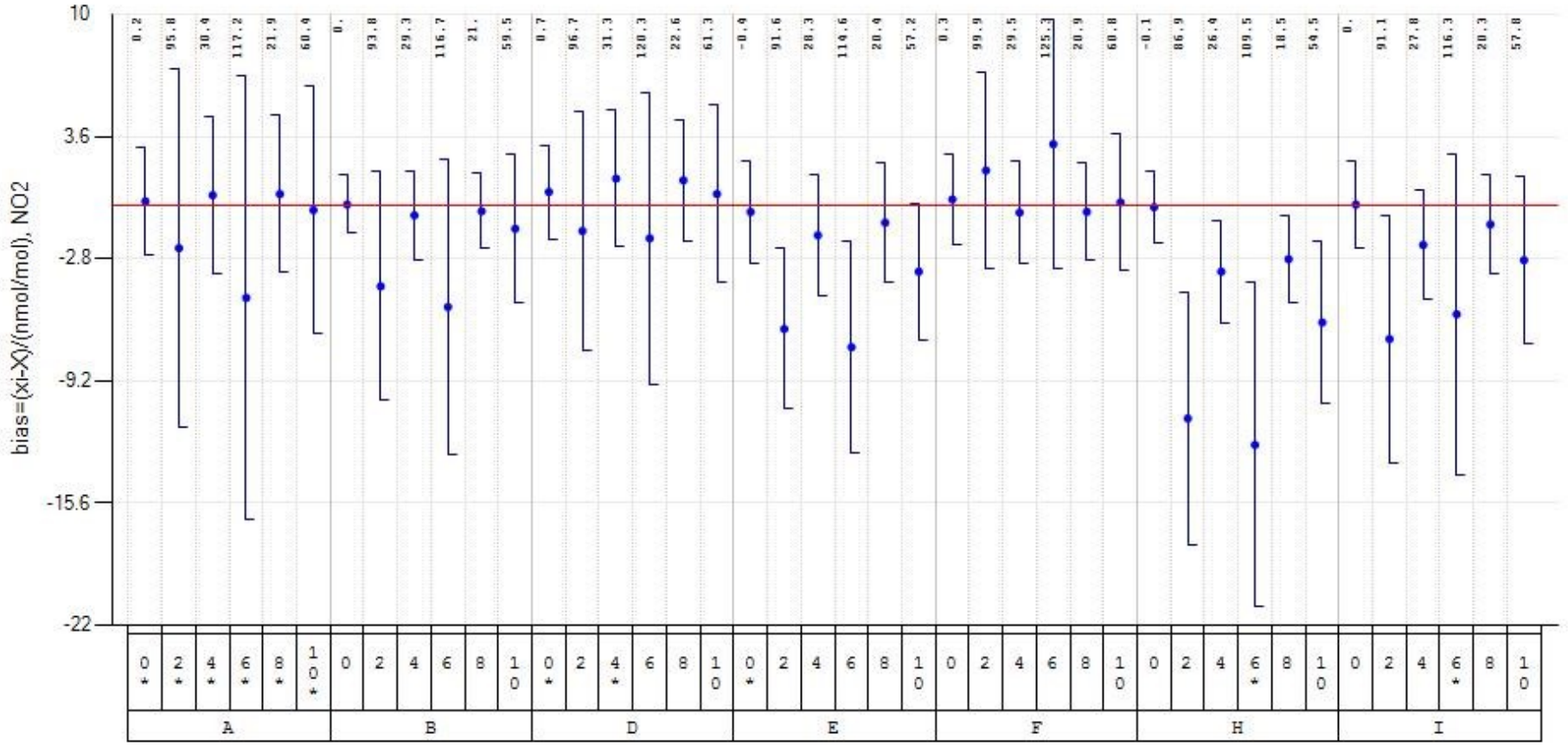

Figure 10: Bias of participant's NO2 measurement results

Expanded uncertainty of bias is presented as error bar for NO_2 run numbers 0, 2, 4, 6, 8 and 10 (see Table 3). Results with error bars touching or crossing the x-axis are satisfactory. For each evaluation the run number together with the participants rounded run average (nmol/mol) is given. The '*' mark indicates reported standard uncertainties bigger than σ_p. Participant C didn't submitted any values for this pollutants.

4. Performance characteristics of individual laboratories

Individual participants' biases were evaluated and are presented in chapter 3.2 (Figure 6 - 10). Since the results of NO_2 runs 1, 3, 5, 7 and 9 were not treated in proficiency evaluation the bias of these runs are presented in Figure 11.

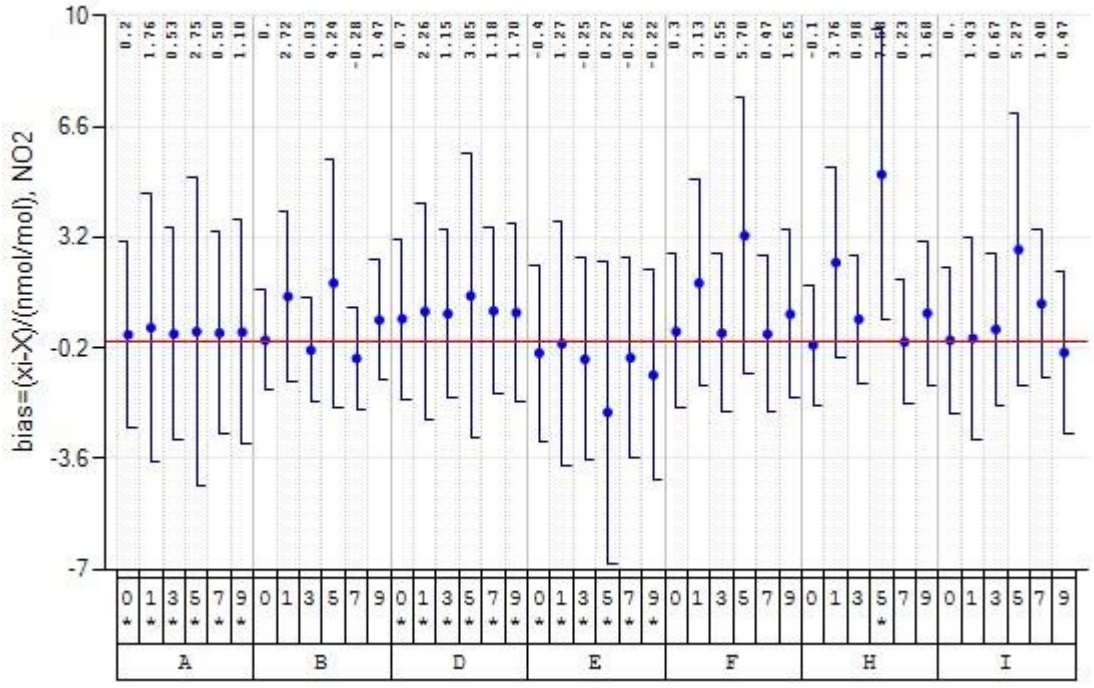

Figure 11: Bias of participant's NO2 measurements with error bars representing expanded uncertainty for run numbers 1, 3, 5, 7 and 9.

Within these test gas mixtures there is no gas phase titration to produce NO_2 (see Table 3). For each evaluation the run number together with the participants rounded run average (nmol/mol) is given. Participant C didn't report any values for this pollutant.

4.1. Converter efficiencies of NO2-to-NO for NOX analysers

Since NO and NO_2 test gases were produced by gas phase titration it is possible to evaluate the efficiency of the NO_2-to-NO converter of each participant's NO_X analyser. The evaluation takes each participant's NO and NO_2 measurements before and after oxidation by O_3. However, possible minor instabilities in the preparation of the test gas mixtures were not taken into account. The converter efficiency (α) is calculated using Equation 3 [4]:

$$\alpha = \frac{[NO2]_i - [NO2]_{i-1}}{[NO]_{i-1} - [NO]_i} \cdot 100\% \qquad \text{Equation 3}$$

Ideal value for α is 100%.

The evaluation of equation 3 for each participant at different concentration levels are given in Table 6.

Lab code	NO2 nmol/mol	α (%)
A	95	100,69
	30	100,54
	120	101,25
	22	101,62
	60	100,88
B	95	102,74
	30	101,84
	120	99,23
	22	100,65
	60	100,53
C	95	nr.
	30	nr.
	120	nr.
	22	nr.
	60	nr.
D	95	97,30
	30	108,42
	120	94,87
	22	80,99
	60	95,61
E	95	101,56
	30	99,61
	120	99,60
	22	100,61
	60	99,98
F	95	98,47
	30	98,90
	120	98,35
	22	98,86
	60	98,59
G	95	100,30
	30	100,01
	120	100,03
	22	100,84
	60	100,26
H	95	99,14
	30	99,48
	120	97,96
	22	98,32
	60	96,06
I	95	102,27
	30	107,38
	120	102,01
	22	110,60
	60	104,19

Table 6: Efficiency of NO2-to-NO converters.

nr. Not reported. Laboratory C didn't reported any values for NO and NO2. In red the values out of the limit.

5. Discussion

For a general assessment of the quality of each result a decision diagram was developed (Figure 12) that results in seven categories (1 to 7). The general comments for each category are:

- **1**: measurement result is completely satisfactory
- **2**: measurement result is satisfactory (z'-score satisfactory and En-score ok) but the reported uncertainty is too high
- **3**: measured value is satisfactory (z'-score satisfactory) but the reported uncertainty is underestimated (En-score not ok)
- **4**: measurement result is questionable (z'-score questionable) but due to a high reported uncertainty can be considered valid (En-score ok)
- **5**: measurement result is questionable (z'-score questionable and En-score not ok)
- **6**: measurement result is unsatisfactory (z'-score unsatisfactory) but due to a high reported uncertainty can be considered valid (En-score ok)
- **7**: measurement result is unsatisfactory (z'-score unsatisfactory and En-score not ok)

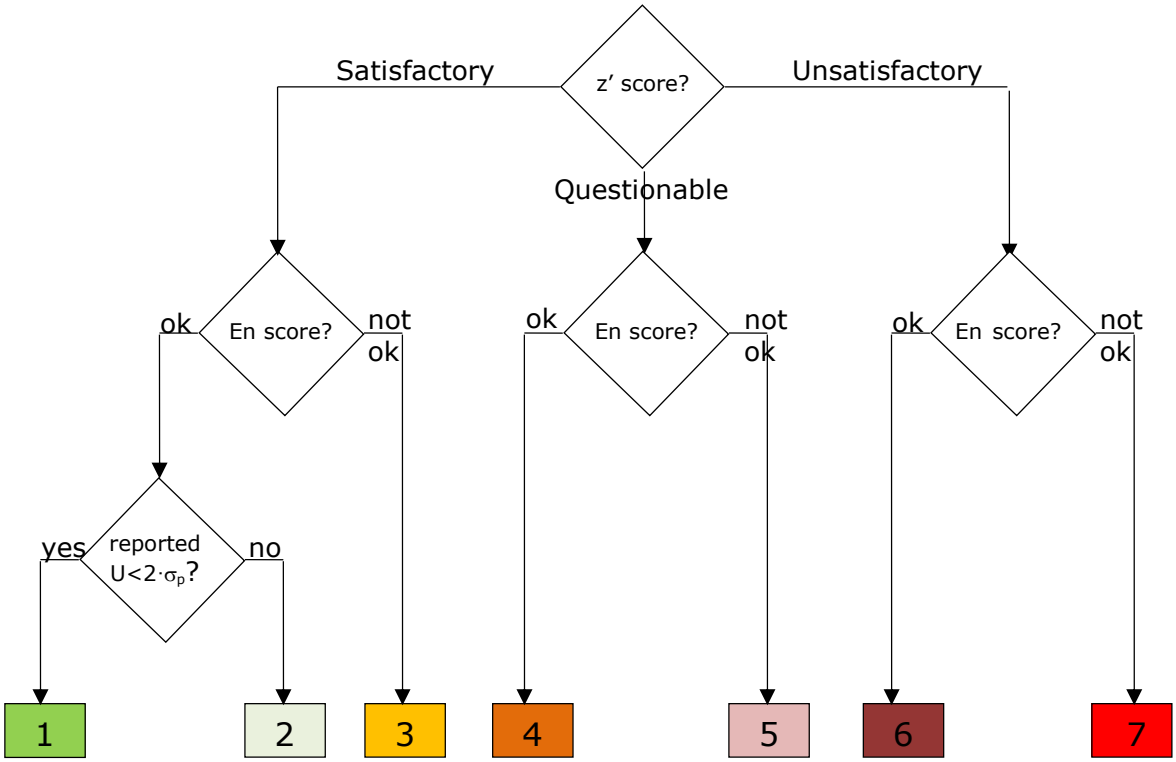

Figure 12: Decision diagram for general assessment of proficiency results.

The results of the ILC were assigned to categories according to the diagram given in Figure 12 and are presented in the following Table 7.

	run numb	Ref. conc. level	IE code							
			A	B	C	D	E	F	H	I
CO (µmol/mol)	0	-0,002	1	1	Unr	1	2	1	1	2
	1	4,993	1	1	1	1	1	3	1	2
	2	3,004	1	1	1	1	1	1	1	2
	3	7,987	1	1	1	1	1	3	1	2
	4	1,024	1	1	3	1	1	1	1	2
	5	2,017	1	1	1	1	1	1	1	2
NO (nmol/mol)	0	0,85	1	1	nr	1	2	1	1	1
	1	287,91	1	1	nr	1	1	1	2	2
	2	190,88	1	1	nr	1	1	1	2	2
	3	54,36	1	1	nr	1	1	1	1	1
	4	24,80	1	1	nr	1	1	1	1	1
	5	498,47	1	1	nr	1	3	1	2	2
	6	378,83	1	1	nr	1	1	1	2	2
	7	34,41	1	1	nr	1	1	1	1	1
	8	13,20	1	1	nr	1	1	1	1	1
	9	129,71	1	1	nr	1	1	1	2	1
	10	69,69	1	1	nr	1	1	1	1	1
NO_2 (nmol/mol)	0	-0,04	1	1	nr	2	2	1	1	1
	2	98,08	1	1	nr	1	3	1	7	5
	4	29,85	1	1	nr	2	1	1	3	1
	6	122,04	1	1	nr	1	3	1	7	2
	8	21,27	1	1	nr	1	1	1	3	1
	10	60,68	1	1	nr	1	1	1	5	1
O_3 (nmol/mol)	0	0,11	1	3	Unr	1	1	1	1	1
	1	90,79	1	1	1	1	1	1	1	2
	2	32,11	1	1	1	1	3	1	1	2
	3	108,63	1	1	1	1	1	1	1	2
	4	21,68	1	1	1	1	3	1	1	1
	5	60,02	1	1	1	1	3	1	1	2
SO_2 (nmol/mol)	0	0,06	1	1	Unr	1	2	1	1	1
	1	14,72	1	1	1	1	1	3	1	1
	2	4,94	1	1	1	1	2	1	1	1
	3	131,26	3	2	1	1	5	7	5	2
	4	60,27	1	1	1	1	5	7	3	2
	5	30,86	1	1	1	1	3	7	3	1

Table 7: General assessment of proficiency results.

"nr" is referring to values not reported.
"Unr" is referring to uncertainty values not reported.

6. Conclusions

The proficiency evaluation scheme has provided an assessment of the participants measured values and their evaluated uncertainties.

In terms of the criteria imposed by the European Directive (σ_p) 78.1% of the results reported during this ILC (see Table 7) by AQUILA laboratories fall into category '1' and are satisfactory both in terms of measured values and evaluated uncertainties. Among the remaining results the majority presented satisfactory measured values, but the evaluated uncertainties were either too high, category '2' (11.5%), or too small, category '3' (6.5%). Few values were found questionable (category 5: 1.9%) and 1.9% not satisfactory for both value and uncertainty (category 7).

ILC	Site	Categories %						
		1	2	3	4	5	6	7
Apr-08	Ispra (IT)	68.4	18.1	7.3	1.0	1.0	2.6	1.6
Oct-08 (I)	Ispra (IT)	37.9	40.8	14.2	0.6	3.6	1.0	1.9
Oct-08 (II)	Ispra (IT)	34.3	38.9	23.7	1.0	2.0	0.0	0.0
Sep-09	Langen (DE)	60.8	29.9	3.1	4.1	1.0	1.0	0.0
Oct-09	Ispra (IT)	85.0	5.7	7.5	0.4	1.4	0.0	0.0
Jun-10	Ispra (IT)	84.6	8.1	4.4	0.7	2.3	0.0	0.0
Sep-11	Ispra (IT)	86.1	7.9	5.4	0.0	0.3	0.0	0.3
Oct-11 (I)	Ispra (IT)	78.6	12.5	7.6	0.0	1.3	0.0	0.0
Oct-11 (II)	Langen (DE)	59.4	39.9	0.0	0.7	0.0	0.0	0.0
Jun-12	Ispra (IT)	92.2	0.5	7.3	0.0	0.0	0.0	0.0
Sep-13	Langen (DE)	75.7	20.9	2.0	0.0	1.4	0.0	0.0
Sep-13	Ispra (IT)	89.4	7.3	3.3	0.0	0.0	0.0	0.0
Oct-13	Ispra (IT)	86.8	8.9	3.6	0.4	0.4	0.0	0.0
May-14	Ispra (IT)	81.8	15.2	1.1	0.0	0.7	0.0	1.1
Oct-15	Langen (DE)	73.2	23.9	0.7	1.4	0.0	0.7	0.0
Oct-15 (I)	Ispra (IT)	90.2	7.6	1.6	0.3	0.3	0.0	0.0
Oct-15 (II)	Ispra (IT)	75.6	10.8	7.3	0.6	3.5	0.0	2.2
Jun-16	Ispra (IT)	79.3	17.8	2.9	0.0	0.0	0.0	0.0
Jun-17 (I)	Ispra (IT)	92.8	4.3	1.8	0.0	0.7	0.0	0.4
Jun-17 (II)	Ispra (IT)	78.1	11.5	6.5	0.0	1.9	0.0	1.9

Table 8: Flags summary

ILC	*Site*	*Satisfactory (%)*	*Questionable (%)*	*Unsatisfactory (%)*
June/05	Ispra (IT)	94.7	2.3	3.0
June/07	Ispra (IT)	97.8	1.9	0.3
October/07	Essen (DE)	93.2	4.6	2.2
April/08	Ispra (IT)	93.8	2.1	4.1
October/08_1	Ispra (IT)	92.9	4.2	2.9
October/08_2	Ispra (IT)	97.0	3.0	0.0
September/09	Langen (DE)	94.3	4.7	0.9
October/09	Ispra (IT)	98.2	1.8	0.0
June/10	Ispra (IT)	97.0	3.0	0.0
September/11	Ispra (IT)	99.4	0.3	0.3
October/11	Ispra (IT)	98.7	1.3	0.0
October/11	Langen (DE)	99.3	0.7	0.0
June/12	Ispra (IT)	100.0	0.0	0.0
September/13	Langen (DE)	98.6	1.4	0.0
September/13	Ispra (IT)	100.0	0.0	0.0
October/13	Ispra (IT)	99.3	0.7	0.0
May/14	Ispra (IT)	98.1	0.7	1.1
October/15	Langen (DE)	97.9	1.4	0.7
October/15_1	Ispra (IT)	99.4	0.6	0.0
October/15_2	Ispra (IT)	93.7	4.1	2.2
June/16	Ispra (IT)	100	0.0	0.0
June/17_1	Ispra (IT)	98.9	0.7	0.4
June/17_2	Ispra (IT)	96.2	1.9	1.9

Table 9: Z'-score summary

Comparability of results among AQUILA participants at the highest concentration level is acceptable only for some pollutant measurements.

The relative reproducibility limits, at the highest studied concentration levels, are 7.9% for CO, 3.7% for O_3, for NO 5.9% all within the objective derived from criteria imposed by the European Commission (σ_p see Table 4). The reproducibility for NO_2 (13.8%) and for SO_2 (26.7%) shows a general negative performance.

During this ILC the performance of all NRL was generally satisfactory for NO, CO and O_3. According to z'-score evaluation Laboratory F had 3 unsatisfactory results for SO_2 and Laboratory H 2 for NO_2. After the evaluation of the E_n-score number many laboratories were found for different pollutants above the limits as described in detail in table 5.

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Annex A. Assigned values

The assigned values of tested concentration levels (run) were derived from ERLAP's measurements which are calibrated against the certified reference values of CRMs and are traceable to international standards. In this perspective the assigned values are reference values as defined in the ISO 13528 [13].

To foster its reference function ERLAP is participating regularly to key comparisons of the Gas Analysis Working Group within the framework of BIPM's CCQM.

During this ILC ERLAP's SO_2, CO and NO analysers were calibrated according to the methodology described in the ISO 6143 [6]. Reference gas mixtures were produced from the primary reference materials (produced and certified by NMi Van Swinden Laboratorium) by dynamic dilution method using mass flow controllers [8]. All flows were measured with a certified molbloc/molbox1 system. For O_3 measurements, the analysers were calibrated using the JRC SRP42 primary standard (constructed by NIST) which has been compared to BIPM primary standard [26]. The photometer absorption cross section uncertainty (1.06%) was included in the uncertainty budget [27], [28].

The reference gas mixture and the calibration experiment evaluation were carried out using two computer applications, the "GUM WORKBENCH" [29] and "B-least" [30] respectively. For extending calibration from the NO to NO_2 channel of NO_X analyser the GPT test was performed to establish the efficiency of NO_2-converter.

ERLAP's measurement results were validated by comparison to the group statistics (x* and s*) for every parameter and concentration level of the ILC. These statistics are calculated from participants, applying the robust method described in the Annex C of the ISO 13528 [13]. The validation is taking into account ERLAP's measurement result (***X***) and its standard uncertainty ($\boldsymbol{u_X}$) as given in Equation 4 [13]:

$$\frac{\left|x^* - X\right|}{\sqrt{\frac{\left(1{,}25 \cdot s^*\right)^2}{p} + u_X^2}} < 2 \qquad \text{Equation 4}$$

Where ***x**** and ***s**** represent robust average and robust standard deviation respectively and ***p*** is the number of participants. Table **10**0 all inputs for Equation 4 are given and all ERLAP's measurement results are confirmed to be valid.

As a group evaluation robust average (x^*) and robust standard deviation (s^*) were calculated (applying the procedure described in Annex C of ISO 13528) for each run, and are presented in the following tables.

run	unit	X	uX	x*	s*	p
NO _0	nmol/mol	0,85	0,72	0,07	0,38	8
NO _1	nmol/mol	287,91	2,08	284,56	3,88	8
NO _2	nmol/mol	190,88	1,49	191,72	2,19	8
NO _3	nmol/mol	54,36	0,81	53,79	0,66	8
NO _4	nmol/mol	24,80	0,74	24,70	0,70	8
NO _5	nmol/mol	498,47	3,43	488,47	9,68	8
NO _6	nmol/mol	378,83	2,66	375,47	5,47	8
NO _7	nmol/mol	34,41	0,75	33,61	0,62	8
NO _8	nmol/mol	13,20	0,72	12,77	0,71	8
NO _9	nmol/mol	129,71	1,14	128,64	1,14	8
NO _10	nmol/mol	69,69	0,87	70,08	0,78	8
NO2 _0	nmol/mol	-0,04	0,72	0,03	0,25	8
NO2 _1	nmol/mol	1,33	1,28	2,18	1,00	8
NO2 _2	nmol/mol	98,08	1,46	94,33	4,63	8
NO2 _3	nmol/mol	0,29	0,76	0,50	0,52	8
NO2 _4	nmol/mol	29,85	0,79	29,17	1,58	8
NO2 _5	nmol/mol	2,44	1,89	4,04	2,32	8
NO2 _6	nmol/mol	122,04	2,08	117,64	4,70	8
NO2 _7	nmol/mol	0,24	0,74	0,41	0,64	8
NO2 _8	nmol/mol	21,27	0,75	20,94	1,02	8
NO2 _9	nmol/mol	0,81	0,88	1,16	0,63	8
NO2 _10	nmol/mol	60,68	0,98	59,42	1,84	8
CO _0	µmol/mol	0,00	0,01	0,00	0,02	9
CO _1	µmol/mol	4,99	0,02	4,96	0,16	9
CO _2	µmol/mol	3,00	0,02	2,96	0,10	9
CO _3	µmol/mol	7,99	0,03	7,92	0,22	9
CO _4	µmol/mol	1,02	0,01	1,00	0,03	9
CO _5	µmol/mol	2,02	0,01	1,98	0,07	9
O3 _0	nmol/mol	0,11	0,21	0,23	0,38	9
O3 _1	nmol/mol	90,79	0,71	90,48	0,61	9
O3 _2	nmol/mol	32,11	0,31	31,96	0,47	9
O3 _3	nmol/mol	108,63	0,84	109,13	1,11	9
O3 _4	nmol/mol	21,68	0,24	21,63	0,21	9
O3 _5	nmol/mol	60,02	0,48	60,22	0,48	9
SO2 _0	nmol/mol	0,06	0,50	0,08	0,07	9
SO2 _1	nmol/mol	14,72	0,52	14,72	1,13	9
SO2 _2	nmol/mol	4,94	0,51	5,00	0,65	9
SO2 _3	nmol/mol	131,26	0,87	131,26	7,82	9
SO2 _4	nmol/mol	60,27	0,61	60,32	3,74	9
SO2 _5	nmol/mol	30,86	0,53	30,93	2,14	9

Table 10: Validation of assigned values (X)

By comparison to the robust averages (x*) with taking into account the standard uncertainties of assigned values (u_X), and robust standard deviations (s*) as denoted by Equation 4.

The homogeneity of test gas was evaluated from measurements at the beginning and end of the distribution line. From the relative differences between beginning and end measurements, average and standard deviation were calculated, and the uncertainty of test gas due to lack of homogeneity was calculated as the sum of squares of these

average and standard deviation. $u_{X'}$ is the assigned value uncertainty without homogeneity contribution.

$$u_X^2 = u_{X'}^2 + \left(X \cdot u_{\mathrm{homogeneity'}}\right)^2 \qquad \text{Equation 5}$$

The upper and lower limits of bias due to homogeneity were evaluated to be smaller than 0.5% which constitutes the relative standard uncertainty of 0.3% of each concentration level. The standard uncertainties of assigned/reference values (u_X) were calculated with Equation 5 and used in the proficiency evaluations of chapter 3.

Annex B. The results of the ILC

In this annex are reported participant's results, presented both in tables and graphs. For all mixture concentration generated (run), participants were asked to report 3 results representing 30 minutes measurement each (x_i).

In this annex are presented the reported data and their uncertainty $u(x_i)$ and $U(x_i)$ expressed in mol/mol units.

For all the runs except concentration levels 0, also average (x_i) and standard deviation (s_i) of each participant are presented.

The assigned value is indicated on the graphs with the red line and the individual laboratories expanded uncertainties (Ux_i) are indicated with error bars.

The uncertainties of the assigned value included in the following tables are calculated with equation 5.

Reported values for SO_2

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	0.12	0.01	0.08	0.51	-0.02	0.06	0.06	0.85	0.10
u(xi)	0.59	0.30		0.75	1.16	0.80	0.50	0.58	0.78
U(xi)	1.17	0.59		1.50	2.32	1.61	1.01	1.16	1.56

Table 11: Reported values for SO2 run 0.

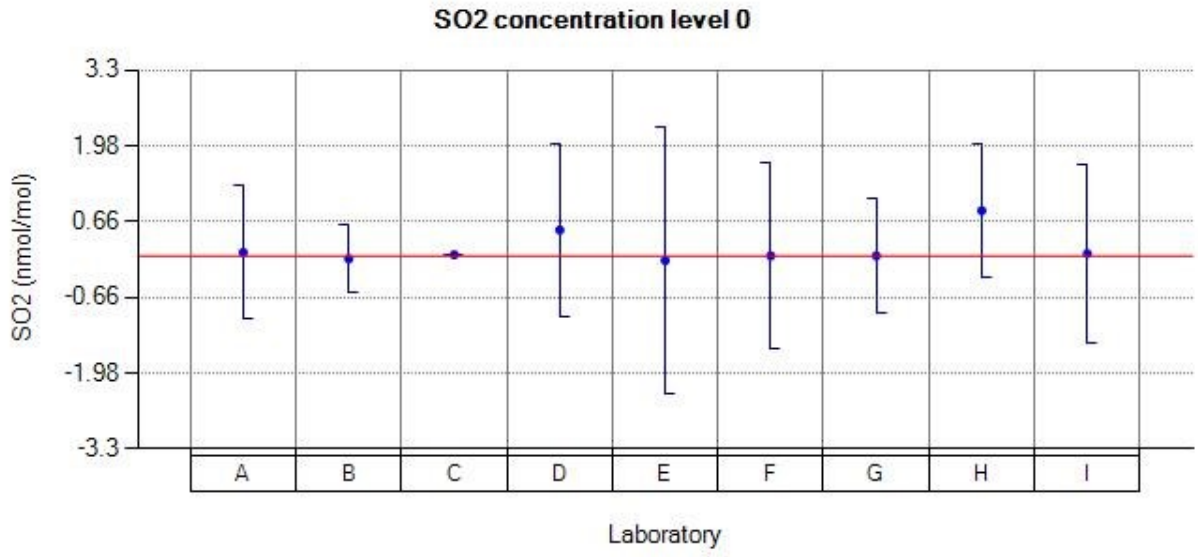

Figure 13: Reported values for SO2 run 0.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	14.11	13.46	15.12	15.09	13.31	17.49	14.73	16.34	14.40
xi, 2	14.08	13.49	14.93	15.10	13.40	17.54	14.74	16.25	14.40
xi, 3	14.12	13.44	15.18	15.08	13.41	17.52	14.70	16.36	14.40
xi	14.10	13.46	15.07	15.09	13.37	17.51	14.72	16.31	14.40
si	0.02	0.02	0.13	0.01	0.05	0.02	0.02	0.05	0.00
u(xi)	0.64	0.56	0.30	1.00	1.09	0.90	0.51	0.67	1.02
U(xi)	1.28	1.12	0.60	2.00	2.18	1.81	1.03	1.34	2.05

Table 12: Reported values for SO2 run 1.

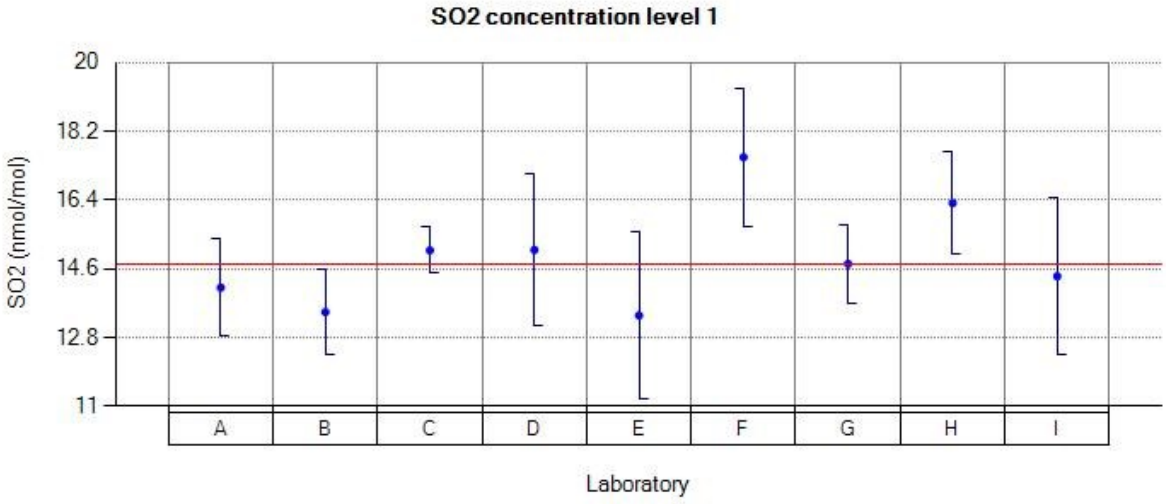

Figure 14: Reported values for SO2 run 1.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	4.69	4.21	4.93	5.36	4.44	5.83	4.95	6.11	4.80
xi, 2	4.69	4.22	5.03	5.38	4.35	5.79	4.94	6.04	4.80
xi, 3	4.66	4.28	4.96	5.35	4.40	5.75	4.94	6.07	4.70
xi	4.68	4.23	4.97	5.36	4.39	5.79	4.94	6.07	4.76
si	0.01	0.03	0.05	0.01	0.04	0.04	0.00	0.03	0.05
u(xi)	0.60	0.33	0.17	0.85	1.14	0.82	0.51	0.60	0.83
U(xi)	1.20	0.66	0.34	1.70	2.27	1.63	1.01	1.20	1.66

Table 13: Reported values for SO2 run 2.

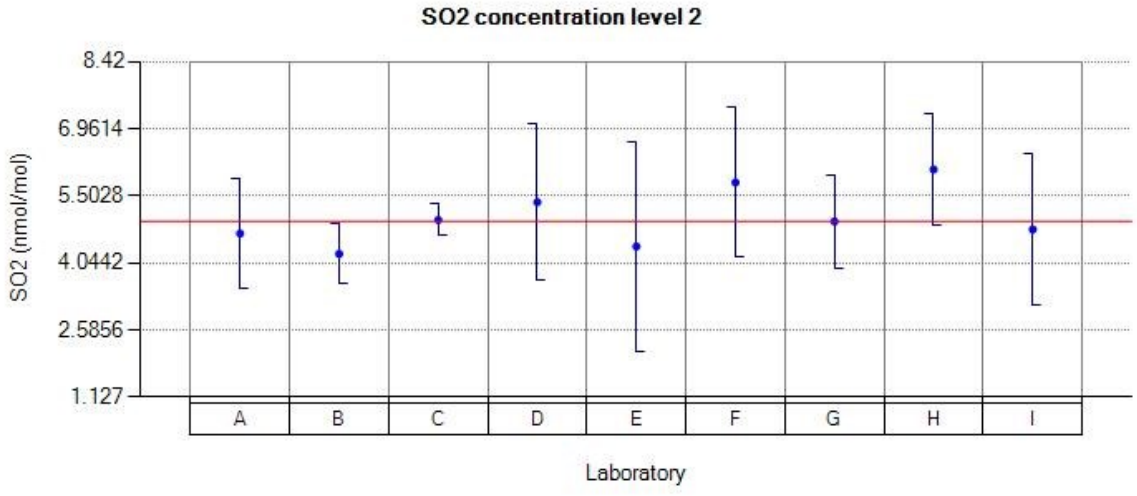

Figure 15: Reported values for SO2 run 2.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	126.37	124.19	135.52	132.05	119.66	157.43	131.06	139.27	129.30
xi, 2	126.46	124.40	135.89	132.40	119.90	157.17	131.32	139.44	129.50
xi, 3	126.84	124.25	135.20	132.49	119.72	157.18	131.41	139.70	129.30
xi	126.55	124.28	135.53	132.31	119.76	157.26	131.26	139.47	129.36
si	0.24	0.10	0.34	0.23	0.12	0.14	0.18	0.21	0.11
u(xi)	2.11	4.41	2.45	3.35	1.26	3.77	0.87	2.91	5.18
U(xi)	4.22	8.81	4.90	6.70	2.52	7.54	1.73	5.82	10.37

Table 14: Reported values for SO2 run 3.

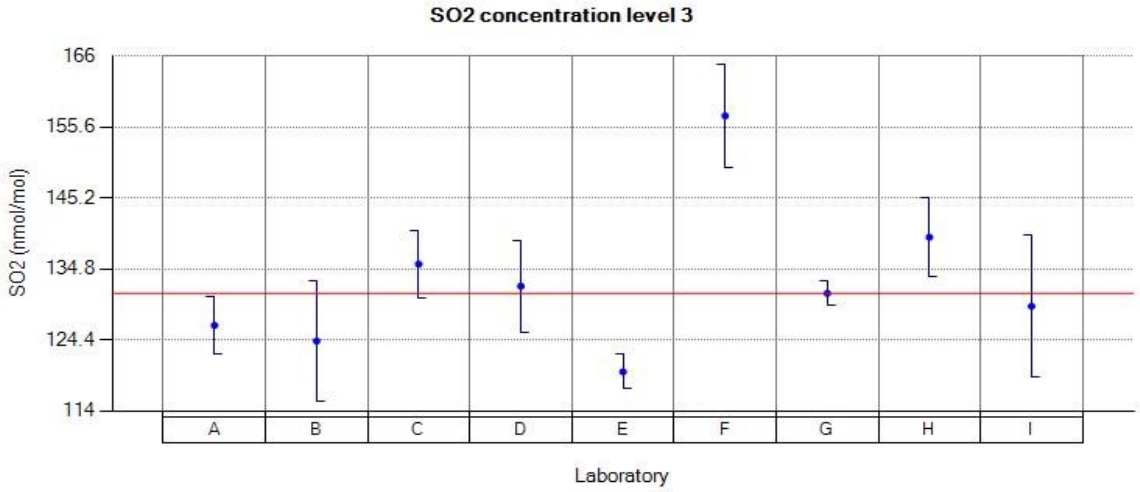

Figure 16: Reported values for SO2 run 3.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	58.12	56.82	62.43	60.82	55.04	72.15	60.29	64.48	59.50
xi, 2	58.01	56.78	62.54	60.83	55.04	72.16	60.28	64.38	59.50
xi, 3	58.09	56.88	62.32	60.89	55.09	72.14	60.24	64.29	59.40
xi	58.07	56.82	62.43	60.84	55.05	72.15	60.27	64.38	59.46
si	0.05	0.05	0.11	0.03	0.02	0.01	0.02	0.09	0.05
u(xi)	1.12	2.03	1.13	1.95	0.97	1.87	0.61	1.44	2.54
U(xi)	2.25	4.06	2.26	3.90	1.93	3.74	1.21	2.88	5.08

Table 15: Reported values for SO2 run 4.

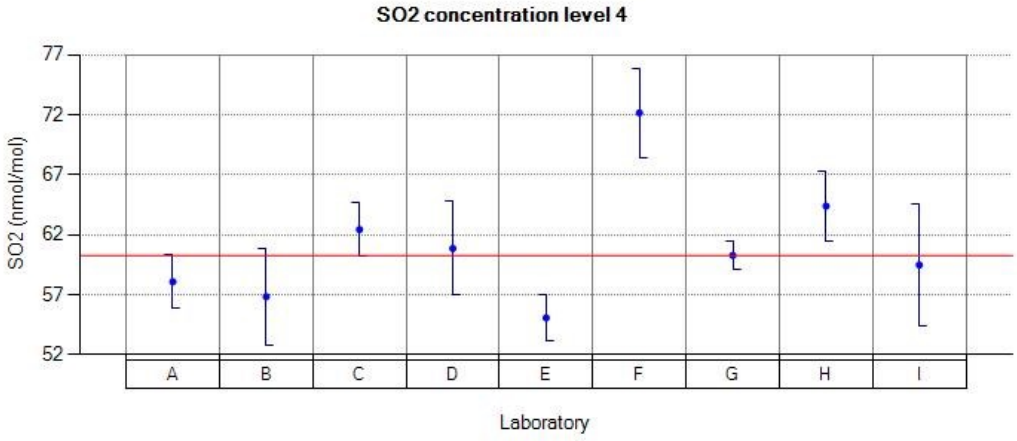

Figure 17: Reported values for SO_2 run 4.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	29.52	28.96	31.90	31.39	28.20	36.93	30.85	33.52	30.40
xi, 2	29.60	28.88	31.83	31.37	28.24	36.97	30.83	33.42	30.40
xi, 3	29.64	28.93	31.76	31.38	28.17	37.06	30.89	33.45	30.40
xi	29.58	28.92	31.83	31.38	28.20	36.98	30.85	33.46	30.40
si	0.06	0.04	0.07	0.01	0.03	0.06	0.03	0.05	0.00
u(xi)	0.77	1.07	0.59	1.35	1.03	1.18	0.53	0.90	1.50
U(xi)	1.53	2.13	1.18	2.70	2.06	2.36	1.05	1.80	3.01

Table 16: Reported values for SO2 run 5.

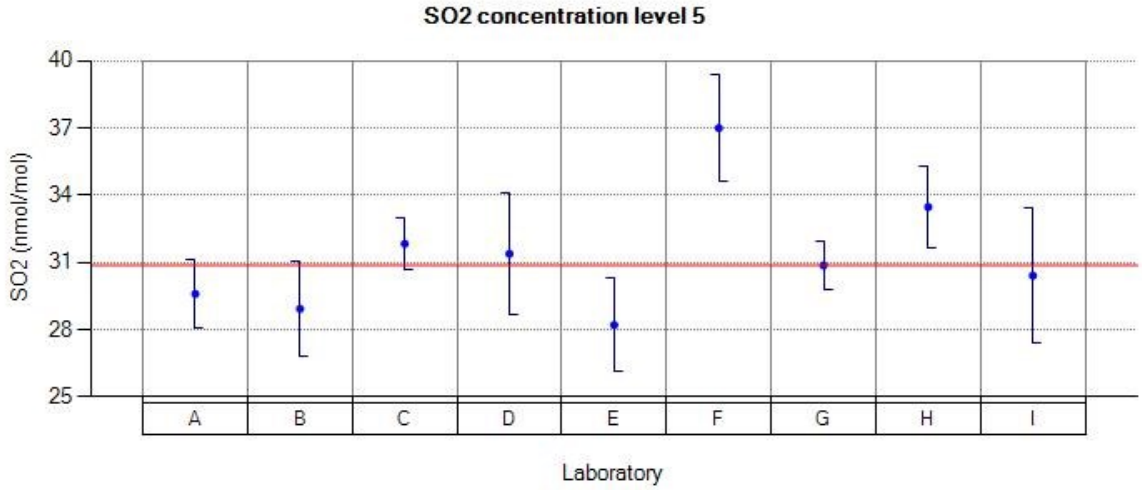

Figure 18: Reported values for SO2 run 5.

Reported values for CO

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	-0.002	0.014	0.097	-0.041	0.000	0.000	-0.002	-0.073	0.010
u(xi)	0.058	0.035		0.090	0.116	0.040	0.008	0.058	0.230
U(xi)	0.116	0.069		0.180	0.232	0.090	0.017	0.116	0.460

Table 17: Reported values for CO run 0.

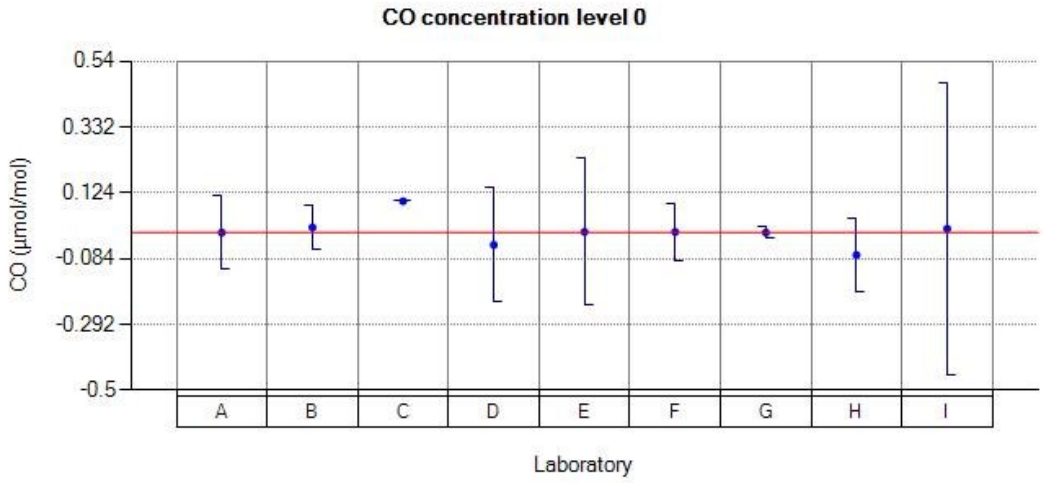

Figure 19: Reported values for CO run 0.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	4.927	5.065	5.197	4.824	5.100	4.850	4.989	4.921	4.737
xi, 2	4.932	5.073	5.207	4.823	5.100	4.850	4.993	4.927	4.758
xi, 3	4.934	5.071	5.197	4.817	5.100	4.850	4.996	4.929	4.768
xi	4.931	5.070	5.200	4.821	5.100	4.850	4.993	4.926	4.754
si	0.004	0.004	0.006	0.004	0.000	0.000	0.004	0.004	0.016
u(xi)	0.110	0.129	0.125	0.150	0.084	0.060	0.022	0.146	0.316
U(xi)	0.220	0.258	0.250	0.300	0.168	0.130	0.045	0.292	0.630

Table 18: Reported values for CO run 1.

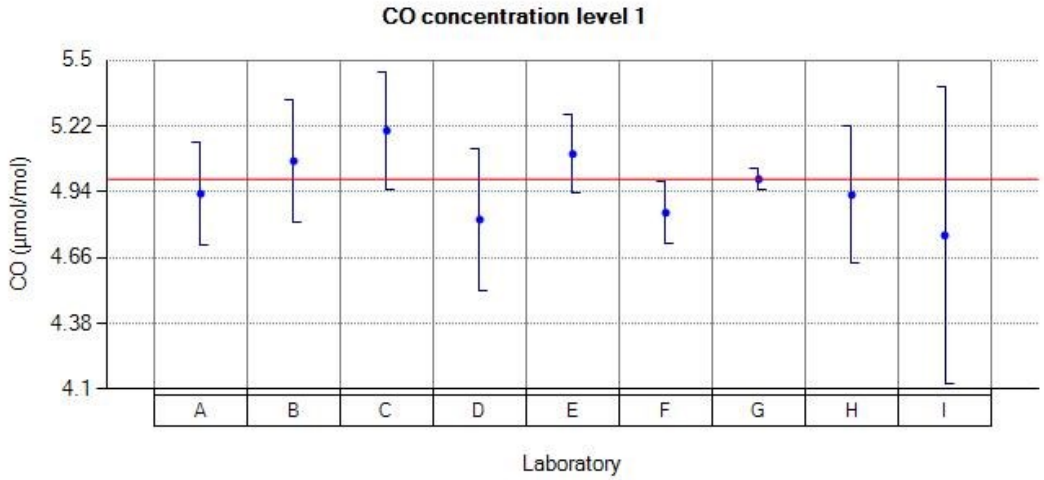

Figure 20: Reported values for CO run **1.**

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	2.965	3.051	3.127	2.858	3.000	2.910	3.004	2.899	2.869
xi, 2	2.966	3.051	3.130	2.853	3.000	2.910	3.004	2.893	2.869
xi, 3	2.966	3.049	3.110	2.844	3.000	2.910	3.005	2.900	2.869
xi	2.966	3.050	3.122	2.852	3.000	2.910	3.004	2.897	2.869
si	0.001	0.001	0.011	0.007	0.000	0.000	0.001	0.004	0.000
u(xi)	0.081	0.083	0.075	0.125	0.095	0.050	0.015	0.098	0.265
U(xi)	0.162	0.165	0.150	0.250	0.190	0.100	0.030	0.196	0.530

Table 19: Reported values for CO run 2.

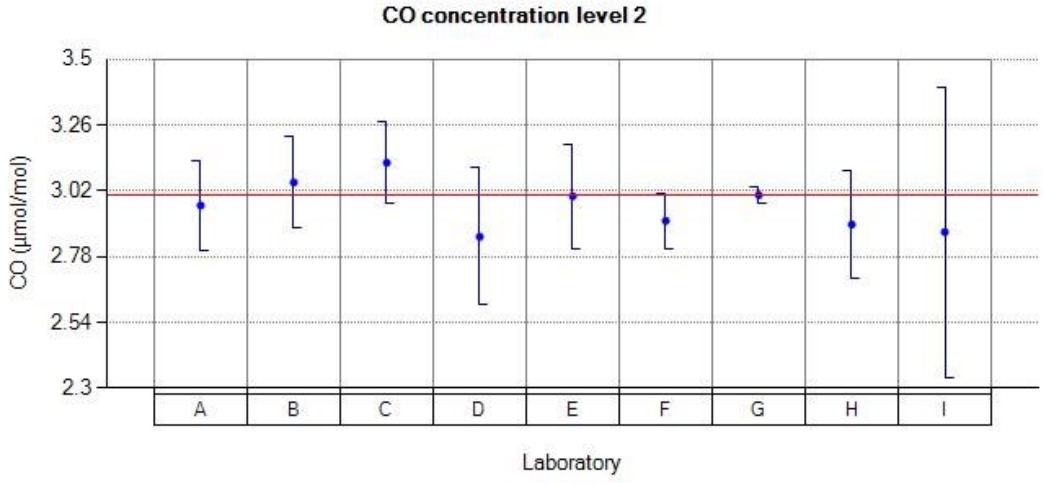

Figure 21: Reported values for CO run 2.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	7.885	8.059	8.203	7.748	8.100	7.780	7.981	7.906	7.576
xi, 2	7.892	8.065	8.213	7.755	8.100	7.780	7.989	7.915	7.607
xi, 3	7.894	8.065	8.223	7.751	8.100	7.780	7.992	7.909	7.617
xi	7.890	8.063	8.213	7.751	8.100	7.780	7.987	7.910	7.600
si	0.005	0.003	0.010	0.004	0.000	0.000	0.006	0.005	0.021
u(xi)	0.161	0.201	0.197	0.180	0.079	0.080	0.034	0.222	0.418
U(xi)	0.322	0.402	0.394	0.360	0.158	0.170	0.069	0.444	0.830

Table 20: Reported values for CO run 3.

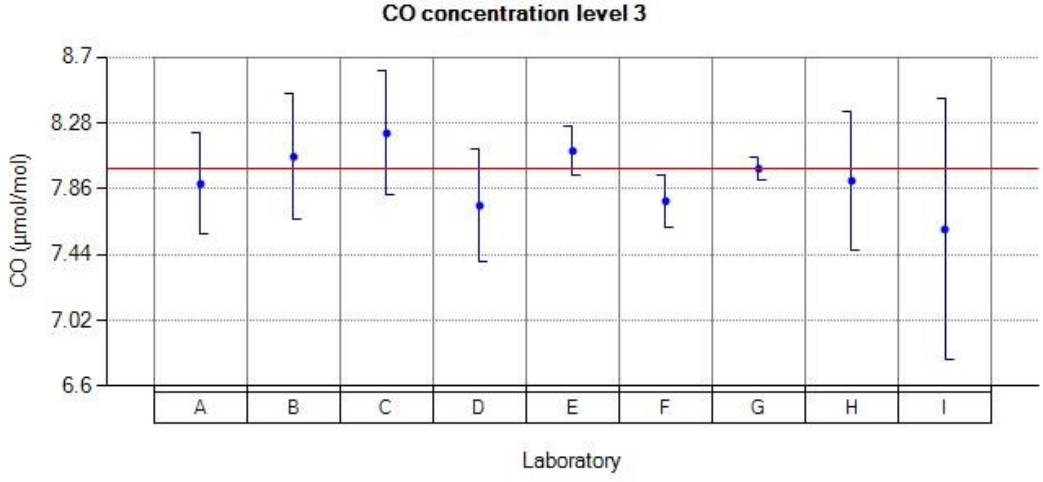

Figure 22: Reported values for CO run 3.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	1.009	1.002	1.120	0.881	1.000	0.990	1.025	0.939	0.990
xi, 2	1.007	1.002	1.120	0.878	1.000	0.990	1.024	0.934	0.980
xi, 3	1.008	1.000	1.113	0.879	1.000	0.990	1.023	0.928	0.980
xi	1.008	1.001	1.118	0.879	1.000	0.990	1.024	0.934	0.983
si	0.001	0.001	0.004	0.002	0.000	0.000	0.001	0.006	0.006
u(xi)	0.061	0.043	0.028	0.100	0.109	0.040	0.009	0.063	0.237
U(xi)	0.122	0.085	0.056	0.200	0.217	0.090	0.019	0.126	0.470

Table 21: Reported values for CO run 4.

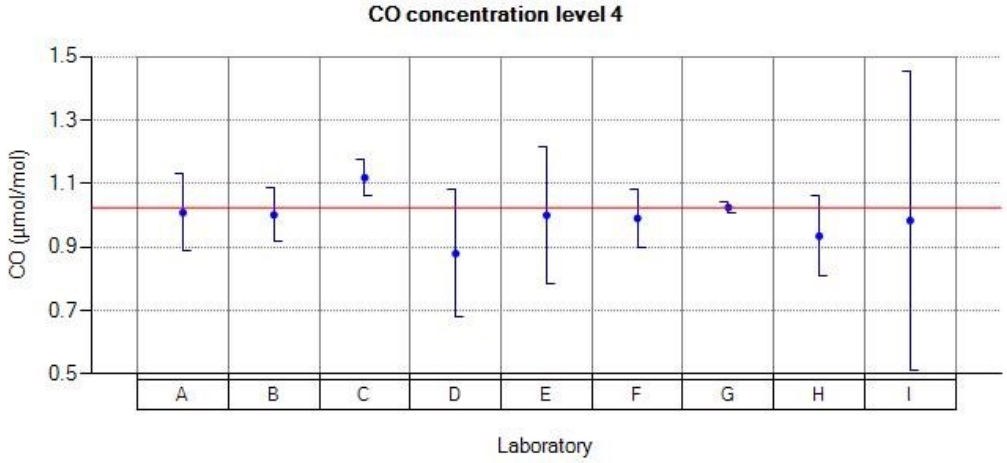

Figure 23: Reported values for CO run 4.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	1.988	2.027	2.103	1.858	2.000	1.950	2.016	1.903	1.919
xi, 2	1.990	2.027	2.107	1.859	2.000	1.950	2.017	1.907	1.929
xi, 3	1.989	2.026	2.120	1.857	2.000	1.950	2.017	1.902	1.929
xi	1.989	2.027	2.110	1.858	2.000	1.950	2.017	1.904	1.926
si	0.001	0.001	0.009	0.001	0.000	0.000	0.001	0.003	0.006
u(xi)	0.069	0.061	0.051	0.115	0.102	0.050	0.012	0.077	0.247
U(xi)	0.138	0.121	0.102	0.230	0.203	0.100	0.023	0.154	0.490

Table 22: Reported values for CO run 5.

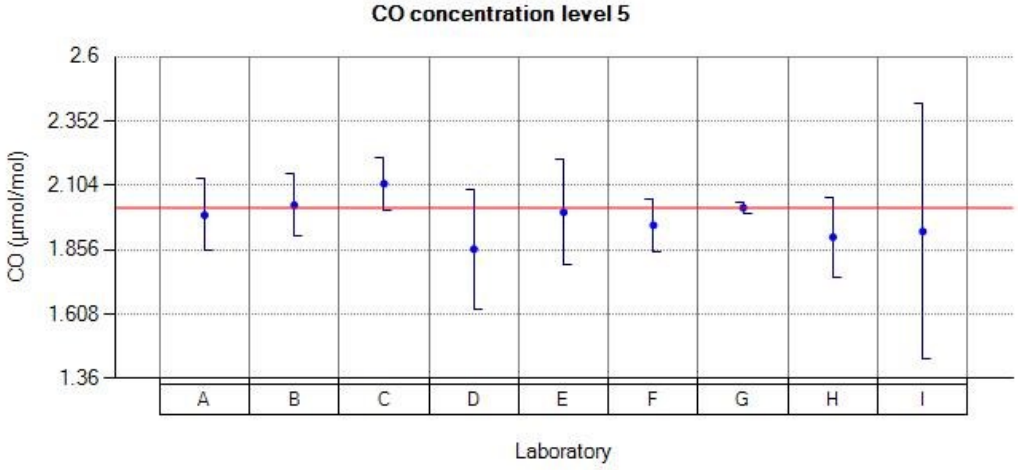

Figure 24: Reported values for CO run 5.

Reported values for O_3

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	0.06	0.78	0.40	-0.89	0.56	0.40	0.11	-0.01	0.10
u(xi)	0.81	0.24		0.65	0.11	0.50	0.21	0.58	0.94
U(xi)	1.62	0.48		1.30	0.22	0.99	0.42	1.16	1.88

Table 23: Reported values for O3 run 0.

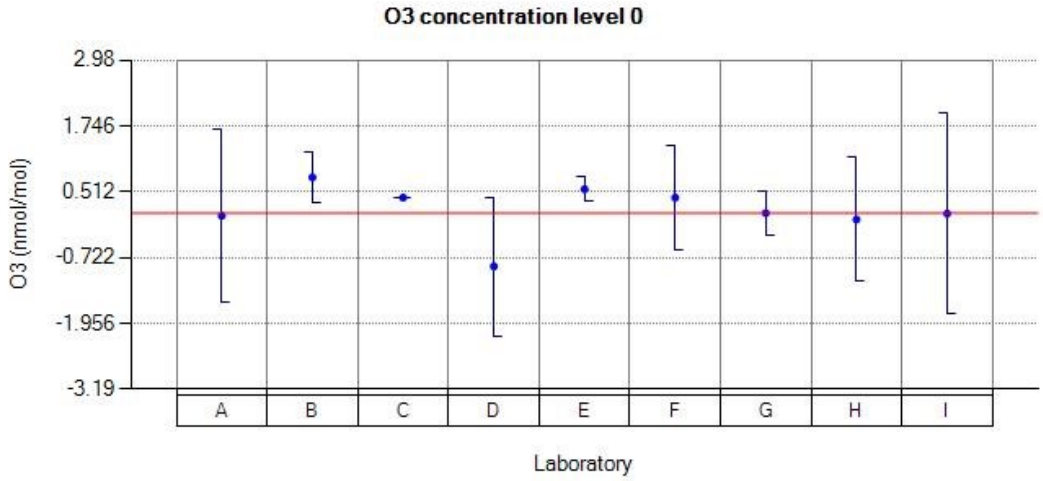

Figure 25: Reported values for O3 run 0.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	90.03	90.36	87.12	90.09	91.31	92.68	90.54	89.44	89.05
xi, 2	90.32	90.85	88.35	90.54	92.36	92.97	90.85	90.32	89.80
xi, 3	90.50	91.12	89.05	90.78	92.72	93.13	90.97	90.70	88.94
xi	90.28	90.77	88.17	90.47	92.13	92.92	90.78	90.15	89.26
si	0.23	0.38	0.97	0.35	0.73	0.22	0.22	0.64	0.46
u(xi)	1.45	2.57	1.72	1.70	0.51	1.32	0.71	1.48	4.14
U(xi)	2.90	5.14	3.44	3.40	1.01	2.65	1.43	2.96	8.29

Table 24: Reported values for O3 run 1

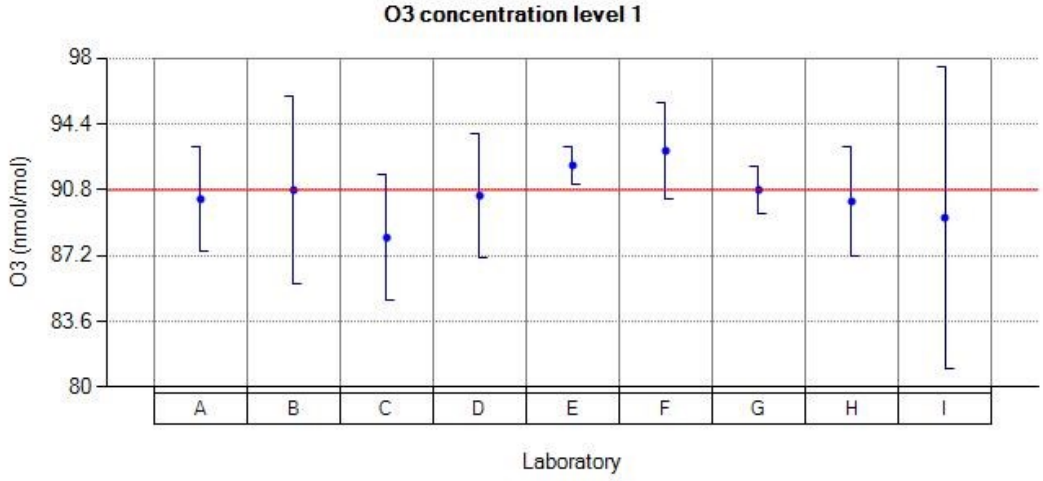

Figure 26: Reported values for O3 run 1.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	31.74	31.83	31.25	31.32	33.44	32.57	31.99	31.75	31.50
xi, 2	31.90	32.05	31.50	31.55	33.85	32.87	32.14	31.94	31.82
xi, 3	31.96	32.09	31.63	31.64	33.93	33.02	32.19	32.03	31.50
xi	31.86	31.99	31.46	31.50	33.74	32.82	32.10	31.90	31.60
si	0.11	0.14	0.19	0.16	0.26	0.22	0.10	0.14	0.18
u(xi)	0.95	0.93	1.10	1.00	0.13	0.66	0.31	0.76	1.71
U(xi)	1.89	1.86	2.20	2.00	0.26	1.32	0.61	1.52	3.42

Table 25: Reported values for O3 run 2.

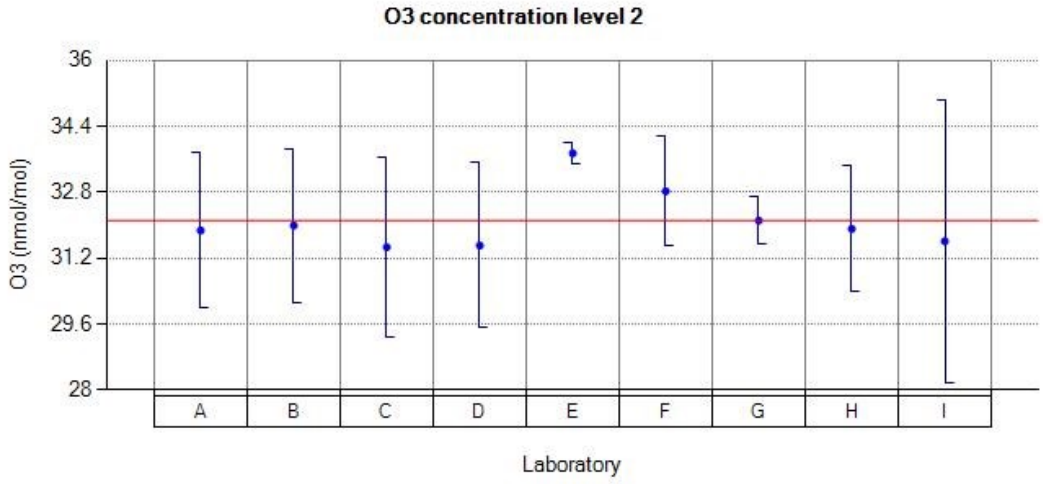

Figure 27: Reported values for O3 run 2.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	108.03	109.18	107.64	108.83	109.78	111.44	108.49	109.26	108.12
xi, 2	108.25	109.48	108.33	109.07	110.61	111.85	108.67	109.47	108.44
xi, 3	108.32	109.56	108.65	109.13	110.76	111.96	108.74	109.81	107.59
xi	108.20	109.40	108.20	109.01	110.38	111.75	108.63	109.51	108.05
si	0.15	0.20	0.51	0.15	0.52	0.27	0.12	0.27	0.42
u(xi)	1.65	3.09	1.94	1.90	0.71	1.56	0.84	1.75	4.99
U(xi)	3.30	6.18	3.88	3.80	1.43	3.12	1.69	3.50	9.98

Table 26: Reported values for O3 run 3.

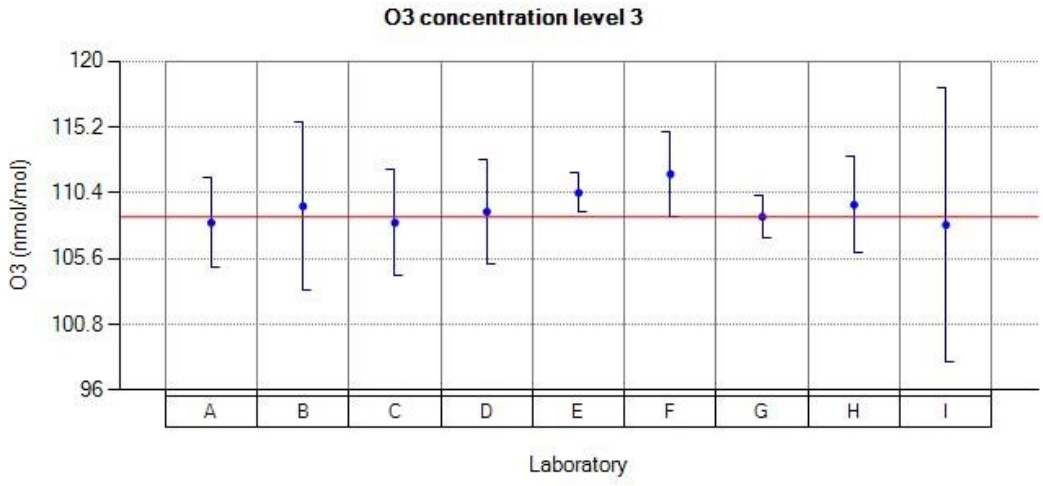

Figure 28: Reported values for O3 run 3.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	21.48	21.44	21.58	21.05	23.31	22.27	21.67	21.62	21.54
xi, 2	21.53	21.44	21.65	21.06	23.49	22.27	21.68	21.75	21.54
xi, 3	21.52	21.56	21.66	21.07	23.44	22.27	21.69	21.70	21.54
xi	21.51	21.48	21.63	21.06	23.41	22.27	21.68	21.69	21.54
si	0.02	0.06	0.04	0.01	0.09	0.00	0.01	0.06	0.00
u(xi)	0.89	0.65	0.99	0.90	0.11	0.58	0.24	0.67	1.35
U(xi)	1.77	1.30	1.98	1.80	0.23	1.16	0.48	1.34	2.71

Table 27: Reported values for O3 run 4.

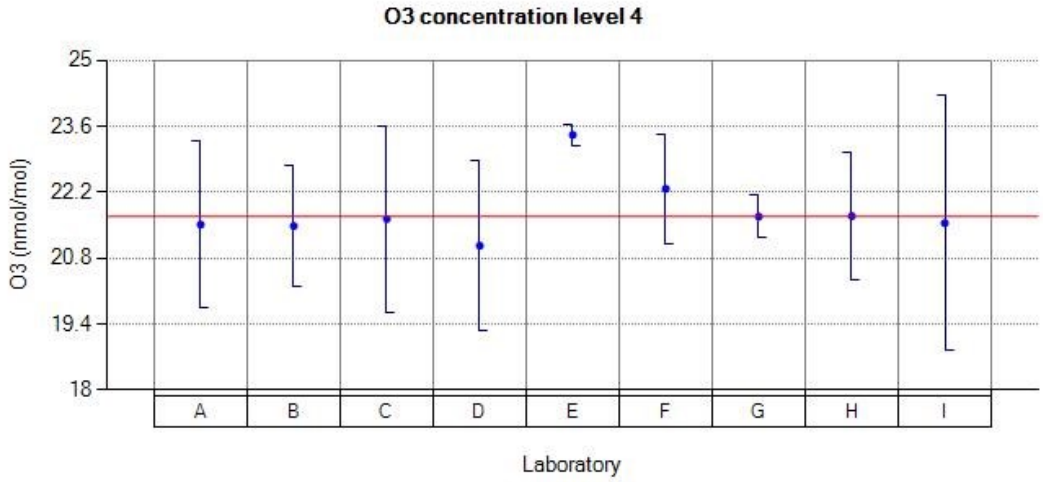

Figure 29: Reported values for O3 run 4.

	laboratories								
values	A	B	C	D	E	F	G	H	I
xi, 1	59.51	60.15	59.54	59.85	61.07	61.60	59.96	60.35	60.01
xi, 2	59.69	60.32	59.77	59.93	61.84	61.59	60.02	60.56	60.12
xi, 3	59.77	60.45	60.12	60.00	61.97	61.61	60.09	60.77	60.22
xi	59.65	60.30	59.81	59.92	61.62	61.60	60.02	60.56	60.11
si	0.13	0.15	0.29	0.07	0.48	0.01	0.06	0.21	0.10
u(xi)	1.15	1.71	1.41	1.35	0.25	0.95	0.48	1.08	2.87
U(xi)	2.31	3.42	2.82	2.70	0.50	1.91	0.95	2.16	5.75

Table 28: Reported values for O_3 run 5.

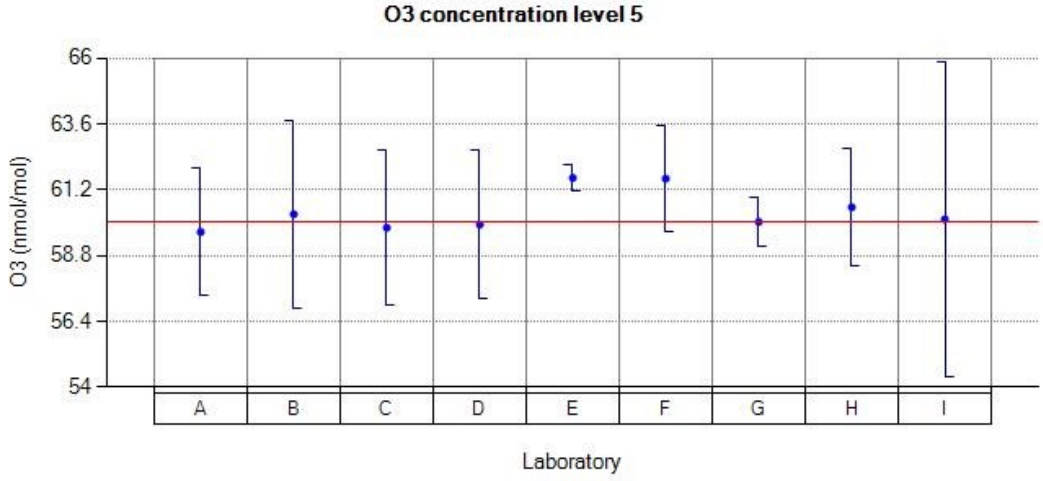

Figure 30: Reported values for O3 run 5.

Reported values for NO

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	-0.54	0.33	-0.85	0.11	0.15	0.85	-0.11	0.20
u(xi)	0.67	0.24	0.70	1.16	0.95	0.71	0.58	0.87
U(xi)	1.34	0.48	1.40	2.31	1.89	1.43	1.16	1.74

Table 29: Reported values for NO run 0.

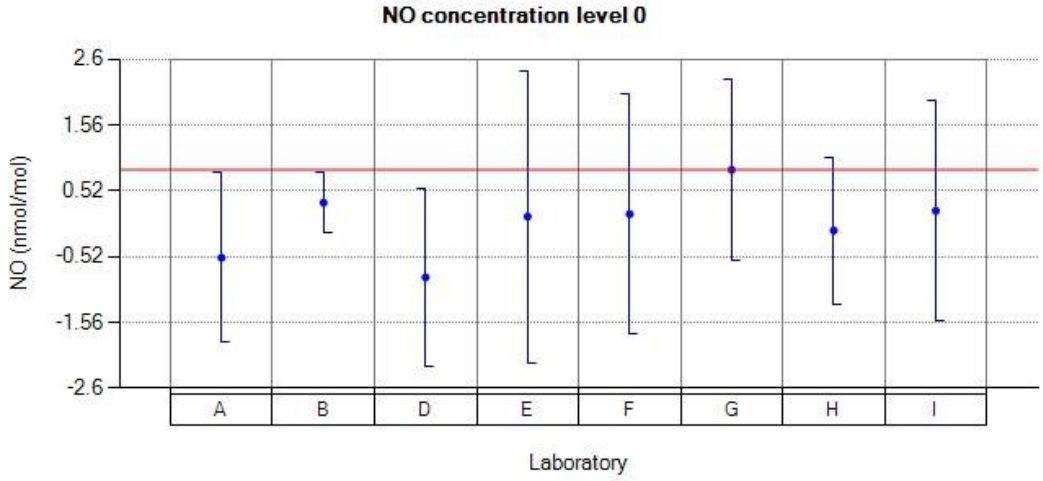

Figure 31: Reported values for NO run 0.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	284.90	286.98	284.88	283.45	288.49	287.87	276.75	277.00
xi, 2	284.98	287.02	285.10	283.96	288.43	288.02	277.60	277.30
xi, 3	285.07	287.45	285.49	284.16	287.79	287.85	278.11	276.70
xi	284.98	287.15	285.15	283.85	288.23	287.91	277.48	277.00
si	0.08	0.26	0.30	0.36	0.38	0.09	0.68	0.30
u(xi)	3.25	7.48	4.70	1.82	3.99	2.08	9.42	8.51
U(xi)	6.51	14.95	9.40	3.64	7.99	4.16	18.84	17.02

Table 30: Reported values for NO run 1.

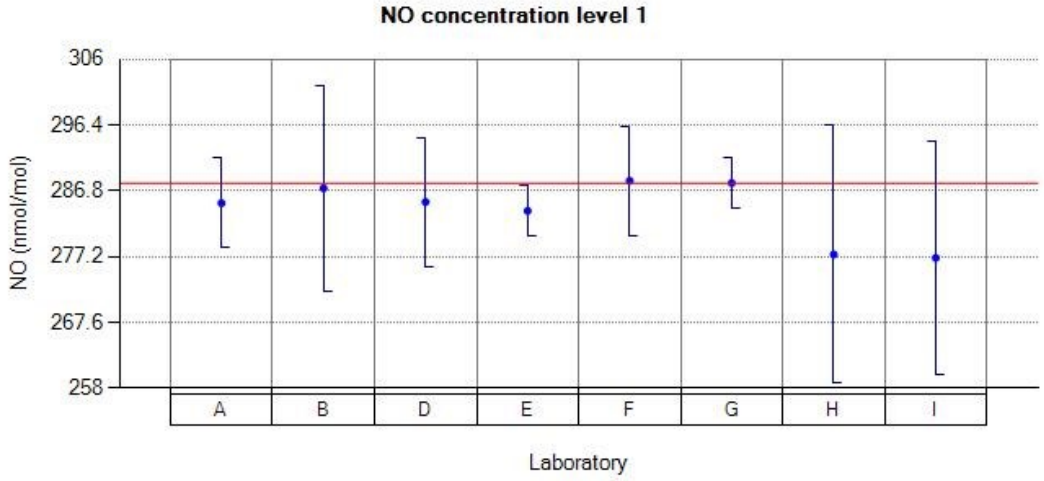

Figure 32: Reported values for NO run 1.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	190.66	194.91	191.26	193.23	193.15	191.19	196.69	185.40
xi, 2	190.20	193.42	190.97	191.71	193.35	190.93	196.27	185.30
xi, 3	189.93	192.31	190.58	191.44	192.31	190.51	192.23	185.30
xi	190.26	193.54	190.93	192.12	192.93	190.87	195.06	185.33
si	0.36	1.30	0.34	0.96	0.55	0.34	2.46	0.05
u(xi)	2.28	5.04	3.40	1.38	2.76	1.49	6.71	5.72
U(xi)	4.55	10.08	6.80	2.76	5.53	2.98	13.42	11.44

Table 31: Reported values for NO run 2.

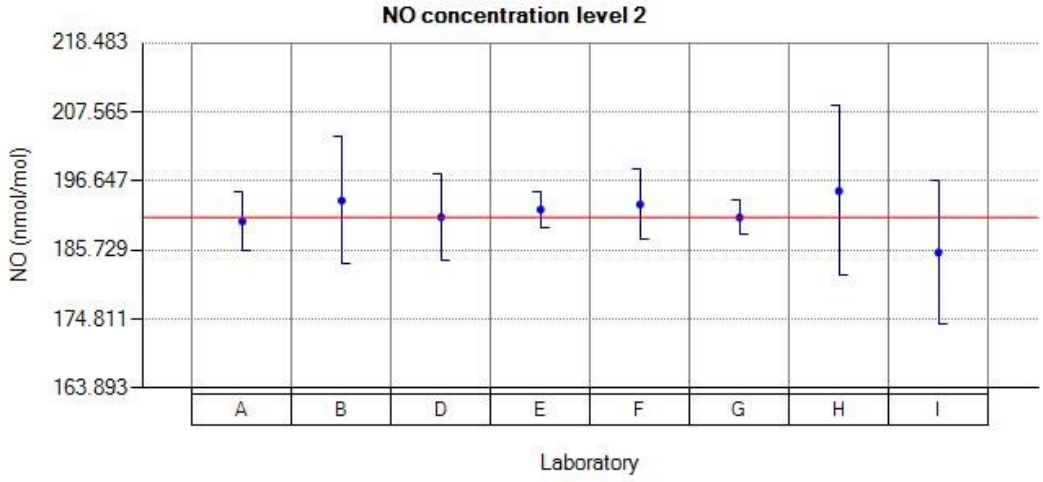

Figure 33: Reported values for NO run 2.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	54.07	54.61	54.14	53.80	53.60	54.36	51.95	53.20
xi, 2	54.11	54.59	54.02	53.41	53.55	54.40	51.95	53.20
xi, 3	54.07	54.49	54.03	53.68	53.48	54.33	51.94	53.00
xi	54.08	54.56	54.06	53.63	53.54	54.36	51.94	53.13
si	0.02	0.06	0.06	0.20	0.06	0.03	0.00	0.11
u(xi)	0.96	1.44	1.50	1.12	1.19	0.81	1.86	1.82
U(xi)	1.91	2.88	3.00	2.23	2.38	1.61	3.72	3.64

Table 32: Reported values for NO run 3.

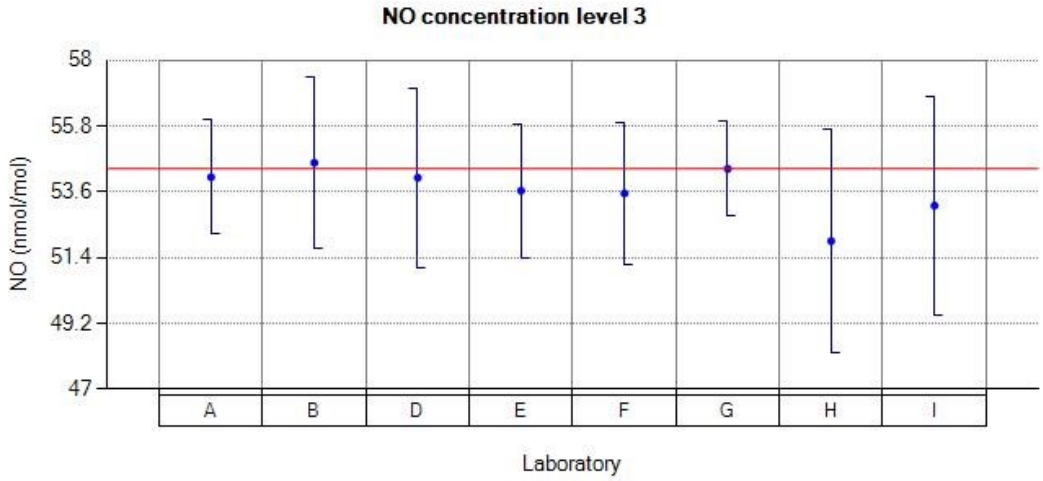

Figure 34: Reported values for NO run 3.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	24.00	24.71	24.08	25.41	24.87	24.80	26.92	24.20
xi, 2	24.04	24.73	24.48	25.28	25.07	24.78	26.48	24.10
xi, 3	24.16	24.76	23.67	24.94	24.89	24.83	26.69	23.80
xi	24.06	24.73	24.07	25.21	24.94	24.80	26.69	24.03
si	0.08	0.02	0.40	0.24	0.11	0.02	0.22	0.20
u(xi)	0.80	0.69	1.05	1.13	1.00	0.74	1.08	1.12
U(xi)	1.61	1.37	2.10	2.26	2.01	1.49	2.16	2.24

Table 33: Reported values for NO run 4.

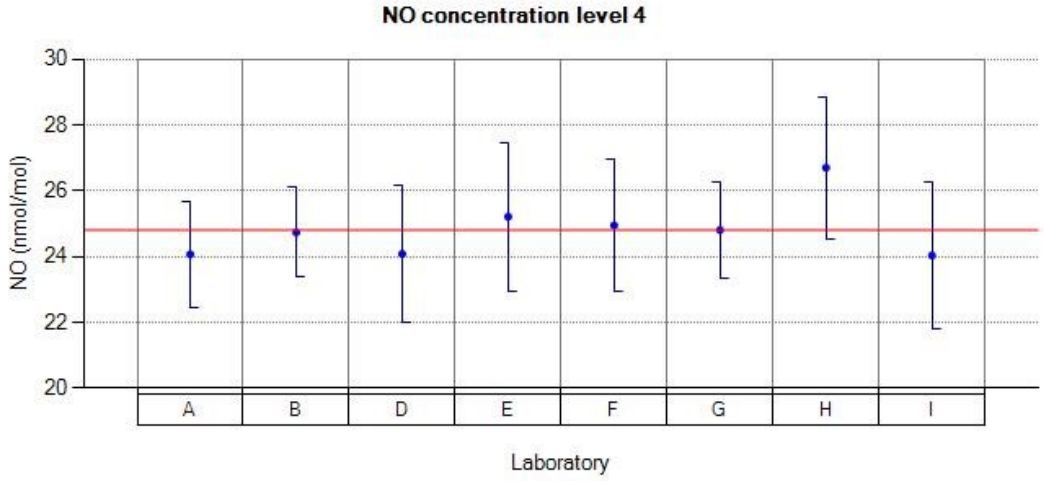

Figure 35: Reported values for NO run 4.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	490.42	480.82	491.97	487.16	499.03	498.41	478.63	476.90
xi, 2	490.79	481.59	493.18	489.24	500.11	498.32	479.72	477.40
xi, 3	490.98	482.65	491.88	489.65	499.90	498.68	479.11	476.70
xi	490.73	481.68	492.34	488.68	499.68	498.47	479.15	477.00
si	0.28	0.91	0.72	1.33	0.57	0.18	0.54	0.36
u(xi)	5.43	12.54	7.60	3.39	6.78	3.43	16.25	14.62
U(xi)	10.86	25.08	15.20	6.78	13.57	6.87	32.50	29.25

Table 34: Reported values for NO run 5.

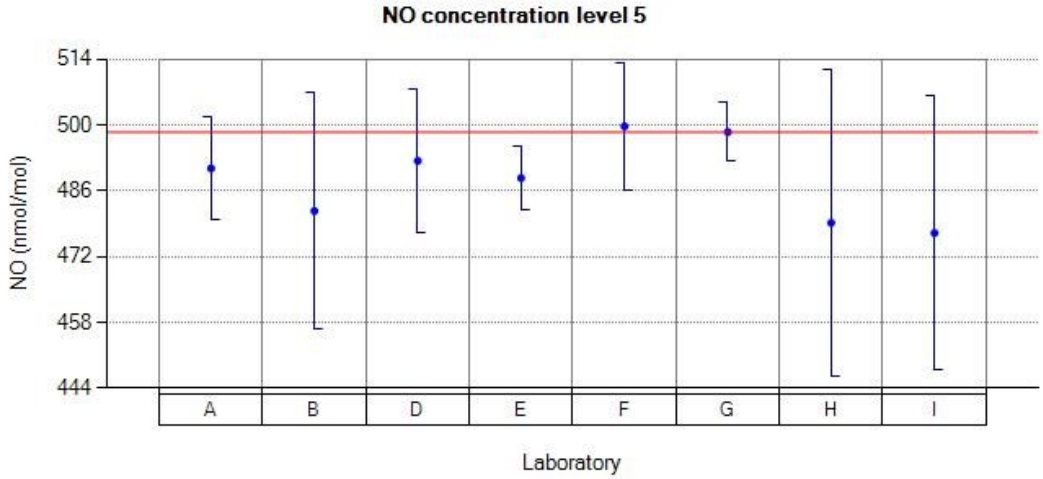

Figure 36: Reported values for NO run 5.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	374.83	369.86	376.69	374.08	381.59	378.77	379.33	364.50
xi, 2	375.04	370.02	375.76	375.42	382.14	378.81	378.93	364.70
xi, 3	374.71	370.38	376.02	374.94	382.56	378.92	379.74	361.90
xi	374.86	370.08	376.15	374.81	382.09	378.83	379.33	363.70
si	0.16	0.26	0.48	0.67	0.48	0.07	0.40	1.56
u(xi)	4.18	9.64	6.00	2.43	5.23	2.66	12.85	11.38
U(xi)	8.37	19.27	12.00	4.85	10.46	5.32	25.70	22.27

Table 35: Reported values for NO run 6.

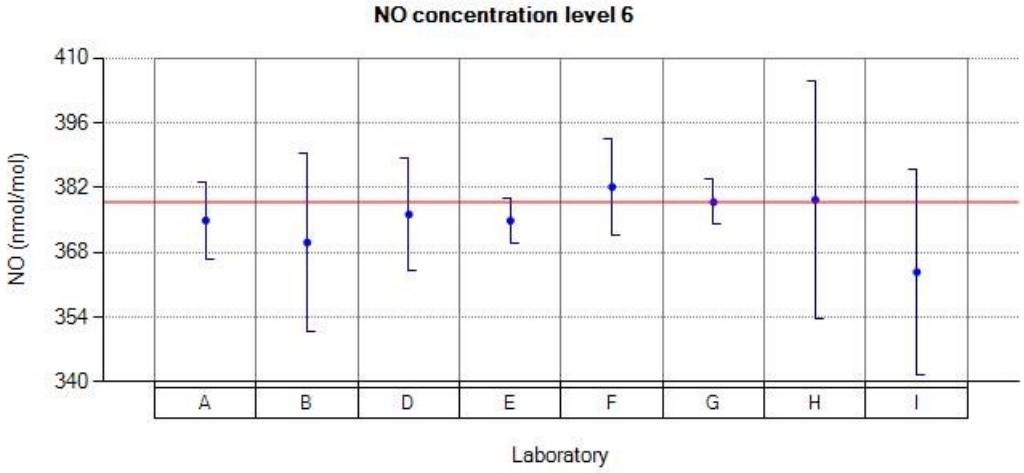

Figure 37: Reported values for NO run 6.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	33.77	34.16	33.62	33.54	33.32	34.40	32.33	33.00
xi, 2	33.90	34.15	33.79	33.84	33.47	34.44	32.43	33.30
xi, 3	34.07	34.19	33.50	33.34	33.18	34.40	32.11	33.10
xi	33.91	34.16	33.63	33.57	33.32	34.41	32.29	33.13
si	0.15	0.02	0.14	0.25	0.14	0.02	0.16	0.15
u(xi)	0.84	0.92	1.20	1.12	1.05	0.75	1.26	1.31
U(xi)	1.68	1.84	2.40	2.25	2.10	1.50	2.52	2.63

Table 36: Reported values for NO run 7.

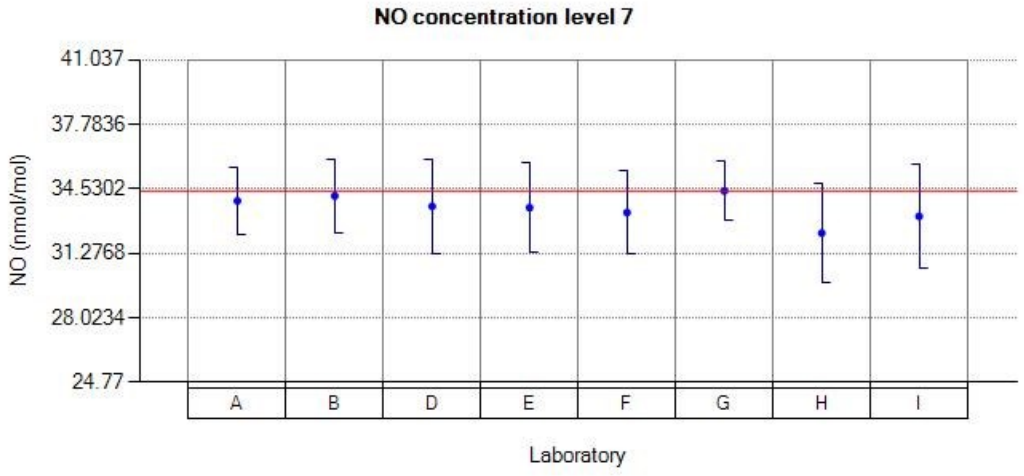

Figure 38: Reported values for NO run 7.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	12.26	12.80	11.94	12.95	13.01	13.24	14.36	12.30
xi, 2	12.19	12.79	11.64	12.75	13.23	13.20	14.36	12.30
xi, 3	12.18	12.77	12.09	12.79	13.05	13.16	14.41	12.20
xi	12.21	12.78	11.89	12.83	13.09	13.20	14.37	12.26
si	0.04	0.01	0.22	0.10	0.11	0.04	0.02	0.05
u(xi)	0.87	0.41	0.90	1.14	0.96	0.72	0.76	0.93
U(xi)	1.74	0.82	1.80	2.28	1.93	1.44	1.52	1.87

Table 37: Reported values for NO run 8.

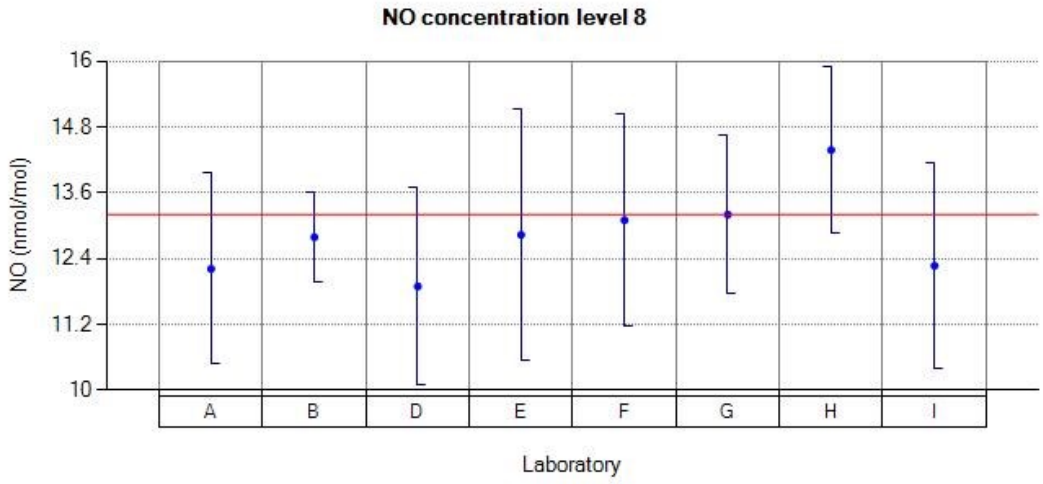

Figure 39: Reported values for NO run 8.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	129.47	128.60	129.54	127.77	128.74	129.57	125.16	126.50
xi, 2	129.54	128.44	129.40	128.30	128.56	129.84	125.14	128.20
xi, 3	129.75	128.70	129.81	128.76	129.10	129.73	125.65	128.20
xi	129.58	128.58	129.58	128.27	128.80	129.71	125.31	127.63
si	0.14	0.13	0.20	0.49	0.27	0.13	0.28	0.98
u(xi)	1.65	3.36	2.55	1.19	1.97	1.14	4.30	3.98
U(xi)	3.31	6.71	5.10	2.39	3.95	2.28	8.60	7.96

Table 38: Reported values for NO run 9.

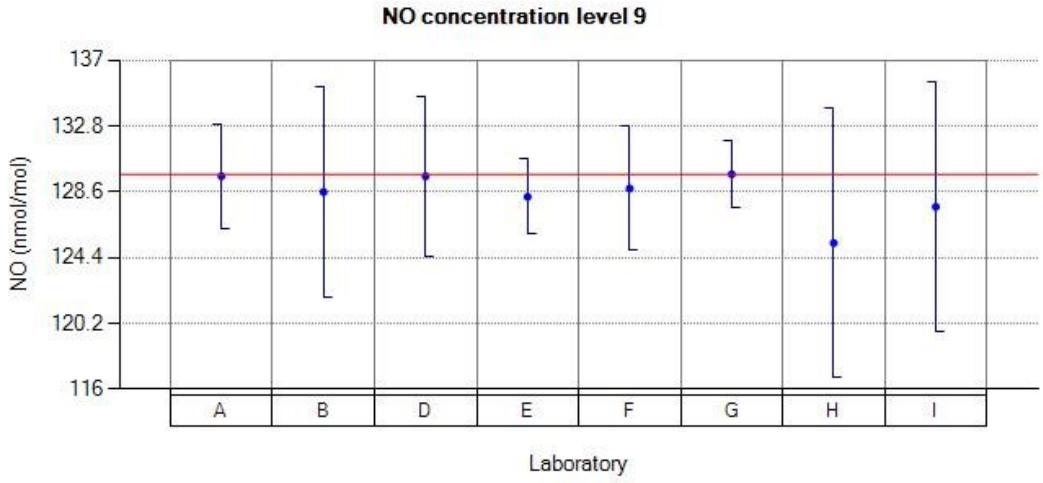

Figure 40: Reported values for NO run 9.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	69.71	70.65	69.75	70.82	70.41	69.79	74.51	67.90
xi, 2	69.83	70.22	69.47	70.96	70.44	69.70	74.76	67.90
xi, 3	69.69	70.01	69.48	70.84	70.53	69.57	74.39	67.90
xi	69.74	70.29	69.56	70.87	70.46	69.68	74.55	67.90
si	0.07	0.32	0.15	0.07	0.06	0.11	0.18	0.00
u(xi)	1.16	1.84	1.70	1.12	1.34	0.87	2.59	2.23
U(xi)	2.32	3.68	3.40	2.24	2.68	1.73	5.18	4.46

Table 39: Reported values for NO run 10.

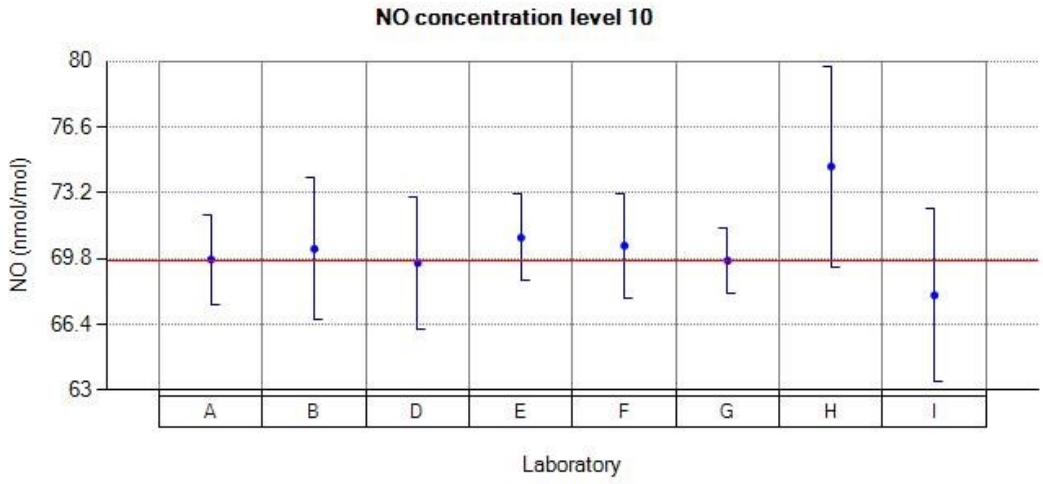

Figure 41: Reported values for NO run 10.

Reported values for NO_2

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	0.17	0.00	0.66	-0.39	0.27	-0.04	-0.13	0.00
u(xi)	0.65	0.26	1.00	1.14	0.95	0.72	0.58	0.87
U(xi)	1.29	0.53	2.00	2.28	1.89	1.43	1.16	1.74

Table 40: Reported values for NO2 run 0.

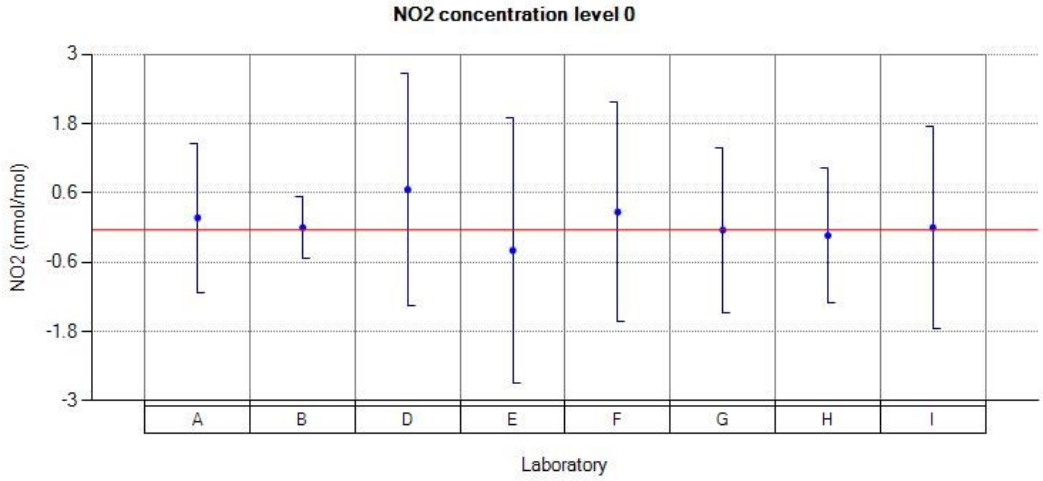

Figure 42: Reported values for NO2 run 0.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	95.84	93.78	96.13	90.05	99.92	97.75	86.45	90.40
xi, 2	95.85	94.02	96.75	92.36	99.52	98.09	87.13	91.40
xi, 3	95.79	93.69	97.32	92.35	100.27	98.39	87.11	91.40
xi	95.82	93.83	96.73	91.58	99.90	98.07	86.90	91.06
si	0.03	0.17	0.59	1.33	0.37	0.32	0.38	0.57
u(xi)	2.41	2.61	2.75	1.50	2.11	1.46	2.96	2.89
U(xi)	4.83	5.22	5.50	3.01	4.22	2.92	5.92	5.79

Table 41: Reported values for NO2 run 2.

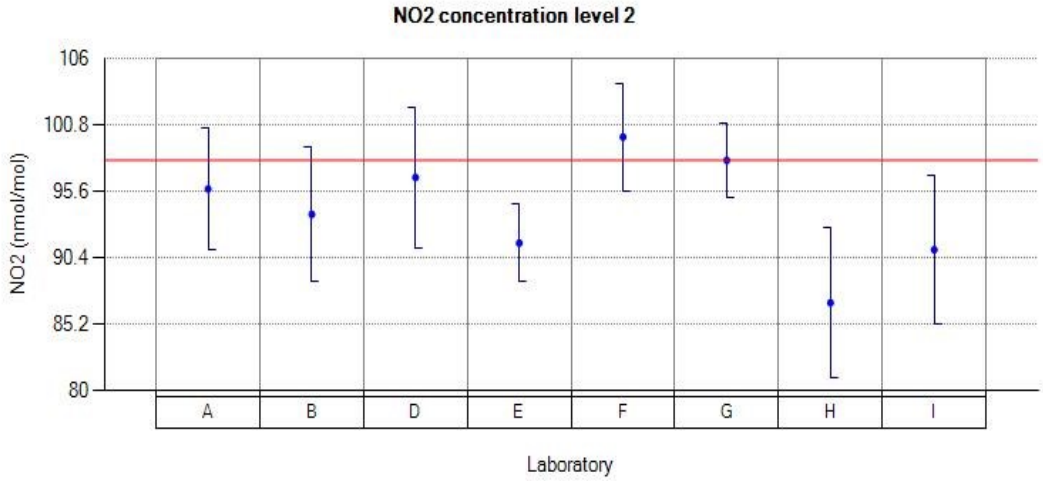

Figure 43: Reported values for NO2 run 2.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	30.46	29.35	30.98	28.25	29.51	29.84	26.19	27.60
xi, 2	30.43	29.34	31.39	28.27	29.33	29.85	26.39	27.90
xi, 3	30.26	29.25	31.38	28.32	29.57	29.86	26.51	27.80
xi	30.38	29.32	31.25	28.28	29.47	29.85	26.36	27.76
si	0.10	0.05	0.23	0.03	0.12	0.01	0.16	0.15
u(xi)	1.01	0.85	1.60	1.39	1.10	0.79	1.08	1.19
U(xi)	2.02	1.71	3.20	2.79	2.20	1.57	2.16	2.39

Table 42: Reported values for NO2 run 4.

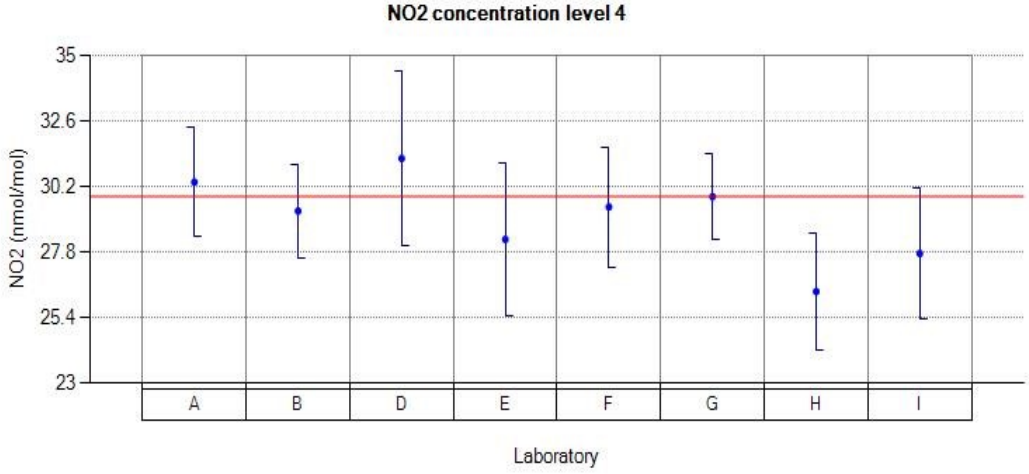

Figure 44: Reported values for NO2 run 4.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	117.81	116.96	119.98	114.87	125.27	122.08	109.38	115.90
xi, 2	117.08	116.66	121.64	114.51	125.40	122.12	109.60	116.50
xi, 3	116.68	116.48	119.31	114.41	125.08	121.93	109.45	116.60
xi	117.19	116.70	120.31	114.59	125.25	122.04	109.47	116.33
si	0.57	0.24	1.20	0.24	0.16	0.10	0.11	0.37
u(xi)	2.84	3.24	3.20	1.83	2.55	2.08	3.70	3.64
U(xi)	5.68	6.48	6.40	3.67	5.09	4.16	7.40	7.29

Table 43: Reported values for NO2 run 6.

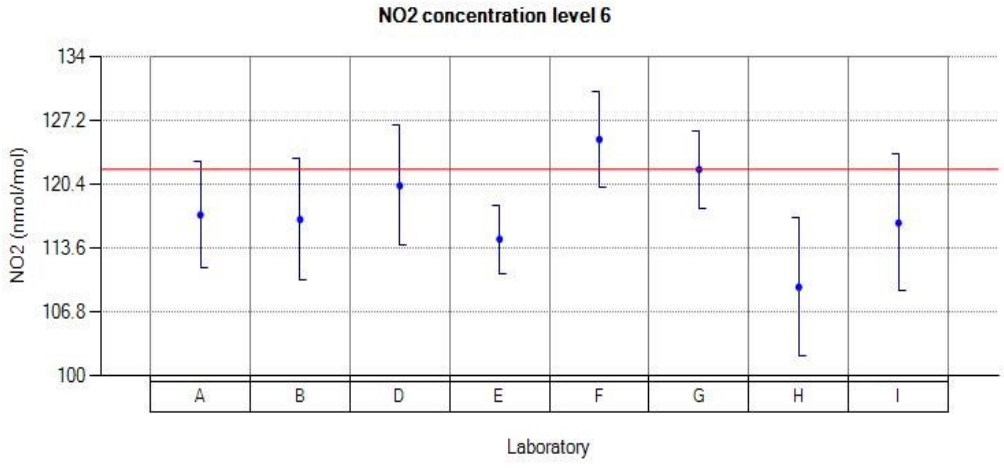

Figure 45: Reported values for NO2 run 6.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	21.81	20.93	22.60	20.59	20.97	21.24	18.57	20.30
xi, 2	21.85	20.97	22.55	20.11	21.02	21.29	18.44	20.30
xi, 3	21.91	20.96	22.59	20.38	20.80	21.29	18.33	20.20
xi	21.85	20.95	22.58	20.36	20.93	21.27	18.44	20.26
si	0.05	0.02	0.02	0.24	0.11	0.02	0.12	0.05
u(xi)	1.01	0.64	1.40	1.38	1.03	0.75	0.87	1.05
U(xi)	2.02	1.28	2.80	2.75	2.06	1.50	1.74	2.11

Table 44: Reported values for NO2 run 8.

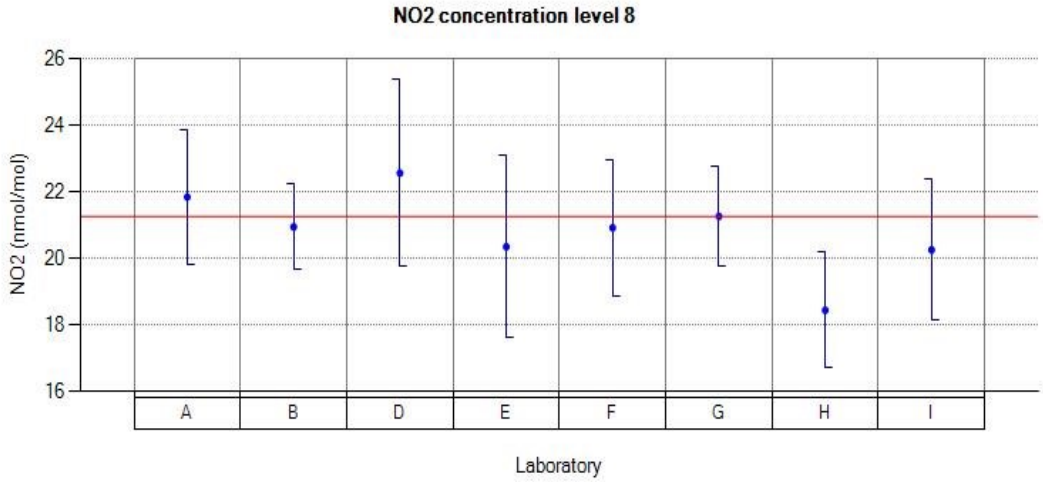

Figure 46: Reported values for NO2 run 8.

	laboratories							
values	A	B	D	E	F	G	H	I
xi, 1	60.39	59.29	60.97	56.91	60.71	60.60	54.64	57.80
xi, 2	60.43	59.43	61.38	57.06	60.99	60.68	54.16	57.80
xi, 3	60.44	59.61	61.47	57.62	60.78	60.75	54.78	57.80
xi	60.42	59.44	61.27	57.19	60.82	60.67	54.53	57.80
si	0.02	0.15	0.26	0.37	0.14	0.07	0.32	0.00
u(xi)	1.65	1.66	2.10	1.49	1.49	0.98	1.91	1.95
U(xi)	3.31	3.33	4.20	2.98	2.97	1.95	3.82	3.90

Table 45: Reported values for NO2 run 10.

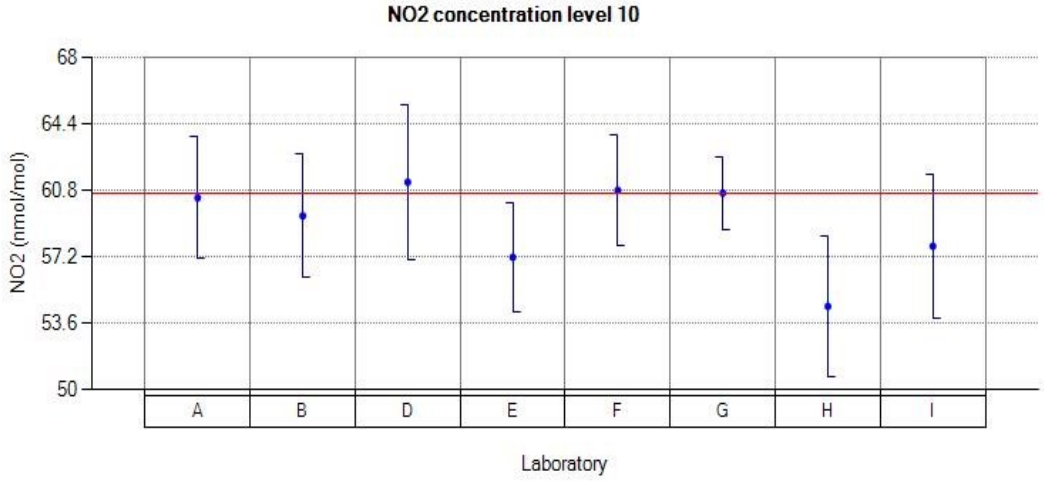

Figure 47: Reported values for NO2 run 10.

Annex C. The precision of standardised measurement methods

For the main purpose of monitoring trends between different ILC undertaken by ERLAP, the precision of standardized SO_2, CO, O_3 and NO_X measurement methods [2], [3], [4] and [5] as implemented by NRLs, was evaluated.

Applied methodology is described in ISO 5725-1, 5725-2 and 5725-6 [14], [15] and [16]. The precision experiment has involved a total of nine laboratories, the actual number of labs (p_j) is reported in Table 46. Six concentration levels (for run 0 only one value is requested so repeatability cannot be evaluated) were tested for O_3, CO, SO_2 and NO_2, and eleven for NO. Outlier tests were performed and results are reported in Annex D.

The repeatability standard deviation (s_r) was calculated in accordance with ISO 5725-6 as the square root of average within-laboratory variance. The repeatability limit (r) is calculated using Equation 6 [16]. It represents the biggest difference between two test results found on an identical test gas by one laboratory using the same apparatus within the shortest feasible time interval that should not be exceeded on average more than once in 20 cases in the normal and correct operation of method.

$$r = t_{95\%,\nu} \cdot \sqrt{2} \cdot s_r \qquad \text{Equation 6}$$

The reproducibility standard deviation (s_R) was calculated in accordance with ISO 5725-6 as the square root of sum of repeatability and between-laboratory variance. The reproducibility limit (R) is calculated using Equation 7 [16]. It represents the biggest difference between two measurements on an identical test gas reported by two laboratories, which should not occur on average more than once in 20 cases in the normal and correct operation of method.

$$R = t_{95\%,\nu} \cdot \sqrt{2} \cdot s_R \qquad \text{Equation 7}$$

The repeatability standard deviation was evaluated with (p_j ***(3-1)**) degrees of freedom (ν) and reproducibility standard deviation with (p_j**-1**) degrees of freedom. The corresponding critical range student factors ($t_{\alpha,\nu}$) are reported in Table 46.

parameter	run	p_j	t critical value 95% for r	t critical value 95% for R
CO	1,2,3,4,5	9	2,101	2,306
NO	1,2,3,4,5,6,7,8,9,10	8	2,120	2,365
NO_2	2,4,6,8,10	8	2,120	2,365
O_3	1,2,3,4,5	9	2,101	2,306
SO_2	1,2,3,4,5	9	2,101	2,306

Table 46: Critical values of t used in the repeatability (r) and reproducibility (R) evaluation.

The repeatability and reproducibility limits of measurement methods are presented from Table 47 to Table 51 and from Figure 48 to Figure 52. Also reported is the 'reproducibility from common criteria (R (from σ_p))' calculated by substituting s_R in Equation 7 with a 'standard deviation for proficiency assessment' (see Table 4). Comparison between R and R (from σ_p) serves to indicate that σ_p is realistic ([13] under 6.3.1) or from the other point of view, that the general methodology implemented by NRLs is appropriate for σ_p.

SO_2 data (nmol/mol) without outliers			
group average	repeatability limit : r	reproducibility limit : R	reproducibility limit (relative)
0,2		0,9	
5,0	0,1	2,0	
14,9	0,2	4,4	
31,3	0,1	8,7	
61,1	0,2	16,4	
132,9	0,6	35,5	26,7%

Table 47: The R and r of SO2 standard measurement method.

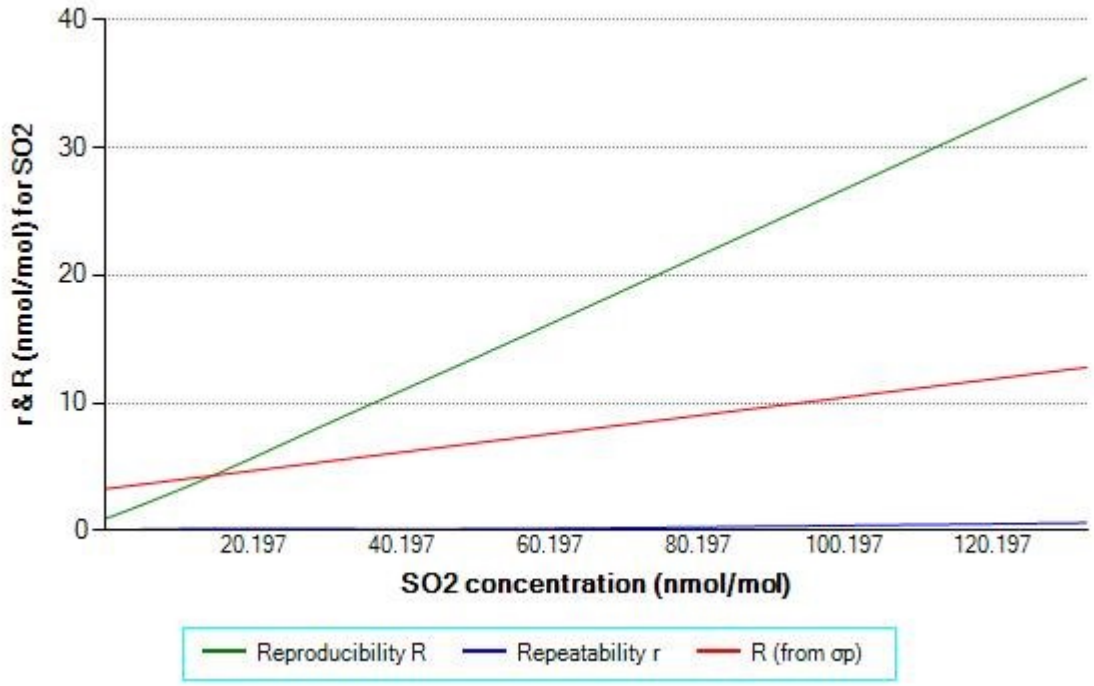

Figure 48: The R and r of SO2 standard measurement method as a function of concentration.

CO data (µmol/mol) without outliers			
group average	repeatability limit: r	reproducibility limit: R	reproducibility limit (relative)
0,000		0,149	
0,993	0,01	0,211	
1,976	0,011	0,246	
2,963	0,014	0,293	
4,961	0,019	0,471	
7,922	0,026	0,627	7,9%

Table 48: The R and r of CO standard measurement method.

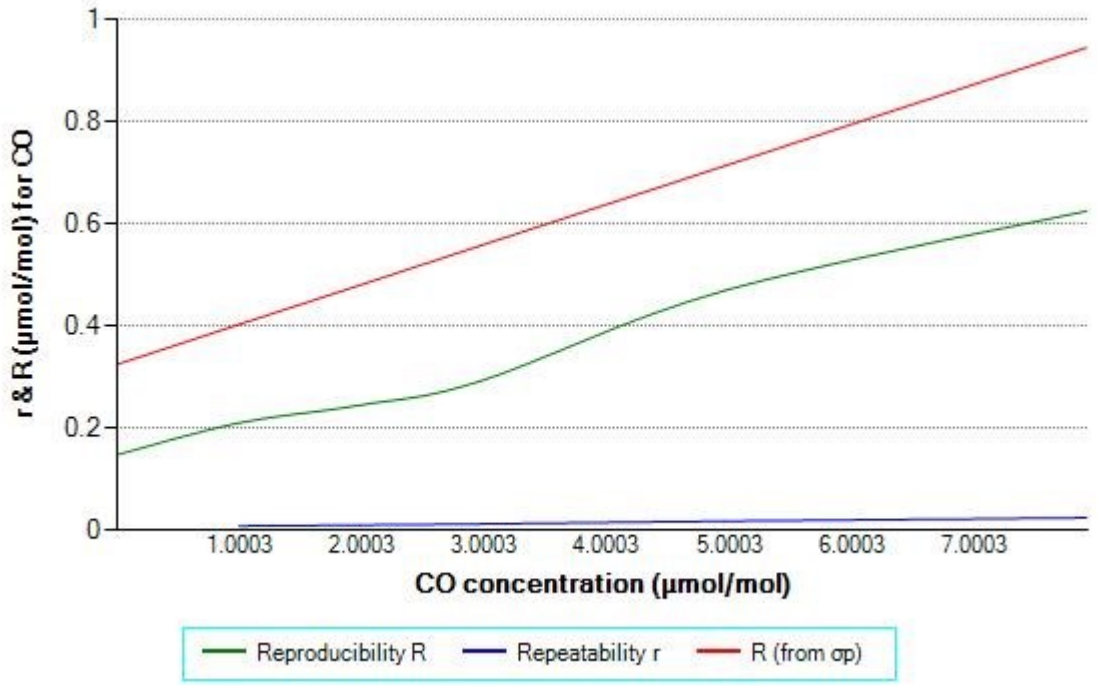

Figure 49: The R and r of CO standard measurement method as a function of concentration.

O_3 data (nmol/mol) without outliers			
group average	repeatability limit: r	reproducibility limit: R	reproducibility limit (relative)
0,2		1,5	
21,8	0,1	2,2	
32,1	0,5	2,4	
60,4	0,6	2,5	
90,6	1,6	4,8	
109,2	1,0	4,0	3,7%

Table 49: The R and r of O3 standard measurement method.

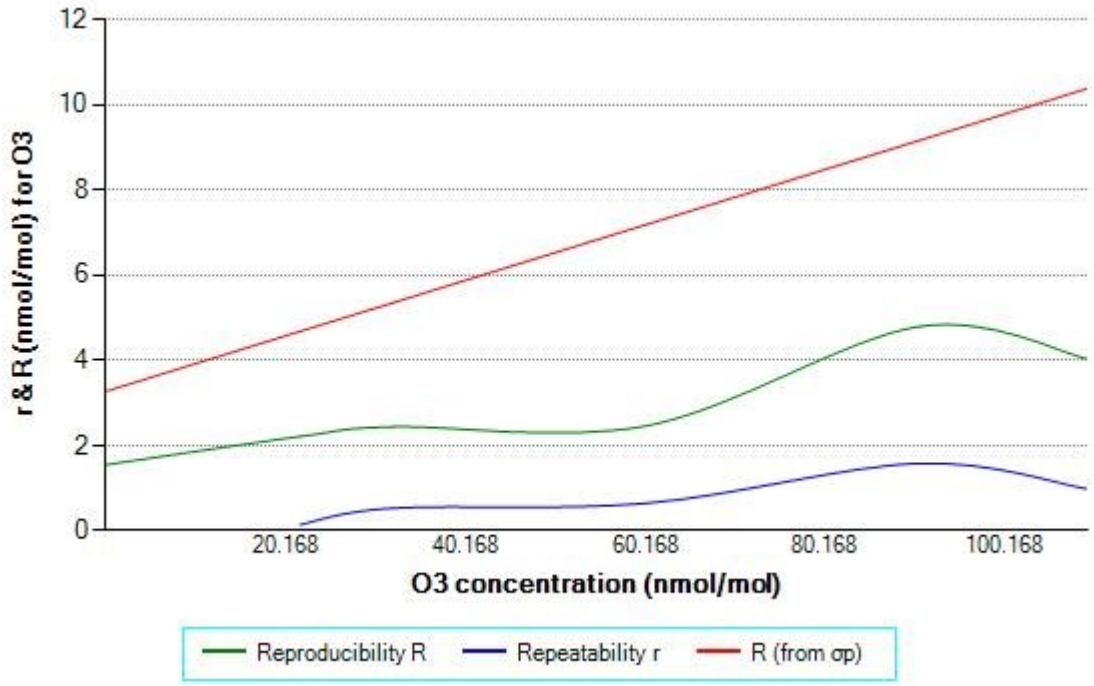

Figure 50: The R and r of O3 standard measurement method as a function of concentration.

NO data (nmol/mol) without outliers			
group average	repeatability limit: r	reproducibility limit: R	reproducibility limit (relative)
0,0		1,8	
12,8	0,3	2,6	
24,8	0,6	3,0	
33,6	0,5	2,3	
53,7	0,3	2,8	
70,4	0,5	6,4	
128,4	1,3	5,0	
191,4	3,2	10,2	
284,0	1,1	14,8	
375,0	2,0	19,5	
488,5	2,1	28,6	5,9%

Table 50: The R and r of NO standard measurement method.

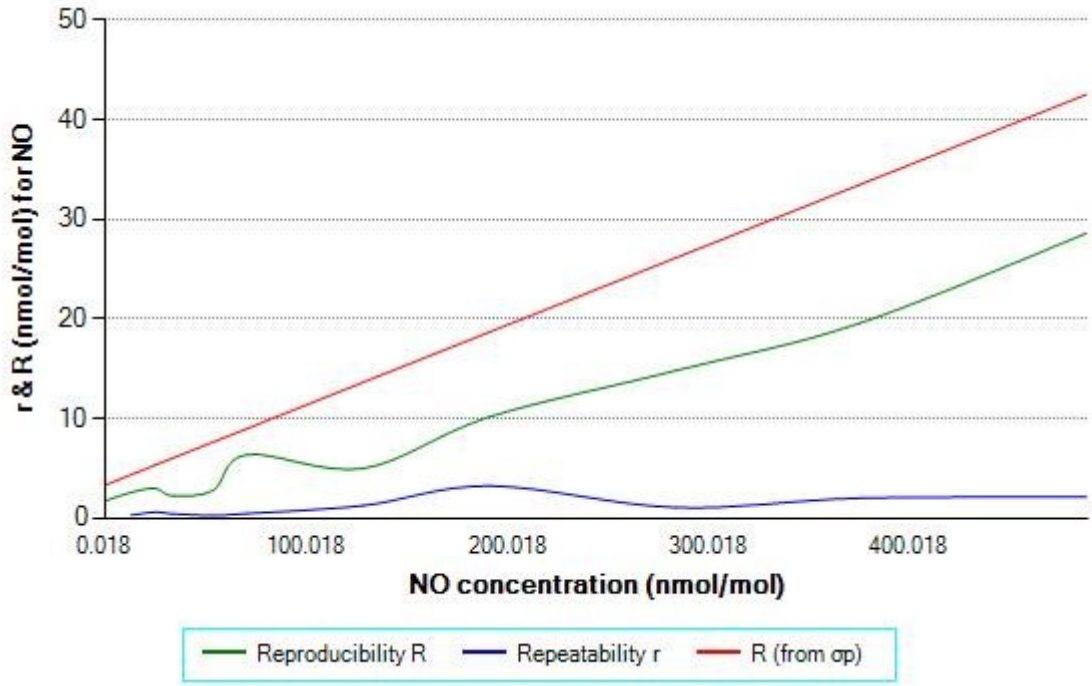

Figure 51: The R and r of NO standard measurement method as a function of concentration.

NO_2 data (nmol/mol) without outliers			
group average	repeatability limit: r	reproducibility limit: R	reproducibility limit (relative)
0,1		1,0	
20,8	0,3	4,1	
29,1	0,4	5,2	
59,0	0,6	7,8	
94,2	1,8	14,3	
117,7	1,5	16,2	13,8%

Table 51: The R and r of NO2 standard measurement method.

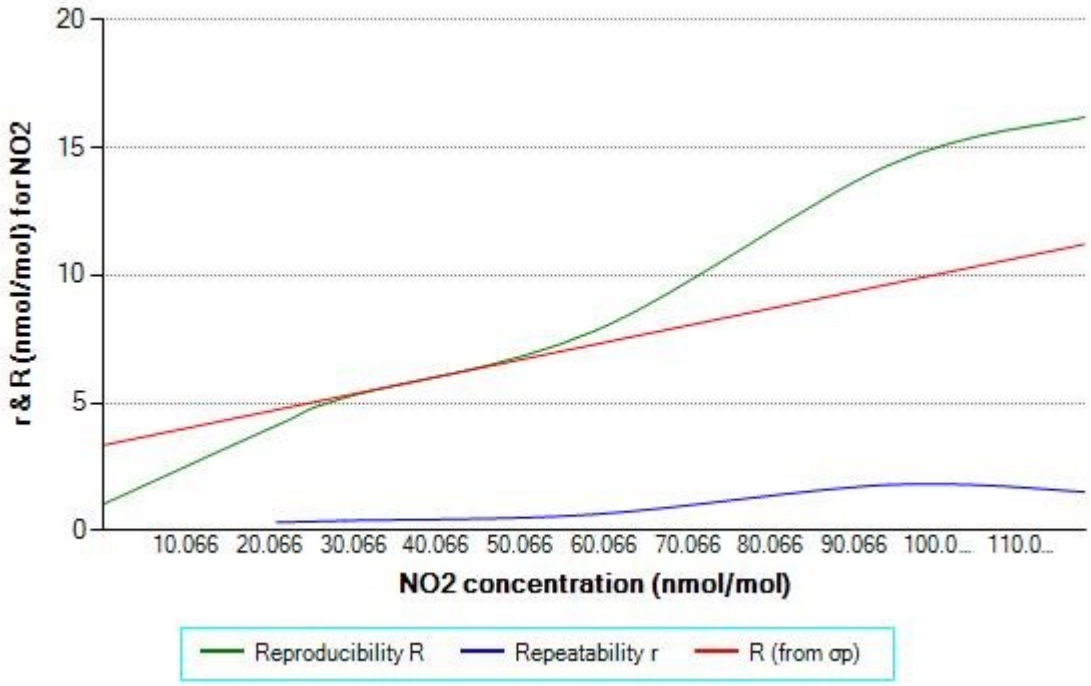

Figure 52: The R and r of NO2 standard measurement method as a function of concentration.

Annex D. The scrutiny of results for consistency and outlier test

The precision evaluation (Annex C) focuses on data that are as much as possible the reflection of every day work of NRLs and thus represents the comparability of participant's standard operating procedures.

For that reason, a procedure for the detection of exceptional errors (error during typing, slip in performing the measurement or the calculation, wrong averaging interval, malfunction of instrumentation, etc.) was applied. In this procedure were carried out tests for data consistency and statistical outliers as described in ISO 5725-2.

Laboratories showing some form of statistical inconsistency were requested to investigate the cause of discrepancies.

Laboratories were allowed to correct their results in case of identification of exceptional errors. Subsequently, data were considered definitive and "Grubb's one outlying observation test" was performed.

For runs where outliers were detected, outliers were removed and "Grubb's one outlying observation test" was repeated until no more outliers were observed. Statistical outliers obtained at this stage are not considered as extraordinary errors but due to significant difference in participant's standard operating procedure.

During this ILC, no statistical outlier was identified.

The precision of standardised measurement methods reported in Annex C are calculated using the database without outliers.

According to Grubb's test, results between a confidence level of 1 and 5% are considered stragglers and they deserve a specific check.

In order to give useful information to the participants for judging their performance also the stragglers are reported in the following table:

Laboratory	parameter	run	value	Gmin_5%	Gmax_5%
E	O_3	4	23,41	OK	Straggler
E	O_3	2	33,74	OK	Straggler
F	SO_2	3	157,26	OK	Straggler
H	NO	10	74,55	OK	Straggler
H	NO	9	125,32	Straggler	OK
H	NO	4	26,70	OK	Straggler

Table 52: Stragglers according to Grubb's one observation test.

Annex E. Accreditation certificates

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Accreditamento n°
Accreditation n°
1362 Rev. **1**

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We declare that
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Directorate C.Energy,Transport and Climate
Joint Research Centre -European Commission
Sede/Headquarters:
- Via E. Fermi 2749 - 21027 Ispra VA

è conforme ai requisiti della norma
UNI CEI EN ISO/IEC 17025:2005 "Requisiti generali per la competenza dei Laboratori di prova e taratura"

meets the requirements of the standard
EN ISO/IEC 17025:2005 "General Requirements for the Competence of Testing and Calibration Laboratories" standard

quale
Laboratorio di Prova

as
Testing Laboratory

L'accreditamento attesta la competenza tecnica del Laboratorio relativamente allo scopo riportato nelle schede allegate al presente certificato. Le schede possono variare nel tempo. I requisiti gestionali della ISO/IEC 17025:2005 (sezione 4) sono scritti in un linguaggio idoneo all'attività dei Laboratori di Prova, sono conformi ai principi della ISO 9001:2008 ed allineati con i suoi requisiti applicabili.
Il presente certificato non è da ritenersi valido se non accompagnato dalle schede allegate e può essere sospeso o revocato in qualsiasi momento nel caso di inadempienza accertata da parte di ACCREDIA.
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ELENCO PROVE ACCREDITATE - CATEGORIA: 0

Ambient Air

Denominazione della prova / Campi di prova	*Metodo di prova*
Particulate Elemental Carbon (EC) (0.2 to 16 µg/m³)	EN16909:2017
Particulate Matter <10 micrometers (PM10) (3.85 to 150 µg/m3)	EN 12341:2014
Particulate Matter <2.5 micrometers (PM2.5) (3.48 to 120 µg/m3)	EN 12341:2014
Particulate Organic Carbon (OC) (1.8 to 45 µg/m³)	EN16909:2017

Synthetic mixture gas

Denominazione della prova / Campi di prova	*Metodo di prova*
carbon monoxide (0.015-86 mmol/mol)	EN 14626:2012
nitrogen oxides (NO: 1-962 nmol/mol; NO2: 1-261 nmol/mol)	EN 14211:2012
ozone (1-250 nmol/mol)	EN 14625:2012
sulphur dioxide (1-376 nmol/mol)	EN 14212:2012

Legenda
En= norma europea

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Il Direttore del Dipartimento
(Dott.ssa Silvia Tramontin)
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