Evaluation of the Inter-Laboratory Comparison exercise for SO$_2$, CO, O$_3$, NO and NO$_2$ (13-16 May 2019, Ispra)

European Commission harmonisation programme for air quality measurements

Barbiere M., Lagler F., Borowiak A.
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1. Acknowledgements

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2. 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 13th to the 16th of May 2019, including ERLAP, ten 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, NO₂, SO₂, CO and O₃) covered by the European Air Quality Directive 2008/50 EC [1] and its recent amendments 2015/1480/EC [42]. One laboratory reported only values for NOx and O₃.

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 (z’-score), 86% of all results reported by AQUILA laboratories were satisfactory both in terms of measured values and reported uncertainties. The rest of the results had satisfactory measured values, but the reported uncertainties were either too high (8%) or too small (4%). The rest of the results consist in four values (2%) found to be questionable always for z’-score. During this ILC no unsatisfactory results were identified.

Comparability of results among AQUILA participants at the highest generated concentration levels is satisfactory for measurements of all pollutants.
### 3. Introduction


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 [1, 42], 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], [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 optimise resources and improve international harmonisation.

The following report deals with the ILC that took place from 13$^{th}$ to the 16$^{th}$ of May 2019 in Ispra (IT).

Since 1990 ERLAP has organised ILC in order to evaluate the comparability of measurements carried out by NRLs and promote information exchange among the expert laboratories. Recently, a more systematic approach has been adopted, in agreement with the Network of National Reference Laboratories for Air Quality (AQUILA) [11], aiming to both provide an alert mechanism for the purposes of the EC legislation and 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.
4. Inter-laboratory organisation

The ILC was announced in February 2019 to the members of the AQUILA network and the WHO CC representative. Registration was opened in April 2019 and closed at the beginning of May 2019.

Every participant, together with the registration confirmation, received a detailed protocol with all the necessary information about the ILC. Each laboratory was 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, 13th of May 2019, for the installation of their equipment. The calibration of NOx and O3 analysers was carried out next day on Tuesday morning and the generation of NOx and O3 gas mixtures started at 11:00.

The calibration of SO2 and CO analysers was carried out on Wednesday afternoon and the generation of CO and SO2 gas mixtures started at 20:00.

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

4.1 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 Belgium, Denmark, Spain, Ireland, Hungary, Slovak Republic, Austria, Finland and Sweden.

Table 1: List of participating organizations.

<table>
<thead>
<tr>
<th>Country</th>
<th>Laboratory</th>
<th>Code</th>
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<td>Spain</td>
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<td>Austria</td>
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<td>H</td>
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<tr>
<td>Finland</td>
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<td>I</td>
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<tr>
<td>Sweden</td>
<td>Stockholm University ACES</td>
<td>K</td>
</tr>
</tbody>
</table>

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 list contains the information reported by participants and cannot be considered as an implicit or explicit endorsement by the organisers of any specific instrumentation.
**Table 2:** List of instruments used by participants.

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4.2 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].

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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 value 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.
5. 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 paragraph 8. In the following proficiency evaluations, the uncertainty of test gas homogeneity (paragraph 8) was added to the uncertainties of ERLAP’s measurement results.

All data reported by participating laboratories are presented in 0.

As described in the AQUILA document 37 [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.

5.1 z’-score

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

$$z' = \frac{x_i - X}{\sqrt{\sigma_p^2 + u_x^2}} = \frac{x_i - X}{\sqrt{(a \cdot X + b)^2 + u_x^2}}$$

where $x_i$ is a participant’s average value for each run, $X$ is the assigned/reference value, $\sigma_p$ is the standard deviation for proficiency assessment and $u_x$ 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’ ($\sigma_p$) [13] is calculated in fitness-for-purpose manner from requirements given in European standards.

Over the whole measurement range $\sigma_p$ 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 $\sigma_p$ are given in Table 4.

<table>
<thead>
<tr>
<th>Gas</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>0.022</td>
<td>1</td>
</tr>
<tr>
<td>CO</td>
<td>0.024</td>
<td>100</td>
</tr>
<tr>
<td>O₃</td>
<td>0.020</td>
<td>1</td>
</tr>
<tr>
<td>NO</td>
<td>0.024</td>
<td>1</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.020</td>
<td>1</td>
</tr>
</tbody>
</table>

$\sigma_p$ 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:

- $|z'| \leq 2$ 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 5) in which the $z'$-scores of each participant are grouped together. The assessment criteria are presented as $z'=\pm 2$ (blue line) and $z'=\pm 3$ (red line). They represent the limits for the questionable and unsatisfactory results.

**Figure 1**: $Z'$-score evaluations of SO$_2$ 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 (115 nmol/mol), 2 (60 nmol/mol), 3 (35 nmol/mol), 4 (18 nmol/mol), 5 (10 nmol/mol).
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 (2.8 μmol/mol), 2 (8.5 μmol/mol), 3 (5 μmol/mol), 4 (2 μmol/mol), 5 (0.9 μmol/mol).

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 (65 nmol/mol), 2 (20 nmol/mol), 3 (35 nmol/mol), 4 (115 nmol/mol), 5 (90 nmol/mol).
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 (135 nmol/mol), 2 (70 nmol/mol), 3 (35 mol/mol), 4 (15 nmol/mol), 5 (65 nmol/mol), 6 (25 nmol/mol), 7 (490 nmol/mol), 8 (380 nmol/mol), 9 (300 nmol/mol), 10 (200 nmol/mol).

Figure 5: $Z'$-score evaluations of NO$_2$ measurements
Scores are given for each participant and each concentration level (run). Run number order (with nominal concentration) is: 0 (0 nmol/mol), 1 (65 nmol/mol), 2 (20 nmol/mol), 3 (40 nmol/mol), 4 (110 nmol/mol), 5 (100 nmol/mol).
5.2 $E_n$-score

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

$$E_n = \frac{x_i - X}{\sqrt{U^2_{x_i} + U^2_X}}$$  \hspace{1cm} \text{Equation 2}$$

where $X$ is the assigned/reference value with an expanded uncertainty $U_X$ and $x_i$ is the participant’s average value with an expanded uncertainty $U_{x_i}$. 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 $\left(\sqrt{U^2_{x_i} + U^2_X}\right)$. These plots represent also the $E_n$-score evaluations where, considering the $E_n$ criterion (\(|E_n| < 1\)), all results with error bars crossing the x-axis are satisfactory. Reported standard uncertainties (0) that are larger than the “standard deviation for proficiency assessments” ($\sigma_p$, Table 4) are considered not fit-for-purpose and are denoted with “*” in the x-axis of each figure. The $E_n$ evaluation showed few unsatisfactory results for different parameters and concentrations, as reported in table 5.

Table 5: Unsatisfactory results according to $E_n$-score.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lab Code</th>
<th>Value</th>
<th>Run</th>
<th>$E_n$</th>
<th>$E_n$ evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>A</td>
<td>0,736</td>
<td>CO _5</td>
<td>-1,3</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>CO</td>
<td>A</td>
<td>1,831</td>
<td>CO _4</td>
<td>-1,5</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>A</td>
<td>36,11</td>
<td>SO$_2$ _3</td>
<td>-1,2</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>A</td>
<td>117,55</td>
<td>SO$_2$ _1</td>
<td>-1,8</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>A</td>
<td>61,52</td>
<td>SO$_2$ _2</td>
<td>-1,5</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>CO</td>
<td>D</td>
<td>1,9</td>
<td>CO _4</td>
<td>-1,1</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>CO</td>
<td>D</td>
<td>0,8</td>
<td>CO _5</td>
<td>-2,1</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>O$_3$</td>
<td>D</td>
<td>97,3</td>
<td>O$_3$ _5</td>
<td>2,2</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>O$_3$</td>
<td>D</td>
<td>123,38</td>
<td>O$_3$ _4</td>
<td>2</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>O$_3$</td>
<td>D</td>
<td>35,38</td>
<td>O$_3$ _3</td>
<td>1,3</td>
<td>unsatisfactory</td>
</tr>
<tr>
<td>CO</td>
<td>E</td>
<td>0,798</td>
<td>CO _5</td>
<td>-1,5</td>
<td>unsatisfactory</td>
</tr>
</tbody>
</table>
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 σ₀.
Laboratory K didn’t reported results for this pollutant.

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 $\sigma_p$. Laboratory K didn’t reported results for this pollutant.
Figure 8: Bias of participant’s $O_3$ 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 $\sigma_p$. 

![Graph showing bias of participant's O3 measurement results]
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 $\sigma_p$. 
Figure 10: Bias of participant’s NO₂ measurement results

Expanded uncertainty of bias is presented as error bar for NO₂ 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 $\sigma_0$. 
6. Performance characteristics of individual laboratories

Individual participants’ biases were evaluated and are presented in chapter 5 (Figure 6 - 10). Since the results of NO₂ 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 NO₂ (see table 3). For each evaluation the run number together with the participants rounded run average (nmol/mol) is given.

6.1 Converter efficiencies of NO₂-to-NO for NOX analysers

Since NO and NO₂ test gases were produced by gas phase titration, it is possible to evaluate the efficiency of the NO₂-to-NO converter of each participant’s NOₓ analyser. The evaluation takes each participant’s NO and NO₂ measurements before and after oxidation by O₃. 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]:

\[
\alpha = \frac{[NO] - [NO_{\text{e}}]}{[NO]_{\text{e}} - [NO]} \cdot 100\%
\]

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

<table>
<thead>
<tr>
<th>Lab code</th>
<th>NO₂ nmol/mol</th>
<th>α (%)</th>
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<tbody>
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<td></td>
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</tr>
<tr>
<td></td>
<td>65</td>
<td>100,4</td>
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<tr>
<td></td>
<td>100</td>
<td>99,3</td>
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<td>B</td>
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<td></td>
<td>65</td>
<td>99,5</td>
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<td></td>
<td>100</td>
<td>100,3</td>
</tr>
</tbody>
</table>
7. 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 satisfactory, but the reported uncertainty is too high
- **3**: measured value is satisfactory (z’-score satisfactory) but the reported uncertainty is underestimated (En-score unsatisfactory)
- **4**: measurement result is questionable (z’-score questionable), but due to a high reported uncertainty can be considered valid (En-score satisfactory)
- **5**: measurement result is questionable (z’-score questionable and En-score unsatisfactory)
- **6**: measurement result is unsatisfactory (z’-score unsatisfactory) but due to a high reported uncertainty can be considered valid (En-score satisfactory)
- **7**: measurement result is unsatisfactory (z’-score unsatisfactory and En-score unsatisfactory)

*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.
Table 7: General assessment of proficiency results.

"n.r." is referring to values not reported. "U n.r." is referring to Uncertainty values not reported.

<table>
<thead>
<tr>
<th>run numb</th>
<th>Ref. conc. level</th>
<th>ILC code</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>CO (μmol/mol)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>NO (μmol/mol)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>NO2 (μmol/mol)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>O3 (μmol/mol)</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SO2 (μmol/mol)</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>
8. 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 SO₂, 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 O₃ 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 NO₂ channel of NOₓ analyser the GPT test was performed to establish the efficiency of NO₂-converter.

ERLAP’s measurement results were verified 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 verification is taking into account ERLAP’s measurement result (X) and its standard uncertainty (ux) as given in Equation 4 [13]:

\[
\frac{|x^* - X|}{\sqrt{\frac{(1.25s^*)^2}{p} + u_x^2}} \leq 2
\]

Equation 4

Where x* and s* represent robust average and robust standard deviation respectively and p is the number of participants. In table 8 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.
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. The relative differences between beginning and end measurements are calculated.

\[ u_X^2 = u_X^2 + (X \cdot u_{\text{homogeneity}})^2 \]  \hspace{1cm} \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 assuming a rectangular distribution of the bias. The standard uncertainties of assigned/reference values (\( u_X \)) were calculated with Equation 5 and used in the proficiency evaluations of chapter 3.

All calculations about the homogeneity testing data are retained by ERLAP, they are not published in this ILC report but, are available on request.
9. 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 ($\sigma_p$) 86% 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 all results presented satisfactory measured values, but the evaluated uncertainties were either too high, category ‘2’ (8%), or too small, category ‘3’ (4%). Four values were found questionable for $z^*$-score but two of them were satisfactory (category 4, 1% of total values) and two were unsatisfactory for En-score (category 5, 1% of total values). No values were found unsatisfactory for both value and uncertainty (category 6 and 7).

Table 9: Flags summary

<table>
<thead>
<tr>
<th>ILC</th>
<th>Site</th>
<th>Categories %</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>1</td>
</tr>
<tr>
<td>Apr-08</td>
<td>Ispra (IT)</td>
<td>68.4</td>
</tr>
<tr>
<td>Oct-08 (I)</td>
<td>Ispra (IT)</td>
<td>37.9</td>
</tr>
<tr>
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As in previous ILC, the adopted criteria for high concentrations were the standard deviations for proficiency assessment, deriving from the European Standards’ uncertainty requirements.

The reproducibility standard deviation obtained at this and previous ILC [20], [21], [22], [23], [24], [25], [33], [34], [35], [36], [37], [38], [39], [40], [41], [43], [44], [45], [46], [47] and [48] is comparable to the mentioned criteria. On the other hand, the uncertainty criteria for zero levels were those set in AQUILA’s position paper [12].

In this exercise 99% of the results in the z’-score evaluations were satisfactory and only 1% questionable.

Table 10: Z’-score summary

<table>
<thead>
<tr>
<th>ILC</th>
<th>Site</th>
<th>Satisfactory (%)</th>
<th>Questionable (%)</th>
<th>Unsatisfactory (%)</th>
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<tr>
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<tr>
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<tr>
<td>October/08_1</td>
<td>Ispra (IT)</td>
<td>92.9</td>
<td>4.2</td>
<td>2.9</td>
</tr>
<tr>
<td>October/08_2</td>
<td>Ispra (IT)</td>
<td>97.0</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>September/09</td>
<td>Langen (DE)</td>
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<tr>
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<tr>
<td>June/10</td>
<td>Ispra (IT)</td>
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<td>0.0</td>
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<td>99.3</td>
<td>0.7</td>
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<tr>
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<td>0.0</td>
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<td>Langen (DE)</td>
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<td>1.4</td>
<td>0.0</td>
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<tr>
<td>September/13</td>
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<td>0.0</td>
<td>0.0</td>
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<tr>
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<tr>
<td>June/17_1</td>
<td>Ispra (IT)</td>
<td>98.9</td>
<td>0.7</td>
<td>0.4</td>
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<tr>
<td>June/17_2</td>
<td>Ispra (IT)</td>
<td>96.2</td>
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<td>1.9</td>
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<td>0.0</td>
<td>0.0</td>
</tr>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>May/19</td>
<td>Ispra (IT)</td>
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<td>1.0</td>
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</table>

Comparability of results among AQUILA participants at the highest concentration level is acceptable for all pollutant measurements.
The relative reproducibility limits, at the highest studied concentration levels, are 6.7% for SO\textsubscript{2}, 3.3% for CO, 8.7% for O\textsubscript{3}, for NO 4.8% and for NO\textsubscript{2} 11.8% all within the objective derived from criteria imposed by the European Commission ($\sigma_p$ see Table 4).

During this ILC the performance of all NRL was generally satisfactory. No values were identified as outliers.
10. References


[3] CEN, EN 14212:2012, ambient air quality - Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence

[4] CEN, EN 14211:2012, ambient air quality - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence

[5] CEN, EN 14625:2012, ambient air quality - Standard method for the measurement of the concentration of ozone by ultraviolet photometry


[18] De Saeger E. et al., European comparison of Nitrogen Dioxide calibration methods, EUR 17661, 1997


[40] Barbiere M., Lagler F., Evaluation of the Laboratory Comparison Exercise for SO$_2$, CO, O$_3$, NO and NO$_2$ 7th-10th October 2013 Ispra. EUR 26639. 2014

[41] Barbiere M., Lagler F., Evaluation of the Laboratory Comparison Exercise for SO$_2$, CO, O$_3$, NO and NO$_2$ 19th-22nd May 2014 Ispra. EUR 27199. 2014


[49] Barbiere M., Lagler F., Borowiak A. Evaluation of the Laboratory Comparison Exercise for SO$_2$, CO, O$_3$, NO and NO$_2$ 4-7 June 2018, Ispra. EUR 29671. 2018

[50] Barbiere M., Lagler F., Mücke H.G., Wirtz K. and Stummer V. Evaluation of the Laboratory Comparison Exercise for NO, NO$_2$, SO$_2$, CO, and O$_3$ Langen (D) 2-7 September 2018. EUR 29694. 2018
**List of abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AQUILA</td>
<td>Network of National Reference Laboratories for Air Quality</td>
</tr>
<tr>
<td>CEN</td>
<td>European Committee for Standardization</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CRM</td>
<td>Certified Reference Material</td>
</tr>
<tr>
<td>DQO</td>
<td>Data Quality Objective</td>
</tr>
<tr>
<td>ERLAP</td>
<td>European Reference Laboratory for Air Pollution</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>GPT</td>
<td>Gas Phase Titration</td>
</tr>
<tr>
<td>ILC</td>
<td>Inter-Laboratory Comparison Exercise</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>JRC</td>
<td>Joint Research Centre</td>
</tr>
<tr>
<td>NO</td>
<td>Nitrogen monoxide</td>
</tr>
<tr>
<td>NO₂</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td>NOₓ</td>
<td>The oxides of nitrogen, the sum of NO and NO₂</td>
</tr>
<tr>
<td>NRL</td>
<td>National Reference Laboratory</td>
</tr>
<tr>
<td>O₃</td>
<td>Ozone</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulphur dioxide</td>
</tr>
<tr>
<td>VDI</td>
<td>Verein Deutscher Ingenieure</td>
</tr>
<tr>
<td>WHO-CC</td>
<td>World Health Organization Collaborating Centre for Air Quality Management and Air Pollution Control, Berlin</td>
</tr>
</tbody>
</table>
Mathematical Symbols

\( \alpha \) \hspace{1cm} \text{converter efficiency (EN 14211)}

\( E_n \) \hspace{1cm} \text{score statistic (ISO 13528)}

\( r \) \hspace{1cm} \text{repeatability limit (ISO 5725)}

\( R \) \hspace{1cm} \text{reproducibility limit (ISO 5725)}

\( \sigma_p \) \hspace{1cm} \text{standard deviation for proficiency assessment (ISO 13528)}

\( x^* \) \hspace{1cm} \text{robust average (Annex C ISO 13528)}

\( s^* \) \hspace{1cm} \text{robust standard deviation (Annex C ISO 13528)}

\( s_r \) \hspace{1cm} \text{repeatability standard deviation (ISO 5725)}

\( s_R \) \hspace{1cm} \text{reproducibility standard deviation (ISO 5725)}

\( U_X \) \hspace{1cm} \text{expanded uncertainty of the assigned/reference value (ISO 13528)}

\( U_{xi} \) \hspace{1cm} \text{expanded uncertainty of the participant’s value (ISO 13528)}

\( u_X \) \hspace{1cm} \text{standard uncertainty of the assigned/reference value (ISO 13528)}

\( X \) \hspace{1cm} \text{assigned/reference value (ISO 13528)}

\( x_i \) \hspace{1cm} \text{average of three values reported by the participant } i \text{ (for particular parameter and concentration level) (ISO 5725)}

\( x_{i,j} \) \hspace{1cm} \text{the reported value of participant } i \text{ (for particular parameter and concentration level) (ISO 5725)}

\( z' \) \hspace{1cm} \text{z’-score statistic (ISO 13528)}
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Table 14: Reported values for SO$_2$ run 3 ................................................................. 40
Table 15: Reported values for SO$_2$ run 4 ................................................................. 40
Table 16: Reported values for SO$_2$ run 5 ................................................................. 41
Table 17: Reported values for CO run 0 ................................................................. 42
Table 18: Reported values for CO run 1 ................................................................. 43
Table 19: Reported values for CO run 2 ................................................................. 43
Table 20: Reported values for CO run 3 ................................................................. 44
Table 21: Reported values for CO run 4 ................................................................. 44
Table 22: Reported values for CO run 5 ................................................................. 45
Table 23: Reported values for O$_3$ run 0 ................................................................. 46
Table 24: Reported values for O$_3$ run 1 ................................................................. 46
Table 25: Reported values for O$_3$ run 2 ................................................................. 47
Table 26: Reported values for O$_3$ run 3 ................................................................. 47
Table 27: Reported values for O$_3$ run 4 ................................................................. 48
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Table 29: Reported values for NO run 0 ................................................................. 49
Table 30: Reported values for NO run 1 ................................................................. 49
Table 31: Reported values for NO run 2 ................................................................. 50
Table 32: Reported values for NO run 3 ................................................................. 50
Table 33: Reported values for NO run 4 ................................................................. 51
Table 34: Reported values for NO run 5 ................................................................. 51
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Annex A: 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 ($\bar{x}_i$) 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.

Reported values for SO$_2$

**Table 11:** Reported values for SO$_2$ run 0.

<table>
<thead>
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<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
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</thead>
<tbody>
<tr>
<td>$x_i$</td>
<td>-0.31</td>
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<td>1.27</td>
<td>-1.60</td>
<td>0.28</td>
<td>0.49</td>
<td>-0.01</td>
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<tr>
<td>$U(x_i)$</td>
<td>0.59</td>
<td>0.64</td>
<td>0.31</td>
<td>0.51</td>
<td>0.52</td>
<td>0.16</td>
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<td>$U(x_i)$</td>
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<td>1.27</td>
<td>-0.01</td>
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**Figure 13:** Reported values for SO$_2$ run 0.

SO$_2$ concentration level 0

[Graph showing reported values for SO$_2$ run 0]
Table 12: Reported values for SO$_2$ run 1

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
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<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>117.30</td>
<td>119.47</td>
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<td>123.28</td>
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<td>$x_{i,2}$</td>
<td>117.65</td>
<td>119.58</td>
<td>124.57</td>
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<td>$x_{i,3}$</td>
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<td>120.02</td>
<td>124.47</td>
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<td>119.31</td>
<td>123.41</td>
<td>120.90</td>
<td>123.95</td>
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Figure 14: Reported values for SO$_2$ run 1.

Table 13: Reported values for SO$_2$ run 2.

<table>
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<tr>
<th>values</th>
<th>A</th>
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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>61.60</td>
<td>62.91</td>
<td>56.03</td>
<td>64.40</td>
<td>63.25</td>
<td>62.13</td>
<td>64.81</td>
<td>53.56</td>
<td>65.00</td>
</tr>
<tr>
<td>$x_{i,2}$</td>
<td>61.48</td>
<td>62.89</td>
<td>55.99</td>
<td>64.45</td>
<td>63.77</td>
<td>62.14</td>
<td>64.83</td>
<td>53.64</td>
<td>65.09</td>
</tr>
<tr>
<td>$x_{i,3}$</td>
<td>61.46</td>
<td>63.07</td>
<td>55.88</td>
<td>64.50</td>
<td>64.13</td>
<td>62.12</td>
<td>64.83</td>
<td>53.56</td>
<td>65.19</td>
</tr>
</tbody>
</table>

Figure 15: Reported values for SO$_2$ run 2.
Table 14: Reported values for SO₂ run 3.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₁, 1</td>
<td>36.06</td>
<td>37.16</td>
<td>39.30</td>
<td>37.30</td>
<td>37.00</td>
<td>36.37</td>
<td>38.15</td>
<td>37.36</td>
<td>38.18</td>
</tr>
<tr>
<td>x₁, 2</td>
<td>36.17</td>
<td>37.16</td>
<td>38.10</td>
<td>37.45</td>
<td>37.65</td>
<td>36.26</td>
<td>39.17</td>
<td>37.47</td>
<td>38.29</td>
</tr>
<tr>
<td>x₁, 3</td>
<td>36.00</td>
<td>37.20</td>
<td>39.19</td>
<td>37.45</td>
<td>37.59</td>
<td>36.32</td>
<td>38.24</td>
<td>37.45</td>
<td>38.24</td>
</tr>
<tr>
<td>s₁</td>
<td>0.05</td>
<td>0.02</td>
<td>0.10</td>
<td>0.09</td>
<td>0.39</td>
<td>0.05</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>U(x₁)</td>
<td>0.66</td>
<td>0.90</td>
<td>0.71</td>
<td>1.14</td>
<td>0.61</td>
<td>1.41</td>
<td>0.50</td>
<td>0.49</td>
<td>0.72</td>
</tr>
<tr>
<td>U(x₁)</td>
<td>1.31</td>
<td>1.80</td>
<td>1.42</td>
<td>2.28</td>
<td>1.23</td>
<td>2.82</td>
<td>1.20</td>
<td>0.39</td>
<td>1.44</td>
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</table>

Figure 16: Reported values for SO₂ run 3.

![SO₂ concentration level 3](image)

Table 15: Reported values for SO₂ run 4.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₁, 1</td>
<td>16.84</td>
<td>17.63</td>
<td>16.11</td>
<td>17.10</td>
<td>18.39</td>
<td>16.06</td>
<td>18.13</td>
<td>17.82</td>
<td>18.17</td>
</tr>
<tr>
<td>x₁, 2</td>
<td>16.93</td>
<td>17.56</td>
<td>18.14</td>
<td>17.15</td>
<td>18.49</td>
<td>17.11</td>
<td>18.15</td>
<td>17.82</td>
<td>18.14</td>
</tr>
<tr>
<td>x₁, 3</td>
<td>16.87</td>
<td>17.61</td>
<td>19.07</td>
<td>17.10</td>
<td>18.20</td>
<td>17.29</td>
<td>19.16</td>
<td>17.76</td>
<td>18.21</td>
</tr>
<tr>
<td>s₁</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.62</td>
<td>0.14</td>
<td>0.15</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>U(x₁)</td>
<td>0.60</td>
<td>0.70</td>
<td>0.35</td>
<td>0.52</td>
<td>0.40</td>
<td>0.93</td>
<td>0.54</td>
<td>0.25</td>
<td>0.56</td>
</tr>
<tr>
<td>U(x₁)</td>
<td>1.21</td>
<td>1.41</td>
<td>0.70</td>
<td>1.04</td>
<td>0.81</td>
<td>1.86</td>
<td>1.08</td>
<td>0.50</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Figure 17: Reported values for SO₂ run 4.

![SO₂ concentration level 4](image)
Table 16: Reported values for SO$_2$ run 5.

<table>
<thead>
<tr>
<th>values</th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_i$, 1</td>
<td>9.18</td>
<td>9.81</td>
<td>11.14</td>
<td>8.60</td>
<td>10.15</td>
<td>9.46</td>
<td>10.09</td>
<td>9.82</td>
<td>10.06</td>
</tr>
<tr>
<td>$X_i$, 3</td>
<td>9.06</td>
<td>8.81</td>
<td>10.92</td>
<td>8.90</td>
<td>10.47</td>
<td>9.51</td>
<td>10.07</td>
<td>9.36</td>
<td>10.07</td>
</tr>
</tbody>
</table>

Figure 18: Reported values for SO$_2$ run 5.
## Reported values for CO

### Table 17: Reported values for CO run 0.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>-0.079</td>
<td>-0.030</td>
<td>-0.098</td>
<td>-0.100</td>
<td>-0.075</td>
<td>0.033</td>
<td>0.002</td>
<td>-0.008</td>
<td>0.004</td>
</tr>
<tr>
<td>$u_i(x_i)$</td>
<td>0.065</td>
<td>0.069</td>
<td>-0.002</td>
<td>0.029</td>
<td>0.200</td>
<td>0.009</td>
<td>0.025</td>
<td>0.043</td>
<td></td>
</tr>
<tr>
<td>$U_i(x_i)$</td>
<td>0.129</td>
<td>0.139</td>
<td>-0.004</td>
<td>0.059</td>
<td>0.401</td>
<td>0.018</td>
<td>0.050</td>
<td>0.085</td>
<td></td>
</tr>
</tbody>
</table>

### Figure 19: Reported values for CO run 0.

![CO concentration level 0](image_url)
Table 18: Reported values for CO run 1.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i$, 1</td>
<td>2.698</td>
<td>2.843</td>
<td>2.760</td>
<td>2.800</td>
<td>2.749</td>
<td>2.836</td>
<td>2.817</td>
<td>2.792</td>
<td>2.792</td>
</tr>
<tr>
<td>$x_i$, 2</td>
<td>2.690</td>
<td>2.843</td>
<td>2.774</td>
<td>2.750</td>
<td>2.760</td>
<td>2.631</td>
<td>2.837</td>
<td>2.822</td>
<td>2.809</td>
</tr>
<tr>
<td>$x_i$, 3</td>
<td>2.688</td>
<td>2.833</td>
<td>2.781</td>
<td>2.790</td>
<td>2.763</td>
<td>2.832</td>
<td>2.840</td>
<td>2.822</td>
<td>2.805</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.006</td>
<td>0.006</td>
<td>0.011</td>
<td>0.050</td>
<td>0.007</td>
<td>0.001</td>
<td>0.002</td>
<td>0.003</td>
<td>0.009</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.070</td>
<td>0.085</td>
<td>0.087</td>
<td>0.092</td>
<td>0.062</td>
<td>0.226</td>
<td>0.011</td>
<td>0.039</td>
<td>0.078</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.139</td>
<td>0.171</td>
<td>0.134</td>
<td>0.133</td>
<td>0.125</td>
<td>0.457</td>
<td>0.021</td>
<td>0.078</td>
<td>0.155</td>
</tr>
</tbody>
</table>

Figure 20: Reported values for CO run 1.

![Graph](image)

Table 19: Reported values for CO run 2

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i$, 1</td>
<td>8.610</td>
<td>8.790</td>
<td>8.532</td>
<td>8.600</td>
<td>8.561</td>
<td>8.660</td>
<td>8.648</td>
<td>8.624</td>
<td>8.543</td>
</tr>
<tr>
<td>$x_i$, 2</td>
<td>8.502</td>
<td>8.790</td>
<td>8.539</td>
<td>8.600</td>
<td>8.557</td>
<td>8.561</td>
<td>8.649</td>
<td>8.629</td>
<td>8.547</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.012</td>
<td>0.000</td>
<td>0.004</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.034</td>
<td>0.169</td>
<td>0.205</td>
<td>0.240</td>
<td>0.174</td>
<td>0.286</td>
<td>0.033</td>
<td>0.112</td>
<td>0.151</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.188</td>
<td>0.338</td>
<td>0.410</td>
<td>0.490</td>
<td>0.349</td>
<td>0.571</td>
<td>0.046</td>
<td>0.223</td>
<td>0.301</td>
</tr>
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</table>

Figure 21: Reported values for CO run 2.

![Graph](image)
Table 20: Reported values for CO run 3.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>4.016</td>
<td>5.167</td>
<td>5.020</td>
<td>5.000</td>
<td>5.036</td>
<td>5.037</td>
<td>5.074</td>
<td>5.056</td>
<td>5.131</td>
</tr>
<tr>
<td>$x_i, 2$</td>
<td>4.814</td>
<td>5.167</td>
<td>5.027</td>
<td>5.000</td>
<td>5.033</td>
<td>5.046</td>
<td>5.075</td>
<td>5.057</td>
<td>5.136</td>
</tr>
<tr>
<td>$x_i, 3$</td>
<td>4.915</td>
<td>5.157</td>
<td>5.027</td>
<td>5.000</td>
<td>5.033</td>
<td>5.046</td>
<td>5.075</td>
<td>5.057</td>
<td>5.136</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.001</td>
<td>0.006</td>
<td>0.004</td>
<td>0.000</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.074</td>
<td>0.114</td>
<td>0.121</td>
<td>0.140</td>
<td>0.194</td>
<td>0.250</td>
<td>0.015</td>
<td>0.065</td>
<td>0.107</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.149</td>
<td>0.228</td>
<td>0.242</td>
<td>0.279</td>
<td>0.203</td>
<td>0.501</td>
<td>0.029</td>
<td>0.130</td>
<td>0.214</td>
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</table>

Figure 22: Reported values for CO run 3.

Table 21: Reported values for CO run 4.

<table>
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<tr>
<th>values</th>
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<th>B</th>
<th>C</th>
<th>D</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>1.838</td>
<td>1.991</td>
<td>1.997</td>
<td>1.900</td>
<td>1.933</td>
<td>2.026</td>
<td>2.022</td>
<td>1.908</td>
<td>2.002</td>
</tr>
<tr>
<td>$x_i, 2$</td>
<td>1.828</td>
<td>1.991</td>
<td>2.000</td>
<td>1.900</td>
<td>1.932</td>
<td>2.030</td>
<td>2.021</td>
<td>1.991</td>
<td>2.000</td>
</tr>
<tr>
<td>$x_i, 3$</td>
<td>1.827</td>
<td>1.991</td>
<td>2.001</td>
<td>1.900</td>
<td>1.930</td>
<td>2.026</td>
<td>2.022</td>
<td>1.989</td>
<td>2.006</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.006</td>
<td>0.000</td>
<td>0.002</td>
<td>0.000</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
<td>0.005</td>
<td>0.003</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.054</td>
<td>0.078</td>
<td>0.046</td>
<td>0.053</td>
<td>0.043</td>
<td>0.220</td>
<td>0.010</td>
<td>0.029</td>
<td>0.058</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>0.128</td>
<td>0.155</td>
<td>0.096</td>
<td>0.196</td>
<td>0.097</td>
<td>0.441</td>
<td>0.019</td>
<td>0.058</td>
<td>0.136</td>
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</table>

Figure 23: Reported values for CO run 4.
Table 22: Reported values for CO run 5.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>0.736</td>
<td>0.864</td>
<td>0.890</td>
<td>0.890</td>
<td>0.800</td>
<td>0.824</td>
<td>0.906</td>
<td>0.868</td>
<td>0.998</td>
</tr>
<tr>
<td>$x_i, 2$</td>
<td>0.736</td>
<td>0.854</td>
<td>0.889</td>
<td>0.830</td>
<td>0.736</td>
<td>0.925</td>
<td>0.964</td>
<td>0.859</td>
<td>0.910</td>
</tr>
<tr>
<td>$x_i, 3$</td>
<td>0.732</td>
<td>0.854</td>
<td>0.886</td>
<td>0.830</td>
<td>0.796</td>
<td>0.924</td>
<td>0.905</td>
<td>0.865</td>
<td>0.903</td>
</tr>
<tr>
<td>$x_i$</td>
<td>0.736</td>
<td>0.857</td>
<td>0.888</td>
<td>0.890</td>
<td>0.798</td>
<td>0.924</td>
<td>0.905</td>
<td>0.864</td>
<td>0.907</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.000</td>
<td>0.006</td>
<td>0.002</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>$U_{</td>
<td>x</td>
<td>}$</td>
<td>0.063</td>
<td>0.071</td>
<td>0.021</td>
<td>0.022</td>
<td>0.033</td>
<td>0.209</td>
<td>0.009</td>
</tr>
<tr>
<td>$U_{</td>
<td>x</td>
<td>}$</td>
<td>0.125</td>
<td>0.142</td>
<td>0.042</td>
<td>0.045</td>
<td>0.067</td>
<td>0.418</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Figure 24: Reported values for CO run 5.
Reported values for O₃

Table 23: Reported values for O₃ run 0.

<table>
<thead>
<tr>
<th></th>
<th>laboratories</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>( x_i )</td>
<td>-0.89</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>0.71</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Figure 25: Reported values for O₃ run 0.

Table 24: Reported values for O₃ run 1.

<table>
<thead>
<tr>
<th></th>
<th>laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>( x_i )</td>
<td>52.10</td>
</tr>
<tr>
<td>( x_i )</td>
<td>52.09</td>
</tr>
<tr>
<td>( x_i )</td>
<td>52.05</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>62.08</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>0.02</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>1.46</td>
</tr>
<tr>
<td>( u(x) )</td>
<td>2.92</td>
</tr>
</tbody>
</table>

Figure 26: Reported values for O₃ run 1.
Table 25: Reported values for O₃ run 2.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₀</td>
<td>17.36</td>
<td>16.32</td>
<td>13.04</td>
<td>18.60</td>
<td>13.71</td>
<td>18.27</td>
<td>18.08</td>
<td>18.23</td>
<td>17.69</td>
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<tr>
<td>x₀</td>
<td>2</td>
<td>17.37</td>
<td>16.37</td>
<td>13.01</td>
<td>18.60</td>
<td>13.61</td>
<td>18.26</td>
<td>18.06</td>
<td>18.17</td>
<td>17.65</td>
</tr>
<tr>
<td>x₀</td>
<td>3</td>
<td>17.36</td>
<td>16.31</td>
<td>13.04</td>
<td>18.70</td>
<td>13.74</td>
<td>18.39</td>
<td>18.03</td>
<td>18.16</td>
<td>17.60</td>
</tr>
</tbody>
</table>

Figure 27: Reported values for O₃ run 2.

Table 26: Reported values for O₃ run 3.

<table>
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<tr>
<th></th>
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<th>B</th>
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<th>I</th>
<th>K</th>
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<tbody>
<tr>
<td>x₀</td>
<td>32.90</td>
<td>34.51</td>
<td>34.88</td>
<td>35.65</td>
<td>34.05</td>
<td>33.81</td>
<td>33.50</td>
<td>33.76</td>
<td>33.38</td>
<td>32.83</td>
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<tr>
<td>x₀</td>
<td>2</td>
<td>32.91</td>
<td>34.49</td>
<td>34.70</td>
<td>35.40</td>
<td>34.43</td>
<td>33.80</td>
<td>33.51</td>
<td>33.75</td>
<td>33.33</td>
</tr>
<tr>
<td>x₀</td>
<td>3</td>
<td>32.80</td>
<td>34.47</td>
<td>34.89</td>
<td>35.36</td>
<td>34.21</td>
<td>33.79</td>
<td>33.51</td>
<td>33.75</td>
<td>33.34</td>
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</tbody>
</table>

Figure 28: Reported values for O₃ run 3.
Table 27: Reported values for O₃ run 4.

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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x i,1</td>
<td>113.21</td>
<td>118.01</td>
<td>116.06</td>
<td>122.86</td>
<td>114.77</td>
<td>114.40</td>
<td>113.88</td>
<td>114.39</td>
<td>113.61</td>
<td>112.44</td>
</tr>
<tr>
<td>x i,2</td>
<td>113.47</td>
<td>118.34</td>
<td>116.22</td>
<td>123.30</td>
<td>114.65</td>
<td>114.63</td>
<td>114.03</td>
<td>114.61</td>
<td>113.83</td>
<td>112.71</td>
</tr>
<tr>
<td>x i,3</td>
<td>113.53</td>
<td>118.53</td>
<td>116.39</td>
<td>124.00</td>
<td>114.75</td>
<td>114.84</td>
<td>114.16</td>
<td>114.55</td>
<td>113.95</td>
<td>112.93</td>
</tr>
<tr>
<td>S i</td>
<td>0.17</td>
<td>0.26</td>
<td>0.16</td>
<td>0.58</td>
<td>0.11</td>
<td>0.22</td>
<td>0.14</td>
<td>0.11</td>
<td>0.17</td>
<td>0.24</td>
</tr>
<tr>
<td>U(%)</td>
<td>2.43</td>
<td>2.77</td>
<td>2.03</td>
<td>2.10</td>
<td>1.71</td>
<td>2.22</td>
<td>0.81</td>
<td>1.49</td>
<td>1.72</td>
<td>0.57</td>
</tr>
<tr>
<td>U(%)</td>
<td>4.66</td>
<td>5.55</td>
<td>4.66</td>
<td>4.19</td>
<td>3.42</td>
<td>4.44</td>
<td>3.33</td>
<td>2.86</td>
<td>3.44</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Figure 29: Reported values for O₃ run 4.

Table 28: Reported values for O₃ run 5.

<table>
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<tr>
<th>values</th>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x i,1</td>
<td>89.55</td>
<td>92.36</td>
<td>90.97</td>
<td>96.80</td>
<td>89.25</td>
<td>89.66</td>
<td>89.15</td>
<td>89.40</td>
<td>89.01</td>
<td>87.84</td>
</tr>
<tr>
<td>x i,2</td>
<td>89.73</td>
<td>92.66</td>
<td>91.04</td>
<td>97.60</td>
<td>90.07</td>
<td>89.81</td>
<td>89.19</td>
<td>89.53</td>
<td>89.01</td>
<td>88.06</td>
</tr>
<tr>
<td>x i,3</td>
<td>89.75</td>
<td>92.61</td>
<td>91.08</td>
<td>97.50</td>
<td>89.78</td>
<td>89.84</td>
<td>89.21</td>
<td>89.53</td>
<td>89.00</td>
<td>88.06</td>
</tr>
<tr>
<td>S i</td>
<td>0.11</td>
<td>0.13</td>
<td>0.05</td>
<td>0.43</td>
<td>0.41</td>
<td>0.09</td>
<td>0.03</td>
<td>0.07</td>
<td>0.00</td>
<td>0.12</td>
</tr>
<tr>
<td>U(%)</td>
<td>1.85</td>
<td>2.20</td>
<td>1.75</td>
<td>1.65</td>
<td>1.39</td>
<td>1.65</td>
<td>0.71</td>
<td>1.24</td>
<td>1.47</td>
<td>0.53</td>
</tr>
<tr>
<td>U(%)</td>
<td>3.82</td>
<td>4.41</td>
<td>3.50</td>
<td>3.30</td>
<td>2.78</td>
<td>3.69</td>
<td>1.43</td>
<td>2.49</td>
<td>2.34</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Figure 30: Reported values for O₃ run 5.
Reported values for NO

Table 29: Reported values for NO run 0.

<table>
<thead>
<tr>
<th>values</th>
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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>-0.02</td>
<td>0.88</td>
<td>-0.56</td>
<td>-0.40</td>
<td>0.08</td>
<td>0.01</td>
<td>-0.07</td>
<td>-0.15</td>
<td>0.16</td>
<td>0.08</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>0.58</td>
<td>0.68</td>
<td>0.00</td>
<td>0.16</td>
<td>0.50</td>
<td>0.71</td>
<td>0.47</td>
<td>0.32</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>$U(x)$</td>
<td>1.16</td>
<td>1.35</td>
<td>0.01</td>
<td>0.32</td>
<td>1.00</td>
<td>1.42</td>
<td>0.95</td>
<td>0.53</td>
<td>1.26</td>
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</tr>
</tbody>
</table>

Figure 31: Reported values for NO run 0.

![Graph](image)

Table 30: Reported values for NO run 1.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>137.94</td>
<td>136.87</td>
<td>137.36</td>
<td>133.00</td>
<td>137.23</td>
<td>137.55</td>
<td>137.90</td>
<td>137.52</td>
<td>137.07</td>
<td>131.43</td>
</tr>
<tr>
<td>$x_{i,2}$</td>
<td>137.99</td>
<td>136.42</td>
<td>137.27</td>
<td>133.85</td>
<td>137.40</td>
<td>137.57</td>
<td>138.01</td>
<td>137.45</td>
<td>136.91</td>
<td>131.47</td>
</tr>
<tr>
<td>$x_{i,3}$</td>
<td>138.01</td>
<td>136.86</td>
<td>137.25</td>
<td>131.10</td>
<td>137.52</td>
<td>137.54</td>
<td>137.88</td>
<td>137.70</td>
<td>136.89</td>
<td>131.45</td>
</tr>
<tr>
<td>$s_1$</td>
<td>0.03</td>
<td>0.22</td>
<td>0.05</td>
<td>1.60</td>
<td>0.14</td>
<td>0.01</td>
<td>0.07</td>
<td>0.12</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>1.21</td>
<td>2.34</td>
<td>2.49</td>
<td>4.12</td>
<td>1.50</td>
<td>3.25</td>
<td>1.14</td>
<td>1.75</td>
<td>2.77</td>
<td>5.98</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>2.42</td>
<td>4.67</td>
<td>4.86</td>
<td>6.23</td>
<td>3.01</td>
<td>6.50</td>
<td>2.28</td>
<td>3.48</td>
<td>5.54</td>
<td>11.36</td>
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</table>

Figure 32: Reported values for NO run 1.

![Graph](image)
Table 31: Reported values for NO run 2.

<table>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i$, 1</td>
<td>72.50</td>
<td>71.94</td>
<td>72.11</td>
<td>69.95</td>
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<td>72.75</td>
<td>72.14</td>
<td>72.59</td>
<td>72.46</td>
<td>69.36</td>
</tr>
<tr>
<td>$x_i$, 2</td>
<td>72.82</td>
<td>71.88</td>
<td>72.30</td>
<td>70.05</td>
<td>72.74</td>
<td>72.89</td>
<td>72.29</td>
<td>72.89</td>
<td>72.72</td>
<td>69.55</td>
</tr>
<tr>
<td>$x_i$, 3</td>
<td>72.94</td>
<td>72.63</td>
<td>72.44</td>
<td>70.00</td>
<td>72.85</td>
<td>73.15</td>
<td>72.36</td>
<td>72.77</td>
<td>72.82</td>
<td>69.65</td>
</tr>
<tr>
<td>S</td>
<td>0.17</td>
<td>0.41</td>
<td>0.16</td>
<td>0.05</td>
<td>0.19</td>
<td>0.20</td>
<td>0.11</td>
<td>0.15</td>
<td>0.19</td>
<td>0.14</td>
</tr>
<tr>
<td>$u(x_i)$</td>
<td>0.01</td>
<td>1.36</td>
<td>1.33</td>
<td>2.15</td>
<td>0.00</td>
<td>1.96</td>
<td>0.05</td>
<td>1.60</td>
<td>1.65</td>
<td>3.16</td>
</tr>
<tr>
<td>$u(x_i)$</td>
<td>1.61</td>
<td>2.72</td>
<td>2.66</td>
<td>4.36</td>
<td>1.61</td>
<td>3.92</td>
<td>1.71</td>
<td>2.00</td>
<td>3.31</td>
<td>6.32</td>
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</table>

Figure 33: Reported values for NO run 2.

Table 32: Reported values for NO run 3.

<table>
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<tr>
<th>values</th>
<th>A</th>
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<th>C</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
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</thead>
<tbody>
<tr>
<td>$x_i$, 1</td>
<td>36.14</td>
<td>36.92</td>
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<td>34.55</td>
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<td>35.91</td>
<td>35.66</td>
<td>35.88</td>
<td>35.70</td>
<td>33.51</td>
</tr>
<tr>
<td>$x_i$, 2</td>
<td>36.16</td>
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<td>35.74</td>
<td>34.25</td>
<td>35.82</td>
<td>35.78</td>
<td>35.64</td>
<td>36.01</td>
<td>35.71</td>
<td>33.41</td>
</tr>
<tr>
<td>$x_i$, 3</td>
<td>36.19</td>
<td>36.42</td>
<td>35.02</td>
<td>34.50</td>
<td>35.70</td>
<td>35.93</td>
<td>35.60</td>
<td>36.06</td>
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<td>33.58</td>
</tr>
<tr>
<td>S</td>
<td>0.02</td>
<td>0.25</td>
<td>0.15</td>
<td>0.15</td>
<td>0.03</td>
<td>0.06</td>
<td>0.01</td>
<td>0.09</td>
<td>0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>$u(x_i)$</td>
<td>0.64</td>
<td>0.90</td>
<td>0.89</td>
<td>1.07</td>
<td>0.42</td>
<td>1.22</td>
<td>0.75</td>
<td>0.51</td>
<td>1.10</td>
<td>1.64</td>
</tr>
<tr>
<td>$u(x_i)$</td>
<td>1.26</td>
<td>1.81</td>
<td>1.36</td>
<td>2.14</td>
<td>0.84</td>
<td>2.43</td>
<td>1.30</td>
<td>1.02</td>
<td>2.19</td>
<td>3.28</td>
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</table>

Figure 34: Reported values for NO run 3.
Table 33: Reported values for NO run 4.

<table>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{1}$</td>
<td>17.41</td>
<td>16.48</td>
<td>17.18</td>
<td>16.30</td>
<td>17.30</td>
<td>17.31</td>
<td>17.04</td>
<td>17.42</td>
<td>17.40</td>
<td>15.13</td>
</tr>
<tr>
<td>$x_{2}$</td>
<td>17.46</td>
<td>16.50</td>
<td>17.15</td>
<td>16.65</td>
<td>17.42</td>
<td>17.28</td>
<td>17.08</td>
<td>17.44</td>
<td>17.28</td>
<td>15.06</td>
</tr>
<tr>
<td>$x_{3}$</td>
<td>17.44</td>
<td>16.50</td>
<td>17.17</td>
<td>16.90</td>
<td>17.47</td>
<td>17.35</td>
<td>17.09</td>
<td>17.40</td>
<td>17.42</td>
<td>15.90</td>
</tr>
</tbody>
</table>

$S_{1}$ 0.02 0.01 0.01 0.32 0.08 0.03 0.02 0.02 0.02 0.11
$U(\%)$ 0.59 0.74 0.37 0.60 0.25 0.85 0.72 0.46 0.76 0.98
$U(\%)$ 1.18 1.48 0.74 1.19 0.50 1.69 1.44 0.51 1.52 1.32

Figure 35: Reported values for NO run 4.

Table 34: Reported values for NO run 5.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{1}$</td>
<td>56.00</td>
<td>66.01</td>
<td>66.30</td>
<td>63.85</td>
<td>65.01</td>
<td>66.46</td>
<td>66.01</td>
<td>66.84</td>
<td>66.12</td>
<td>62.48</td>
</tr>
<tr>
<td>$x_{2}$</td>
<td>56.98</td>
<td>66.32</td>
<td>65.50</td>
<td>63.75</td>
<td>65.38</td>
<td>66.55</td>
<td>65.98</td>
<td>66.79</td>
<td>66.10</td>
<td>62.59</td>
</tr>
<tr>
<td>$x_{3}$</td>
<td>57.06</td>
<td>66.24</td>
<td>65.41</td>
<td>63.90</td>
<td>65.31</td>
<td>66.55</td>
<td>65.90</td>
<td>66.78</td>
<td>66.07</td>
<td>62.55</td>
</tr>
</tbody>
</table>

$S_{1}$ 0.04 0.15 0.05 0.12 0.09 0.03 0.01 0.03 0.02 0.11
$U(\%)$ 0.78 1.29 1.22 1.96 0.74 1.83 0.93 0.87 1.56 2.90
$U(\%)$ 1.55 2.55 2.44 3.92 1.48 3.66 1.87 1.73 3.11 5.80

Figure 36: Reported values for NO run 5.
**Table 35:** Reported values for NO run 6.

<table>
<thead>
<tr>
<th>laboratories</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_i, 1 )</td>
<td>27.30</td>
<td>27.76</td>
<td>26.92</td>
<td>26.75</td>
<td>27.27</td>
<td>27.22</td>
<td>26.68</td>
<td>27.31</td>
<td>27.56</td>
<td>25.07</td>
</tr>
<tr>
<td>( x_i, 2 )</td>
<td>27.43</td>
<td>26.06</td>
<td>26.87</td>
<td>25.90</td>
<td>27.19</td>
<td>27.36</td>
<td>26.77</td>
<td>27.46</td>
<td>27.56</td>
<td>25.26</td>
</tr>
<tr>
<td>( x_i, 3 )</td>
<td>27.53</td>
<td>26.07</td>
<td>27.12</td>
<td>26.15</td>
<td>27.32</td>
<td>27.53</td>
<td>26.90</td>
<td>27.50</td>
<td>27.43</td>
<td>25.42</td>
</tr>
</tbody>
</table>

**Figure 37:** Reported values for NO run 6.

**Table 36:** Reported values for NO run 7.

<table>
<thead>
<tr>
<th>laboratories</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_i, 1 )</td>
<td>499.02</td>
<td>486.18</td>
<td>489.55</td>
<td>476.60</td>
<td>493.85</td>
<td>495.38</td>
<td>403.74</td>
<td>496.08</td>
<td>492.35</td>
<td>479.64</td>
</tr>
<tr>
<td>( x_i, 2 )</td>
<td>499.45</td>
<td>486.31</td>
<td>489.95</td>
<td>477.25</td>
<td>493.83</td>
<td>495.95</td>
<td>494.04</td>
<td>497.46</td>
<td>492.59</td>
<td>480.11</td>
</tr>
<tr>
<td>( x_i, 3 )</td>
<td>499.52</td>
<td>487.03</td>
<td>489.76</td>
<td>477.10</td>
<td>494.54</td>
<td>496.08</td>
<td>494.39</td>
<td>497.76</td>
<td>493.60</td>
<td>480.35</td>
</tr>
</tbody>
</table>

**Figure 38:** Reported values for NO run 7.
Table 37: Reported values for NO run 8.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>388.43</td>
<td>379.11</td>
<td>381.64</td>
<td>371.06</td>
<td>385.40</td>
<td>387.78</td>
<td>384.68</td>
<td>388.25</td>
<td>386.45</td>
<td>372.30</td>
</tr>
<tr>
<td>$x_i, 2$</td>
<td>387.86</td>
<td>378.97</td>
<td>381.16</td>
<td>373.96</td>
<td>384.62</td>
<td>387.28</td>
<td>384.72</td>
<td>387.98</td>
<td>385.31</td>
<td>371.67</td>
</tr>
<tr>
<td>$x_i, 3$</td>
<td>387.13</td>
<td>379.37</td>
<td>381.17</td>
<td>371.06</td>
<td>384.65</td>
<td>386.92</td>
<td>385.52</td>
<td>387.60</td>
<td>385.04</td>
<td>371.46</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.62</td>
<td>0.94</td>
<td>0.39</td>
<td>0.46</td>
<td>0.44</td>
<td>0.43</td>
<td>0.47</td>
<td>0.32</td>
<td>0.20</td>
<td>0.48</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>3.04</td>
<td>5.25</td>
<td>6.86</td>
<td>11.41</td>
<td>4.18</td>
<td>8.25</td>
<td>2.38</td>
<td>4.87</td>
<td>5.86</td>
<td>18.53</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>6.03</td>
<td>12.49</td>
<td>13.76</td>
<td>22.82</td>
<td>9.39</td>
<td>16.46</td>
<td>5.16</td>
<td>9.73</td>
<td>13.71</td>
<td>33.56</td>
</tr>
</tbody>
</table>

Figure 39: Reported values for NO run 8.

Table 38: Reported values for NO run 9.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i, 1$</td>
<td>304.84</td>
<td>297.24</td>
<td>299.11</td>
<td>291.15</td>
<td>300.77</td>
<td>302.28</td>
<td>302.88</td>
<td>302.79</td>
<td>300.84</td>
<td>290.10</td>
</tr>
<tr>
<td>$x_i, 2$</td>
<td>304.13</td>
<td>297.72</td>
<td>299.42</td>
<td>291.65</td>
<td>301.56</td>
<td>302.68</td>
<td>302.92</td>
<td>303.34</td>
<td>301.11</td>
<td>290.69</td>
</tr>
<tr>
<td>$x_i, 3$</td>
<td>304.50</td>
<td>298.03</td>
<td>299.62</td>
<td>291.50</td>
<td>301.86</td>
<td>302.74</td>
<td>303.03</td>
<td>303.63</td>
<td>301.73</td>
<td>290.96</td>
</tr>
<tr>
<td>$s_i$</td>
<td>0.33</td>
<td>0.39</td>
<td>0.25</td>
<td>0.25</td>
<td>0.56</td>
<td>0.24</td>
<td>0.07</td>
<td>0.42</td>
<td>0.20</td>
<td>0.44</td>
</tr>
<tr>
<td>$U(x_i)$</td>
<td>2.41</td>
<td>4.92</td>
<td>5.41</td>
<td>8.95</td>
<td>3.29</td>
<td>6.55</td>
<td>2.07</td>
<td>3.80</td>
<td>5.44</td>
<td>13.16</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>4.62</td>
<td>9.64</td>
<td>10.82</td>
<td>17.91</td>
<td>6.58</td>
<td>13.10</td>
<td>4.14</td>
<td>7.60</td>
<td>10.68</td>
<td>25.32</td>
</tr>
</tbody>
</table>

Figure 40: Reported values for NO run 9.
Table 39: Reported values for NO run 10.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1, 1</td>
<td>202.60</td>
<td>138.94</td>
<td>199.62</td>
<td>194.46</td>
<td>201.12</td>
<td>203.12</td>
<td>201.92</td>
<td>203.31</td>
<td>202.38</td>
<td>193.26</td>
</tr>
<tr>
<td>x1, 2</td>
<td>202.03</td>
<td>139.23</td>
<td>199.78</td>
<td>194.50</td>
<td>200.77</td>
<td>202.85</td>
<td>201.68</td>
<td>203.09</td>
<td>201.86</td>
<td>192.61</td>
</tr>
<tr>
<td>x1, 3</td>
<td>201.98</td>
<td>139.15</td>
<td>199.54</td>
<td>194.25</td>
<td>200.62</td>
<td>202.70</td>
<td>201.78</td>
<td>202.98</td>
<td>201.86</td>
<td>192.54</td>
</tr>
<tr>
<td>x2</td>
<td>202.17</td>
<td>139.10</td>
<td>199.74</td>
<td>194.40</td>
<td>200.63</td>
<td>202.89</td>
<td>201.76</td>
<td>203.12</td>
<td>202.01</td>
<td>192.87</td>
</tr>
<tr>
<td>s</td>
<td>0.28</td>
<td>0.15</td>
<td>0.19</td>
<td>0.13</td>
<td>0.25</td>
<td>0.21</td>
<td>0.17</td>
<td>0.16</td>
<td>0.22</td>
<td>0.36</td>
</tr>
<tr>
<td>U(x)</td>
<td>1.66</td>
<td>3.33</td>
<td>3.62</td>
<td>5.97</td>
<td>2.19</td>
<td>4.56</td>
<td>1.49</td>
<td>2.57</td>
<td>3.81</td>
<td>8.75</td>
</tr>
<tr>
<td>U(x1)</td>
<td>3.32</td>
<td>5.65</td>
<td>7.24</td>
<td>11.94</td>
<td>4.38</td>
<td>8.12</td>
<td>2.87</td>
<td>5.13</td>
<td>7.82</td>
<td>17.50</td>
</tr>
</tbody>
</table>

Figure 41: Reported values for NO run 10.
Reported values for NO₂

Table 40: Reported values for NO₂ run 0.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>-0.08</td>
<td>-0.21</td>
<td>0.01</td>
<td>1.30</td>
<td>0.11</td>
<td>-0.14</td>
<td>0.03</td>
<td>-0.03</td>
<td>0.20</td>
<td>0.03</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>0.58</td>
<td>0.88</td>
<td>0.01</td>
<td>0.18</td>
<td>0.50</td>
<td>0.71</td>
<td>0.77</td>
<td>0.32</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>$U(u)$</td>
<td>1.16</td>
<td>1.35</td>
<td>0.01</td>
<td>0.36</td>
<td>0.99</td>
<td>1.43</td>
<td>1.54</td>
<td>0.53</td>
<td>1.26</td>
<td></td>
</tr>
</tbody>
</table>

Figure 42: Reported values for NO₂ run 0.

![Graph showing NO₂ concentration level 0]

Table 41: Reported values for NO₂ run 2.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{i,1}$</td>
<td>86.23</td>
<td>64.06</td>
<td>67.25</td>
<td>62.15</td>
<td>65.06</td>
<td>65.01</td>
<td>66.19</td>
<td>65.99</td>
<td>64.62</td>
<td>62.35</td>
</tr>
<tr>
<td>$x_{i,2}$</td>
<td>86.02</td>
<td>65.94</td>
<td>68.94</td>
<td>62.65</td>
<td>65.44</td>
<td>64.65</td>
<td>66.02</td>
<td>65.88</td>
<td>64.65</td>
<td>62.24</td>
</tr>
<tr>
<td>$x_{i,3}$</td>
<td>85.90</td>
<td>63.90</td>
<td>68.84</td>
<td>62.25</td>
<td>65.21</td>
<td>64.75</td>
<td>65.83</td>
<td>65.47</td>
<td>64.44</td>
<td>61.78</td>
</tr>
<tr>
<td>$y$</td>
<td>66.08</td>
<td>63.96</td>
<td>67.00</td>
<td>62.35</td>
<td>65.53</td>
<td>64.87</td>
<td>66.01</td>
<td>65.58</td>
<td>64.60</td>
<td>62.12</td>
</tr>
<tr>
<td>$s$</td>
<td>0.13</td>
<td>0.08</td>
<td>0.21</td>
<td>0.26</td>
<td>0.38</td>
<td>0.13</td>
<td>0.17</td>
<td>0.21</td>
<td>0.19</td>
<td>0.30</td>
</tr>
<tr>
<td>$U(x)$</td>
<td>1.36</td>
<td>1.79</td>
<td>1.80</td>
<td>1.90</td>
<td>1.80</td>
<td>0.98</td>
<td>1.03</td>
<td>1.45</td>
<td>2.88</td>
<td></td>
</tr>
<tr>
<td>$U(u)$</td>
<td>2.71</td>
<td>3.57</td>
<td>3.60</td>
<td>3.58</td>
<td>3.59</td>
<td>1.37</td>
<td>2.66</td>
<td>3.10</td>
<td>5.76</td>
<td></td>
</tr>
</tbody>
</table>

Figure 43: Reported values for NO₂ run 2.

![Graph showing NO₂ concentration level 2]
Table 42: Reported values for NO₂ run 4.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₁, 1</td>
<td>18.77</td>
<td>17.86</td>
<td>19.14</td>
<td>17.30</td>
<td>18.78</td>
<td>18.53</td>
<td>18.77</td>
<td>18.57</td>
<td>18.40</td>
<td>17.40</td>
</tr>
<tr>
<td>x₂, 2</td>
<td>18.72</td>
<td>16.12</td>
<td>19.07</td>
<td>17.10</td>
<td>19.57</td>
<td>18.59</td>
<td>18.74</td>
<td>18.77</td>
<td>18.44</td>
<td>17.47</td>
</tr>
<tr>
<td>x₃, 3</td>
<td>18.73</td>
<td>17.97</td>
<td>19.19</td>
<td>17.55</td>
<td>19.75</td>
<td>18.46</td>
<td>18.72</td>
<td>18.70</td>
<td>18.43</td>
<td>17.43</td>
</tr>
</tbody>
</table>

| SI    | 0.02 | 0.13 | 0.05 | 0.22 | 0.11 | 0.06 | 0.02 | 0.05 | 0.03 | 0.03 |
| U(%)  | 0.67 | 0.82 | 0.55 | 4.99 | 0.38 | 0.67 | 0.74 | 0.77 | 0.77 | 1.01 |
| U(%)  | 1.35 | 1.64 | 1.10 | 9.97 | 0.76 | 1.74 | 1.48 | 1.53 | 1.53 | 2.02 |

Figure 44: Reported values for NO₂ run 4.

![Graph showing NO₂ concentration level 4](image)

Table 43: Reported values for NO₂ run 6.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x₁, 1</td>
<td>39.85</td>
<td>37.64</td>
<td>40.63</td>
<td>36.80</td>
<td>39.52</td>
<td>39.01</td>
<td>39.60</td>
<td>39.64</td>
<td>38.66</td>
<td>37.20</td>
</tr>
<tr>
<td>x₂, 2</td>
<td>39.68</td>
<td>36.11</td>
<td>40.30</td>
<td>37.10</td>
<td>39.39</td>
<td>38.97</td>
<td>39.41</td>
<td>39.60</td>
<td>38.64</td>
<td>37.14</td>
</tr>
<tr>
<td>x₃, 3</td>
<td>39.62</td>
<td>38.33</td>
<td>40.19</td>
<td>36.55</td>
<td>39.41</td>
<td>38.83</td>
<td>39.28</td>
<td>39.42</td>
<td>38.72</td>
<td>38.74</td>
</tr>
</tbody>
</table>

| SI    | 0.11 | 0.19 | 0.17 | 0.27 | 0.07 | 0.09 | 0.11 | 0.11 | 0.13 | 0.25 |
| U(%)  | 0.94 | 1.19 | 1.10 | 10.55 | 0.72 | 1.28 | 0.31 | 0.60 | 1.11 | 1.79 |
| U(%)  | 1.67 | 2.39 | 2.20 | 21.19 | 1.45 | 2.56 | 1.51 | 1.20 | 2.21 | 3.56 |

Figure 45: Reported values for NO₂ run 6.

![Graph showing NO₂ concentration level 6](image)
Table 44: Reported values for NO\textsubscript{2} run 8.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x\textsubscript{i}, 1</td>
<td>118.07</td>
<td>113.54</td>
<td>123.24</td>
<td>109.55</td>
<td>117.90</td>
<td>117.89</td>
<td>117.13</td>
<td>117.64</td>
<td>114.98</td>
<td>111.07</td>
</tr>
<tr>
<td>x\textsubscript{i}, 2</td>
<td>118.34</td>
<td>114.56</td>
<td>123.94</td>
<td>109.90</td>
<td>118.73</td>
<td>118.84</td>
<td>117.89</td>
<td>117.92</td>
<td>115.19</td>
<td>111.90</td>
</tr>
<tr>
<td>x\textsubscript{i}, 3</td>
<td>118.72</td>
<td>112.92</td>
<td>123.83</td>
<td>108.18</td>
<td>118.35</td>
<td>118.63</td>
<td>116.91</td>
<td>118.25</td>
<td>115.41</td>
<td>112.15</td>
</tr>
<tr>
<td>(s)</td>
<td>0.32</td>
<td>0.88</td>
<td>0.37</td>
<td>0.40</td>
<td>0.41</td>
<td>0.90</td>
<td>0.47</td>
<td>0.30</td>
<td>0.21</td>
<td>0.56</td>
</tr>
<tr>
<td>(U(x))</td>
<td>2.27</td>
<td>3.02</td>
<td>3.30</td>
<td>3.21</td>
<td>2.11</td>
<td>2.88</td>
<td>2.07</td>
<td>1.57</td>
<td>2.59</td>
<td>5.99</td>
</tr>
<tr>
<td>(U(x))</td>
<td>4.54</td>
<td>6.03</td>
<td>6.60</td>
<td>6.43</td>
<td>4.22</td>
<td>5.75</td>
<td>4.14</td>
<td>3.13</td>
<td>5.17</td>
<td>10.18</td>
</tr>
</tbody>
</table>

Figure 46: Reported values for NO\textsubscript{2} run 8.

![Graph showing NO\textsubscript{2} concentration level 8 with data points and error bars for each laboratory.]

Table 45: Reported values for NO\textsubscript{2} run 10.

<table>
<thead>
<tr>
<th>values</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>x\textsubscript{i}, 1</td>
<td>104.88</td>
<td>101.16</td>
<td>107.69</td>
<td>98.20</td>
<td>104.73</td>
<td>105.23</td>
<td>104.70</td>
<td>104.48</td>
<td>102.78</td>
<td>99.91</td>
</tr>
<tr>
<td>x\textsubscript{i}, 2</td>
<td>105.01</td>
<td>101.35</td>
<td>107.66</td>
<td>98.10</td>
<td>104.83</td>
<td>105.63</td>
<td>106.09</td>
<td>104.75</td>
<td>103.19</td>
<td>99.37</td>
</tr>
<tr>
<td>x\textsubscript{i}, 3</td>
<td>105.18</td>
<td>102.38</td>
<td>108.29</td>
<td>97.95</td>
<td>105.07</td>
<td>106.05</td>
<td>105.44</td>
<td>104.93</td>
<td>103.78</td>
<td>99.48</td>
</tr>
<tr>
<td>(s)</td>
<td>0.16</td>
<td>0.65</td>
<td>0.35</td>
<td>0.12</td>
<td>0.17</td>
<td>0.41</td>
<td>0.32</td>
<td>0.22</td>
<td>0.26</td>
<td>0.24</td>
</tr>
<tr>
<td>(U(x))</td>
<td>2.03</td>
<td>2.71</td>
<td>2.88</td>
<td>2.81</td>
<td>1.88</td>
<td>2.61</td>
<td>1.49</td>
<td>1.41</td>
<td>2.33</td>
<td>4.54</td>
</tr>
<tr>
<td>(U(x))</td>
<td>4.07</td>
<td>5.42</td>
<td>5.76</td>
<td>5.42</td>
<td>3.76</td>
<td>5.23</td>
<td>2.96</td>
<td>2.61</td>
<td>4.56</td>
<td>9.06</td>
</tr>
</tbody>
</table>

Figure 47: Reported values for NO\textsubscript{2} run 10.

![Graph showing NO\textsubscript{2} concentration level 10 with data points and error bars for each laboratory.]

57
### Annex B: precision of standardised measurement methods

For the main purpose of monitoring trends between different ILC undertaken by ERLAP, the precision of standardized SO\textsubscript{2}, CO, O\textsubscript{3} and NO\textsubscript{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\textsubscript{3}, CO, SO\textsubscript{2} and NO\textsubscript{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.

\[
r = t_{99\%,v} \cdot \sqrt{2} \cdot s_r \tag{Equation 6}
\]

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.

\[
R = t_{99\%,v} \cdot \sqrt{2} \cdot s_R \tag{Equation 7}
\]

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Run</th>
<th>(p_j)</th>
<th>t critical value 95% for r</th>
<th>T critical value 95% for R</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1,2,3,4,5</td>
<td>9</td>
<td>2.101</td>
<td>2.306</td>
</tr>
<tr>
<td>NO</td>
<td>1,2,3,4,5,6,7,8,9,10</td>
<td>10</td>
<td>2.086</td>
<td>2.262</td>
</tr>
<tr>
<td>NO\textsubscript{2}</td>
<td>2,4,6,8,10</td>
<td>10</td>
<td>2.086</td>
<td>2.262</td>
</tr>
<tr>
<td>O\textsubscript{3}</td>
<td>1,2,3,4,5</td>
<td>10</td>
<td>2.086</td>
<td>2.262</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>1,2,3,4,5</td>
<td>9</td>
<td>2.101</td>
<td>2.306</td>
</tr>
</tbody>
</table>
The repeatability \((r)\) and reproducibility \((R)\) limits of measurement methods are presented from Table 47 to Table 51 and from Figure 48 to Figure 52.

It is also reported the ‘reproducibility from common criteria \((R \text{ (from } \sigma_p)\)’ calculated by substituting \(s_R\) in Equation 7 with a ‘standard deviation for proficiency assessment’ (see Table 4). Comparison between \(R\) and \(R \text{ (from } \sigma_p)\) serves to indicate that \(\sigma_p\) is realistic \([13]\) or from the other point of view, that the general methodology implemented by NRLs is appropriate for \(\sigma_p\).

**Table 47:** The \(R\) and \(r\) of \(\text{SO}_2\) standard measurement method.

<table>
<thead>
<tr>
<th>SO(_2) data (nmol/mol) without outliers</th>
<th>repeatability limit : (r)</th>
<th>reproducibility limit : (R)</th>
<th>reproducibility limit (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>group average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.8</td>
<td>0.3</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>17.8</td>
<td>0.2</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td>0.4</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>63.8</td>
<td>0.5</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>121.4</td>
<td>0.9</td>
<td>8.1</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

**Figure 48:** The \(R\) and \(r\) of \(\text{SO}_2\) standard measurement method as a function of concentration.
Table 48: The R and r of CO standard measurement method.

<table>
<thead>
<tr>
<th>CO data (μmol/mol) without outliers</th>
<th>repeatability limit: r</th>
<th>reproducibility limit: R</th>
<th>reproducibility limit (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>group average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.040</td>
<td>0.162</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.853</td>
<td>0.01</td>
<td>0.206</td>
<td></td>
</tr>
<tr>
<td>1.967</td>
<td>0.009</td>
<td>0.215</td>
<td></td>
</tr>
<tr>
<td>2.789</td>
<td>0.053</td>
<td>0.171</td>
<td></td>
</tr>
<tr>
<td>5.049</td>
<td>0.009</td>
<td>0.238</td>
<td></td>
</tr>
<tr>
<td>8.607</td>
<td>0.014</td>
<td>0.285</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

Figure 49: The R and r of CO standard measurement method as a function of concentration.
Table 49: The R and r of O₃ standard measurement method.

<table>
<thead>
<tr>
<th>O₃ data (nmol/mol) without outliers</th>
<th>group average</th>
<th>repeatability limit: r</th>
<th>reproducibility limit: R</th>
<th>reproducibility limit (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1</td>
<td>-0.1</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.2</td>
<td>0.1</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.9</td>
<td>0.3</td>
<td>2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63.5</td>
<td>0.6</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.5</td>
<td>0.6</td>
<td>8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>115.6</td>
<td>0.7</td>
<td>10.1</td>
<td>8.7%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 50: The R and r of O₃ standard measurement method as a function of concentration.
**Table 50:** The R and r of NO standard measurement method.

<table>
<thead>
<tr>
<th>NO data (nmol/mol) without outliers</th>
<th>repeatability limit: r</th>
<th>reproducibility limit: R</th>
<th>reproducibility limit (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.2</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.0</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.5</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65.8</td>
<td>4.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.9</td>
<td>4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>136.4</td>
<td>7.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>199.9</td>
<td>11.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>299.4</td>
<td>15.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>382.2</td>
<td>20.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>490.6</td>
<td>23.7</td>
<td></td>
<td>4.8%</td>
</tr>
</tbody>
</table>

**Figure 51:** The R and r of NO standard measurement method as a function of concentration.
Table 51: The R and r of NO₂ standard measurement method.

<table>
<thead>
<tr>
<th>NO₂ data (nmol/mol)</th>
<th>without outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>group average</td>
<td>repeatability limit: r</td>
</tr>
<tr>
<td>0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>18.4</td>
<td>0.3</td>
</tr>
<tr>
<td>38.8</td>
<td>0.5</td>
</tr>
<tr>
<td>64.8</td>
<td>0.7</td>
</tr>
<tr>
<td>103.5</td>
<td>1.0</td>
</tr>
<tr>
<td>116.4</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Figure 52: The R and r of NO₂ standard measurement method as a function of concentration.
**Annex C: 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 z’-scores calculation was performed to estimate outliers.

Statistical outliers obtained at this stage are not considered as extraordinary errors but due to significant difference in participant’s standard operating procedure.

The precision of standardised measurement methods reported in 0 are calculated using the database without outliers.

According to z’-score calculation, results between $|2|$ and $|3|$ are considered stragglers and they deserve a specific check. Four values were evaluated as stragglers: level 4 and 5 of O$_3$ and level 8 and 10 of NO$_2$, all for Laboratory D.

During this ILC, no outliers were identified.
Annex D: Confidentiality

Results of the ILC are published according to the agreements included in the document AQUILA-N37 [12] approved by all NRL.

In order to ensure confidentiality of the laboratories information, ERLAP guarantees the submitted data as follows:

- Any administrative information provided by the laboratory is confidential and cannot be communicated to a third party.
- Access to ERLAP facilities is allowed only to members of the Unit JRC-C5 and authorized persons (cleaning staff, maintenance staff, safety and security staff etc.)
- Confidential passwords to access the web application for data submission are sent once the registration to ILC is completed. Confidential passwords allow access to the WEB interface and to on-line questionnaire. Passwords are valid until the ILC is closed. Laboratories can change their password online.
- The form LAB-REC-2000 (Confidentiality involvement form) is asked to be signed by the participants during their first participation to an ILC organized by ERLAP.
Annex E: Accreditation certificates

CERTIFICATO DI ACCREDITAMENTO
Accreditation Certificate

0018P REV. 00

DIPARTIMENTO LABORATORI DI PROVA
European Reference Laboratory for air Pollution (ERLAP)
Sede/Headquarters:
- Via E. Fermi 2749 - 21027 (spra VA)

UNI CEI EN ISO/IEC 17043:2010
ISO/IEC 17043:2010

QALE
Organizzatori di prove valutative interlaboratorio
Proficiency Testing Provider

Data di 1a emissione
1st Issue date
17-01-2019

Dott.ssa Silvia Tramontin
Il Direttore di Dipartimento
The Department Director

Data di modifica
Modification date
17-01-2019

Dott.ssa Filippo Ruffetti
Il Direttore Generale
The General Director

Data di scadenza
Expiring date
16-01-2023

Ing. Giuseppe Rossi
Il Presidente
The President

L'accreditamento attesta la competenza tecnica dell'Organizzazione relativamente al campo di accreditamento riportato nell'Elenco Schemi allegato al presente Certificato di accreditamento. Il presente certificato non è da ritenersi valido se non accompagnato dagli elenchi Schemi, che possono variare nel tempo.

The accreditation certifies the technical competence of the organisation limited to the scope detailed in the attached Enclosure. The present certificate is valid only if associated to the annexed schedule, that may vary in the time.

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Sede operativa e legale: Via Guglielmo Saliceto, 7/9 | 00161 Roma - Italy | Tel. +39 06 8440991 | Fax +39 06 8841199
info@accredia.it | www.accredia.it | Partita IVA - Codice Fiscale 10566361001
<table>
<thead>
<tr>
<th>Codice identificativo</th>
<th>Settore</th>
<th>Oggetto / Materiale / Prodotto/ Matrix</th>
<th>Misurando / Proprietà misurata / Grandezza</th>
<th>Tipologia</th>
</tr>
</thead>
<tbody>
<tr>
<td>ambientale</td>
<td>purified ambient air</td>
<td>carbon monoxide</td>
<td>schema quantitativo</td>
<td></td>
</tr>
<tr>
<td>ambientale</td>
<td>purified ambient air</td>
<td>nitrogen oxides</td>
<td>schema quantitativo</td>
<td></td>
</tr>
<tr>
<td>ambientale</td>
<td>purified ambient air</td>
<td>ozone</td>
<td>schema quantitativo</td>
<td></td>
</tr>
<tr>
<td>ambientale</td>
<td>purified ambient air</td>
<td>sulphur dioxide</td>
<td>schema quantitativo</td>
<td></td>
</tr>
</tbody>
</table>

Il QRcode consente di accedere direttamente al sito [www.accredia.it](http://www.accredia.it) per verificare la validità dell'elenco schemi e del certificato di accreditamento rilasciato al PIP.

L'eventuale simbolo (*) indica che è attiva una sospensione dell'accreditamento per la specifica attività riportata a fianco.
CERTIFICATO DI ACCREDITAMENTO
Accreditation Certificate

Accreditamento n° 1362
Accreditation n°

Si dichiara che
We declare that

European Reference Laboratory for Air Pollution (ERLAP) Air and Climate Unit
Directorate C. Energy, Transport and Climate
Joint Research Centre - European Commission
Sede/Headquarters:
- Via E. Fermi 2749 - 21027 Ispra VA

è conforme al requisiti della norma
meets the requirements of the standard
UNI CEI EN ISO/IEC 17025:2005 "Requisiti generali per la competenza dei Laboratori di prova e taratura"

quale
as
Laboratorio di Prova
Testing Laboratory


The accreditation certifies the technical competence of the laboratory limited to the scope detailed in the attached Enclosure. The scope may vary in the time. The management system requirements in ISO/IEC 17025:2005 (Section 4) are written in a language relevant to the Laboratory of Proof operations and meet the principles of ISO 9001:2008 and are aligned with its pertinent requirements. The present certificate is valid only if associated to the annexed schedule, and can be suspended or withdrawn at any time in the event of non fulfillment as ascertained by ACCREDIA. The in force status of the accreditation may be checked in the WEB site (www.accredia.it) or on direct request to appointed Department.

Data di 1° emissione
1st issue date
2013-06-19

Data di modifica
Modification date
2017-05-24

Data di scadenza
Expiring date
2021-06-17

Il Direttore di Dipartimento
The Department Director
(Dott.ssa Silvia Tramontin)

Il Direttore Generale
The General Director
(Dr. Filippo Trifletti)

Il Presidente
The President
(Ing. Giuseppe Rossi)

Mod. CA-01 rev. 02
Pag. 1 di 1
<table>
<thead>
<tr>
<th>Elenco Prove Accreditate - Categoria: 0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient Air</strong></td>
</tr>
<tr>
<td>Denominazione della prova / Campi di prova</td>
</tr>
<tr>
<td>Particulate Elemental Carbon (EC) (0.2 to 18 µg/m³)</td>
</tr>
<tr>
<td>Particulate Matter &lt;10 micrometers (PM10) (3.85 to 150 µg/m³)</td>
</tr>
<tr>
<td>Particulate Matter &lt;2.5 micrometers (PM2.5) (3.48 to 120 µg/m³)</td>
</tr>
<tr>
<td>Particulate Organic Carbon (OC) (1.8 to 45 µg/m³)</td>
</tr>
<tr>
<td>Synthetic mixture gas</td>
</tr>
<tr>
<td>Denominazione della prova / Campi di prova</td>
</tr>
<tr>
<td>carbon monoxide (0.015-0.06 nmol/mol)</td>
</tr>
<tr>
<td>nitrogen oxides (NO: 1-1062 nmol/mol; NO₂: 1-261 nmol/mol)</td>
</tr>
<tr>
<td>ozone (1-250 nmol/mol)</td>
</tr>
<tr>
<td>sulphur dioxide (1-375 nmol/mol)</td>
</tr>
</tbody>
</table>

Legenda
En= norma europea

La decorrenza del presente elenco delle prove accreditate, coincide con la data di revisione del documento, posta in alto a destra. Non rileva il fatto che la firma digitale sia stata apposta successivamente.
End of report
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