Final report, Ongoing Key Comparison BIPM.QM-K1, Ozone at ambient level, comparison with NPLI, (February 2018)

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**Abstract**

As part of the ongoing key comparison BIPM.QM-K1, a comparison has been performed between the ozone national standard of India maintained by the CSIR-National Physical Laboratory, India (NPLI) and the common reference standard of the key comparison, maintained by the Bureau International des Poids et Mesures (BIPM). The instruments have been compared over a nominal ozone amount-of-substance fraction range from 0 nmol/mol to 500 nmol/mol.

Contents:

1. FIELD .............................................................................................................................................................. 2
2. SUBJECT .......................................................................................................................................................... 2
3. PARTICIPANTS ................................................................................................................................................. 2
4. ORGANIZING BODY .......................................................................................................................................... 2
5. RATIONALE ..................................................................................................................................................... 2
6. TERMS AND DEFINITIONS ................................................................................................................................. 2
7. MEASUREMENT SCHEDULE .............................................................................................................................. 2
8. MEASUREMENT PROTOCOL ............................................................................................................................. 3
9. REPORTING MEASUREMENT RESULTS .............................................................................................................. 4
10. POST COMPARISON CALCULATION ................................................................................................................ 4
11. DEVIATIONS FROM THE COMPARISON PROTOCOL ...................................................................................... 4
12. MEASUREMENT STANDARDS ............................................................................................................................ 4
13. MEASUREMENT RESULTS AND UNCERTAINTIES ...................................................................................... 7
14. ANALYSIS OF THE MEASUREMENT RESULTS BY GENERALISED LEAST-SQUARE REGRESSION ................. 7
15. DEGREES OF EQUIVALENCE ........................................................................................................................... 8
16. HISTORY OF COMPARISONS BETWEEN BIPM SRP27, SRP28 AND NPLI SRP43 ........................................... 9
17. SUMMARY OF PREVIOUS COMPARISONS INCLUDED IN BIPM.QM-K1 ......................................................... 10
18. CONCLUSION ............................................................................................................................................... 10
19. REFERENCES ............................................................................................................................................... 10

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1. Field
Amount of substance.

2. Subject
Comparison of reference measurement standards for ozone at ambient level.

3. Participants
BIPM.QM-K1 is an ongoing key comparison, which is structured as an ongoing series of bilateral comparisons. The results of the comparison with the CSIR-National Physical Laboratory, India (NPLI) are reported here.

4. Organizing body
BIPM

5. Rationale
The ongoing key comparison BIPM.QM-K1 has been running since January 2007. It follows the pilot study CCQM-P28 that included 23 participants and was performed between July 2003 and February 2005 [1]. It is aimed at evaluating the degree of equivalence of ozone photometers that are maintained as national standards, or as primary standards within international networks for ambient ozone measurements. The reference value is determined using the NIST Standard Reference Photometer (BIPM-SRP27) maintained by the BIPM as a common reference.

6. Terms and definitions
- \(x_{\text{nom}}\): nominal ozone amount-of-substance fraction in dry air furnished by the ozone generator
- \(x_{A,i}\): \(i\)th measurement of the nominal value \(x_{\text{nom}}\) by the photometer A.
- \(\bar{x}_A\): the mean of \(N\) measurements of the nominal value \(x_{\text{nom}}\) measured by the photometer A: 
  \[
  \bar{x}_A = \frac{1}{N} \sum_{i=1}^{N} x_{A,i}
  \]
- \(s_A\): standard deviation of \(N\) measurements of the nominal value \(x_{\text{nom}}\) measured by the photometer A: 
  \[
  s_A^2 = \frac{1}{N-1} \sum_{i=1}^{N} (x_{A,i} - \bar{x}_A)^2
  \]
- The result of the linear regression fit performed between two sets of data measured by the photometers A and B during a comparison is written: 
  \[
  x_A = a_{A,B} x_B + b_{A,B}.
  \]
  With this notation, the photometer A is compared against the photometer B. \(a_{A,B}\) is dimensionless and \(b_{A,B}\) is expressed in units of nmol/mol.

7. Measurement schedule
The key comparison BIPM.QM-K1 was initially organised in 2 years cycles. The 2007-2008 round, the results of which were published in the Key Comparison Database of the BIPM, included 16 participants. The second round of BIPM.QM-K1 started in March 2009 for a period of 4 years, following the decision of the CCQM/GAWG to reduce the repeat frequency...
of bilateral comparisons. Measurements reported in this report were performed on 14 February 2018 at the BIPM.

8. Measurement protocol

The comparison protocol is summarized in this section. The complete version can be found on the BIPM website (http://www.bipm.org/utils/en/pdf/BIPM.QM-K1_protocol.pdf).

This comparison was performed following protocol A, corresponding to a direct comparison between the NPLI national standard SRP43 and the common reference standard BIPM-SRP27 maintained at the BIPM. A comparison between two (or more) ozone photometers consists of producing ozone-air mixtures at different amount-of-substance fractions over the required range, and measuring these with the photometers.

8.1. Ozone generation

The same source of purified air is used for all the ozone photometers being compared. This air is used to provide reference air as well as the ozone-air mixture to each ozone photometer. Ambient air is used as the source for reference air. The air is compressed with an oil-free compressor, dried and scrubbed with a commercial purification system so that the amount-of-substance fractions of ozone and nitrogen oxides remaining in the air are below detectable limits. The relative humidity of the reference air is monitored and the amount-of-substance fraction of water in air typically is below 3 μmol/mol. The amount-of-substance fraction of volatile organic hydrocarbons in the reference air was measured (November 2002), with no amount-of-substance fraction of any detected component exceeding 1 nmol/mol.

A common dual external manifold in Pyrex is used to furnish the necessary flows of reference air and ozone-air mixtures to the ozone photometers. The two columns of this manifold are vented to atmospheric pressure.

8.2. Comparison procedure

Prior to the comparison, all the instruments were switched on and allowed to stabilise for at least 8 hours. The pressure and temperature measurement systems of the instruments were checked at this time. If any adjustments were required, these were noted. For this comparison, no adjustments were necessary.

One comparison run includes 10 different amount-of-substance fractions distributed to cover the range, together with the measurement of zero reference air at the beginning and end of each run. The nominal amount-of-substance fractions were measured in a sequence imposed by the protocol (0, 220, 80, 420, 120, 320, 30, 370, 170, 500, 270, and 0) nmol/mol. Each of these points is an average of 10 single measurements.

For each nominal value of the ozone amount-of-substance fraction $x_{\text{nom}}$ furnished by the ozone generator, the standard deviation $s_{\text{SRP27}}$ on the set of 10 consecutive measurements $x_{\text{SRP27},i}$ recorded by BIPM-SRP27 was calculated. The measurement results were considered as valid if $s_{\text{SRP27}}$ was less than 1 nmol/mol, which ensures that the photometers were measuring a stable ozone concentration. If not, another series of 10 consecutive measurements was performed.

8.3. Comparison repeatability

The comparison procedure was repeated three times to evaluate its repeatability. The participant and the BIPM commonly decided when both instruments were stable enough to
start recording a set of measurement results to be considered as the official comparison results.

8.4. SRP27 stability check

A second ozone reference standard, BIPM-SRP28, was included in the comparison to verify its agreement with BIPM-SRP27 and thus follow its stability over the period of the ongoing key comparison.

9. Reporting measurement results

The participant and the BIPM staff reported the measurement results in the result form BIPM.QM-K1-R1 provided by the BIPM and available on the BIPM website. It includes details on the comparison conditions, measurement results and associated uncertainties, as well as the standard deviation for each series of 10 ozone amount-of-substance fractions measured by the participant’s standard and the common reference standard. The completed form BIPM.QM-K1-R1-NPLI-2018 is given in Appendix 1.

10. Post comparison calculation

All calculations were performed by the BIPM using the form BIPM.QM-K1-R1. It includes the two degrees of equivalence that are reported as comparison results in the Appendix B of the BIPM KCDB (key comparison database). Additionally, the degrees of equivalence at all nominal ozone amount-of-substance fractions are reported in the same form, as well as the linear relationship between the participant standard and the common reference standard.

11. Deviations from the comparison protocol

In this comparison, there was no deviation from the protocol.

12. Measurement standards

The instruments maintained by the BIPM and by the NPLI are Standard Reference Photometers (SRP) built by the NIST. More details on the NIST SRP principle and its capabilities can be found in [2]. The following section describes briefly the instruments’ measurement principle and their uncertainty budgets.

12.1. Measurement equation of a NIST SRP

The measurement of the ozone amount-of-substance fraction by an SRP is based on the absorption of radiation at 253.7 nm by ozonized air in the gas cells of the instrument. One particularity of the instrument design is the use of two gas cells to overcome the instability of the light source. The measurement equation is derived from the Beer-Lambert and ideal gas laws. The number concentration \( C \) of ozone is calculated from:

\[
C = \frac{-1}{2\sigma L_{\text{opt}}} \frac{T}{T_{\text{std}}} \frac{P_{\text{std}}}{P} \ln(D)
\]

where
\[
\begin{align*}
\sigma & \quad \text{is the absorption cross-section of ozone at 253.7 nm under standard conditions of temperature and pressure, } 1.1476 \times 10^{-17} \text{ cm}^2/\text{molecule} \ [3]. \\
L_{\text{opt}} & \quad \text{is the mean optical path length of the two cells;} \\
T & \quad \text{is the measured temperature of the cells;} \\
T_{\text{std}} & \quad \text{is the standard temperature (273.15 K);}
\end{align*}
\]
$P$ is the measured pressure of the cells;

$P_{\text{std}}$ is the standard pressure (101.325 kPa);

$D$ is the product of transmittances of two cells, with the transmittance ($T_r$) of one cell defined as

$$T_r = \frac{I_{\text{ozone}}}{I_{\text{air}}}$$

where

$I_{\text{ozone}}$ is the UV radiation intensity measured from the cell when containing ozonized air, and

$I_{\text{air}}$ is the UV radiation intensity measured from the cell when containing pure air (also called reference or zero air).

Using the ideal gas law equation (1) can be recast in order to express the measurement results as a amount-of-substance fraction ($x$) of ozone in air:

$$x = \frac{-1}{2\sigma L_{\text{opt}} P N_A} \ln(D)$$

where

$N_A$ is the Avogadro constant, $6.022142 \times 10^{23}$ mol$^{-1}$, and

$R$ is the gas constant, 8.314472 J mol$^{-1}$ K$^{-1}$

The formulation implemented in the SRP software is:

$$x = \frac{-1}{2\alpha_x L_{\text{opt}} P_{\text{std}}} \ln(D)$$

where

$\alpha_x$ is the linear absorption coefficient at standard conditions, expressed in cm$^{-1}$, linked to the absorption cross-section with the relation:

$$\alpha_x = \sigma \frac{N_A}{R} \frac{P_{\text{std}}}{T_{\text{std}}}$$

12.2. Absorption cross-section for ozone

The linear absorption coefficient under standard conditions $\alpha_x$ used within the SRP software algorithm is 308.32 cm$^{-1}$. This corresponds to a value for the absorption cross section $\sigma$ of $1.1476 \times 10^{-17}$ cm$^2$/molecule, rather than the more often quoted $1.147 \times 10^{-17}$ cm$^2$/molecule. In the comparison of two SRP instruments, the absorption cross-section can be considered to have a conventional value and its uncertainty can be set to zero. However, in the comparison of different methods or when considering the complete uncertainty budget of the method the uncertainty of the absorption cross-section should be taken into account. A consensus value of 2.12 % at a 95 % level of confidence for the uncertainty of the absorption cross-section has been proposed by the BIPM and the NIST in a recent publication [4].
12.3. Condition of the BIPM SRPs

Compared to the original design described in [2], SRP27 and SRP28 have been modified to deal with two biases revealed by the study conducted by the BIPM and the NIST [4]. In 2009, an “SRP upgrade kit” was installed in the instruments, as described in the report [5].

12.4. Uncertainty budget of the common reference BIPM-SRP27

The uncertainty budget for the ozone amount-of-substance fraction in dry air ($x$) measured by the instruments BIPM-SRP27 and BIPM-SRP28 in the range from 0 nmol/mol to 500 nmol/mol is given in Table 1.

| Table 1: Uncertainty budget for the SRPs maintained by the BIPM |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Component ($y$) | Source          | Distribution    | Standard Uncertainty | Combined standard uncertainty $u(y)$ | Sensitivity coefficient $c_i = \frac{\partial x}{\partial y}$ | Contribution to $u(x)$ $\left| c_i \right| u(y)$ nmol/mol |
| Optical Path $L_{opt}$ | Measurement scale | Rectangular     | 0.0006 cm            | 0.52 cm            | $- \frac{x}{L_{opt}}$ | $2.89 \times 10^{-3} \times x$ |
|                  | Repeatability   | Normal          | 0.01 cm              |                   |                      |                                 |
|                  | Correction factor | Rectangular     | 0.52 cm              |                   |                      |                                 |
| Pressure $P$     | Pressure gauge  | Rectangular     | 0.029 kPa            | 0.034 kPa          | $- \frac{x}{P}$      | $3.37 \times 10^{-4} \times x$ |
|                  | Difference between cells | Rectangular | 0.017 kPa            |                   |                      |                                 |
| Temperature $T$  | Temperature probe | Rectangular     | 0.03 K               | 0.07 K             | $\frac{x}{T}$       | $2.29 \times 10^{-4} \times x$ |
|                  | Temperature gradient | Rectangular | 0.058 K              |                   |                      |                                 |
| Ratio of intensities $D$ | Scaler resolution | Rectangular | $8 \times 10^{-6}$ | $1.4 \times 10^{-3}$ | $\frac{x}{D \ln(D)}$ | 0.28 |
|                  | Repeatability   | Triangular      | $1.1 \times 10^{-5}$ |                   |                      |                                 |
| Absorption Cross section $\sigma$ | Hearn value | Rectangular | $1.22 \times 10^{-19}$ cm$^2$/molecule | $1.22 \times 10^{-19}$ cm$^2$/molecule | $\frac{x}{\alpha}$ | $1.06 \times 10^{-7} \times x$ |

As explained in the protocol of the comparison, following this budget the standard uncertainty associated with the ozone amount-of-substance fraction measurement with the BIPM SRPs can be expressed as a numerical equation (numerical values expressed as nmol/mol):

$$ u(x) = \sqrt{(0.28)^2 + (2.92 \cdot 10^{-3} \cdot x)^2} $$  \hspace{1cm} (6)

12.5. Covariance terms for the common reference BIPM-SRP27

As explained in section 14, correlations in between the results of two measurements performed at two different ozone amount-of-substance fractions with BIPM-SRP27 were taken into account using the software OzonE. Details about the analysis of the covariance can be found in the protocol. The following expression was applied:

$$ u(x_i, x_j) = x_i \cdot x_j \cdot u_i^2 $$  \hspace{1cm} (7)

where:
The value of $u_b$ is given by the expression of the measurement uncertainty: $u_b = 2.92 \times 10^{-3}$.

12.6. Condition of the NPLI SRP43
The standard instrument NPLI SRP43 was not modified since it last took part in this comparison [6]. It has been constructed by NIST in 2008 with the new design, which includes the “SRP upgrade kit” in order to deal with the two biases revealed in [4].

12.7. Uncertainty budget of the NPLI SRP43
The uncertainty budget for the ozone mole fraction in dry air $x$ measured by the NPLI standard SRP43 in the nominal range 0 nmol/mol to 500 nmol/mol will follow the BIPM/NIST paper [4] (see Table 1) with an additional component based on the temperature probe heating effect. The initial uncertainty can be summarised by the formula:

$$u(x) = \sqrt{(0.28)^2 + (2.92 \times 10^{-3} x)^2}$$  \hspace{1cm} (9)

After correcting for the temperature probe heating bias, the final uncertainty is calculated by:

$$u(x)^+ = u(x); u(x)^- = u(x) + (-0.001 \times x)$$  \hspace{1cm} (10)

To avoid using asymmetric uncertainties, this was approximated by the following expression:

$$u(x) = u(x) + (0.001 \times x)$$  \hspace{1cm} (11)

No covariance term for the NPLI SRP43 was included in the calculations.

13. Measurement results and uncertainties
Details of the measurement results, the measurement uncertainties and the standard deviations at each nominal ozone amount-of-substance fraction are provided in appendix (form BIPM.QM-K1-R1-NPLI–2018).

14. Analysis of the measurement results by generalised least-square regression
The relationship between the national and reference standards was first evaluated with a generalised least-square regression fit, using the software OzonE. This software, which is documented in a publication [7], is an extension of the previously used software B_Least recommended by the ISO 6143:2001 [8]. It includes the possibility to take into account correlations between measurements performed with the same instrument at different ozone amount-of-substance fractions. It also facilitates the use of a transfer standard, by handling of unavoidable correlations, which arise since this instrument needs to be calibrated by the reference standard.

In a direct comparison, a linear relationship between the ozone amount-of-substance fractions measured by the instrument $i$ and SRP27 is obtained:

$$x_i = a_0 + a_1 x_{SRP27}$$  \hspace{1cm} (12)
The associated uncertainties on the slope \( u(a_1) \) and the intercept \( u(a_0) \) are given by OzonE, as well as the covariance between them and the usual statistical parameters to validate the fitting function.

14.1. Least-squares regression results

The two relationships between SRP43 and SRP27 is:

\[
x_{SRP37} = 1.0001x_{SRP27} + 0.04
\]  
(13)

The standard uncertainties on the parameters of the regression are \( u(a_1) = 0.0033 \) for the slope and \( u(a_0) = 0.22 \text{ nmol/mol} \) for the intercept. The covariance between the two parameters is \( \text{cov}(a_0, a_1) = -2.07 \times 10^{-4} \).

The least-squares regression results confirm that a linear fit is appropriate, with a sum of the squared deviations (SSD) of 0.57 and a goodness of fit (GoF) equals to 0.40.

To assess the agreement of the standards using equations 11 and 12, the difference between the calculated slope value and unity, and the intercept value and zero, together with their measurement uncertainties need to be considered. In this comparison, the value of the intercept is not consistent with an intercept of zero, considering the uncertainty in the value of this parameter; i.e. \( |a_0| < 2u(a_0) \), and the value of the slope is consistent with a slope of 1; i.e. \( |1 - a_1| < 2u(a_1) \).

15. Degrees of equivalence

Degrees of equivalence are calculated at two nominal ozone amount-of-substance fractions among the twelve measured in each comparison, in the range from 0 nmol/mol to 500 nmol/mol: 80 nmol/mol and 420 nmol/mol. These values correspond to points number 3 and 4 recorded in each comparison. As an ozone generator has limited reproducibility, the ozone amount-of-substance fractions measured by the ozone standards can differ from the nominal values. However, as stated in the protocol, the value measured by the common reference SRP27 was expected to be within \( \pm 15 \text{ nmol/mol} \) of the nominal value. Hence, it is meaningful to compare the degree of equivalence calculated for all the participants at the same nominal value.

15.1. Definition of the degrees of equivalence

The degree of equivalence of the participant \( i \), at a nominal value \( x_{\text{nom}} \) is defined as:

\[
D_i = x_i - x_{SRP27}
\]  
(14)

where \( x_i \) and \( x_{SRP27} \) are the measurement result of the participant \( i \) and of SRP27 at the nominal value \( x_{\text{nom}} \).

Its associated standard uncertainty is:

\[
u(D_i) = \sqrt{u_i^2 + u_{SRP27}^2}
\]  
(15)

where \( u_i \) and \( u_{SRP27} \) are the measurement uncertainties of the participant \( i \) and of SRP27 respectively.
15.2. Values of the degrees of equivalence

The degrees of equivalence and their uncertainties calculated in the form BIPM.QM-K1-R1-NPLI–2018 are reported in the table below. Corresponding graphs of equivalence are displayed in Figure 1. The expanded uncertainties are calculated with a coverage factor $k = 2$.

**Table 2**: degrees of equivalence of the NPLI at the ozone nominal amount-of-substance fractions 80 nmol/mol and 420 nmol/mol

<table>
<thead>
<tr>
<th>Nominal value / (nmol/mol)</th>
<th>$x_i$ / (nmol/mol)</th>
<th>$u_i$ / (nmol/mol)</th>
<th>$x_{SRP27}$ / (nmol/mol)</th>
<th>$u_{SRP27}$ / (nmol/mol)</th>
<th>$D_i$ / (nmol/mol)</th>
<th>$u(D_i)$ / (nmol/mol)</th>
<th>$U(D_i)$ / (nmol/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>80.23</td>
<td>0.37</td>
<td>80.10</td>
<td>0.36</td>
<td>0.12</td>
<td>0.52</td>
<td>1.03</td>
</tr>
<tr>
<td>420</td>
<td>415.92</td>
<td>1.25</td>
<td>415.88</td>
<td>1.25</td>
<td>0.04</td>
<td>1.76</td>
<td>3.53</td>
</tr>
</tbody>
</table>

![Figure 1: degrees of equivalence of the NPLI at the two nominal ozone amount-of-substance fractions 80 nmol/mol and 420 nmol/mol](image)

The degrees of equivalence between the NPLI standard and the common reference standard BIPM SRP27 indicate good agreement between the standards. A discussion on the relation between degrees of equivalence and CMC statements can be found in [1].

16. History of comparisons between BIPM SRP27, SRP28 and NPLI SRP43

Results of the previous comparisons performed with NPLI since 2009 are displayed in Figure 2 together with the results of this comparison. The slopes $a_1$ of the linear relation $x_i = a_0 + a_1 x_{SRP27}$ are represented together with their associated uncertainties calculated at the time of each comparison. Results of the comparison performed in 2009 has been corrected to take into account the changes in the reference BIPM-SRP27 described in [5], which explains the
larger uncertainties associated with the corresponding slopes. Figure 2 shows that all standards included in these comparisons stayed in close agreement.

![Figure 2: Results of previous comparisons between SRP27, SRP28 and NPLI-SRP43 realised at the BIPM. Uncertainties are calculated at $k = 2$, with the uncertainty budget in use at the time of each comparison.](image)

17. Summary of previous comparisons included in BIPM.QM-K1

The comparison with NPLI is the eight one in the 2017-2020 round of BIPM.QM-K1. An updated summary of BIPM.QM-K1 results can be found in the BIPM key comparison database: [http://kcdb.bipm.org/appendixB/](http://kcdb.bipm.org/appendixB/).

18. Conclusion

For the second time since the launch of the ongoing key comparison BIPM.QM-K1, a comparison has been performed between the ozone national standard of India maintained by the NPLI and the common reference standard of the key comparison maintained by the BIPM. The instruments have been compared over a ozone amount-of-substance fraction range from 0 nmol/mol to 500 nmol/mol. Degrees of equivalence of this comparison indicated very good agreement between the two standards.

19. References


Appendix 1 - Form BIPM.QM-K1-R1-NPLI−2018

See the following pages.
OZONE COMPARISON RESULT - PROTOCOL A - DIRECT COMPARISON

Participating institute information

<table>
<thead>
<tr>
<th>Institute</th>
<th>NPLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Room n°212, Main building, NPL New Delhi - 110012 India</td>
</tr>
<tr>
<td>Contact</td>
<td>Dr. C. Sharma</td>
</tr>
<tr>
<td>Email</td>
<td></td>
</tr>
<tr>
<td>Telephone</td>
<td>011-45608299</td>
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Instruments information

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Reference Standard</th>
<th>National Standard</th>
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<tbody>
<tr>
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<tr>
<td>SRP</td>
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<td>SRP27</td>
<td>SRP43</td>
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</table>

Content of the report

page 1  general informations  
page 2  comparison results  
page 3  measurements results  
page 4  comparison description  
page 5  uncertainty budgets
comparison reference standard (RS) - national standard (NS)

Comparison results

Equation

\[ x_{NS} = a_{NS,RS} x_{RS} + b_{NS,RS} \]

Least-square regression parameters

<table>
<thead>
<tr>
<th>( a_{TS,RS} )</th>
<th>( u(a_{TS,RS}) )</th>
<th>( b_{TS,RS} )</th>
<th>( u(b_{TS,RS}) )</th>
<th>( u(a,b) )</th>
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<tr>
<td>1.0001</td>
<td>0.0033</td>
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<td>0.22</td>
<td>-2.07E-04</td>
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</tbody>
</table>

(Least-square regression parameters will be computed by the BIPM using the software OzonE v2.0)

Degrees of equivalence at 80 nmol/mol and 420 nmol/mol:

<table>
<thead>
<tr>
<th>Nom value (nmol/mol)</th>
<th>( D_i ) (nmol/mol)</th>
<th>( u(D_i) ) (nmol/mol)</th>
<th>( U(D_i) ) (nmol/mol)</th>
</tr>
</thead>
<tbody>
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<td>80</td>
<td>0.1246473</td>
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<td>1.0327825</td>
</tr>
<tr>
<td>420</td>
<td>0.0377995</td>
<td>1.7634123</td>
<td>3.5268247</td>
</tr>
</tbody>
</table>

All degrees of equivalence (k=2)

[Graph showing all degrees of equivalence (k=2)]
### Measurement results

<table>
<thead>
<tr>
<th>Nominal value</th>
<th>$x_{RS}$ nmol/mol</th>
<th>$s_{RS}$ nmol/mol</th>
<th>$u(x_{RS})$ mmol/mol</th>
<th>$x_{NS}$ nmol/mol</th>
<th>$s_{NS}$ nmol/mol</th>
<th>$u(x_{NS})$ mmol/mol</th>
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<td>0</td>
<td>0.01</td>
<td>0.21</td>
<td>0.28</td>
<td>0.16</td>
<td>0.21</td>
<td>0.28</td>
</tr>
<tr>
<td>220</td>
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<td>0.15</td>
<td>0.69</td>
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</tr>
<tr>
<td>80</td>
<td>80.10</td>
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<td>80.23</td>
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### Degrees of Equivalence

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<th>Point Number</th>
<th>Nominal value (nmol/mol)</th>
<th>$D_{ij}$ (nmol/mol)</th>
<th>$u(D_{ij})$ (nmol/mol)</th>
<th>$U(D_{ij})$ (nmol/mol)</th>
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Covariance terms in between two measurement results of each standard

Equation $u(x_i, x_j) = \alpha \cdot x_i \cdot x_j$

Value of $\alpha$ for the reference standard 8.50E-06
Value of $\alpha$ for the national standard 0.00E+00
Comparison conditions

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<th>Parameter</th>
<th>Details</th>
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<tr>
<td>Ozone generator manufacturer</td>
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<td>Ozone generator type</td>
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<td>Ozone generator serial number</td>
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<td>Room temperature (min-max) / °C</td>
<td>20.5 - 22.6</td>
</tr>
<tr>
<td>Room pressure (min-max) / hpa</td>
<td>1001.3 - 1002.7</td>
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<tr>
<td>Zero air source</td>
<td>oil free compressor + dryer+ aadco 737-R</td>
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<tr>
<td>Reference air flow rate (L/min)</td>
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<td>Sample flow rate (L/min)</td>
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<td>Instruments stabilisation time</td>
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<td>Instruments acquisition time /s (one measurement)</td>
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<td>Instruments averaging time /s</td>
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<tr>
<td>Total time for ozone conditioning</td>
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<td>Ozone mole fraction during conditioning</td>
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<td>Comparison repeated continuously (Yes/No)</td>
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<td>If no, ozone mole fraction in between the comparison repeats</td>
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<td>Total number of comparison repeats realised</td>
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Data files names and location
\chem83\D:\P-Data\Gas\2018\C-A1.1.1\Data\SRP\2018\c180206001.xls to c180214011.xls

Instruments checks and adjustments

Reference Standard

National Standard

Temperature circuit voltage (in CAL position) changed from -0.4 mV to 0.3 mV.
NPLI procedure stating this value should be between 0.1 and 1 mV
Uncertainty budgets (description or reference)

Reference Standard

BIPM-SRP27 uncertainty budget is described in the protocol of this comparison: document BIPM.QM-K1 protocol, date 10 January 2007, available on BIPM website. It can be summarised by the formula:

\[ u(x) = \sqrt{(0.28)^2 + (2.92 \times 10^{-3} x)^2} \text{nmol/mol} \]

National Standard

The uncertainty budget for NIST SRP 43 will follow the BIPM/NIST bias paper with the addition of an additional component based on the temperature probe heating affect. The initial uncertainty can be summarised by the formula:

\[ u(x) = \sqrt{(0.28)^2 + (2.92 \times 10^{-3} x)^2} \text{nmol/mol} \]

After correcting for the temperature probe heating bias, the final uncertainty is calculated by:

\[ u(x)^+ = u(x); \quad u(x)^- = u(x) + (-0.001 \times x) \text{nmol/mol} \]

Because the BIPM.QM-K1-R1 spreadsheet does not allow the uncertainty to be expressed with different positive and negative amounts, it has been expressed as:

\[ u(x) = u(x) + (0.001 \times x) \text{nmol/mol} \]