



## **Low-Pressure Gas Flow Comparison:**

**EURAMET 1571 (REG. NO.)**

**EURAMET.M.FF-S18 (KCDB)**

## **Supplementary Bilateral Comparison for small flow rates (1.2 to 450) mL/min@STP with Laminar Flow Elements**

**Report  
(27.05.2025, final report)**

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## Abstract

The objective of this bilateral comparison is to compare volume gas flow measurements in the flow range (1.2 to 450) mL/min@STP using Laminar Flow Elements (DH Instruments™ MOLBLOCs with the associated MOLBOX) as the main parts of the transfer standard (hereinafter referred to as TS).

The goal is the evaluation of the degree of equivalence of the participating laboratories respectively the calculation of the En-factors at every single flow measuring point.

The comparison is carried out on request of the METAS Laboratory Flow and Hydrometry.

METAS was the pilot laboratory and has performed the repeatability and reproducibility tests of the transfer standard to include these contributions to the measurement uncertainty of the transfer standard.

## Revision History

Date	Revision version.	Changes
2024/05/30	draft A	Incomplete version for discussion.
2024/10/24	draft B	The measured values and measurement deviations etc. are confirmed and can no longer be changed.
2025/05/27	Final version	Final version of the report.

## Contents

1	Introduction .....	4
2	Participants and time schedule .....	4
2.1	Measurement uncertainty of reference standard .....	5
3	Short description of the transfer standard .....	5
3.1	Characteristics of the TS: .....	6
3.2	Piping & instrumentation diagram (P&ID) of the TS.....	6
4	Technical protocol.....	7
4.1	Pressure Controller (PrC) .....	7
4.2	Mass Flow Controller (MFC).....	7
4.3	MOLBOX.....	7
4.4	Inventory list / Handling and shipping of the TS.....	8
4.5	Measuring procedure.....	8
4.6	Reporting the measurement results .....	9
5	Methods of measurements.....	9
5.1	Facility of METAS.....	10
5.1.1	Measuring setup and operating mode used for this specific comparison.....	10
5.2	Facilities of INRIM .....	10
5.2.1	Measuring setup and operating mode used for this specific comparison.....	11
6	Characterisation of the Transfer Standards .....	11
6.1	Repeatability and reproducibility .....	11
6.1.1	Repeatability .....	13
6.1.1.1	MOLBLOC #A .....	13
6.1.1.2	MOLBLOC #B .....	13
6.1.1.3	MOLBLOC #C .....	13
6.1.2	Reproducibility .....	14
6.1.2.1	MOLBLOC #A .....	14
6.1.2.2	MOLBLOC #B .....	14
6.1.2.3	MOLBLOC #C .....	14
6.1.3	Total expanded uncertainty for analysis.....	14
6.1.3.1	MOLBLOC #A .....	15
6.1.3.2	MOLBLOC #B .....	15
6.1.3.3	MOLBLOC #C .....	15
6.2	Calibration of the MOLBOX.....	15

7	Data processing and computation of KCRV .....	16
8	Results .....	16
8.1	MOLBLOC #A .....	16
8.2	MOLBLOC #B .....	18
8.3	MOLBLOC #C .....	19
9	The Key Comparison Reference Value and its Uncertainty .....	20
9.1	KCRV .....	20
9.1.1	Results of the consistency check.....	20
10	Degree of Equivalence between individual participants and the KCRV.....	20
10.1	Differences between the participant $i$ to KCRV: $d_i, U(d_i)$ .....	20
10.2	Degree of Equivalence (DoE): $E_n$ .....	20
10.2.1	MOLBLOC #A .....	20
10.2.2	MOLBLOC #B .....	21
10.2.3	MOLBLOC #C .....	21
11	Confirmation of the CMCs.....	21
12	Summary and Conclusions .....	22
13	Explanations for Discrepant Reported Values.....	22
13.1	Discrepant values .....	22
14	Terms and abbreviations.....	22
15	References.....	22
Appendix A	Formula for KCRV .....	23
Appendix B	Formula for uncertainty of KCRV .....	23
Appendix C	Comparison pass/fail criterion .....	23

## List of Tables

Table 1: Participants and time scheduling .....	4
Table 2: Expanded measurement uncertainties (%) of the reference standard for the different flow rates of the transfer standard of all participants ( $U_{base,i}$ , $k=2$ ) .....	5
Table 3: Characteristics of the TS.....	6
Table 4: Flow measuring points .....	9
Table 5: The type of reference standard and facilities used by each participant are listed below. ....	9
Table 6: METAS 6.5-L Piston Prover facility flow range .....	10
Table 7: MOLBLOC #A: Repeatability at METAS (%) ( $k=2$ ) .....	13
Table 8: MOLBLOC #B: Repeatability at METAS (%) ( $k=2$ ) .....	13
Table 9: MOLBLOC #C: Repeatability at METAS (%) ( $k=2$ ) .....	13
Table 10: MOLBLOC #A: Reproducibility at METAS (%) ( $k=2$ ) .....	14
Table 11: MOLBLOC #B: Reproducibility at METAS (%) ( $k=2$ ) .....	14
Table 12: MOLBLOC #C: Reproducibility at METAS (%) ( $k=2$ ) .....	14
Table 13: MOLBLOC #A: Total expanded uncertainty for the analysis (%) ( $k=2$ ).....	15
Table 14: MOLBLOC #B: Total expanded uncertainty for the analysis (%) ( $k=2$ ).....	15
Table 15: MOLBLOC #C: Total expanded uncertainty for the analysis (%) ( $k=2$ ).....	15
Table 16: MOLBLOC #A: Results at 10 mL/min@STP. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ).....	17
Table 17: MOLBLOC #A: Results at 5 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	17
Table 18: MOLBLOC #A: Results at 3 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	17
Table 19: MOLBLOC #A: Results at 2 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	17
Table 20: MOLBLOC #A: Results at 1.2 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	17
Table 21: MOLBLOC #B: Results at 50 mL/min@STP. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ).....	18
Table 22: MOLBLOC #B: Results at 20 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	18
Table 23: MOLBLOC #B: Results at 10 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	18
Table 24: MOLBLOC #C: Results at 450 mL/min@STP. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ).....	19
Table 25: MOLBLOC #C: Results at 200 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ).....	19
Table 26: MOLBLOC #C: Results at 100 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ).....	20
Table 27: MOLBLOC #C: Results at 50 mL/min. $U_{Lab}$ includes $U_{Base}$ and $U_{Repeat}$ . $U_{xi}$ includes $U_{Base}$ , $U_{Repeat}$ and $U_{TS}$ , ( $k=2$ ). .....	20
Table 28: MOLBLOC #A: Listing of the $E_n$ values .....	20
Table 29: MOLBLOC #B: Listing of the $E_n$ values .....	21
Table 30: MOLBLOC #C: Listing of the $E_n$ values .....	21

## 1 Introduction

The objective of this bilateral comparison is to compare volume gas flow measurements in the flow range (1.2 to 450) mL/min@STP<sup>1</sup> using Laminar Flow Elements (DH Instruments™ MOLBLOCs with the associated MOLBOX) as the main parts of the transfer standard (hereinafter referred to as TS). Laminar flow elements are known to be highly suitable as transfer standards for small gas flows.

The goal is the evaluation of the degree of equivalence of the participating laboratories respectively the calculation of the En-factors at every single flow measuring point.

The comparison is carried out on request of the METAS Laboratory Flow and Hydrometry.

The technical protocol was finalized in September 2023 and the circulation of the transfer standards lasted from October 2023 to November 2023.

## 2 Participants and time schedule

Table 1 summarizes the participant information (including the address to which the TS should be sent), and the intended time schedule.

Due to various delays, in particular the high workload of the involved METAS laboratories, there were deviations from the schedule.

Date	Laboratory	Shipping address	Contact
till 14.09.2023	Eidgenössisches Institut für Metrologie METAS Laboratory Flow and Hydrometry	Lindenweg 50, CH-3003 Bern-Wabern, Switzerland	Martin Tschannen <a href="mailto:martin.tschannen@metas.ch">martin.tschannen@metas.ch</a> +41 58 387 08 91
15.09.2023 – 31.10.2023	Istituto Nazionale di Ricerca Metrologica INRIM Gas Flow & Volume Laboratory	Strada delle Cacce 91, 10135 Torino, Italy	Pier Giorgio Spazzini <a href="mailto:p.spazzini@inrim.it">p.spazzini@inrim.it</a> +39 011 3919941
01.11.2023	Eidgenössisches Institut für Metrologie METAS Laboratory Flow and Hydrometry	Lindenweg 50, CH-3003 Bern-Wabern, Switzerland	Martin Tschannen <a href="mailto:martin.tschannen@metas.ch">martin.tschannen@metas.ch</a> +41 58 387 08 91

Table 1: Participants and time scheduling

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<sup>1</sup> The indication STP refers to 1013.25 hPa and 0 °C

## 2.1 Measurement uncertainty of reference standard

The corresponding expanded measurement uncertainties of the reference standards for the different flow rates of the transfer standard of all participants are listed in Table 2. The flow rates are given in units of mL/min@STP.

Table 2: Expanded measurement uncertainties (%) of the reference standard for the different flow rates of the transfer standard of all participants ( $U_{base,i}$ ,  $k=2$ )

Nominal flow (mL/min@STP)	METAS	INRIM
450	0.067	0.05
200		
100	0.15	
50		
20		
10		
5		
3		
2		
1.2		

Note: the symbol “[-]” states that this flow rate has not been measured

## 3 Short description of the transfer standard

The transfer standard was provided from METAS: A assembly group with Laminar Flow Elements (DH Instruments™ MOLBLOCs with the associated MOLBOX) as the main parts of the transfer standard.

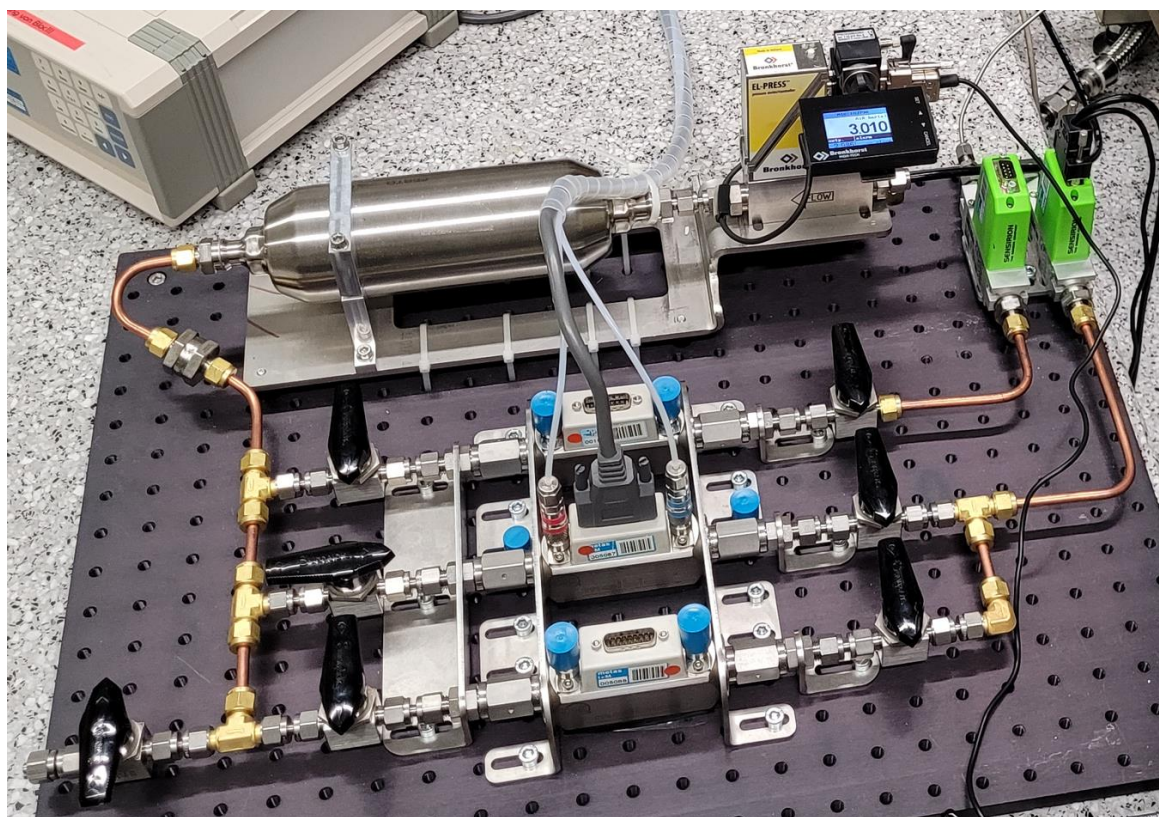


Figure 1: TS: assembly group with Laminar Flow Elements (DH Instruments™ MOLBLOCs with the associated MOLBOX) as the main parts

### 3.1 Characteristics of the TS:

The following MOLBLOCs from the manufacturer DH Instruments, Phoenix AZ (USA) with the corresponding MOLBOX are used.

Table 3: Characteristics of the TS

MOLBLOC (#)	Model (-)	S/N (#)	Q <sub>max</sub> (cm <sup>3</sup> /min@STP)
A	10 SCCM-VCR-V-Q	532	10
B	5E1-VCR-V-Q	2262	50
C	5E2-VCR-V-Q	2274	500

Associated MOLBOX: MOLBOX1+, S/N 2076

Furthermore, all accessories necessary for the installation and operation of the TS (e.g. pressure regulators, ball valves, MFCs and filters) are part of the equipment provided by the pilot laboratory and are delivered completely assembled as a complete "ready-to-use" measuring unit.

### 3.2 Piping & instrumentation diagram (P&ID) of the TS

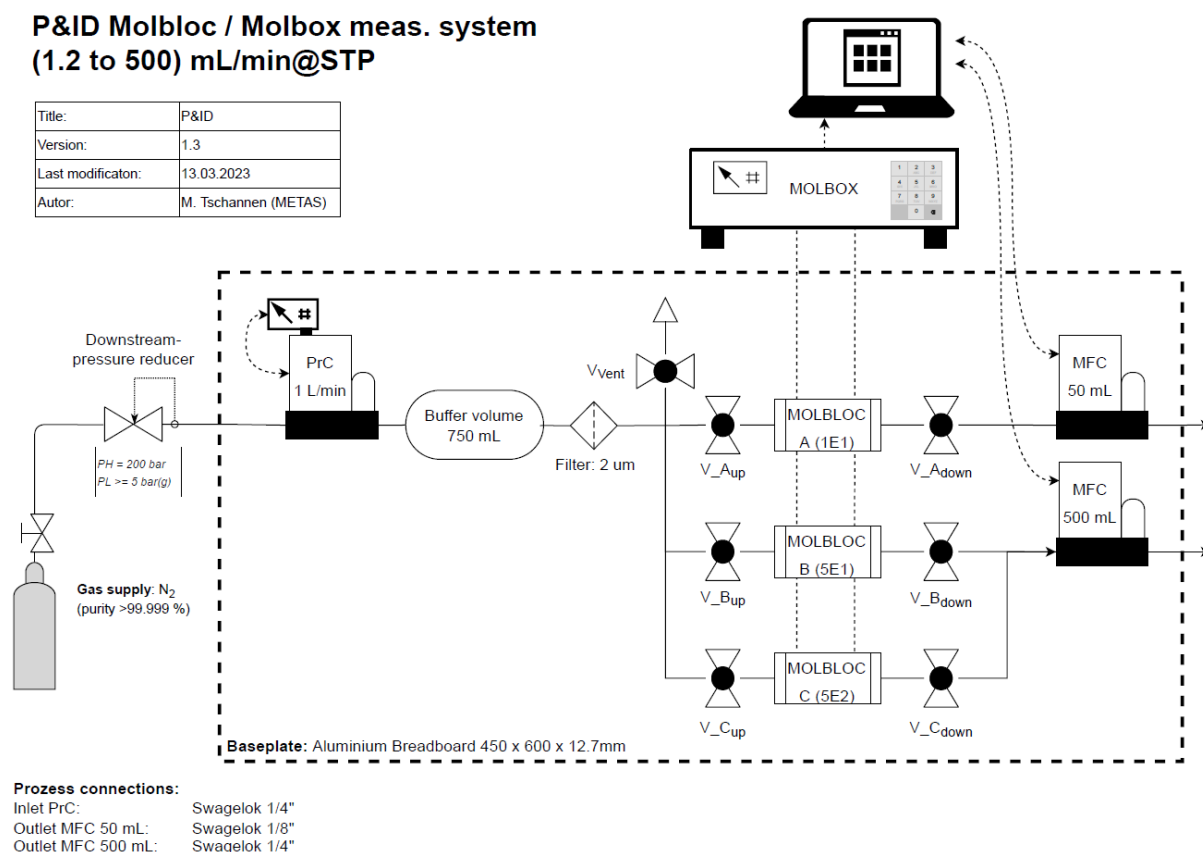


Figure 2: Piping & instrumentation diagram (P&ID) of the TS

## 4 Technical protocol

Only the most important aspects will be discussed here. The handling of the peripheral devices (mass flow controller, pressure controller, MOLBOX) as well as special functions and processes relating to the MOLBOX such as leak tests, tare functions etc. are described in detail in the technical protocol (TP).

### 4.1 Pressure Controller (PrC)

The PrC can be controlled without additional software (integrated display) and is equipped with a 750 mL-buffer volume.

Manufacturer:	Bronkhorst Hightec
Type:	EL-PRESS, downstream pressure controller
Max. input pressure:	900 kPa(a)
Max. differential pressure:	200 kPa(a)
Nominal flow rate:	1 L/min

For all subsequent measurements within this measurement comparison, the downstream pressure is set to ~300 kPa(a) so that the pressure display  $P_{\text{Upstream}}$  of the MOLBOX shows exactly 300 kPa(a).

Thus, the inlet pressure to the PrC can be set to ~500 kPa(a) constant.

### 4.2 Mass Flow Controller (MFC)

The SFC5500 series is the latest generation of Sensirion MFCs for gases. The control range is 1000:1. The gas type is automatically detected and the corresponding calibration set is loaded. The reference conditions are 1013.25 hPa & 20°C.

The MFC is controlled with the software "Sensirion Viewer Software" (USB memory stick).

Manufacturer:	Sensirion
Type:	SFC5500 (controller)
Max. input pressure:	1000 kPa(a)
Max. differential pressure:	500 kPa(a)
Nominal flow rate:	(50 & 500) mL/min

### 4.3 MOLBOX

#### Important remarks:

- ➔ The warmup-time for thermal stabilization of the integrated absolute pressure transducers (RPTs) is about >24 h. (connect the MOLBOX to the electricity supply and switch it on.)
- ➔ The **TARE** function must be performed at each calibration point before measurement.
- ➔ After changing to another MOLBLOC, the functionality **LEAK CHECK** of the MOLBOX must be passed (the gas pressure during the leak check should correspond to the operating pressure).

#### Reading out & logging the data:

Usage of the METAS Software "MOLBOXAcqSystem".



Figure 3: Icon METAS Software "MOLBOXAcqSystem"

### Device settings:

The following settings must be checked and adjusted if necessary:

- ✓ Operating channel: MOLBLOC A
- ✓ Gas type: N<sub>2</sub>
- ✓ Unit: sccm

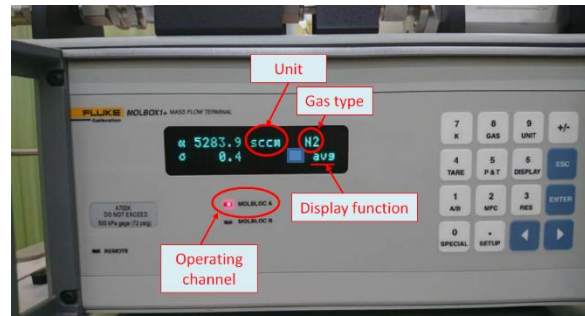


Figure 4: MOLBOX settings

### 4.4 Inventory list / Handling and shipping of the TS

The complete measuring equipment is packed in a plastic transport case (Peli-Case). The contents of the case are listed below:

- ✓ TS (BRIGHT-display of the PrC dismantled for shipping)
- ✓ MOLBOX
- ✓ Plastic bag A: Pressure, power and signal cable for the MOLBOX
- ✓ Plastic bag B: BRIGHT-display and power supply unit for the PrC & USB cable connection and power supply for the MFC & USB memory stick



Figure 5: Transport case (Peli-Case) tied on EURO-pallet

### 4.5 Measuring procedure

Generally, the participants perform the measurements according to their calibration instructions as usual.

- Nitrogen (purity at least 99.999%) must be used as test gas (dynamically produced nitrogen is strictly not recommended because it contains Argon).
- The inlet pressure to the MOLBLOCs is fixed at 300 kPa(a) for all measurements. The permitted deviation is 5 hPa (according to the MOLBOX display).  
**Note:** The maximum permissible gas pressure of 500 kPa(a) must never be exceeded.
- The ambient temperature in the laboratory must be in the range of (18 to 23) °C.
- An acclimatisation time in the laboratory of 24h for the whole TS package must be respected.
- The MOLBOX should be supplied with voltage at least 24h before the measurements (thermal stabilisation).
- Before starting the first measurement with a new MOLBLOC, it is necessary to generate a flow rate of  $Q_{max}$  (according to table Chapter 3.1) through the MOLBLOC for at least two hours to achieve temperature stabilization (temperature difference between the gas flowing through the MOLBLOC and the ambient shall be less than 0.5 °C).
- After each flow change, the MOLBLOC must be thermally stabilised for at least 20 min.

**Flow measuring points:**

*Table 4: Flow measuring points*

MOLBLOC (#)	Flow rates (cm <sup>3</sup> /min@STP)
A	1.2/2/3/5/10
B	10/20/50
C	50/100/200/450

- At least three repetitions must be carried out per flow measuring point.
- The calibration sequence is from the large to the small flow and must be followed.
- The flow reading indicated by the TS should be matched as exactly as possible (at least within  $\pm 2\%$ ) to the nominal flows.

The flow ranges of the MOLBLOCs are partially overlapping, which allows checking the consistency of the calibration results obtained from different flow elements at the same nominal flow. Any drift in a transfer standard can therefore be detected and taken into account when evaluating the final comparison results.

#### 4.6 Reporting the measurement results

Participants shall submit at least the following measurement results (average of the mean values over at least 3 individual measurements) to the pilot laboratory for each flow measuring point:

- Flow rate of the reference (cm<sup>3</sup>/min@STP)
- Flow indication of the TS (cm<sup>3</sup>/min@STP)
- Upstream pressure display of the TS (hPa abs.)
- Gas temperature display of the TS (°C)
- Relative error of the TS (%)
- Relative expanded uncertainty  $U_{(k=2)}$  (%)
- Tare value (Pa)

In addition, the environmental conditions during the measurements must be logged (range over all measurements).

## 5 Methods of measurements

In this section the facilities and the measurement methods of each laboratory are briefly described. More details about the facilities are described in the annexes and the references mentioned there, but an overview of the measurement methods is given in Table 5.

*Table 5: The type of reference standard and facilities used by each participant are listed below.*

No	Participant	Type of reference standard	Measurement method
1	METAS (Switzerland)	Piston Prover (primary standard)	Dynamic volumetric method with flying start and stop, pressure regulated mode
2	INRIM (Italy)	Piston Prover (primary standard)	Dynamic volumetric method with flying start and stop, pressure regulated mode

## 5.1 Facility of METAS

The METAS 6.5-L Piston Prover facility consist of a homemade piston prover to generate and calibrate the volume or mass flow rate<sup>2</sup>. The position the piston prover is determined by counting the pulses sent by the linear measuring system. The cross section of the piston is determined by the calibrated outer diameter. The corresponding mass flow rate can be calculated with the appropriate density of the test gas.

The METAS 6.5-L Piston Prover facility covers the following flow range:

*Table 6: METAS 6.5-L Piston Prover facility flow range*

Flow range	Measuring uncertainty (k=2)
(1.2 to 100) mL/min	0.15 %
(0.1 to 6) L/min	0.067 %

### 5.1.1 Measuring setup and operating mode used for this specific comparison

The METAS 6.5-L Piston Prover facility operated in pressure-controlled driving mode, i.e. the piston speed has been controlled in such a way that the absolute gas pressure in the cylinder chamber was kept constant at the level of the barometric ambient pressure prevailing at the beginning of the measurement during the entire measurement time per individual measurement.

Measurement setup:

Source ► PrR (mech.)<sup>3</sup> ► TS ► METAS 6.5-L Piston prover

## 5.2 Facilities of INRIM

The INRIM 3-L Piston Prover facility consist of a homemade piston prover which allows to accurately measure the volume flow rate, both entering or exiting the piston. The position of the piston prover is determined by a laser interferometer. The cross section of the piston is determined by the calibrated outer diameter. The corresponding mass flow rate can be calculated by considering appropriate values of the gas density, which can be determined very precisely due to the fact that thermodynamic conditions are measured with high accuracy and only pure gases are used. The cylinder and piston are temperature controlled and allow a stability within 0.05 K during a single measurement.

The INRIM 3-L Piston Prover facility covers the following flow range:

*Table 7: INRIM 3-L Piston Prover facility flow range*

Flow range	Measuring uncertainty (k=2)
(0.1 to 2) mL/min	0.05 % (CMC not yet registered)
(2 to 1200) mL/min	0.05 % (CMC in the KCDB Database)

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<sup>2</sup> Mass flow rate: only when using air as test gas.

<sup>3</sup> Mechanical pressure reducer.

### 5.2.1 Measuring setup and operating mode used for this specific comparison

The INRIM 3-L Piston Prover facility operated in pressure-controlled driving mode, i.e. the piston speed has been controlled in such a way that the absolute gas pressure in the cylinder chamber was kept constant at the level of the surrounding barometric ambient pressure. The initial and final pressures within the piston are recorded and used for the determination of appropriate corrections according to the mass balance method.

Measurement setup:

Source ► PrR (mech.) ► TS ► INRIM 3-L Piston prover

## 6 Characterisation of the Transfer Standards

### 6.1 Repeatability and reproducibility

The calibration results performed at METAS between May 2023 and February 2024 are shown in Figure 6, Figure 7 and Figure 8. The measurement errors at the flow rates are consistent within the stated uncertainty, with only minor outliers. We have included these outliers in MOLBLOC #B (see red rectangular outline in the diagram in Figure 7) in our calculations for repeatability and reproducibility of the TS. There is no obvious or logical explanation for them, so we have decided to include them anyway.

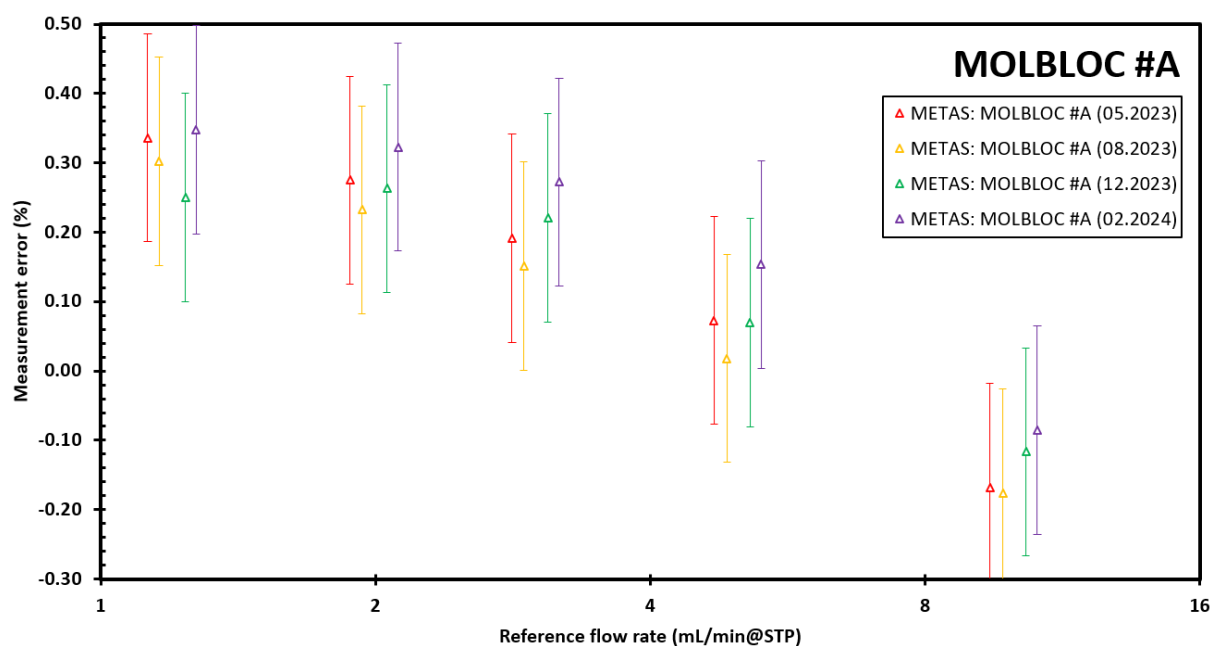


Figure 6: Calibration at METAS of MOLBLOC #A. The results for the flow rates calibrated between May 2023 and February 2024 are consistent within the measurement uncertainty.

# Low-Pressure Gas Flow Comparison (bilateral).

## Comparison of Primary Standards for Gas Flow in the Range (1.2 to 450) mL/min@STP

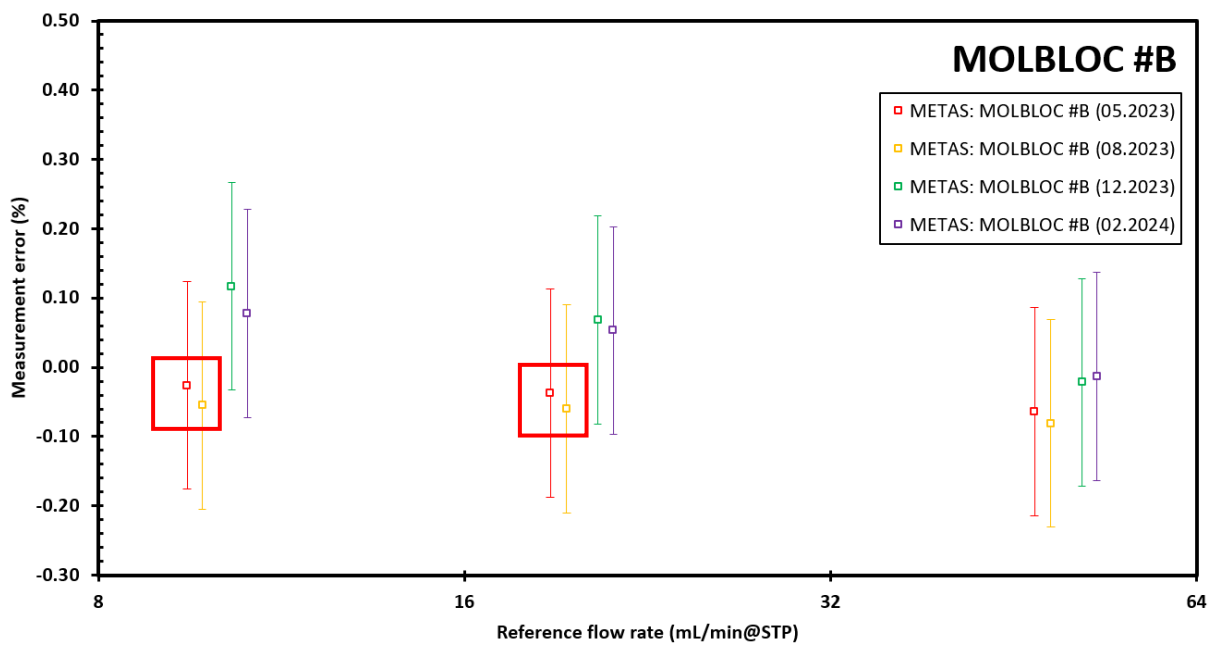


Figure 8: Calibration at METAS of MOLBLOC #B. The results for the flow rates calibrated between May 2023 and February 2024 are consistent within the measurement uncertainty, although there are some outliers (see red rectangular outline in the diagram).

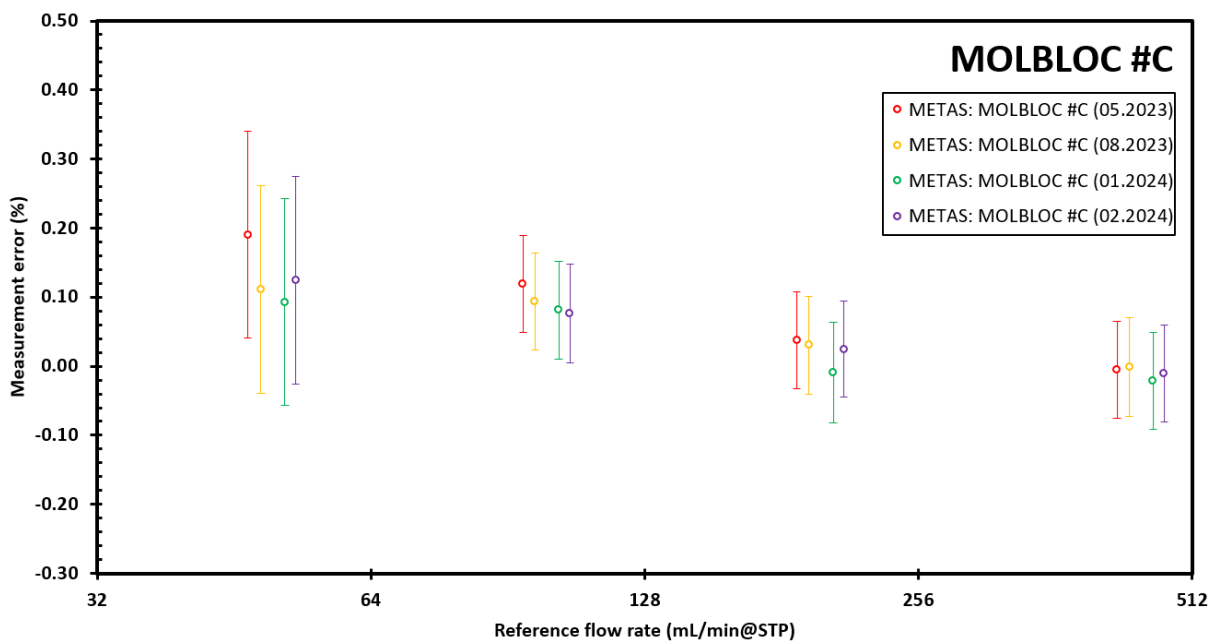


Figure 7: Calibration at METAS of MOLBLOC #C. The results for the flow rates calibrated between May 2023 and February 2024 are consistent within the measurement uncertainty.

### 6.1.1 Repeatability

The repeatability at the different calibration points has been determined several times, when some measurement series were performed within a short time window under the same installation conditions. The repeatability is quantified by the standard deviation  $s$  of the mean divided by the square root of the number of measurements  $n$ .

$$u_{Repeat} = s/\sqrt{n} \quad \text{with } (k=1)$$

Four different series of measurements were performed leading to four repeatability values, which were averaged to get the representative repeatability listed in Table 7, Table 8, Table 9 below. Therefore, the representative repeatability uncertainty is calculated as the average of the four values.

#### 6.1.1.1 MOLBLOC #A

Table 7: MOLBLOC #A: Repeatability at METAS (%) ( $k=2$ )

Nominal flow rate (mL/min@STP)	U Repeat (%) ( $k=2$ )
10	0.020
5	0.012
3	0.024
2	0.038
1.2	0.037

#### 6.1.1.2 MOLBLOC #B

Table 8: MOLBLOC #B: Repeatability at METAS (%) ( $k=2$ )

Nominal flow rate (mL/min@STP)	U Repeat (%) ( $k=2$ )
10	0.016
5	0.017
3	0.008

#### 6.1.1.3 MOLBLOC #C

Table 9: MOLBLOC #C: Repeatability at METAS (%) ( $k=2$ )

Nominal flow rate (mL/min@STP)	U Repeat (%) ( $k=2$ )
450	0.005
200	0.007
100	0.007
50	0.008

### 6.1.2 Reproducibility

The reproducibility of the deviations at a flow set point was determined with series of measurements performed under the same installation conditions, but after removing the TS from the facility and installing it again several days or months later. For each series of measurement, the average deviation was calculated. The scatter of deviation<sub>ave</sub> over time represents the reproducibility. The representative reproducibility uncertainty (k=1) is calculated according to:

$$u_{Reprod} = \frac{(\text{deviation}_{ave,max} - \text{deviation}_{ave,min})}{2\sqrt{3}}$$

Four different series of measurements were used to calculate the representative reproducibility uncertainty listed in Table 10, Table 11, Table 12.

#### 6.1.2.1 MOLBLOC #A

Table 10: MOLBLOC #A: Reproducibility at METAS (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
10	0.052
5	0.078
3	0.070
2	0.052
1.2	0.056

#### 6.1.2.2 MOLBLOC #B

Table 11: MOLBLOC #B: Reproducibility at METAS (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
10	0.039
5	0.074
3	0.099

#### 6.1.2.3 MOLBLOC #C

Table 12: MOLBLOC #C: Reproducibility at METAS (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
450	0.012
200	0.027
100	0.025
50	0.056

### 6.1.3 Total expanded uncertainty for analysis

The total expanded uncertainty for the analysis consists of the contributions of the repeatability and the reproducibility and is reported in Table 13, Table 14, Table 15.

## Low-Pressure Gas Flow Comparison (bilateral).

### Comparison of Primary Standards for Gas Flow in the Range (1.2 to 450) mL/min@STP

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#### 6.1.3.1 MOLBLOC #A

Table 13: MOLBLOC #A: Total expanded uncertainty for the analysis (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
10	0.056
5	0.079
3	0.074
2	0.065
1.2	0.067

#### 6.1.3.2 MOLBLOC #B

Table 14: MOLBLOC #B: Total expanded uncertainty for the analysis (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
10	0.042
5	0.076
3	0.100

#### 6.1.3.3 MOLBLOC #C

Table 15: MOLBLOC #C: Total expanded uncertainty for the analysis (%) (k=2)

Nominal flow rate (mL/min@STP)	Reproducibility (rectangular, %) (k=2)
450	0.012
200	0.028
100	0.026
50	0.057

## 6.2 Calibration of the MOLBOX

The MOLBOX was fully calibrated and adjusted by METAS pressure laboratory before the first series of measurements (measurements from 05.2023) and before the last series of measurements (measurements from 02.2024). The reason for the second calibration of the MOLBOX was the change in the TARE parameter of approximately +70 Pa after the transport of the TS from INRIM to METAS. The renewed calibration & adjustment did not have any measurable effect on the measurement results as you can see in chapter 6.1.

## 7 Data processing and computation of KCRV

The key comparison reference value<sup>4</sup> (KCRV) has been determined at each flow rate following procedure presented by M. G. Cox [1] and the  $\chi^2$  consistency check [1], which ensures the overall consistency of the set of the results from the laboratories used to calculate the comparison reference value. If the consistency check passed, all results of the laboratories were accepted for the calculation of the reference value. If it failed, the result of the laboratory with the largest contribution  $\chi^2_{\text{obs}}$  is omitted from the calculation of the reference value.

The uncertainty of each laboratory consists of the contribution of the facility ( $U_{\text{Base}}$ ), the repeatability of the transfer standard at the laboratory ( $U_{\text{Repeat}}$ ) and the total expanded uncertainty of the transfer standard ( $U_{\text{TS}}$ ):

$$U_{x_i} = \sqrt{U_{\text{Base}}^2 + U_{\text{Repeat}}^2 + U_{\text{TS}}^2}$$

## 8 Results

### 8.1 MOLBLOC #A

The results with the expanded uncertainties at (10, 5, 3, 2, 1.2) mL/min@STP are shown in Figure 9 and listed in Table 16 to Table 20 below.

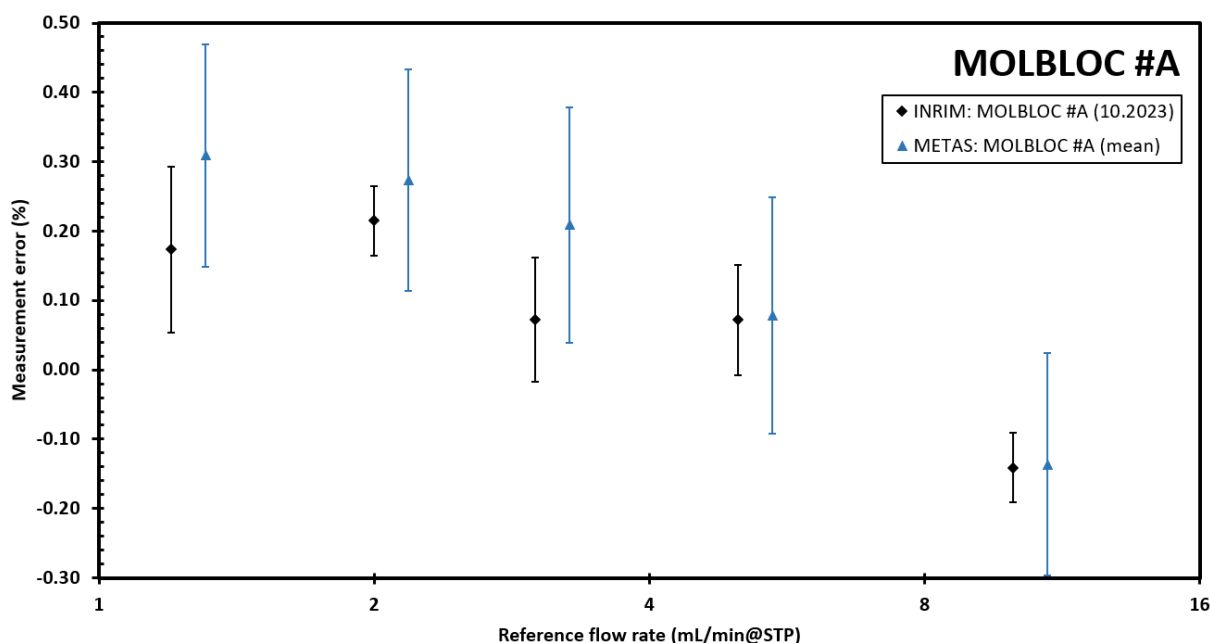


Figure 9: MOLBLOC #A: Relative Error at (10, 5, 3, 2, 1.2) mL/min@STP with the expanded uncertainty  $U_{\text{Lab}}$ .

<sup>4</sup> Not applicable within a bilateral measurement comparison

Low-Pressure Gas Flow Comparison (bilateral).

Comparison of Primary Standards for Gas Flow in the Range (1.2 to 450) mL/min@STP

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Table 16: MOLBLOC #A: Results at 10 mL/min@STP.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	-0.14	-0.14
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.05
$U_{TS}$ (%)	0.06	0.06
$U_{xi}$ (%)	0.16	0.08

Table 17: MOLBLOC #A: Results at 5 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.08	0.07
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.08
$U_{TS}$ (%)	0.08	0.08
$U_{xi}$ (%)	0.17	0.11

Table 18: MOLBLOC #A: Results at 3 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.21	0.07
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.09
$U_{TS}$ (%)	0.07	0.07
$U_{xi}$ (%)	0.17	0.12

Table 19: MOLBLOC #A: Results at 2 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.27	0.21
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.05
$U_{TS}$ (%)	0.06	0.06
$U_{xi}$ (%)	0.16	0.08

Table 20: MOLBLOC #A: Results at 1.2 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.31	0.17
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.12
$U_{TS}$ (%)	0.07	0.07
$U_{xi}$ (%)	0.16	0.14

## 8.2 MOLBLOC #B

The results with the expanded uncertainties at (50, 20, 10) mL/min@STP are shown in Figure 10 and listed in Table 21 to Table 23 below.

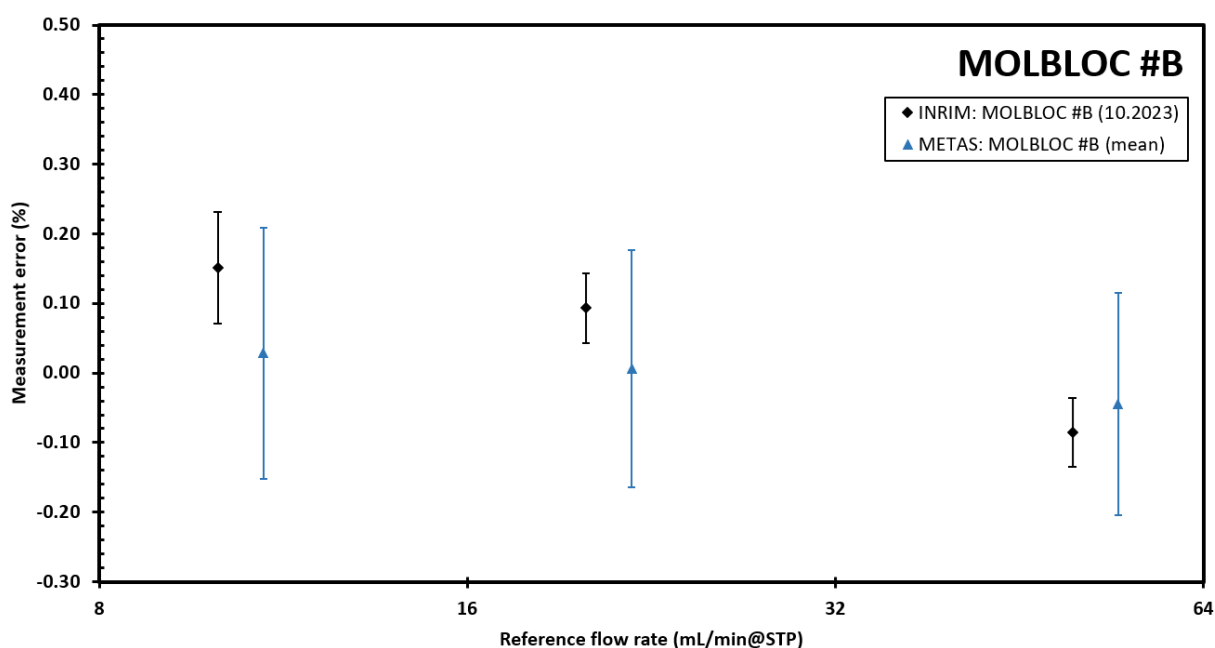


Figure 10: MOLBLOC #B: Relative Error at (50, 20, 10) mL/min@STP with the expanded uncertainty  $U_{Lab}$ .

Table 21: MOLBLOC #B: Results at 50 mL/min@STP.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	-0.04	-0.09
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.05
$U_{TS}$ (%)	0.04	0.04
$U_{xi}$ (%)	0.16	0.07

Table 22: MOLBLOC #B: Results at 20 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.01	0.09
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.05
$U_{TS}$ (%)	0.08	0.08
$U_{xi}$ (%)	0.17	0.09

Table 23: MOLBLOC #B: Results at 10 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.03	0.15
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.08
$U_{TS}$ (%)	0.10	0.10
$U_{xi}$ (%)	0.18	0.13

### 8.3 MOLBLOC #C

The results with the expanded uncertainties at (450, 200, 100, 50) mL/min@STP are shown in Figure 11 and listed in Table 24 to Table 27 below.

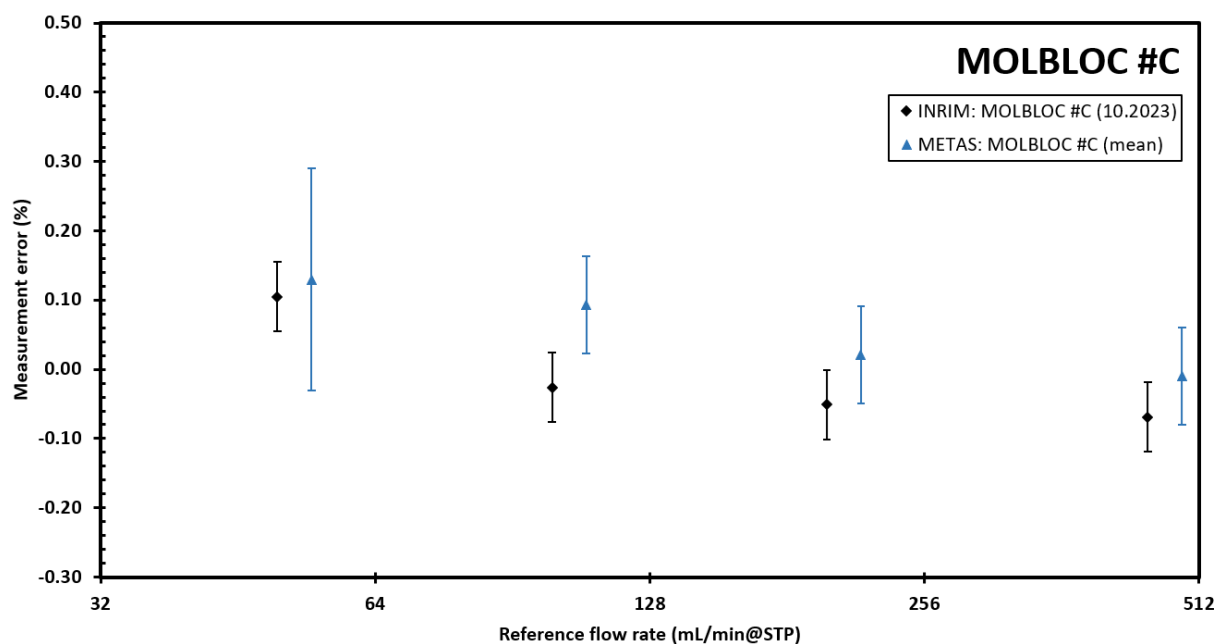


Figure 11: MOLBLOC #C: Relative Error at (450, 200, 100, 50) mL/min@STP with the expanded uncertainty  $U_{Lab}$ .

Table 24: MOLBLOC #C: Results at 450 mL/min@STP.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	-0.01	-0.07
$U_{Base}$ (%)	0.067	0.05
$U_{Lab}$ (%)	0.067	0.05
$U_{TS}$ (%)	0.01	0.01
$U_{xi}$ (%)	0.07	0.05

Table 25: MOLBLOC #C: Results at 200 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.02	-0.05
$U_{Base}$ (%)	0.067	0.05
$U_{Lab}$ (%)	0.067	0.05
$U_{TS}$ (%)	0.03	0.03
$U_{xi}$ (%)	0.07	0.06

## Low-Pressure Gas Flow Comparison (bilateral).

### Comparison of Primary Standards for Gas Flow in the Range (1.2 to 450) mL/min@STP

Table 26: MOLBLOC #C: Results at 100 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.09	-0.03
$U_{Base}$ (%)	0.067	0.05
$U_{Lab}$ (%)	0.067	0.05
$U_{TS}$ (%)	0.03	0.03
$U_{xi}$ (%)	0.07	0.06

Table 27: MOLBLOC #C: Results at 50 mL/min.  $U_{Lab}$  includes  $U_{Base}$  and  $U_{Repeat}$ .  $U_{xi}$  includes  $U_{Base}$ ,  $U_{Repeat}$  and  $U_{TS}$ , ( $k=2$ ).

Lab	METAS	INRIM
Error (%)	0.13	0.10
$U_{Base}$ (%)	0.15	0.05
$U_{Lab}$ (%)	0.15	0.05
$U_{TS}$ (%)	0.06	0.06
$U_{xi}$ (%)	0.16	0.08

## 9 The Key Comparison Reference Value and its Uncertainty

Not applicable.

### 9.1 KCRV

Not applicable.

#### 9.1.1 Results of the consistency check

Not applicable.

## 10 Degree of Equivalence between individual participants and the KCRV

### 10.1 Differences between the participant i to KCRV: $d_i, U(d_i)$

Not applicable.

### 10.2 Degree of Equivalence (DoE): $E_n$

The definitions of the presently used comparison pass/fail/inconclusive criterion are stated in Appendix C .

#### 10.2.1 MOLBLOC #A

Table 28: MOLBLOC #A: Listing of the  $E_n$  values

Nominal flow rate (mL/min@STP)	$E_n$ - value	Criterion A	$U_{comp}/U_{base}$	Criterion B	$U_{comp}/U_{base}$	Criterion B	Criterion D
		METAS & INRIM	METAS	METAS	INRIM	INRIM	
10	0.03	pass	0.37	pass	1.12	pass	n/a
5	0.03	pass	0.53	pass	0.99	pass	n/a
3	0.67	pass	0.49	pass	0.82	pass	n/a
2	0.32	pass	0.43	pass	1.30	pass	n/a
1.2	0.63	pass	0.45	pass	0.56	pass	n/a

## Low-Pressure Gas Flow Comparison (bilateral).

### Comparison of Primary Standards for Gas Flow in the Range (1.2 to 450) mL/min@STP

#### 10.2.2 MOLBLOC #B

Table 29: MOLBLOC #B: Listing of the  $E_n$  values

Nominal flow rate (mL/min@STP)	$E_n$ - value	Criterion A	$U_{comp}/U_{base}$	Criterion B	$U_{comp}/U_{base}$	Criterion B	Criterion D
		METAS & INRIM	METAS	METAS	INRIM	INRIM	
50	0.24	pass	0.28	pass	0.84	pass	n/a
20	0.46	pass	0.51	pass	1.52	pass	n/a
10	0.56	pass	0.66	pass	1.25	pass	n/a

#### 10.2.3 MOLBLOC #C

Table 30: MOLBLOC #C: Listing of the  $E_n$  values

Nominal flow rate (mL/min@STP)	$E_n$ - value	Criterion A	$U_{comp}/U_{base}$	Criterion B	$U_{comp}/U_{base}$	Criterion B	Criterion D
		METAS & INRIM	METAS	METAS	INRIM	INRIM	
450	0.69	pass	0.18	pass	0.25	pass	n/a
200	0.78	pass	0.41	pass	0.55	pass	n/a
100	1.30	fail	0.39	fail	0.52	fail	n/a
50	0.14	pass	0.38	pass	1.14	pass	n/a

➔ One (1)  $E_n$  value is larger than 1 at 100 mL/min@STP.

## 11 Confirmation of the CMCs

Current CMCs entries for both labs are confirmed, except at 100 mL/min.

The cause of the outlier at 100 mL/min could not be evaluated. However, it is very unlikely that the measuring systems of METAS and INRIM provide incorrect or inconsistent values at this uncritical flow rate with a theoretically perfect TS.

### Modification of CMC entries for METAS:

Current entries:

#	Institute service code	Value CMC	Expanded uncertainty CMC	Parameters
1	5232.18-01 5232.18-02	(100 to 3e4) mL/min	0.09%	Absolute pressure: (100 to 500) kPa Temperature: 20 °C
2	5135-CH5	(6e-3 to 18) m3/h	0.067%	Air / inert gas Ambient conditions
3	5232.18-03	(3 to 100) mL/min	0.15%	Absolute pressure: (100 to 500) kPa Temperature: 20 °C

Updated entries:

#	Institute service code	Value CMC	Expanded uncertainty CMC	Parameters
1	<del>5232.18-01</del> <del>5232.18-02</del>	<del>(100 to 3e4)</del> mL/min	<del>0.09%</del>	<del>Absolute pressure: (100 to 500) kPa</del> <del>Temperature: 20 °C</del>
2	5135-CH5	(0.1 to 300) L/min	0.067%	Absolute pressure: (0 to 1000) kPa Ambient temperature conditions
3	5135-CH14	(1.2 to 100) mL/min	0.15%	Absolute pressure: (0 to 1000) kPa Ambient temperature conditions

## 12 Summary and Conclusions

The bilateral comparison between INRIM and METAS to compare volume gas flow measurements in the flow range (1.2 to 450) mL/min@STP using Laminar Flow Elements (DH Instruments™ MOLBLOCs with the associated MOLBOX) in the range of (1.2 to 450) mL/min@STP was successfully completed. The data obtained are valid for analysis.

The current CMC entries for both laboratories were confirmed.

Based on the outcome of this comparison, METAS will propose to update its CMC entries linked to its piston provers.

## 13 Explanations for Discrepant Reported Values

### 13.1 Discrepant values

None.

## 14 Terms and abbreviations

BIPM = Bureau International des Poids et Mesures (the International Bureau of Weights and Measures)

CCM = Consultative Committee for Mass and Related Quantities

CIPM = Comité International des Poids et Mesures (International Committee for Weights and Measures)

CMC = Calibration and Measurement Capabilities

DoE = Degree of Equivalence

FF = Fluid Flow

GUM = Guide to the Expression of Uncertainty in Measurement

KC = Key Comparison

KCRV = Key Comparison Reference Value

NMI = National Metrology Institute

TS = Transfer Standard

VIM = Vocabulaire International de Metrologie

WGFF = Working Group for Fluid Flow

## 15 References

[1] Cox M. The evaluation of key comparison data: determining the largest consistent subset. *Metrologia*, Vol 44, p. 187-200, 2007.

[10] BIPM JSGM 200, International vocabulary of metrology - Basic and general concepts and associated terms (VIM), 3rd Edition, 2012

[11] K. Beissner, "On a measure of constancy in comparison measurements," vol. 39, no. 59-63, 2002

[12] J. Wright, B. Toman, B. Mickan, G. Wubbeler and O. Bodnar, "Pass / Fail / Inconclusive Criteria for Inter-Laboratory Comparisons," in *9th International Symposium on Fluid Flow Measurement*, Arlington, 2015

[13] J. Wright, B. Toman, B. Mickan, G. Wubbeler, O. Bodnar and C. Elster. "Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons", Metrologia, 2016, 53(6), 1243–1258.

## Appendix A Formula for KCRV

Not applicable.

## Appendix B Formula for uncertainty of KCRV

Not applicable.

## Appendix C Comparison pass/fail criterion

The definitions and the results of the presently used comparison pass/fail/inconclusive criterion are listed as follows:

- Criterion A: Participant  $i$  passes if  $|E_n| \leq 1$  and fails if  $|E_n| > 1$ .
  - Pass:  $|E_n| \leq 1$
  - Fail(X):  $|E_n| > 1$
  
- Criterion B: with  $U_{Comp,i} = \sqrt{U_{Repeat,i}^2 + U_{TS}^2}$ 
  - Pass:  $|E_n| \leq 1$  and  $\left| \frac{U_{Comp,i}}{U_{Base,i}} \right| \leq 2$
  - Fail(X):  $|E_n| > 1$  and  $\left| \frac{U_{Comp,i}}{U_{Base,i}} \right| \leq 2$
  - ?: Otherwise
  
- Criterion D: Not applicable.