EURAMET Project 1395

EURAMET.M.FF-K4.1.2016:

Volume comparison at 20 L

Final Report

Pilot
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Participants
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Mihailović Mirjana – MBM, Montenegro
Erinda Piluri – DPM, Albania
Gunn Kristin Svendsen – JV, Norway
Marc de Huu – METAS, Switzerland
Anastazija Sarevska – BoM, Republic of Macedonia
Milan Mišovich – SMU, Slovakia
Urška Turnšek – MIRS, Slovenia
Agim Xhuraj – AMK, Republic of Kosovo
Mariana Miteva – BIM, Bulgaria
Ilona Milkamanavičienė – VMC, Lithuania
Erik Smits – VSL, Netherlands
Jose Ángel Terradillos González – CEM, Spain
Per Wennergren – RISE, Sweden
Anton Niessner – BEV, Austria
Csaba Czibulka – MKEH, Hungary
Miroslava Benkova – CMI, Czech Republic

April, 2020

1. Introduction

During the TC-F annual meeting, held in Boras in 2015, it was agreed to perform the follow up of the CCM.FF-K4.1.2011 [1] organized for the EURAMET NMIs for Volume of Liquids at 20 L. INRIM offered to act as the pilot laboratory, and IPQ as co-pilot.This comparison was registered at BIPM as EURAMET.M.FF-K4.1.2016.
The transfer standard (TS) was a 20 L pipette supplied by CENAM (s/n 710-06FYV) which was re-manufacturing for the intended purpose.
The main purpose of this project was to compare the experimental results and uncertainty calculations in calibrating this 20 L pipette and linking the intra-regional European results with the results obtained in the previous inter-regional CIPM key comparison CCM.FF-K4.1.2011 [1].
The participants of this comparison also involved in the comparison CCM.FF-K4.1.2011 were: CENAM, INRIM, IPQ, RISE and VSL. CENAM was involved in the first measurement, performed just before to sent the transfer standard to INRIM.
The protocol was essentially equivalent to the protocol of CCM.FF-K4.1.2011, where the information concerning the 100 mL pycnometer were removed.
The comparison was organized in two petals, in the first took part laboratories which need ATA Carnet. INIRM perform three measurements, at the beginning, after the first petal and at the end of the circulation.
Each participant had 3 weeks to receive the TS, make the measurements and send the TS to the next participant.
The comparison measurements started in April 2016 and ended in October 2017.

2. Participants and schedule

Twenty-one laboratories took part in the comparison, nineteen from EURAMET and two from outside Euramet: AMK from Kosovo (Liaison Organisation of EURAMET) and CENAM from Mexico (SIM), with the consent of all participating members of EURAMET.

FORCE from Denmark, was initially among the participants, but was not able to perform the measurements due to problems with the balance, so it was removed from the comparison.

List of the participants and the circulation scheme is shown in table 1.

3. Transfer Standard

The TS consist of a 20 L pipette (see figure 1) made of stainless steel, it has been designed to:

a) Minimize the contribution of the meniscus reading to the volume uncertainty,
b) Provide a leak-free metal to metal seal between the two parts of the container,
c) Minimize the risk of volume changes,
d) Keep the air/liquid interface as small as possible.

The temperature of the water inside the TS was measured using a hand held digital thermometer (supplied with the TS) coupled to fixed installed 4-wire Pt-100 temperature sensor, with a standard uncertainty of 0,015 °C.
A torque wrench was supplied with the transfer package to provide repeatable and reproducible torque values while assembling the transfer standard. The wrench has been set to 16 Nm for assembling purposes.

Table 1. Circulation scheme of the comparison.

Country NMI	**Contact Person**	**Measurements**
Mexico, CENAM	Roberto Arias	April 2016
Italy, INRIM	Andrea Malengo	May 2016
Serbia, DMDM	Ljiljana Mićić	June 2016
Bosnia and Herzegovina, IMBIH	Alen Bošnjaković	July 2016
Montenegro, MBM	Mihailović Mirjana	July 2016
Albania, DPM	Erinda Piluri	August 2016
Norway, JV	Gunn Kristin Svendsen	September 2016
Switzerland, METAS	Marc de Huu	October 2016
R. Macedonia, BoM	Anastazija Sarevska	November 2016
Italy, INRIM	Andrea Malengo	November 2016
Slovakia, SMU	Milan Mišovich	December 2016
Slovenia, MIRS	Urška Turnšek	January 2017
Republic of Kosovo, AMK	Agim Xhuraj	January 2017
Bulgaria, BIM	Mariana Miteva	February 2017
Lithuania, VMC	Ilona Milkamanavičienė	March 2017
Portugal, IPQ	Elsa Batista	April 2017
Netherlands, VSL	Erik Smits	May 2017
Spain, CEM	Jose Ángel Terradillos González	June 2017
Sweden, RISE	Per Wennergren	July 2017
Austria, BEV	Anton Niessner	July 2017
Hungary, MKEH	Csaba Czibulka	August 2017
CMI, Czech Republic	Miroslava Benkova	August 2017
Italy, INRIM	Andrea Malengo	October 2017

Figure 1. The 20 L pipette.

4. Comparison Protocol

The participating laboratories determined the volume of water that the TS of 20 L is able to deliver after a 60 second period of dripping-off at a reference temperature of 20 °C.

Based on experience and on reference data, cubic coefficient of expansion for the TS was (47.7 ± 2.0)$\times 10^{-6}$ °C^{-1} (uncertainty expressed as standard uncertainty).

The transfer package included a temperature measurement system.

The transfer standard had to be cleaned and assembled by each participant before starting the measurements.

Each participating laboratory performed 10 measurements on the transfer standard. .

During the comparison no significant damages of the inner surfaces of the TS were observed.

5. Methods of measurement and working conditions

According to the protocol all the participating NMIs applied a gravimetric method to determine the volume.
The majority of the NMIs used distilled water, the Tanaka density formula and balances with a resolution of 10 mg, a summary of the equipments used and the working conditions employed at the different NMIs is given in table 2.

Table 2. Summary of the equipments used and working conditions. Water: O Inverse osmosis; DI distilled, DE demineralized.

Country NMI	**Balance range, resolution**	**Water**	**De-aerated water**	**Density formula**	**Water temp./°C**	**Air temp. /°C**
Mexico, CENAM	60 kg, 0,01 g	DE	no	Tanaka et al	21,2	19,2
Italy, INRIM (first)	64 kg, 0,005 g	DI	no	Tanaka et al	19,9	19,6
Serbia, DMDM	120 kg, 0,1 g	DI	no	Tanaka et al	20,6	20,6
Bosnia and Herzegovina, IMBIH	64 kg, 0,1 g	DI	yes	Tanaka et al	20,6	21,1
Montenegro, MBM	60 kg, 0,01 g	DI	no	Tanaka et al	19,7	20,6
Albania, DPM	64 kg, 0,01 g	DI	no	Spieweck et al	19,9	19,9
Norway, JV	600 kg, 0,01 g	DE	yes	Spieweck et al	20,8	22,6
Switzerland, METAS	50 kg, 0,005 g	DE	no	Tanaka et al	17,1	21,3
R. Macedonia, BoM	60 kg, 0,002 g	DE+O	no	Kell	20,6	22,1
Italy, INRIM (second)	64 kg, 0,005 g	DI	no	Tanaka et al	19,9	20,0
Slovakia, SMU	64 kg, 0,1 g	DI	no	Tanaka et al	19,9	19,7
Slovenia, MIRS	32 kg, 0,1 g	DE	no	Kell	19,7	20,7
Republic of Kosovo, AMK	30 kg, 0,01 g	DI	yes	Tanaka et al	20,1	20,3
Bulgaria, BIM	60 kg, 1 g	DI	no	Tanaka et al	22,2	22,5
Lithuania, VMC	60 kg, 0,01 g	DI	no	Tanaka et al	18,3	19,3
Portugal, IPQ	150 kg, 0,05 g	DI	no	Tanaka et al	20,1	20,8
Netherlands, VSL	64 kg, 0,01 g	DE	no	Spieweck et al	20,1	23,0
Spain, CEM	50 kg, 0,01 g	DE	no	Tanaka et al	19,8	19,9
Sweden, RISE	30 kg, 0,005 g	DE	yes	Tanaka et al	20,5	21,2
Austria, BEV	30 kg, 0,01 g	DI	no	Spieweck	20,0	19,7
Hungary, MKEH	64 kg, 0,01 g	DE	no	Spieweck	20,5	20,7
CMI	35 kg, 0,01 g	DI	no	Tanaka et al	19,4	19,4
Italy, INRIM (third)	64 kg 0,005 g	DI	no	Tanaka et al	19,7	20,3

6. Uncertainty due to the Transfer Standard

The stability of the transfer standard was checked by the pilot laboratory, before starting the first petal, at the end of the first petal and at the end of the comparison. The results are shown in table 3.
The maximum variation, observed between the first and the second measurement, was Δ*V*= 0,25 mL, the values between the second and third measurement were almost similar. Although all the three measurements are consistent, the variation of 0,25 mL can be due to the instability of the transfer standard.
It has been evaluated an uncertainty contribution u_{inst} considering a rectangular distribution

$$u_{\mathrm{inst}} = \frac{\Delta V}{2\sqrt{3}} = 0{,}07 \text{ mL}. \qquad (1)$$

This uncertainty contribution has been taken into account for the evaluation of the degrees of equivalence, both for the first and second petal.

INRIM also performed the check of the supplied thermometer, the stability was within 0,005 °C.

Table 3. Measurements performed by the pilot laboratory.

Volume *V*/mL	Uncertainty *U*(*V*) /mL	Date
19 995,37	0,38	May 2016
19 995,12	0,38	November 2016
19 995,15	0,38	October 2017

The INRIM value for the comparison as been calculated as mean value of the three measurements:

INRIM Volume *V*/mL	Uncertainty *U*(*V*) /mL
19 995,21	0,38

7. Results

The measurement results presented by each participant are shown in table 4 and figure 2 (uncertainties and error bars given in term of expanded uncertainty). The summary of the uncertainty budget for each participant is shown in Appendix A tables 9 and 10. The uncertainty contribution "Other" includes uncertainties due to: evaporation, meniscus, air bubble, draining and stability.

Table 4. Results as reported by the participants.

NMI	*V*/mL	*U*(*V*) / mL
CENAM	19 995,56	0,77
INRIM	19 995,21	0,38
DMDM	19 996,06	1,69
IMBIH	19 994,94	0,58
MBM	19 994,50	1,24
DPM	19 999,22	1,04
JV	19 995,30	0,52
METAS	19 994,73	2,11
BoM	19 994,22	1,70
SMU	19 995,01	0,67
MIRS	19 995,20	1,00
AMK	19 994,18	2,80
BIM	19 996,50	1,60
VMC	19 995,18	1,52
IPQ	19 994,87	1,70
VSL	19 995,42	0,72
CEM	19 994,88	0,72
RISE	19 995,33	0,55
BEV	19 995,40	0,77
MKEH	19 995,14	0,39
CMI	19 995,05	0,66

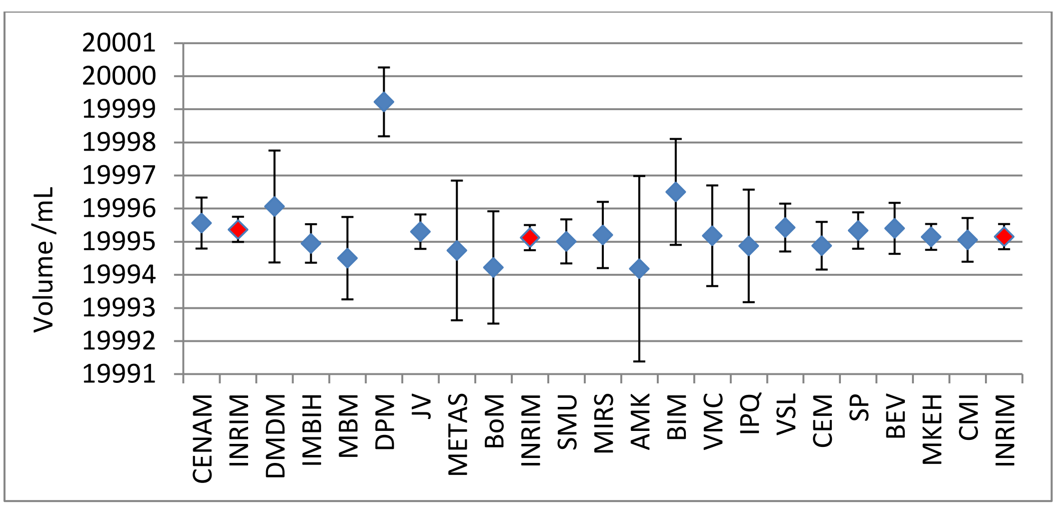

Figure 2. Results as reported by the participants. Results from the INRIM pivot laboratory in red.

8. Link to CCM.FF-K4.1.2011 and Degrees of equivalence

According to the EURAMET Guide No. 4 [2] in this EURAMET key comparison no reference value was determined, the degrees of equivalence were calculated by linking to the *KCRV* of the CCM key comparison CCM.FF-K4.1.2011 in which two 20 L pipettes supplied by CENAM, the pilot laboratory, were used as travelling standard.

The link to CCM.FF-K4.1.2011 has been provided by CENAM, INRIM, VLS, IPQ and RISE. The EURAMET participants performed their measurements in 2012.

Table 5 lists the degrees of equivalence of the volume measurements on the TS No. 710-04 as determined in the CCM.FF-K4.1.2011 comparison. In the Final Report of CCM.FF-K4.1.2011 this standard has been suggested as TS to be used to link others comparisons.

The *KCRV* value and the associated standard uncertainty of the TS no. 710-04 were:

KCRV = 19 990,75 mL , $u(KCRV)$=0,10 mL

Table 5. Degrees of equivalence for the linking laboratories in CCM.FF-K4.1.2011 comparison.

CCM.FF-K4.1.2011, TS 710-04				
Linking laboratories	D_i/x_{ref} × 10^6	$U(D_i)/x_{ref}$ × 10^6	D_i/ mL	$U(D_i)$/ mL
CENAM	-0,08	39	-0,002	0,780
IPQ	-2,7	84	-0,054	1,679
VSL	-11	32	-0,220	0,640
RISE	-6,5	23	-0,130	0,460
INRIM	-1,05	16	-0,021	0,320

The difference D_{CCM} evaluated as weighted mean [3] of the D_i of the linking laboratories was:

D_{CCM} = -0,07 mL,

with a standard uncertainty

$u(D_{CCM})$ = 0,12 mL,

this result is used to correct the value obtained in this EURAMET comparison by the linking laboratories.

In table 6 the results obtained by the linking laboratories in this comparison are given.

Table 6. Results of the linking laboratories in EURAMET.M.FF-K4.1.2016.

EURAMET.M.FF-K4.1.2016		
Linking laboratories	V/mL	$u(V)$/mL
CENAM	19 995,56	0,39
IPQ	19 994,87	0,85
VSL	19 995,42	0,36
RISE	19 995,33	0,27
INRIM	19 995,21	0,19

From the results in table 6, by the weighted mean method the value V_{Eur} and the associated standard uncertainty $u(V_{\mathrm{Eur}})$ have been evaluated:

V_{Eur}= 19 995,30 mL, and $u(V_{\mathrm{Eur}})$ = 0,13 mL

In order to link the EURAMET.M.FF-K4.1.2016 comparison to the *KCRV* of the CCM.FF-K4.1.2011, the difference has been calculated as:

$$\boldsymbol{D}_{\mathbf{Eur-KCRV}} = \boldsymbol{V}_{\mathbf{Eur}} - D_{\mathrm{CCM}} - KCRV = 4{,}62 \text{ mL} \quad (2)$$

As consequence the reference value of this comparison is:

$$\boldsymbol{V}_{\mathbf{ref}} = \boldsymbol{V}_{\mathbf{Eur}} - D_{\mathrm{CCM}} = 19\,995{,}37 \text{ mL}$$
(3)

The correlation coefficient associated with a measured values provided by the linking laboratories in this comparison and the CCM.FF-K4.1.2011 *KCRV* value can be considered negligible, based on the relative long time between the CCM comparison and this comparison.

Considering the uncertainty contribution due to the instability, evaluated in chapter 6, the standard uncertainty associated to $D_{\mathrm{Eur\text{-}KCRV}}$ is given by:

$$u(\boldsymbol{D}_{\mathbf{Eur-KCRV}}) = \sqrt{u^2\,(V_{\mathrm{Eur}}) + u^2(D_{\mathrm{CCM}}) + u^2(KCRV) + u_{\mathrm{inst}}^2} = 0{,}21 \text{ mL} \quad (4)$$

To calculate the degrees of equivalence D_{i} between the laboratories results x_i and the *KCRV*, the following formula is used:

$$D_i = x_i - \boldsymbol{D}_{\mathbf{Eur-KCRV}} - KCRV \quad (5)$$

$$U(D_i) = 2\sqrt{u^2(x_i) + u^2(\boldsymbol{D}_{\mathbf{Eur-KCRV}})} \quad (6)$$

In table 7 and figure 3 the results are shown, the normalized error E_n is calculated as:

$$E_n = \frac{D_i}{U(D_i)} \qquad (7)$$

The DPM from Albania result was discrepant, the pilot laboratory informed DPM about this anomaly in the value, but no mistake in the result was found.

Table 7. Degrees of equivalence with *KCRV*, and the E_n value.

NMI	**D_i/mL**	**$U(D_i)$/mL**	**E_n**
INRIM	-0,16	0,58	-0,27
CENAM	0,19	0,89	0,21
DMDM	0,69	1,75	0,40
IMBIH	-0,43	0,73	-0,58
MBM	-0,87	1,32	-0,66
DPM	3,85	1,13	3,41
JV	-0,07	0,68	-0,10
METAS	-0,64	2,16	-0,30
BoM	-1,15	1,75	-0,66
SMU	-0,36	0,80	-0,46
MIRS	-0,17	1,09	-0,16
AMK	-1,19	2,83	-0,42
BIM	1,13	1,66	0,68
VMC	-0,19	1,58	-0,12
IPQ	-0,50	1,76	-0,28
VSL	0,05	0,85	0,06
CEM	-0,49	0,84	-0,59
RISE	-0,04	0,69	-0,05
BEV	0,03	0,89	0,03
MKEH	-0,23	0,59	-0,39
CMI	-0,32	0,79	-0,40

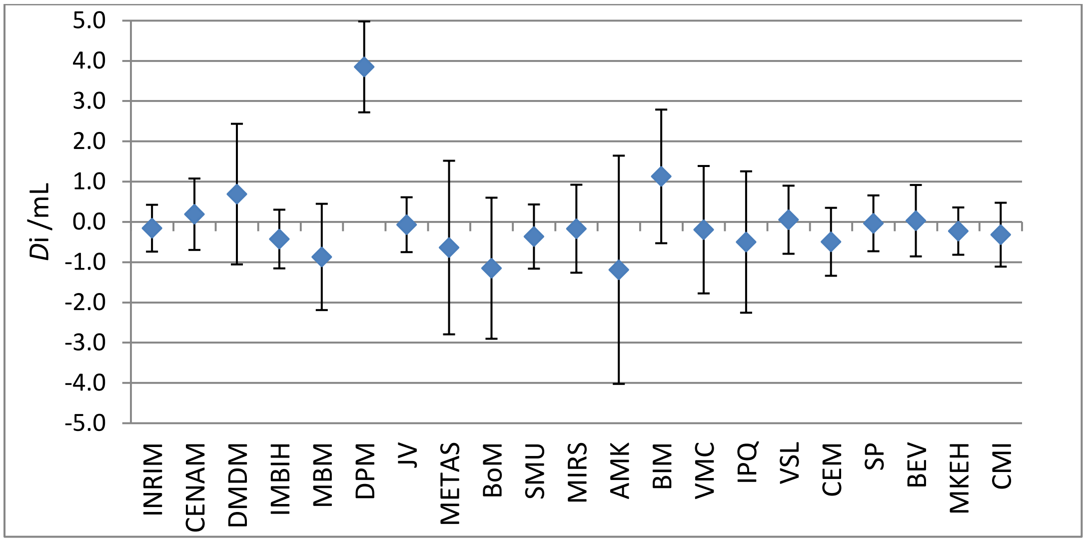

Figure 3. Degree of equivalence with *KCRV*.

The degrees of equivalence between laboratories have been evaluated as:

$$D_{i,j} = x_i - x_j \tag{8}$$

$$U(D_{i,j}) = 2\sqrt{u^2(x_i) + u^2(x_j) + u_{\text{inst}}^2} \tag{9}$$

In Appendix A, in tables 11, 12 and 13, the results are shown.

9. Summary and Conclusions

The comparison EURAMET.M.FF-K4.1.2016 was piloted by INRIM, twenty-one NMIs tested the 20 L transfer standard.

The comparison was conducted during April 2016 – October 2017.

Although negligible, an uncertainty contribution due to the instability (u_{inst}=0,07 mL) of the transfer standard as been considered in the evaluation of the degrees of equivalence.

The degrees of equivalence of this key comparison have been evaluated with the linkage to the *KCRV* value of the CCM.FF-K4.1.2011. Five laboratories were used as linking laboratories: CENAM, INRIM, IPQ, RISE and VSL.

Only one participant produced anomalous result, however, at present, it does not have CMCs on volume of liquid.

It should be noted that most of the participants (thirteen) declared an expanded uncertainty less than 0,00 5 %.

In order to assess the support of CMCs entries provided by this comparison, it is necessary to compare D_i against declared uncertainty values from the CMC tables. It is expected that D_i values are smaller than U_{CMCs} for supporting purposes, results are in table 8.

For NMIs without CMC on 20 L at present, the label n/a is shown, for the others NIMs all the CMCs are supported.

It is to be noted that METAS in this comparison declared an expanded uncertainty bigger than the CMC.

Table 8. Consistency check for CMC entries for volume of liquids at 20 L.

NMI	U_{CMCs} /%	$U_{\text{K4.1.2016}}$/%	$\frac{d_i}{x_{\text{KCRV}}}$ / %	Passed/Failed K4.1.2016	CMCs supported
INRIM	0,005	0,001 9	-0,000 8	Passed	Yes
CENAM	0,004	0,003 9	0,001 0	Passed	Yes
DMDM	0,020	0,008 5	0,003 5	Passed	Yes
IMBIH	n/a	0,002 9	-0,002 1	Passed	n/a
MBM	0,020	0,006 2	-0,004 4	Passed	Yes
DPM	n/a	0,003 3	0,019 3	Failed	n/a
JV	0,006	0,002 6	-0,000 4	Passed	Yes
METAS	0,006	0,010 6	-0,003 2	Passed	No
BoM	n/a	0,008 5	-0,005 8	Passed	n/a
SMU	0,040	0,003 3	-0,001 8	Passed	Yes
MIRS	0,020	0,005 0	-0,000 9	Passed	Yes
AMK	n/a	0,014 0	-0,006 0	Passed	n/a
BIM	n/a	0,008 0	0,005 7	Passed	n/a
VMC	n/a	0,007 6	-0,001 0	Passed	n/a
IPQ	0,010	0,008 5	-0,002 5	Passed	Yes
VSL	0,010	0,003 6	0,000 3	Passed	Yes
CEM	0,020	0,003 6	-0,002 5	Passed	Yes
RISE	0,003	0,002 7	-0,000 2	Passed	Yes
BEV	0,005	0,003 9	0,000 2	Passed	Yes
MKEH	0,020	0,002 0	-0,001 1	Passed	Yes
CMI	0,010	0,003 3	-0,001 6	Passed	Yes

10. Appendix A

Table 9. Uncertainty contributions (in milliliters) to the uncertainty of the measurand (no.1).

<table>
<tr><th></th><th>INRIM</th><th>CENAM</th><th>DMDM</th><th>IMBIH</th><th>MBM</th><th>DPM</th><th>JV</th><th>METAS</th><th>BoM</th><th>SMU</th><th>MIRS</th></tr>
<tr><td>Weighing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Balance</td><td>0,058</td><td>0,147</td><td>0,041</td><td>0,147</td><td rowspan="2">0,175</td><td>0,328</td><td>0,110</td><td rowspan="2">0,184</td><td>0,115</td><td>0,084</td><td>0,401</td></tr>
<tr><td>Mass standards</td><td>0,011</td><td>0,012</td><td>0,392</td><td>0,025</td><td>0,035</td><td>0,039</td><td>0,015</td><td>0,039</td><td>0,025</td></tr>
<tr><td>Water Density</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Density</td><td>0,100</td><td>0,008</td><td>0,151</td><td>0,204</td><td>0,071</td><td>0,224</td><td rowspan="2">0,068</td><td rowspan="2">0,480</td><td>0,606</td><td rowspan="2">0,062</td><td rowspan="2">0,244</td></tr>
<tr><td>Temperature</td><td>0,085</td><td>0,343</td><td>0,114</td><td>0,031</td><td>0,031</td><td>0,004</td><td>0,138</td></tr>
<tr><td>Ambient Conditions</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Temperature</td><td>0,016</td><td>0,016</td><td rowspan="3">0,005</td><td rowspan="3">0,005</td><td rowspan="3">0,005</td><td>0,001</td><td rowspan="3">0,013</td><td rowspan="3">0,090</td><td rowspan="3">0,008</td><td>0,00001</td><td rowspan="3">0,044</td></tr>
<tr><td>Humidity</td><td>0,004</td><td>0,001</td><td>0,0002</td><td>0,000001</td></tr>
<tr><td>Pressure</td><td>0,005</td><td>0,006</td><td>0,00005</td><td>0,000003</td></tr>
<tr><td>Arifact</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Expansion coefficient</td><td>0,005</td><td rowspan="2">0,025</td><td rowspan="2">0,025</td><td rowspan="2">0,025</td><td rowspan="2">0,187</td><td rowspan="2"></td><td>0,033</td><td rowspan="2">0,820</td><td rowspan="2">0,006</td><td>0,000004</td><td rowspan="2">0,014</td></tr>
<tr><td>Temperature</td><td>0,095</td><td>0,014</td><td>0,00008</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Repeatability</td><td>0,040</td><td>0,083</td><td>0,207</td><td>0,058</td><td>0,121</td><td>0,328</td><td>0,146</td><td>0,400</td><td>0,139</td><td>0,034</td><td>0,151</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td>0,040</td><td>0,015</td><td>0,695</td><td>0,125</td><td>0,548</td><td>0,010</td><td>0,050</td><td></td><td>0,548</td><td>0,297</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Standard uncertainty</td><td>0,190</td><td>0,385</td><td>0,847</td><td>0,297</td><td>0,622</td><td>0,520</td><td>0,263</td><td>1,057</td><td>0,848</td><td>0,333</td><td>0,499</td></tr>
<tr><td>k</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td></tr>
<tr><td>Expanded uncertainty</td><td>0,38</td><td>0,77</td><td>1,69</td><td>0,60</td><td>1,24</td><td>1,04</td><td>0,53</td><td>2,11</td><td>1,70</td><td>0,67</td><td>1,00</td></tr>
</table>

Table 10. Uncertainty contributions (in milliliters) to the uncertainty of the measurand (no.1).

<table>
<tr><th></th><th>AMK</th><th>BIM</th><th>VMC</th><th>IPQ</th><th>VSL</th><th>CEM</th><th>RISE</th><th>BEV</th><th>MKEH</th><th>CMI</th></tr>
<tr><td>Weighing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Balance</td><td>0,227</td><td>0,758</td><td>0,570</td><td>0,240</td><td rowspan="2">0,049</td><td>0,146</td><td>0,005</td><td>0,050</td><td>0,016</td><td>0,023</td></tr>
<tr><td>Mass standards</td><td>0,017</td><td>0,014</td><td>0,025</td><td>0,017</td><td>0,015</td><td>0,064</td><td>0,004</td><td>0,028</td><td>0,032</td></tr>
<tr><td>Water Density</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Density</td><td rowspan="2">0,063</td><td>0,081</td><td>0,100</td><td>0,072</td><td>0,250</td><td>0,309</td><td>0,230</td><td>0,359</td><td>0,066</td><td>0,300</td></tr>
<tr><td>Temperature</td><td>0,014</td><td>0,021</td><td>0,014</td><td>0,214</td><td>0,068</td><td>0,054</td><td>0,109</td><td>0,097</td><td>0,090</td></tr>
<tr><td>Ambient Conditions</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Temperature</td><td rowspan="3">0,005</td><td rowspan="3">0,037</td><td>0,065</td><td rowspan="3">0,00005</td><td rowspan="3">0,012</td><td rowspan="3">0,019</td><td>0,021</td><td>0,020</td><td>0,001</td><td>0,008</td></tr>
<tr><td>Humidity</td><td>0,480</td><td>0,005</td><td>0,004</td><td>0,001</td><td>0,001</td></tr>
<tr><td>Pressure</td><td>0,048</td><td>0,002</td><td>0,004</td><td>0,000</td><td>0,037</td></tr>
<tr><td>Arifact</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Expansion coefficient</td><td rowspan="2">0,003</td><td rowspan="2">0,087</td><td>0,000</td><td rowspan="2">0,003</td><td>0,002</td><td rowspan="2">0,007</td><td>0,019</td><td>0,030</td><td>0,019</td><td>0,000</td></tr>
<tr><td>Temperature</td><td>0,015</td><td>0,049</td><td>0,054</td><td>0,028</td><td>0,014</td><td>0,007</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Repeatability</td><td>0,009</td><td>0,024</td><td>0,025</td><td>0,075</td><td>0,017</td><td>0,092</td><td>0,020</td><td>0,032</td><td>0,051</td><td>0,091</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Others</td><td>1,390</td><td></td><td>0,036</td><td>0,816</td><td>0,130</td><td></td><td>0,087</td><td>0,049</td><td>0,141</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Standard uncertainty</td><td>1,410</td><td>0,800</td><td>0,760</td><td>0,860</td><td>0,361</td><td>0,360</td><td>0,268</td><td>0,383</td><td>0,195</td><td>0,331</td></tr>
<tr><td>k</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,00</td><td>2,05</td><td>2,00</td><td>2,00</td><td>2,00</td></tr>
<tr><td>Expanded uncertainty</td><td>2,82</td><td>1,60</td><td>1,52</td><td>1,70</td><td>0,72</td><td>0,72</td><td>0,55</td><td>0,77</td><td>0,39</td><td>0,66</td></tr>
</table>

Table 11. Degrees of equivalence between laboratories (no.1).

	x_j		INRIM		CENAM		DMDM		IMBIH		MBM		DPM		JV	
x_i	Di/x_{ref} × 10^6	$U(Di/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6
INRIM	-8	29			-17	45	-42	87	13	35	36	65	-200	56	-4	33
CENAM	10	44	17	45			-25	93	31	49	53	74	-183	65	13	47
DMDM	35	87	42	88	25	94			56	90	78	105	-158	99	38	89
IMBIH	-21	36	-13	38	-31	50	-56	90			22	69	-214	60	-18	40
MBM	-44	66	-36	67	-53	75	-78	105	-22	69			-236	81	-40	68
DPM	193	56	200	57	183	66	158	99	214	60	236	81			196	59
JV	-4	34	4	35	-13	49	-38	89	18	40	40	68	-196	59		
METAS	-32	108	-24	108	-41	113	-66	135	-11	110	12	123	-224	118	-28	109
BoM	-58	88	-50	88	-67	94	-92	120	-36	90	-14	105	-250	100	-54	89
SMU	-18	40	-10	41	-28	53	-53	91	3	45	25	71	-211	62	-15	43
MIRS	-9	55	-1	55	-18	65	-43	98	13	58	35	80	-201	72	-5	57
AMK	-60	142	-52	142	-69	146	-94	164	-38	143	-16	153	-252	150	-56	143
BIM	57	83	64	83	47	90	22	117	78	85	100	102	-136	96	60	84
VMC	-10	79	-2	80	-19	86	-44	114	12	82	34	98	-202	92	-6	81
IPQ	-25	88	-17	88	-35	94	-60	120	-4	90	19	106	-218	100	-22	89
VSL	3	42	11	43	-7	55	-32	92	24	47	46	72	-190	64	6	45
CEM	-25	42	-17	43	-34	55	-59	92	-3	47	19	72	-217	64	-21	45
RISE	-2	35	6	36	-11	49	-36	89	20	40	42	68	-194	59	2	38
BEV	2	44	9	45	-8	56	-33	93	23	49	45	74	-191	65	5	47
MKEH	-11	29	-4	31	-21	46	-46	87	10	36	32	66	-204	56	-8	33
CMI	-16	40	-8	41	-25	53	-50	91	5	45	28	71	-208	62	-12	43

Table 12. Degrees of equivalence between laboratories (no.2).

	x_j		METAS		BoM		SMU		MIRS		AMK		BIM		VMC	
x_i	D_i/x_{ref} × 10^6	$U(D_i/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6	D_{ij}/x_{ref} × 10^6	$U(D_{ij}/)x_{ref}$ × 10^6
INRIM	-8	29	24	107	50	87	10	39	1	54	52	141	-64	83	2	79
CENAM	10	44	41	113	67	93	28	51	18	64	69	145	-47	89	19	86
DMDM	35	87	66	135	92	120	53	91	43	98	94	164	-22	117	44	114
IMBIH	-21	36	11	110	36	90	-3	45	-13	58	38	143	-78	85	-12	82
MBM	-44	66	-12	123	14	105	-25	71	-35	80	16	153	-100	102	-34	98
DPM	193	56	224	118	250	100	211	62	201	72	252	150	136	96	202	92
JV	-4	34	28	109	54	89	15	43	5	57	56	143	-60	84	6	81
METAS	-32	108			26	136	-14	111	-23	117	28	175	-88	133	-22	130
BoM	-58	88	-26	136			-39	91	-49	99	2	164	-114	117	-48	114
SMU	-18	40	14	111	39	91			-10	60	41	144	-75	87	-9	83
MIRS	-9	55	23	117	49	99	10	60			51	149	-65	95	1	91
AMK	-60	142	-28	175	-2	164	-41	144	-51	149			-116	161	-50	159
BIM	57	83	88	133	114	117	75	87	65	95	116	161			66	111
VMC	-10	79	22	130	48	114	9	83	-1	91	50	159	-66	111		
IPQ	-25	88	7	136	33	120	-7	92	-17	99	35	164	-82	117	-15	114
VSL	3	42	35	112	60	92	21	50	11	62	62	145	-54	88	12	84
CEM	-25	42	7	112	33	92	-7	50	-16	62	35	145	-81	88	-15	84
RISE	-2	35	30	109	56	89	16	43	7	57	58	143	-58	85	8	81
BEV	2	44	33	113	59	93	20	51	10	64	61	145	-55	89	11	86
MKEH	-11	29	20	108	46	87	7	39	-3	54	48	142	-68	83	-2	79
CMI	-16	40	16	111	42	91	2	47	-7	60	44	144	-72	87	-6	83

Table 13. Degree of equivalence between laboratories (no.3).

	x_j		IPQ		VSL		CEM		RISE		BEV		MKEH		CMI	
x_i	Di/x_{ref} × 10^6	$U(Di/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6	Dij/x_{ref} × 10^6	$U(Dij/)x_{ref}$ × 10^6
INRIM	-8	29	17	87	-11	41	17	41	-6	34	-9	44	4	28	8	39
CENAM	10	44	35	94	7	53	34	53	11	47	8	55	21	44	25	51
DMDM	35	87	60	120	32	92	59	92	36	89	33	93	46	87	50	91
IMBIH	-21	36	4	90	-24	47	3	47	-20	40	-23	49	-10	36	-5	45
MBM	-44	66	-19	106	-46	72	-19	72	-42	68	-45	74	-32	66	-28	71
DPM	193	56	218	100	190	64	217	64	194	59	191	65	204	56	208	62
JV	-4	34	22	89	-6	45	21	45	-2	38	-5	47	8	33	12	43
METAS	-32	108	-7	136	-35	112	-7	112	-30	109	-33	113	-20	108	-16	111
BoM	-58	88	-33	120	-60	92	-33	92	-56	89	-59	93	-46	87	-42	91
SMU	-18	40	7	92	-21	50	7	50	-16	43	-20	51	-7	39	-2	47
MIRS	-9	55	17	99	-11	62	16	62	-7	57	-10	64	3	54	7	60
AMK	-60	142	-35	164	-62	145	-35	145	-58	143	-61	145	-48	142	-44	144
BIM	57	83	82	117	54	88	81	88	58	85	55	89	68	83	72	87
VMC	-10	79	15	114	-12	84	15	84	-8	81	-11	86	2	79	6	83
IPQ	-25	88			-28	93	0	93	-23	89	-27	94	-14	88	-9	91
VSL	3	42	28	93			27	51	4	46	1	53	14	42	19	49
CEM	-25	42	0	93	-27	51			-23	45	-26	53	-13	42	-9	49
RISE	-2	35	23	89	-4	46	23	45			-3	47	10	34	14	43
BEV	2	44	27	94	-1	53	26	53	3	47			13	44	17	51
MKEH	-11	29	14	88	-14	42	13	42	-10	34	-13	44			4	39
CMI	-16	40	9	91	-19	49	9	49	-14	43	-17	51	-4	39		

11. References

[1] R. Arias et all "BIPM/CIPM key comparison CCM.FF-K4.1.2011. Final report for volume of liquids at 20 L and 100 mL", 2015, Metrologia, 52, 07011.

[2] EURAMET Guide on Comparison, EURAMET Guide No. 4 Version 1.0 (05/2016).

[3] M. G.Cox, The Evaluation of Key Comparison Data, Metrologia, 2002, 39, 589-595.