Instituto Português da Qualidade

GOVERNO DE PORTUGAL | MINISTÉRIO DA ECONOMIA E DO EMPREGO

VSL Dutch Metrology Institute

EURAMET Project no. 1157

Inter-comparison of a 1000 L proving tank

EURAMET European Association of National Metrology Institutes

Final Report

IPQ (Elsa Batista) – Coordinator of the comparison
VSL (Erik Smits) – Pilot and coordinator of the comparison

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Contents

1. Introduction

During the EURAMET TC Flow meeting, held in Scotland in March 2010, it was agreed to start a comparison with a 1000 L proving tank in order to compare results, uncertainties and calibration methods. Both the gravimetric method and the volumetric method were used by several laboratories.

Within EURAMET it is the first time that a comparison is organised in the large volume capacity range. So far there have been only EURAMET comparisons in the µL range, and volumes of 100 mL, 5 L and 20 L. Compared to small volume standards, the calibration of large proving tanks involves a number of circumstances that may vary considerably between the laboratories (type and preparation of water and its actual temperature, control of surrounding air temperature and humidity, practical handling, different surface conditions inside, techniques to read the scale, use of balance or volumetric standards etc.).

The Portuguese and Dutch Metrology Institutes, IPQ and VSL, were the coordinators of this comparison. VSL, acting as the pilot laboratory, performed the initial and final measurements on the 1000 L proving tank.

The project protocol was sent to all the EURAMET TC Flow members and 11 NMIs agreed to participate. During the comparison two other NMIs joined and one withdrew due to customs problems. The circulation of the 1000 L proving tank started in September 2010 and ended in June 2012.
Each NMI had one month to perform the calibration of the 1000 L proving tank. The participants are presented in table 1, in order of participation date.

Table 1 – Participants of the EURAMET Project 1157

NMI	Country	Participation date	Responsible person
VSL	Netherlands	September 2010	Erik Smits
SP	Sweden	October	Per Wennergren
JV	Norway	November	Gunn Svendsen
SMU	Slovakia	December	Miroslava Benkova
MIRS	Slovenia	January 2011	Matjaz Korosec
IPQ	Portugal	February	Elsa Batista
BEV	Austria	March	Michael Matus
EIM	Greece	August	Zoe Metaxiotou
CEM	Spain	November	Nieves Medina
DMDM	Republic of Serbia	February 2012	Branislav Tanasic
BOM	Republic of Macedonia	May 2012	Anastazija Sarevska
LNE	France	August 2012	Paul-André Meury

The same transport company was hired by all the participants but still there were some delays due to all sorts of problems but mainly because of customs issues.
Participants presented a report of their measurements before the end of the comparison according to a spreadsheet supplied by the coordinators of the comparison, Annex 1.

2. The transfer standard

The 1000 L proving tank that was circulated in this comparison is the property of VSL. It has the following characteristics (see figure 1):

- carbon steel construction with a coating on the inside
- 1000 L nominal volume at 20 °C
- double windows (glass plates) in the neck (front and back)
- scale extending from -1% to +1%, scale interval 0,01%, with a length of 225 mm
- approximate mass excluding the transport box: 300 kg
- diameter of main body: 1,35 m
- height including the wheels: 2,40 m
- inner diameter of the neck: 330 mm
- coefficient of cubical thermal expansion of the TS: 0,0000335 °C^{-1}
- RTD (Pt-100) length 300 mm, calibrated by VSL including read-out unit

Figure 1 – proving thank of 1000 L

3. Calibration method

The participating laboratories used their normal calibration method(s)/procedure(s) to determine the volume at the zero graduation mark of 1000 L. The gravimetric method (weighing of water) as well as the volumetric method (filling with water from one proving tank to another) was used, see figure 2.
The measurements were performed at varying room temperature conditions and the results recalculated for a liquid temperature of 20 °C.
The proposed liquid delivering time was about 6 minutes.
After emptying the proving tank the laboratories waited 30 seconds before closing the valve.
In the spreadsheet that was supplied by the coordinators of the comparison, each laboratory described the equipment that was used during the calibration and its traceability.

3.1. Type of calibration method

Both the gravimetric and volumetric method were allowed to be used. Three laboratories used both methods, five laboratories used the volumetric method and four laboratories used the gravimetric method, see table 2.

Table 2 – Used calibration method

NMI	Method
SP	Gravimetric and volumetric
MIRS	Volumetric
IPQ	Gravimetric and volumetric
BEV	Gravimetric and volumetric
EIM	Volumetric
CEM	Volumetric
VSL	Gravimetric
SMU	Gravimetric
DMDM	Volumetric
JV	Gravimetric
BOM	Volumetric
LNE	Gravimetric

3.2. Gravimetric method

The majority of laboratories that performed the calibration of the 1000 L proving tank (PT) with the gravimetric method used the formula described in ISO 4787 [1]:

$$V_{20} = (I_L - I_{E1}) \times \frac{1}{\rho_W - \rho_A} \times \left(1 - \frac{\rho_A}{\rho_B}\right) \times \left[1 - \gamma(t - 20)\right] \tag{1}$$

V_{20} - Volume, at 20 ºC
I_L - Weighing result (or result of the substitution, double substitution or other method of weighing) of the recipient full of liquid
I_E - Weighing result (or result of the substitution, double substitution or other method of weighing) of the empty recipient
ρ_W - Liquid density, in g/mL, at the calibration temperature t
ρ_A - Air density
ρ_B - Density of masses used during measurement (substitution) or during calibration of the balance, assumed to be 8,0 g/mL
γ - Cubic thermal expansion coefficient of the material of the proving tank under calibration
t - Liquid temperature used in the calibration

Some laboratories used their own model and equation.

3.3. Volumetric method

The majority of the laboratories that performed the calibration of the 1000 L proving tank by the volumetric method used the following formula:

$$V_t = V_0\left[1 - \gamma_{RS}(t_{0RS} - t_{RS}) + \beta(t_{PT} - t_{RS}) + \gamma_{PT}(t - t_{PT})\right] \tag{2}$$

V_t - Volume of the proving tank (PT) at t °C
V_0 - Volume of the reference standard (RS) at the reference temperature t_{0RS}
t_{0RS} - Reference temperature of the RS
t - Reference temperature of the PT
t_{RS} - Temperature of the liquid in the RS
t_{PT} - Temperature of the liquid in the PT
γ_{RS} - Coefficient of cubical thermal expansion of the material of the RS
β - Coefficient of cubical thermal expansion of the liquid (water) at the average test temperature: 0,5 (t_{RS} + t_{SCM})
γ_{PT} - Coefficient of cubical thermal expansion of the material of the PT

Some laboratories used their own calibration model and formula.

4. Working conditions and equipment used

4.1. Gravimetric method

4.1.1. Working conditions

The working conditions in the laboratories of each participant using the gravimetric method are described in table 3:

Table 3 – Working conditions of gravimetric method

NMI	Temperature of water t_w °C	Density of water ρ_w kg/L	Air temperature t_a °C	Atmospheric pressure P hPa	Relative humidity RH %
SP	17,668	0,998753	19,83	988,39	33,89
IPQ	17,204	0,999158	19,234	1004,8	55,96
BEV	20,06	0,998323	20,5	1000,6775	29,15
VSL	19,19	0,998695	20,84	1026,29	49,7
SMU	20,55	0,998583	20,16	980,3	49,9
JV	5,87	0,99994	18,6	1011,6	39,7
LNE	20,38	0,998136	20,1	1016	60

One laboratory presented a low value for temperature in comparison to the reference temperature of the proving tank. Nevertheless if the temperature of this quantity of water is controlled and the volume is corrected for the working condition this will not affect the results significantly.

4.1.2. Type of water

The water production method and the formula or method used to determine the density are described in table 4.

Table 4 – Water characteristics of gravimetric method

NMI	Production Method	Density formula (or table)
SP	Regular tap water	PTB-Mitt. 3/90
IPQ	Tap water	Determined by density meter
BEV	Distilled by GFL 2012	Wagenbreth & Blanke
VSL	Tap water stored for in the lab for at least one week	PTB 1990 (Spiweck, Bettin) Density off set calibrated with Anton Paar by direct comparison with double distilled water
SMU	-	-
JV	Tap water direct from the public water system	OIML R49
LNE	Demineralized water by osmosis and resin	Density at 20°C by pycnometer method + density variation with temperature

The water used by the majority of the laboratories is tap water. Corrections were applied for the impurity to the used water density formula in order to have the correct water density.

4.1.3. Mass standards

Some information about the type of mass standards is given in table 5.

Table 5 – Mass characteristics

NMI	Manufacturer	Type	Upper range Value (kg)
SP	Mettler		0,001 to 500
IPQ	FRA	M1	1000
BEV	-	rect. bar	20
VSL	Eegema	-	1000
SMU	-	-	-
JV	Unknown	-	500
LNE	LNE	-	0,001 to 200

The laboratories did not report the OIML class of the mass used [2] in the type column.
Only two laboratories used a mass standard of the same nominal volume as the calibrated proving tank.

4.1.4. Balance

Information about the type of balance is given in table 6:

Table 6 – Balance

NMI	Manufacturer	Type	Upper range Value (kg)	Resolution (kg)
SP	Mettler	XP6002KL	6100	0,01
IPQ	Mettler	KE 1500	1500	0,02
BEV	PEUKO	mechanical comparator	1300	0,002
VSL	Wohwa	40	3500	0,020
SMU	METTLER	KG 6000	6000	0,01
JV	Kambo	-	3150	0,02
LNE	Mettler	KC 600	600	0,0001

The upper range and resolution of the balance is variable and can influence the declared uncertainty.

4.2. Volumetric method

4.2.1. Working conditions during the measurements

The working conditions as mentioned by the participants are described in table 7:

Table 7 – Volumetric method working conditions

NMI	Temperature of water t_w (°C)	Air temperature t_a (°C)	Atmospheric pressure P (hPa)	Relative humidity RH (%)
SP	18,62	20	-	-
MIRS	-	-	-	-
IPQ	16,948	19,96	1009,44	64,4
BEV	19,77	19,7	-	-
EIM	22,70	22,0	1024	53,3
CEM	20,02	20,38	935,97	47,6
DMDM	19,01	21,51	1011,9	43,47
BOM	24,15	25,0	984,3	48,8

The presented values are more or less the same for the different laboratories.
The majority of the laboratories used the PT 100 that was installed in the 1000 L proving tank for the water temperature measurements. The calibration certificate of the probe was supplied by VSL, Annex 2.

4.2.2. Type of water

The majority of the laboratories used tap water. For the volumetric method the water impurity is not an issue for the calculations nor is it an uncertainty source for the results.

4.2.3. Volume standard

Information about the type of volume standard is reported in table 8.

Table 8 – Volume standard

NMI	Manufacturer	Type	Volume (L)	Resolution
SP	Furhoffs Rostfria AB	Overflow	1000	20,3 ml/mm
MIRS	Aleksander Lozar s.p.	Overflow	500	-
IPQ	Atenic	Overflow	500	-
BEV	Pachschwöll	Stripping plate	500	N.A.
EIM	Edelstahlbau Tannroda GmbH	Overflow pipette	200	-
CEM	Vial-Metrologie	Overflow	500	-
DMDM	JUSTING s.r.o., Slovakia	Overflow pipette	500	-
BOM	Edelstahlbau Tannroda GmbH	Ex	500	0,1 L

The majority of the laboratories used a 500 L overflow standard.

5. Measurement results

5.1. Stability of the TS

VSL, acting as the pivot laboratory, made a calibration of the TS at the beginning, the middle and the end of the comparison. The first value was taken as the official result of VSL. The results of the stability measurements are presented in table 9.

Table 9 - Stability of the TS

NMI	Measurement	Date	Volume (L)	Uncertainty (L)	Δ*V* (L)
VSL	**Initial**	September 2010	999,598	0,094	0,041
	Middle	March 2012	999,620	0,092	
	Final	August 2012	999,579	0,099	

The three results obtained by VSL are consistent. The difference in measured volume is considerably smaller than the stated uncertainty. This demonstrates that the TS had a stable volume during the entire comparison.

5.2. Measurement results

The measurement results presented by each participant are collected in table 10.

Table 10 – Volume measurements

	Gravimetric		Volumetric	
NMI	**Volume (L)**	**Uncertainty (L)**	**Volume (L)**	**Uncertainty (L)**
SP	999,700	0,090	999,70	0,13
MIRS			999,83	0,49
IPQ	999,55	0,20	999,70	0,24
BEV	999,705	0,048	999,724	0,063
EIM			999,74	0,19
CEM			999,73	0,21
VSL	999,598	0,094		
SMU	999,64	0,72		
DMDM			999,97	0,28
JV	999,64	0,25		
BOM			999,52	0,26
LNE	999,55	0,10		
Mean value	**999,664**	**0,035**	**999,722**	**0,049**

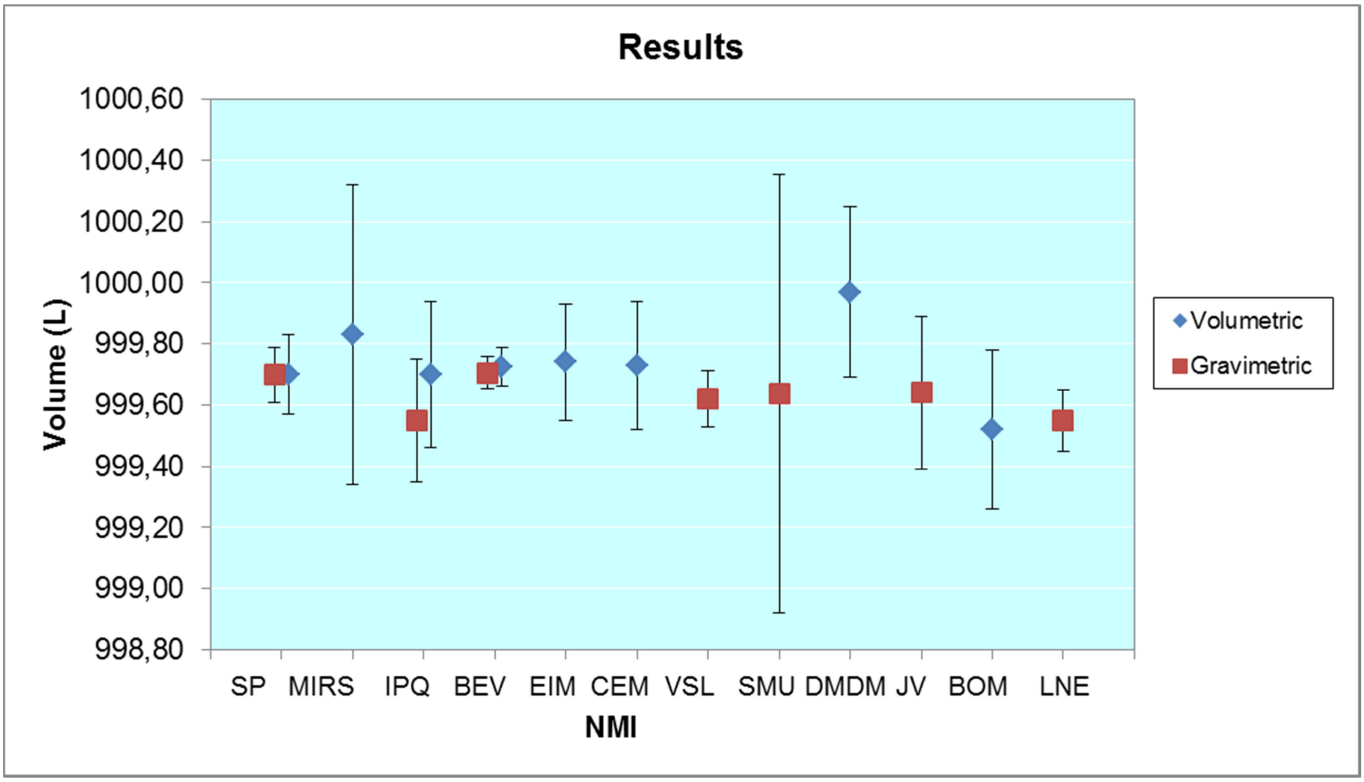

Figure 2 – Volume measurements with error bars representing the laboratory reported uncertainties.

There are a total of 15 measurements of 12 laboratories. For the laboratories that presented both volumetric and gravimetric results only one was used for the determination of the reference value, the one with the lower uncertainty.
A difference between the results from the gravimetric method and the results from volumetric method can be observed. The mean volume of the gravimetric method is 999,664 L and for the volumetric method the mean volume is 999,722 L. From the 3 laboratories that performed both measurements only IPQ observed a similar difference between the results.
The presented uncertainties for the volumetric method are in all cases larger than for the gravimetric method, as expected, because it is a secondary calibration method.

5.3. Determination of the reference value

To determine the reference value of this comparison (RV) the weighted mean (3) was selected, using the inverses of the squares of the associated standard uncertainties as the weighing factors [3], according to the instructions given by the BIPM:

$$y = \frac{x_1/u^2(x_1) + \ldots + x_n/u^2(x_n)}{1/u^2(x_1) + \ldots + 1/u^2(x_n)} \qquad (3)$$

To calculate the standard deviation $u(y)$ associated with the volume y, equation (4) was used:

$$u(y) = \sqrt{\frac{1}{1/u^2(x_1) + \ldots + 1/u^2(x_n)}} \quad (4)$$

The expanded uncertainty of the reference value is $U(y) = 2 \times u(y)$.

To identify an overall consistency of the results a chi-square test can be applied to all n calibration results.

$$\chi^2_{obs} = \frac{(x_1 - y)^2}{u^2(x_1)} + \ldots + \frac{(x_n - y)^2}{u^2(x_n)} \quad (5)$$

where the degrees of freedom are: $\nu = n - 1$

The set of results is inconsistent when: $\Pr\{\chi^2(\nu) > \chi^2_{obs}\} < 0{,}05$. The function *CHIINV(0,05; n-1)* in MS Excel was used. The set of results is rejected when *CHIINV(0,05; n-1)* $< \chi^2_{obs.}$

If the consistency check has a positive result then y is accepted as the RV x_{ref} and $U(x_{ref})$ is accepted as the expanded uncertainty of the RV.
If the set of results appears to be inconsistent then the laboratory with the highest value of $\frac{(x_i - y)^2}{u^2(x_i)}$ is excluded from the next round of evaluation and the new reference value, reference standard uncertainty and observed chi-squared value is calculated again without the excluded laboratory. When the set or results passes the consistency check, the degree of equivalence d_i between each laboratory result x_i and the RV (x_{ref}) is calculated using the following formulas:

$d_i = x_I - x_{ref}$ (6)

$U(d_i) = 2 \times u(d_i)$ (7)

where $u(d_i)$ is calculated from

$u^2(d_i) = u^2(x_i) - u^2(x_{ref})$ (8)

Discrepant values can be identified when $|d_i| > 2u(d_i)$,
To calculate the degrees of equivalence d_{ij} between the laboratories the following formulas are used:

$d_{i,j} = x_i - x_j$ (9)

$U(d_{i,j}) = 2 \times u(d_{i,j})$ (10)

Where $u(d_{i,j})$ is calculated from

$u^2(d_{i,j}) = u^2(x_i) + u^2(x_j)$ (11)

The factor 2 in equation (7 and 10) corresponds to a 95% coverage interval under the assumption of normal distribution of the results.

5.4. Results with reference value and RV uncertainty

The obtained reference value is 999,671 L. The expanded uncertainty $U = 2 \times u(y)$ of the reference value is: 0,033 L.
The calculated value $\chi^2(\nu)$ = 19,67 is larger than χ^2_{obs} = 19,40, the observed value, therefore the set of results is consistent from a statistical point of view and the reference value is accepted.
All the measurement results, the reference value and its uncertainty are presented in the following figure 3:

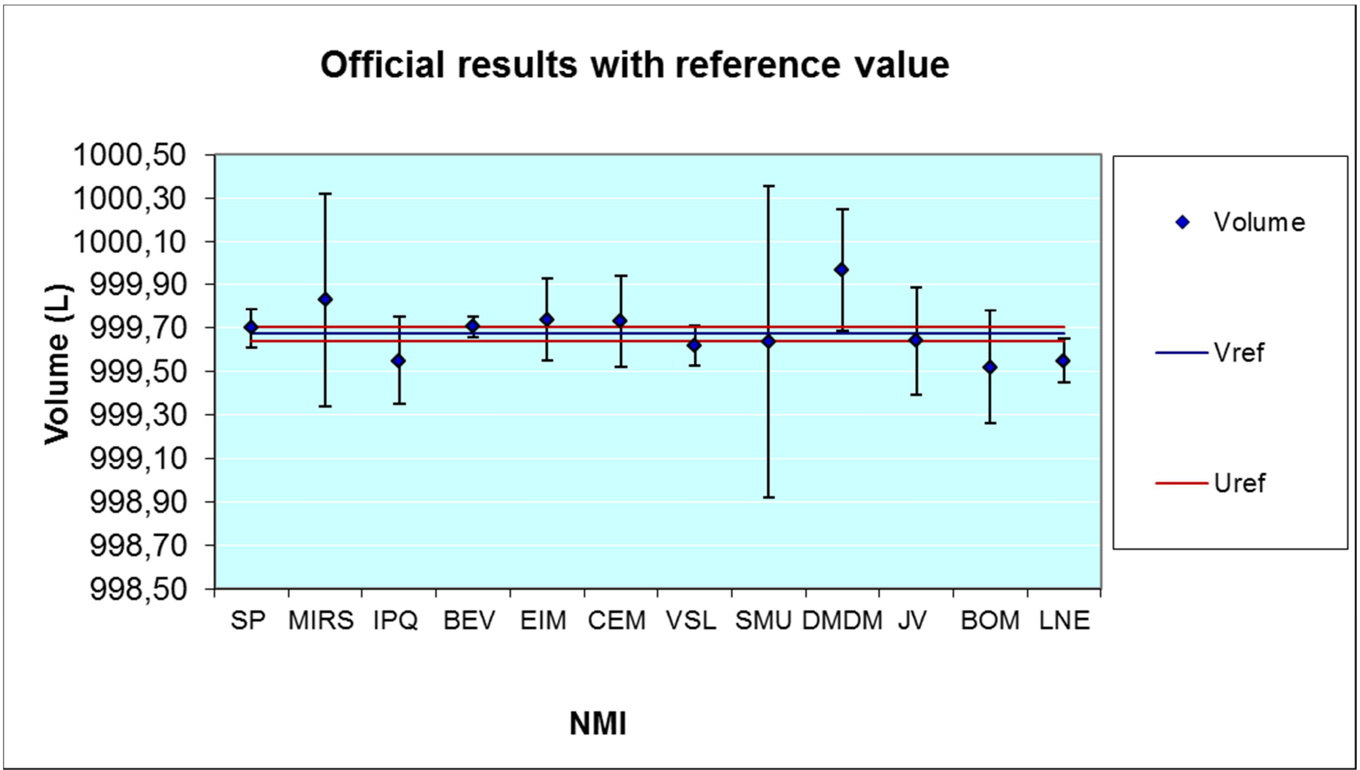

Figure 3 – Reference value and uncertainty

The degree of equivalence with the RV is presented in figure 4:

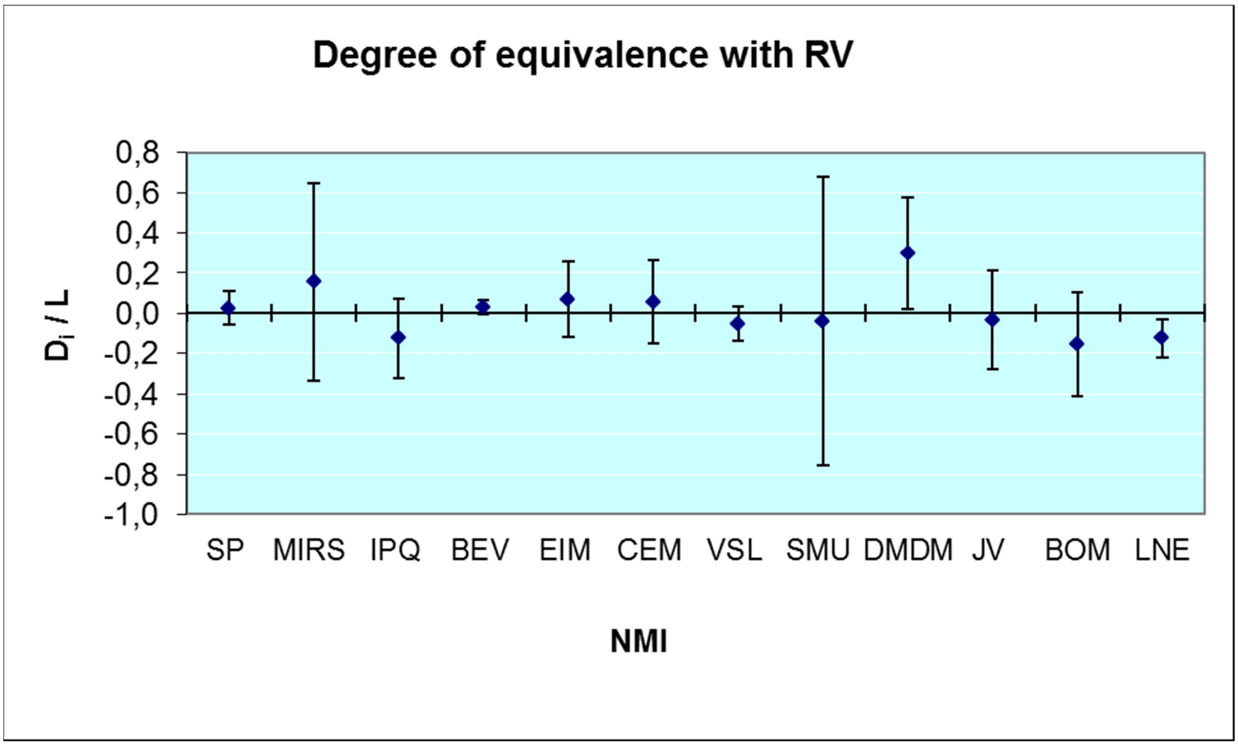

Figure 4 - Degree of equivalence with reference value

Table 11 – Degree of equivalence with RV

NMI	d_i(L)	Ud_i(L)
SP	0,03	0,08
MIRS	0,16	0,49
IPQ	-0,12	0,20
BEV	0,03	0,03
EIM	0,07	0,19
CEM	0,06	0,21
VSL	-0,07	0,09
SMU	-0,03	0,72
DMDM	0,30	0,28
JV	-0,03	0,25
BOM	-0,15	0,26
LNE	-0,12	0,09

There are two laboratories that present slightly discrepant values when compared with the reference value, DMDM and LNE.

The results of the degree of equivalence between all the laboratories can be found in Annex 3.

6. Uncertainty presentation

It was requested that all participants present there uncertainty calculations based on the GUM [4]. Because the used methods are different, so are the uncertainty analyses.

6.1. Gravimetric method

The uncertainty components for each NMI that used the gravimetric method are as follows:

Table 12 – Uncertainty components for gravimetric method

Uncertainty contributions (L)	**NMI**						
	SP	**IPQ**	**BEV**	**VSL**	**SMU**	**JV**	**LNE**
Balance							
Eccentricity Resolution Linearity	0,011	0,100	-	0,024	0,191	0,083	0,027
Weights							
Calibration	0,0043	-	0,000		-	0,0591	-
Density	0,019	0,001	0,000	0,002	0,053	0,0028	
Water density	0,020	0,015	0,012	0,028	0,184	0,001	0,035
Water temperature	0,022	0,000	0,002	0,002	0,179		
Air density	0,001	0,000	0,001	0,002	0,023	0,0007	0,003
Artefact							
Expansion coefficient	0,007	0,004	0,000	0,002	0,000	0,0149	0,006
Meniscus	0,029	0,025	0,023	0,025	0,016	0,05	0,006
Temperature	0,006	-	-		-	0,0004	0,010
Repeatability	0,003	0,010	0,002	0,009	0,150	0,0191	0,007
Others	0,006		0,002	0,013			0,006
Combined Uncertainty (L)	0,045	0,10	0,026	0,047	0,36	0,12	0,05
Expanded uncertainty (L)	0,090	0,20	0,052	0,094	0,72	0,25	0,10

For the majority of the laboratories the largest uncertainty component is the uncertainty of the balance.

SMU has a significantly higher expanded uncertainty then the other NMIs due to the repeatability.

6.2. Volumetric method

The uncertainty components for the volumetric method are as follows:

Table 13 – Uncertainty components for volumetric method

Uncertainty contributions (L)	NMI				
	MIRS	EIM	CEM	DMDM	BOM
Volume standard					
Calibration	0,03656	0,020	0,050	0,050	0,099995
Expansion coefficient	0,01739	0,003	0,001	0,002	0,008575
Water temperature	0,001068	0,001	0,000	0,060	0,030414
Artifact					
Expansion coefficient	$2{,}94\times10^{-7}$	0,001	0,000	0,001	0,005025
Water temperature	0,001193	0,002	0,081	0,070	0,03016
Meniscus	0,01234	0,060		0,087	0,057735
Expansion coefficient of water	0,0015	0,001	0,003	0,001	0,006054
Evaporation	$5{,}77\times10^{-9}$	0,015	0,000	0,029	0,026
Repeatability	0,214	0,047	0,017	0,004	0,002585
Others		0,050	0,036		0,001258
Combined Uncertainty (L)	0,25	0,09	0,10	0,14	0,13
Expanded uncertainty (L)	0,49	0,19	0,21	0,28	0,26

In the volumetric method the components with the largest contribution to the uncertainty are the volume standard calibration and the meniscus reading.
MIRS has a significantly higher expanded uncertainty then the other NMIs due to the repeatability.

7. Conclusions

The results are quite satisfactory. The majority of the laboratories present results that are consistent with the reference value, and with each other. There are two laboratories, DMDM and LNE, that present slightly discrepant values when compared with the reference value.

The presented uncertainties for the volumetric method are in all cases larger that the uncertainties of the gravimetric method, as expected, because it is a secondary calibration method.

8. References

1. ISO 4787-1984; Laboratory glassware – Volumetric glassware – Methods for use and testing of capacity.
2. OIML R111:2004 - Weights of classes E1, E2, F1, F2, M1, M1–2, M2, M2–3 and M3, Part 1: Metrological and technical requirements.
3. M.G. Cox, The evaluation of key comparison data, Metrologia, 2002, Vol. 39, 589-595.
4. JGCM100:2008 - Guide to the expression of uncertainty in measurement (GUM).
5. JCGM200:2012 – International vocabulary of metrology (VIM).

Annex 1 – Spreadsheets

Instituto Português da Qualidade

VSL Dutch Metrology Institute

EURAMET Project "Inter-comparison of 1000 L proving tank "

Data Form Gravimetric Calibration

General Information

Country		Laboratory	
Responsible		Date	

Technical specifications and traceability

Instrument	Manufacturer	Type	Range	Resolution	Calibration date	Traceability
Balance						
Weights						
Ambient air						
Temperature						
Pressure						
Relative Humidity						
Water						
Temperature						

	Production Method	Density formula (or table)
Water density		

Gravimetric used formula

Measurement procedure (short description)

Cleaning procedure

Comments:

Signature:

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EURAMET Project "Inter-comparison of 1000 L proving tank "

Results Form Gravimetric Calibration

surement results

Test	Mass of water m kg	Temperature of water t_w °C	Density of water ρ_w kg/L	Air temperature t_a °C	Atmospheric pressure P hPa	Relative humidity RH %	Density of air ρ_a kg/L	Volume (L)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
							Mean (L)	
							Standard deviation (L)	

Uncertainty budget (example of uncertainty components, not mandatory)

Quantity (x_i)	Value	Distribution	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty $u(y_i)$	Comment/ Explanation
Repetibility measurements						
Mass (kg)						
Air Density (kg/L)						
Water Density (kg/L)						
Density of the mass pieces (kg/L)						
Coefficient of expansion from the tank material ($°C^{-1}$)						
Water temperature (°C)						
Meniscus reading (L)						
Other						
			Combined Uncertainty (L)			
			Degrees of equivalence			
			k			
			Expanded Uncertainty (L)			

Comments:

Signature:

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VSL Dutch Metrology Institute

EURAMET Project "Inter-comparison of 1000 L proving tank "

Data Form Volumetric Calibration

General Information

Country		**Laboratory**	
Responsible		**Date**	

Technical specifications and traceability

Instrument	Manufacturer	Type	Range	Resolution	Calibration date	Traceability
Volume standard						
Ambient						
Temperature						
Pressure						
Relative Humidity						
Water						
Temperature of laboratory volume standard						
Temperature of VSL proving tank						

	Production Method
Water type	

Volumetric used formula

Measurement procedure (short description)

Cleaning procedure

Comments:

Signature:

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EURAMET Project "Inter-comparison of 1000 L proving tank "

Results form volumetric calibration

ısurement results

Test	Temperature of water t_w °C	Air temperature t_a °C	Atmospheric pressure P hPa	Relative humidity RH %	Volume at 20 °C (L)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
				Mean (L)	
				Standard deviation (L)	

Uncertainty budget

Quantity (x_i)	Value	Distribution	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Uncertainty $u(y_i)$	Comment/ Explanation
Repetibility measurements						
Volume standard [L]						
Expansion coeficient of the standard [°C⁻¹]						
Temperature od the standard [°C]						
Expansion coeficient of the waterL [C⁻¹]						
temperature of the proving tank [°C]						
Expansion coeficient of the proving tank [°C⁻¹]						
Meniscus [L]						
Evaporation [L]						
			Combined Uncertainty (L)			
			Degrees of equivalence			
			k			
			Expanded Uncertainty (L)			

Comments:

Signature:

Annex 2 – Calibration Certificate – 1000 L temperature sensor

VSL
Dutch
Metrology
Institute

Certificate

Number: 3243985
Page 1 of 2

Applicant	VSL B.V. Hugo de Grootplein 1 3314 EG DORDRECHT
Item	A digital temperature indicator with a temperature sensor The indicator: Manufacturer : Dostmann Electronics GmbH Type : P650 Range : 0 °C to 30 °C Resolution : 0.01 °C Identification number : 65010031333 (10T24/1218) The identification of the sensor(s) is given with the results on following page(s).
Calibration Procedure	The thermometer has been calibrated by comparison with a standard thermometer in a liquid bath based on the ITS-90. The ambient temperature was (23.0 ± 1.0) °C.
Calibration period	1 October 2012 until 3 October 2012
Result	The results of the calibrations are given on following page(s). The reported uncertainty of measurement is based on the standard uncertainty of measurement multiplied by a coverage factor of $k = 2$, which for a normal distribution corresponds to a coverage propability of approximately 95 %. The standard uncertainty has been determined in accordance with the 'Guide to the Expression of Uncertainty in Measurement' (GUM).
Traceability	The result of the calibration is traceable to primary and/or (inter)national accepted measurement standards.

Delft, 03 October 2012
VSL B.V.

The calibration is carried out by
R. van Breugel

ing. C.K. de Bruin-Barendregt
Allround Metrologist

This certificate is consistent with Calibration and Measurement Capabilities (CMCs) that are included in Appendix C of the Mutual Recognition Arrangement (MRA) drawn up by the International Committee for Weights and Measures (CIPM). Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in Appendix C (for details see http://kcdb.bipm.fr).

CIPM MRA

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This certificate is issued under the provision that no liability is accepted and that the applicant gives warranty for each responsibility against third parties.

VSL
Dutch Metrology Institute

Certificate

Number: 3243985
Page 2 of 2

The sensor connected to channel 1 :

Manufacturer	:	-
Type	:	Pt100
Identification number	:	T015 (10T22/1192)
The immersion depth	:	at least 20 cm

Results

The result of the calibration and the related uncertainty is given here.

By means of regression a relation is determined between the generated temperature (t_{90}) and the indicated temperature (t). The table below contains this relation and the calculated coefficients. The relation is valid over the calibrated range.

$$(t_{90} - t) = \sum_{i=0}^{i=n} a_i \cdot t_{90}^i$$

i	a_i
0	6.1666×10^{-2}
1	-6.6249×10^{-4}

The table below is made using this relation and contains the following data:
1. the temperature t_{90} according to the ITS-90;
2. the indicator value t;
3. the difference t_{90}-t.

t_{90} /°C	t /°C	t_{90}-t /°C
0.00	-0.06	0.06
5.00	4.94	0.06
10.00	9.94	0.06
15.00	14.95	0.05
20.00	19.95	0.05
25.00	24.95	0.05
30.00	29.96	0.04

The uncertainty in the difference t_{90}-t is 0.02 °C.

This uncertainty includes a contribution from the reproducibility of the instrument, calculated using the deviations from the regression.

Annex 3 – Degree of equivalence between the laboratories

	SP		MIRS		IPQ		BEV		EIM		CEM	
SP			0,13	0,50	-0,15	0,22	0,00	0,10	0,04	0,21	0,03	0,23
MIRS	-0,13	0,50			-0,28	0,53	-0,13	0,49	-0,09	0,53	-0,10	0,53
IPQ	0,15	0,22	0,28	0,53			0,16	0,20	0,19	0,28	0,18	0,29
BEV	0,00	0,10	0,13	0,49	-0,16	0,20			0,03	0,19	0,02	0,21
EIM	-0,04	0,21	0,09	0,53	-0,19	0,28	-0,03	0,19			-0,01	0,28
CEM	-0,03	0,23	0,10	0,53	-0,18	0,29	-0,02	0,21	0,01	0,28		
VSL	0,10	0,13	0,23	0,50	-0,05	0,22	0,11	0,10	0,14	0,21	0,13	0,23
SMU	0,06	0,72	0,19	0,87	-0,09	0,74	0,07	0,72	0,10	0,74	0,09	0,75
DMDM	-0,27	0,29	-0,14	0,56	-0,42	0,34	-0,26	0,28	-0,23	0,34	-0,24	0,35
JV	0,06	0,25	0,19	0,54	-0,09	0,30	0,07	0,23	0,10	0,30	0,09	0,31
BOM	0,18	0,28	0,31	0,55	0,03	0,33	0,19	0,26	0,22	0,32	0,21	0,33
LNE	0,13	0,13	0,26	0,50	-0,02	0,22	0,13	0,11	0,17	0,21	0,16	0,23

	VSL		SMU		DMDM		JV		BOM		LNE	
SP	-0,08	0,13	-0,06	0,72	0,27	0,29	-0,06	0,25	-0,18	0,28	-0,13	0,13
MIRS	-0,21	0,50	-0,19	0,87	0,14	0,56	-0,19	0,54	-0,31	0,55	-0,26	0,50
IPQ	0,07	0,22	0,09	0,74	0,42	0,34	0,09	0,30	-0,03	0,33	0,02	0,22
BEV	-0,09	0,10	-0,07	0,72	0,26	0,28	-0,07	0,23	-0,19	0,26	-0,13	0,11
EIM	-0,12	0,21	-0,10	0,74	0,23	0,34	-0,10	0,30	-0,22	0,32	-0,17	0,21
CEM	-0,11	0,23	-0,09	0,75	0,24	0,35	-0,09	0,31	-0,21	0,33	-0,16	0,23
VSL			0,04	0,72	0,37	0,29	0,04	0,25	-0,08	0,28	-0,03	0,14
SMU	-0,02	0,72			0,33	0,77	0,00	0,75	-0,12	0,76	-0,07	0,72
DMDM	-0,35	0,29	-0,33	0,77			-0,33	0,36	-0,45	0,38	-0,40	0,30
JV	-0,02	0,25	0,00	0,75	0,33	0,36			-0,12	0,35	-0,07	0,25
BOM	0,10	0,28	0,12	0,76	0,45	0,38	0,12	0,35			0,05	0,28
LNE	0,05	0,14	0,07	0,72	0,40	0,30	0,07	0,25	-0,05	0,28		

Discrepant values are found in red letters.