



Physikalisch-Technische Bundesanstalt  
National Metrology Institute

# **Supplementary Comparison EURAMET.L-S2.2.n02**

## **Coefficient of thermal expansion of gauge blocks**

### **Technical protocol**

Physikalisch-Technische Bundesanstalt (PTB)

Braunschweig, February 2025

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## 1 Document control

Version Draft A.1	Issued on 06 November 2024.
Version Draft A.2	Issued on 19 December 2024.
Version Draft A.3	Issued on 23 January 2025.
Version Final	Issued on 06 February 2025.

## 2 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

### 2.1 Comparison topic

At its meetings in October 2024, the Consultative Committee for Length (CCL) and EURAMET TC-L decided upon a supplementary comparison on the measurement of the coefficient of thermal expansion of gauge blocks, numbered EURAMET.L-S2.2.n02, with PTB as the pilot laboratory. The comparison was registered in January 2025, and artefact circulation is planned to start in February 2025.

The procedures outlined in this document cover the technical procedure to be followed during the measurements. A goal of the key and supplementary comparisons for topics in dimensional metrology is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts.

By their declared intention to participate in this supplementary comparison, laboratories accept the general instructions and to strictly follow the technical protocol of this document. It is very important that participating NMIs perform their measurements during assigned dates. Participants should keep in mind that the allocated time period is not only for measurements, but transportation and customs clearance as well. Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

### 2.2 Support for CMCs/service categories

The service categories and CMCs supported by this comparison have been determined by reference to the CCL Competence Matrix. Although there is not a one-to-one mapping to service categories, the following principal techniques are tested by this comparison:

thermal expansion correction.

## 3 Organization

### 3.1 Participants

**Table 1.** List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
(Pilot) PTB	Guido Bartl PTB Bundesallee 100 38116 Braunschweig Germany	Tel. +49 531 592 5430 e-mail: Guido.Bartl@ptb.de

BEV	Georg Zechner BEV Arltgasse 35 1160 Wien Österreich	Tel. +43 1 21110-826509 e-mail: Georg.Zechner@bev.gv.at
GUM	Robert Szumski Główny Urząd Miar Elektoralna 2 00-139 Warszawa Poland	Tel. +48 22 581 93 32 e-mail: robert.szumski@gum.gov.pl
JV	Helge Karlsson Justervesenet Fetveien 99 NO-2027 Kjeller Norway	Tel. +47 6484 8446 e-mail: hka@justervesenet.no
MIKES	Antti Lassila VTT MIKES, VTT Technical Research Centre of Finland Ltd Tekniikantie 1 FI-02150 ESPOO Finland	Tel. +358 40 7678584 e-mail: Antti.Lassila@vtt.fi
NIM	Hengzheng Wei National Institute of Metrology, China NO.18 Bei San Huan Dong Lu Chaoyang District Beijing 100029 China	Tel. +86 10 64524931 e-mail: weihz@nim.ac.cn
NMIJ/AIST	Naofumi Yamada NMIJ, AIST Central 3, 1-1-1 Umezono Tsukuba, Ibaraki Japan	Tel. +81 50-3521-1254 e-mail: naofumi-yamada@aist.go.jp
NPL	Andrew Lewis NPL Hampton Road Teddington Middlesex TW11 OLW England	Tel. +44 20 8943 6074 Fax +44 20 8614 0533 e-mail: Andrew.Lewis@npl.co.uk
VSL	Richard Koops VSL Thijsseweg 11 2629 JA Delft Netherlands	Tel. +31 6 31119917 e-mail: rkoops@vsl.nl

### 3.2 Schedule

The participating laboratories were asked to specify a preferred timetable slot for their own measurements of the gauge blocks – the timetable given in table 2 has been drawn up taking these preferences into account. Each laboratory has a time slot that include customs clearance, calibration and transportation to the pilot laboratory and the following participant. With its confirmation to participate, each laboratory is obliged to perform the measurements in the allocated period and to allow enough time in advance for transportation back to the pilot laboratory so that the following participant receives them in time. If a laboratory has technical problems to perform the measurements or customs clearance takes too long, the laboratory has to contact the pilot laboratory as soon as possible and, according to whatever

it decides, it might eventually be obliged to send the standards directly to the next participant before completing the measurements or even without doing any measurements.

**Table 2.** Schedule of the comparison.

<b>RMO</b>	<b>Laboratory</b>	<b>Starting date of measurement time slot</b>
EURAMET	PTB (pilot)	1 February 2025
EURAMET	BEV	1 June 2025
EURAMET	VSL	1 October 2025
EURAMET	JV	1 March 2026
EURAMET	MIKES	1 July 2026
EURAMET	NPL	1 November 2026
APMP	NMIJ/AIST	1 April 2027
APMP	NIM	1 September 2027
EURAMET	GUM	1 January 2028
EURAMET	PTB (pilot)	1 May 2028

### 3.3 Reception, transportation, insurance, costs

A case containing the gauge blocks is used for the transportation of the artefacts (Figure 1). Upon reception of the package, each laboratory has to check that the content is complete and that there is no apparent damage on the box or any of the standards. The reception has to be confirmed immediately to the pilot, preferably using the form of Appendix A.

The organization costs will be covered by the pilot laboratory, which include the standards themselves, the cases and packaging, and the shipping costs to the next laboratory, while each participating laboratory will bear the costs of shipping back to the pilot laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during the circulation.



Figure 1 – Transporting case

Once the measurements have been completed, the package shall be sent to the pilot. The steel gauge blocks need to be protected against corrosion when not being measured by means of protective oil. Please cover them with this product before packing them for transportation or when stocked for more than three days.

Each participating laboratory shall cover the costs of shipping and transport insurance against loss or damage. The package should be shipped with a reliable parcel service of its choice. Once the measurements have been completed, please inform the pilot laboratory when the package leaves your installations indicating all pertinent information. If, at any point during circulation, the package is damaged, it shall be repaired by the laboratory before shipping it again. In the case that a laboratory or its shipping agent damages one or more artefacts, they may be required by the pilot to replace the artefacts at their own cost (or from the insurance).

## 4 Artefacts

### 4.1 Description of artefacts

The package contains four gauge blocks. The gauge blocks are of rectangular cross section and comply with the calibration grade K of the standard ISO 3650. Note: the gauge blocks were selected for good quality of the faces and small variation in length, the limit deviation  $t_e$  from nominal length may not be met by some of the artefacts.

The coefficients of thermal expansion given in the following table are obtained by the manufacturers and should be used as such. Following a decision by the former WGDM (now CCL WG-MRA) a pre-determination of this important artefact parameter is not to be communicated to the participants.

**Table 3.** List of artefacts.

Material	Identification	Nominal length / mm	Expansion coefficient / $10^{-6} \text{ K}^{-1}$	Manufacturer
steel	6315	100	11.5	Frank
ceramics	10770	100	9.3	KOBA
ceramics	960347	60	9.3	Mitutoyo
steel	144	1000	11.0	Frank

## 5 Measuring instructions

### 5.1 Handling the artefact

The gauge blocks should only be handled by authorized persons and stored in such a way as to prevent damage. Before making the measurements, the gauge blocks need to be checked to verify that their measuring surfaces are not damaged and do not present severe scratches and/or rust that may affect the measurement result. The condition of the blocks before measurement should be registered in the form provided in appendix B. Laboratories should attempt to measure all gauge blocks unless doing so would damage their equipment. If a gauge block will not wring readily, the participant shall inform the pilot about this problem, stating the respective gauge block and face. No participant shall try to re-finish measuring faces by burring, lapping, stoning, or whatsoever. The measurement of the face concerned or the complete gauge block shall be omitted.

Measurements may only be performed using equipment normally used to offer the relevant CMC service. In case of multiple CMC services in this area, only the service/equipment with the smallest uncertainty should be used, unless the pilot and other participants agree to allow additional instruments to be used; in which case, only the results of the instrument/service with the smallest uncertainty may contribute to the comparison reference value (CRV). No other measurements are to be attempted by the participants and the gauge blocks should not be used for any purpose other than described in this document. The gauge blocks may not be given to any party other than the participants in the comparison.

The gauge blocks should be examined before despatch and any change in condition during the measurement at each laboratory should be communicated to the pilot laboratory. After the

measurements, the gauge blocks must be cleaned and greased. Ensure that the content of the package is complete before shipment. Always use the original packaging.

## 5.2 Traceability

Length measurements should be traceable to the latest realisation of the metre as set out in the current “*Mise en Pratique*”. Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

## 5.3 Measurands

The gauge blocks shall be measured based on the standard procedure that the laboratory regularly uses for this calibration service for its customers. The “A” surface is the marked measuring face for gauge blocks with nominal length < 6 mm and the right hand measuring face for gauge blocks with a nominal length ≥ 6 mm, respectively (see Figure 2).

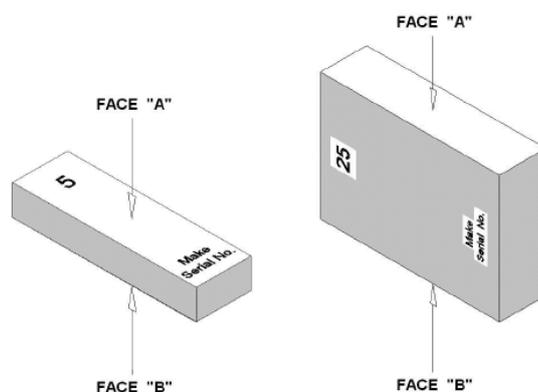


Figure 2 – Nomenclature of faces

The measurand to be reported in this comparison is the coefficient of thermal expansion of gauge blocks around room temperature (here: reference temperature 20 °C). It is determined from measurements of change in length and temperature of the gauge block.

From the measurement result of length and temperature, for example, the average linear coefficient of thermal expansion  $\alpha$  can be obtained by the equation

$$\alpha(T_{ave}) = \frac{1}{L_0} \cdot \frac{L(T_2) - L(T_1)}{T_2 - T_1}; \quad T_{ave} = \frac{T_1 + T_2}{2},$$

where  $L(T_2) - L(T_1)$  and  $T_2 - T_1$  are the length change and the temperature change for a gauge block, respectively. The thermal expansion coefficient,  $\alpha(T_{ave})$ , is the average linear coefficient of thermal expansion in the temperature range from  $T_1$  to  $T_2$  and  $L_0$  is the length of the gauge block at 20 °C. The value of  $\alpha$  at any arbitrary temperature in the measurement temperature range can also be determined by curve fitting on measurement data.

The targeted measurement temperature range is from 18 °C to 22 °C. In particular, the temperature at which the coefficient of thermal expansion is to be reported is 20 °C.

## 5.4 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the ISO *Guide to the Expression of Uncertainty in Measurement*. The participating laboratories are encouraged to use their usual model for the uncertainty calculation.

All measurement uncertainties shall be stated as standard uncertainties. The corresponding effective degree of freedom should be stated by the participants. If none is given,  $\infty$  is assumed. For efficient evaluation and subsequent assessment of CMC claims an uncertainty statement in the functional form according to Appendix C is preferred, if available.

Additionally, in the report of the measurement technique (Appendix D) the participants should list any relevant CMC claims for the service(s) related to the comparison.

## 5.5 Optical phase change and roughness correction

The position of the plane where light is reflected on a surface is depending mainly on the material and surface finish. As the free measuring face of the gauge block under measurement and the platen where it is wrung are in general different in both characteristics, this difference varies.

As the current comparison does not cover the absolute length of the artefacts as a measurand, the application of these corrections should be omitted or, formally more correct, is expected to be considered as correlated contributions in the evaluation of the coefficient of thermal expansion.

## 5.6 Reference condition

Measurement results should be reported for the reference conditions as set down in the standard ISO 3650.

# 6 Reporting of results

## 6.1 Results and standard uncertainties as reported by participants

As soon as possible after measurements have been completed, the results should be communicated to the pilot laboratory **within six weeks** at the latest.

The measurement report forms in appendix C of this document will be sent by e-mail (Word document) to all participating laboratories. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the pilot. In any case, the signed report must also be sent in paper form by mail or electronically as a scanned pdf document. In case of any differences, the signed forms are considered to be the definitive version.

When reporting the results of the comparison, each participant should also report the identifier, range and uncertainty of any existing CMC related to the comparison. This will be used by the pilot when checking whether or not CMC claims are supported by the comparison results.

In the case that the measurement uncertainty reported by a participant in a comparison is significantly higher than the relevant CMC claim, this should be explained at the time of submitting the results (e.g. air conditioning failure at time of measurements, damage on artefacts affecting measurements).

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare within 3 months a first draft A.1 report on the comparison. This will be circulated to the participants for comments, additions and corrections.

# 7 Analysis of results

## 7.1 Calculation of the comparison reference value

The comparison reference value (CRV) is calculated on a gauge-per-gauge basis as the weighted mean of the participant results. The check for consistency of the comparison results with their associated uncertainties will be made according to the guidance in [B Eves 2024 'Formal guidance for acceptance

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criteria on KC supporting CMCs' WGMRA-24-08.01; see also: A Lewis and T Coveney 2024 WG-MRA Meeting No 15, Section 8.1 'Formal guidance for acceptance criteria on KC supporting CMCs'; B J Eves and I D Leroux 2024 Proposed Guidance for the Initial Assessment of CCL Comparisons with Several Measurands (in prep.)). If necessary, artefact instability, correlations between institutes, and the necessity for linking to another comparison will be taken into account.

## 7.2 Artefact instability

Steel gauge blocks occasionally show a growing or a shrinkage the rate of which is approximately linear with time. Since the artefacts used here are of unknown history, the instability of the gauge blocks will be determined in course of the comparison even though the measurand (coefficient of thermal expansion) is not expected to be affected in the same way as the absolute length would be. For this check the measurements of the pilot laboratory are used exclusively, not that of the other participants. Using these data a linear regression line is fitted and the slope together with its uncertainty is determined (per gauge block).

Three cases can be foreseen:

- a) The linear regression line is an acceptable drift model and the absolute drift is smaller than its uncertainty. The gauge block is considered stable and no modification to the standard evaluation procedure will be applied. In fact, the results of the pilot's stability measurements will not influence the numerical results in any way.
- b) The linear regression line is an acceptable drift model and the absolute drift is larger than its uncertainty, i.e. there is a significant drift for the gauge block. In this case an analysis similar to [Nien F Z *et al.* 2004, Statistical analysis of key comparisons with linear trends, *Metrologia* **41**, 231] will be followed. The pilot influences the CRV by the slope of the drift only, not by the measured absolute lengths.
- c) The data are not compatible at all with a linear drift, regarding the uncertainties of the pilot's measurements. In this case the artefact is unpredictably unstable or the pilot has problems with its measurements. TC-L has to determine the further approach.

## 7.3 Correlation between laboratories

Since the topic of this project is the comparison of primary measurements, correlations between the results of different NMIs are unlikely.

## 7.4 Linking of result to other comparisons

The CCL task group on linking CCL TG-L will set guidelines for linking this comparison to any other key comparison within CCL for the same measurement quantity.

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## Appendix A – Reception of Standards

To:	Physikalisch-Technische Bundesanstalt Dr. Guido Bartl  Bundesallee 100, 38116 Braunschweig, Germany  e-mail: guido.bartl@ptb.de		
From:	NMI: .....	Name: .....	
	Signature: .....	Date: .....	

We confirm having received the gauge blocks for the EURAMET.L-S2.2.n02 on the date given above.

After a visual inspection:

- There are no apparent damages; their precise state will be reported in the form provided in Annex B/C once inspected in the laboratory along with the measurement results.
  
- We have detected severe damages putting the measurement results at risk. Please indicate the damages, specifying every detail and, if possible, include photos. If it is necessary, use additional sheets to report it.

## Appendix B – Conditions of Measuring Faces

To:	Physikalisch-Technische Bundesanstalt Dr. Guido Bartl  Bundesallee 100, 38116 Braunschweig, Germany  e-mail: guido.bartl@ptb.de		
From:	NMI: .....	Name: .....	
	Signature: .....	Date: .....	

After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.).

gauge blocks		face		Comments:		Comments:
	Ident. number	A	B		A	B
	$l_n$	6315	10770		100 mm	100 mm
		100 mm			100 mm	
		face		Comments:		Comments:
Ident. number	A	B		A	B	
$l_n$	960347	144		60 mm	1000 mm	
	60 mm			1000 mm		

## Appendix C – Results Report Form

To:	Physikalisch-Technische Bundesanstalt Dr. Guido Bartl  Bundesallee 100, 38116 Braunschweig, Germany  e-mail: guido.bartl@ptb.de		
From:	NMI: .....	Name: .....	
	Signature: .....	Date: .....	

### Results of the measurand

gauge blocks				
$l_n$ / mm	Ident. number	$\alpha$ / $10^{-6}$ K <sup>-1</sup>	$u(\alpha)$ / $10^{-6}$ K <sup>-1</sup>	$\nu_{\text{eff}}$
100	6315	20 °C:		
100	10770	20 °C:		
60	960347	20 °C:		
1000	144	20 °C:		

### Functional form of standard uncertainty (if available)

example:  $u(\alpha) = Q[a, b \cdot l_n] = \sqrt{a^2 + (b \cdot l_n)^2}$

Gauge block	Functional form	Comment

## Appendix D – Description of the measurement instrument

To:	Physikalisch-Technische Bundesanstalt Dr. Guido Bartl  Bundesallee 100, 38116 Braunschweig, Germany  e-mail: guido.bartl@ptb.de		
From:	NMI: .....	Name: .....	
	Signature: .....	Date: .....	

Make and type of instrument(s) .....

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Light sources / wavelengths used or traceability path: .....

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Description of measuring technique (including any corrections): .....

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Range of gauge block temperature during measurements & description of temperature measurement method:.....

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Relevant 95 % CMC uncertainty claim for the service(s) related to this comparison topic (if existing) and identifier of the CMC.....

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If the reported uncertainty is significantly higher than that of the related CMC, explanation for the increased uncertainty .....

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(use additional pages as needed)