EMRP SIB 52 Thermo

Workpackage 2

Deliverable D2.3.2: Protocol for the Round-Robin type inter-comparison in D2.3.2

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Jiyu Wu (NPL, jiyu.wu@npl.co.uk)

TECHNICAL PROTOCOL OF EURAMET. T-XX:

SUPLEMENTARY COMPARISONS OF HIGH TEMPERATURE THERMAL CONDUCTIVITY MEASUREMENT STANDARDS FOR INSULATION FROM 50°C TO 650°C – THE ROUND-ROBIN INTERCOMPARISON IN THE EMRP THERMO PROJECT D2.3.2

Organizer : **EURAMET**

Technical Committee for Thermometry (TCT)

Working Group for Thermophysical Quantities

Pilot Lab : **National Physical Laboratory (NPL)**

Coordinator : **Dr. Jiyu Wu**

E-mail : **Jiyu.wu@npl.co.uk**

Address : **National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, U.K.**

Tel : **+44-20-8943-6045**

Fax : **+44-20-8943-6458**

1. INTRODUCTION

The objective of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2 is to compare the National Standard Guarded Hot Plates and a High Temperature Thermal Conductivity Measurement Apparatus (HTTCMA at MKEH) using at least one insulation reference material up to 650°C. The target is equivalence to no worse than 5%. In addition, to further improve the existing National Standard instruments, particularly in terms of uncertainty, the target for which is 5%. The effect of contact resistance on thermal conductivity measurements will also be evaluated in the inter-comparison.

This protocol describes the sample description, measurement procedures using High-Temperature Guarded Hot-Plates (HTGHP) and a High-Temperature Thermal Conductivity Measurement Apparatus (HTTCMA), data reporting and data analysis method for the supplementary comparison.

2. PARTICIPANTS AND EQUIPMENT

Participants of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2: NPL (LTGHP and HTGHP), LNE (in-house build HTGHP), CMI (HTGHP) and MKEH (HTTCMA). PTB is responsible for independently collecting the test results from each participant and the data analysis, however, PTB does not participating in thermal conductivity measurements. All participants are NMIs in Europe and agree to share the measurement results for analysis. The participant information and their equipment are listed in Table 1.

Table 1 (a) Participant Information

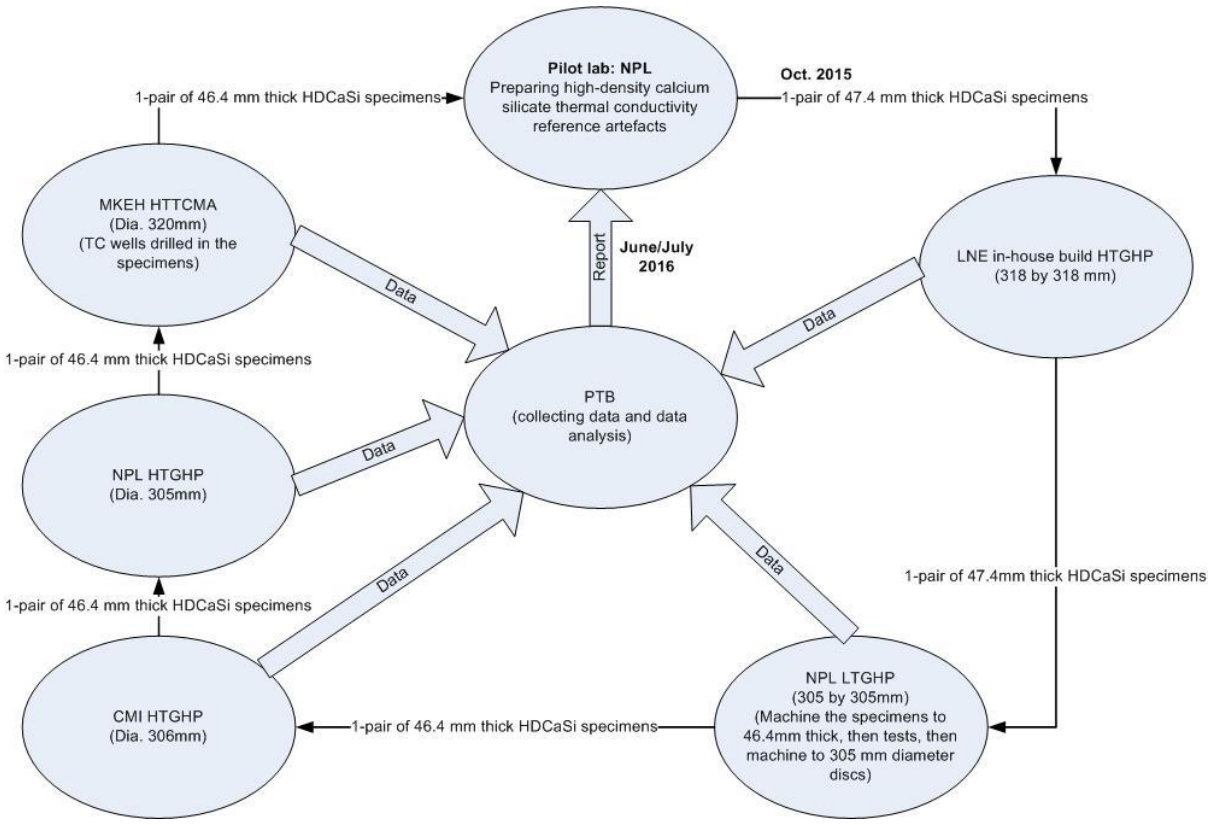
No.	Laboratory	Country	Contact Person	Remark
1	National Physical Laboratory (NPL)	United Kingdom	Jiyu Wu Jiyu.wu@npl.co.uk	NMI
2	Laboratoire National de Métrologie et d'Essais (LNE)	France	Hameury Jacques Jacques.Hameury@lne.fr	NMI
3	Český metrologický institut (CMI)	Czech Republic	Ales Blahut ablahut@cmi.cz	NMI
4	Magyar Kereskedelmi Engedelyezesi Hivatal (MKEH)	Hungary	Emese TURZO-ANDRAS thurzo-a@mkeh.hu	NMI
5	Physikalisch-Technische Bundesanstalt (PTB)	Germany	Ulf Hammerschmidt Ulf.Hammerschmidt@ptb.de	NMI

Laboratory	**NPL**	**NPL**	**LNE**	**CMI**	**MKEH**
Name of the equipment	**LTGHP**	**HTGHP**	**HTGHP**	**HTGHP**	**HTTCMA**
GHP and HTTCMA type	Double	Single	Single & Double	Single & Double	Double
Heater plate lateral dimension (mm)	305 × 305	305 (in dia.)	318 × 318	306 (in dia.)	320 (in dia.)
Metering area (mm)	152.5 × 152.5	150 (in dia.)	152 × 152	150 (in dia.)	200 (in dia.)
Mean temperature (°C)	-170 to 150	140 to 800	30 to 800	50 to 850	70 to 850
Specimen thickness (mm)	25 to 60	25 to 60	10 to 50	18 to 60	20 to 60
Thermal conductivity (W/(m·K))	<0.15	0.02 to 0.2 (0.5)	0.1 to 2	0.02 to 1	0.02 to 5

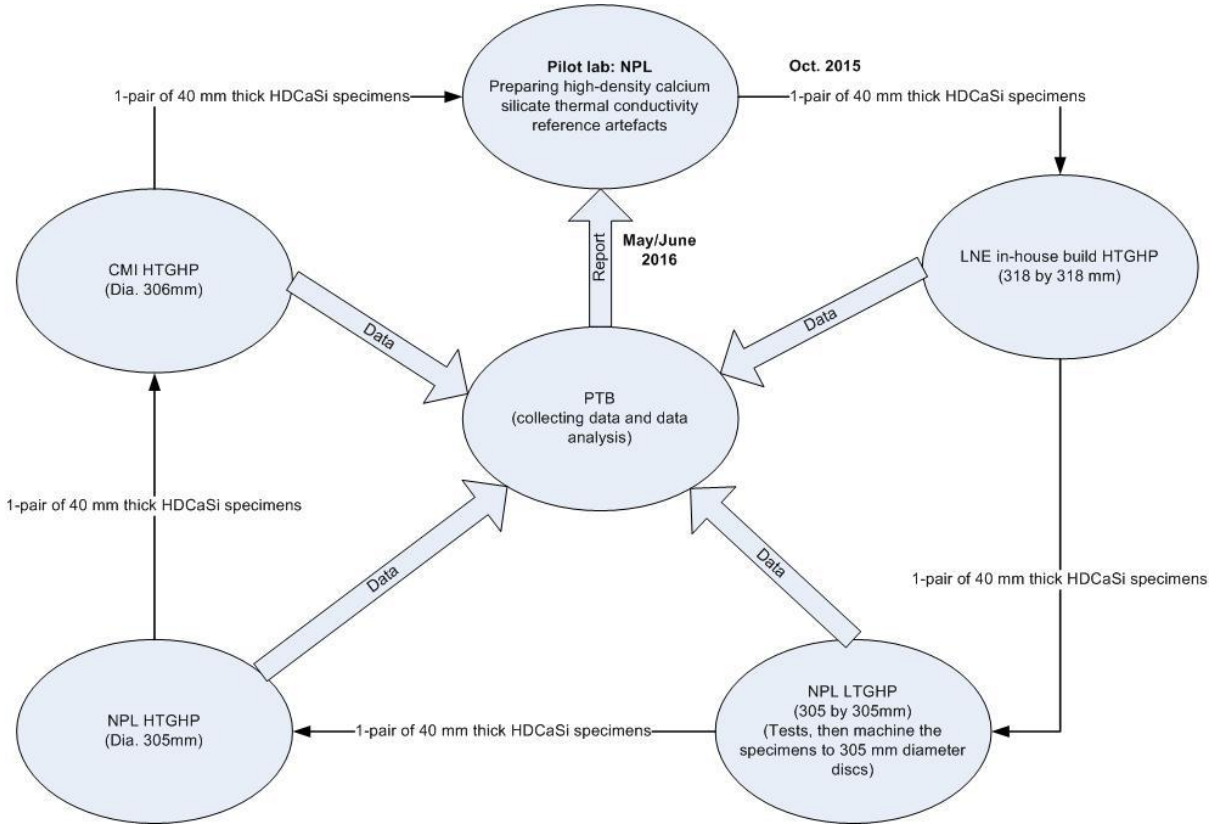
Table 1 (b) The main features of the equipment in each laboratory

3. COMPARISON SCHEDULE

The sequence of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2 is shown in Fig.1. The thermal conductivity measurements using the HTTCMA at MKEH require machining of thermocouple holes in the specimens and also require specimen thickness from 46 mm to 50 mm for the current setup. Therefore, only the pair of high density calcium silicate with thickness 46.4 mm will be sent to MKEH for measurements.



(a)



(b)

Fig. 1 The sequence of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2. (a) for the pair of specimens with thickness 46.4 mm; and (b) for the pair of specimens with thickness 40.0 mm.

Please see the Table 2 for the detailed schedule of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2.

Table 2 The detailed schedule of the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2.

HDCaSi	46.4 mm							
HDCaSi	40 mm							
Year	Month	Week	Week number	LNE In-house HTGHP	NPL LTGHP	NPL HTGHP	CMI HTGHP	MKEH HTTCMA
2015	Oct	40	1	HD 47.4 mm				
		41	2					
		42	3					
		43	4					
		44	5					
	Nov	45	6					
		46	7	47.4mm from LNE to NPL				
		47	8					
		48	9		Re-Machined to 46.4mm			
	Dec	49	10	HD 40mm				
		50	11					
		51	12					
		52	13	Holidays				
2016	Jan.	1	14					
		2	15	40mm from LNE to NPL				
		3	16					
		4	17		HD 46.4 mm			
		5	18					
	Feb	6	19		HD 40mm			
		7	20			Machine to 305 disc, 46.4 mm		
		8	21					
		9	22			Machine to 305 disc, 40mm	46.4mm from NPL to CMI	
	March	10	23			environmental chamber repair		
		11	24			HD 40mm	**HD 46.4mm**	
		12	25					
		13	26					
		14	27				46.4mm from CMI to NPL	
	April	15	28					
		16	29					
		17	30			**HD 46.4 mm**	40mm from NPL to CMI	
		18	31				HD 40 mm	
	May	19	32					
		20	33					
		21	34				40mm from CMI to NPL	
		22	35					
	June	23	36			46.4mm from NPL to MKEH		
		24	37					
		25	38					HD46.4 mm
		26	39					
		27	40					

4. METHOD

The thermal conductivity measurements will be carried out using a Guarded Hot Plate apparatus according to ISO 8302, EN12667 or EN/TS 15548-1 test methods or a High Temperature Thermal Conductivity Measurement Apparatus. The HTGHPs have been designed to ensure the establishment of one-dimensional uniform steady-state heat flux within the metering/measurement zone of the apparatus. However, the thermal conductivity measurements at MKEH will be carried out using a High-Temperature Thermal Conductivity Measurement Apparatus (HTTCMA). The design of the HTTCMA has been based on a two-dimesional axi-symetric steady-state heat transfer model.

5. DESCRIPTION OF THE SAMPLES

5.1 Materials

High Density Calcium Silicate Boards

Nominal bulk density: 800 to 816 $kg \cdot m^{-3}$

Nominal thickness: 47 mm for one pair of specimens and 40 mm for another pair of specimens

Nominal thermal conductivity: 0.2 $W \cdot m^{-1} \cdot K^{-1}$ at mean temperature of 20 °C

5.2 Selection of specimens

One of the insulation manufacturers in UK have supplied 8-off high density calcium silicate boards consecutively from one batch of their product. These boards have been cut into 77-off specimens. All of the specimens have been heat treated at 850°C for 24 hours, then machined flat by a subcontractor in Hungary (arranged by MKEH). NPL has carried out a four-stage selection process and there are 15-off HDCaSi-N14 specimens that have passed the selection process and hence been selected for inter-comparisons and further characterisations. The four-stage selection process is:

(1) Select the specimens that meet the criteria of bulk density variation within +/-1 % and the density band has the maximum number of specimens based on the density, thickness and flatness measurements at MKEH.

↓

(2) Select the specimens based on the confirmation tests at NPL on those within the 800 $kg \cdot m^{-3}$ to 816 $kg \cdot m^{-3}$ density band. The tests include bulk density, thickness and flatness measurements.

↓

(3) Acoustic non-destructive density mapping of each specimen at NPL on the specimens that passed stage 2. Select the ones with density mapping showing variation:

- For specimens with 500mm by 500mm lateral dimensions – the density vary within +/-1% for all 25 points measured at the centre of each grid (100mm by 100mm).
- For specimens with 500mm by 500mm lateral dimensions – the density vary within +/-1% for the centre 300mm by 300mm area and the average density in the surrounding area agree with the average density in the centre area within +/-1%.
- For specimens with 320mm by 320mm lateral dimensions – the density vary within +/-1% for all 9 points measured at the centre of each grid (100mm by 100mm).

↓

(4) Thermal conductivity measurements at NPL on specimens that passed all the three stage selection. Select those with thermal conductivity varying within +/- 1 % at 20°C.

The details of the 15-off selected specimens are shown in Table 2:

Table 2 Details of the 15-off selected specimens

Specimen No.	Variation of measured thermal conductivity at 20°C	Density	Density variation	Owner
	(λ -λ_ave)*100/λ_ave (%)	kg/m3	(%)	
30635 0014 BL1	-0.3	811.8	0.2	RR
30635 0014 BLM 3	0.7	811.3	0.1	FIW
30635 0014 BLM 4	-0.6	805.5	-0.6	RR
30635 0015 CRM8	0.1	814.2	0.5	backup
30635 0016 DL 2	0.7	814.5	0.5	FIW
30635 0018 FLM4	-0.6	814.1	0.4	RR
30635 0019 GRM 9	0.5	812.4	0.2	LNE commercial
30635 0019 GR11	-0.5	803.3	-0.9	RR
30635 0020 HL2	0.4	815.2	0.6	LNE in house
30635 0020 HLM3	0.3	810.2	0.0	MKEH HFM
30635 0021 L5	0.1	808.4	-0.3	NPL HT
30635 0021 LLM7	0.1	810.5	0.0	MKEH HTTCMA
30635 0021 LM7	-0.6	812.8	0.3	PTB
30635 0021 RM5	-0.2	809.7	-0.1	CMI
30635 0021 RRM7	0.0	803.3	-0.9	NPL LT
colour coding				
Use 500 by 500 mm	lateral diamension: 500 by 500mm and can use the whole 500 by 500 mm			
Use 320 by 320 mm	lateral diamension: 320 by 320 mm and can use the whole 320 by 320 mm			
Use centre 320 by 320 mm only	lateral diamension: 500 by 500mm and can only use the centre 320 by 320 mm			
At position A1 (edge) no visable cracks but high values. can only use center 320 by 320mm.				

Specimens for the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2 are shown in Table 3:

Table 3 Details of the 5-off specimens for the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2.

Specimen No.	RR specimen No.	Density ($kg \cdot m^{-3}$)	λ variation (%)	ρ variation (%)	Preparation
30635 0014 BLM4	**3**	805.5	-0.6	-0.6	Cut the central 318 by 318mm from 500 by 500mm board supplied (see the cutting plan in Fig. 2); Thickness 47.4 mm +/-0.1 mm; Flatness within 0.05mm; parallelism within 0.05mm.
30635 0019 GR11	**4**	803.3	-0.5	-0.9	Cut the central 318 by 318mm from 500 by 500mm board supplied (see the cutting plan in Fig. 2); Thickness 47.4 mm +/-0.1 mm; Flatness within 0.05mm; parallelism within 0.05mm.
30635 0014 BL1	**2**	811.8	-0.3	0.2	Cut the central 318 by 318mm from 500 by 500mm board supplied (see the cutting plan in Fig.2); Thickness 40.0 mm +/-0.1 mm; Flatness within 0.05mm; parallelism within 0.05mm.
30635 0018 FLM4	**1**	814.1	-0.6	0.4	Cut the central 318 by 318mm from 500 by 500mm board supplied (see the cutting plan in Fig.2); Thickness 40.0 mm +/-0.1 mm; Flatness within 0.05mm; parallelism within 0.05mm.
30635 0015 CRM8		814.2	0.1	0.5	Backup specimen

5.3 Specimen cutting plan

The 4-off specimens for the Round-Robin inter-comparison in the EMRP Thermo project D2.3.2 have been machined according to the cutting plan shown in Fig. 2.

The 318mm by 318mm specimens consist of 4 strips + 4 triangle shaped corners + central octagon area;

The 305mm by 305mm specimens consist of 4 triangle shaped corners + central octagon area;

The round specimens with 305mm diameter will be cut from the centre octagon area.

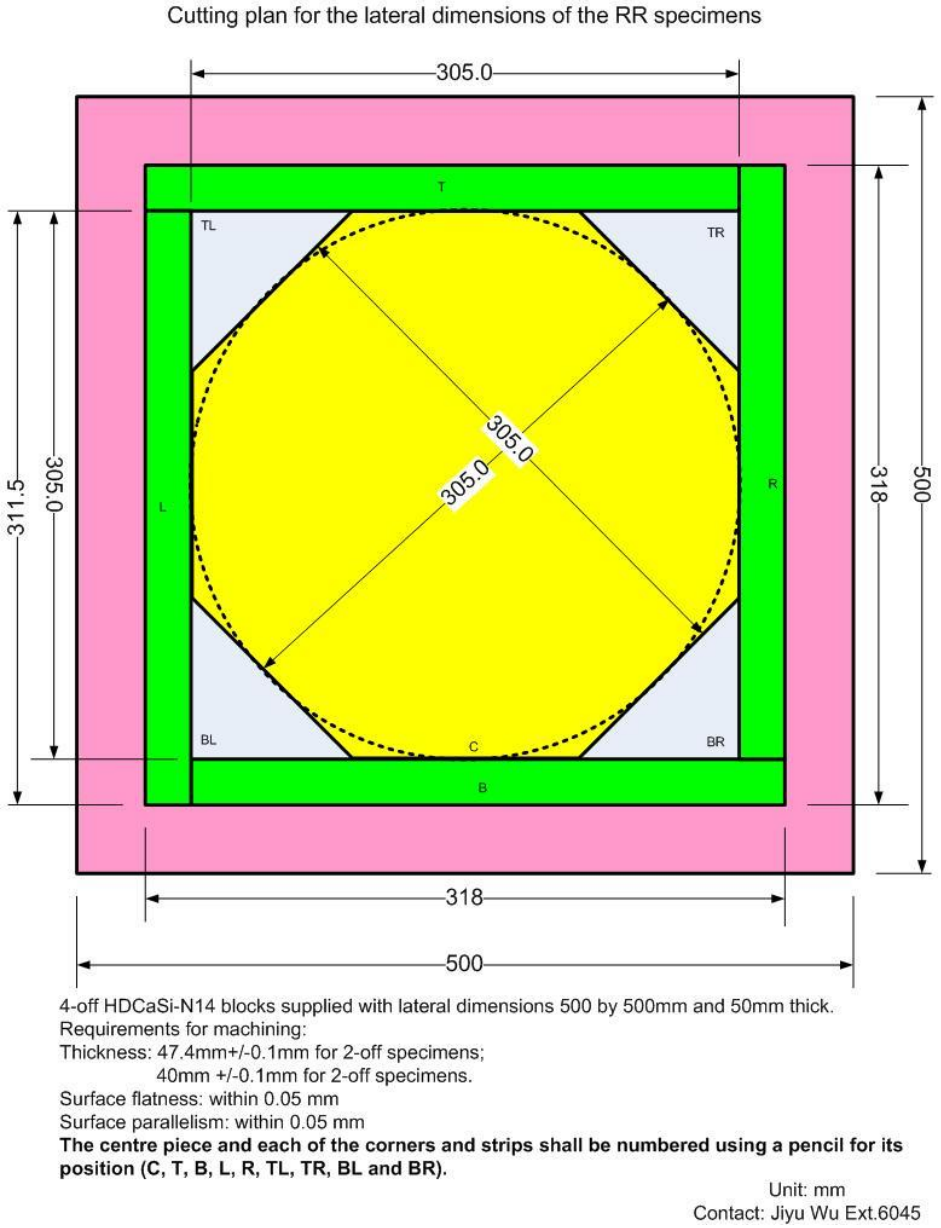


Fig. 2 Cutting plan for the specimens that will be used for the Round-Robin inter-comparison the EMRP Thermo project D2.3.2 (the locations of each corner and strip shall be labelled)

5.4 The prediction of the bowing of specimens

The differential thermal expansion at the cold face and the hot face of a rigid solid specimen will cause it to bow towards the cold face.

The thermal expansion coefficient of HDCaSi-N14 at the in-plane direction is 7.1×10^{-6} °C^{-1}
The thermal expansion coefficient of HDCaSi-N14 at the through direction is 7.4×10^{-6} °C^{-1}

The predicted bowing of high density calcium silicate specimens in each apparatus is shown in Table 4. (note: the temperature of the heated-cold plate is 775°C.)

Table 4 The predicted bowing of the HDCaSi specimens in each apparatus participating the Round-Robin inter-comparison.

Apparatus	LNE in-house HTGHP	NPL LTGHP	NPL HTGHP	CMI HTGHP	MKEH HTTCMA
Lateral dimensions of heater plates (mm)	318 by 318	305 by 305	Dia. 305	Dia. 306	Dia. 320
Metering area (mm)	150 by 150	152.5 by 152.5	Dia. 150	Dia. 150	Dia. 200
Radius for specimen discs or half the longest length of the centre octagon area (see Fig.2)(mm)	165.06	165.06	152.5	152.5 (Specimen 305mm dia.)	152.5 (Specimen 305mm dia.)
Specimen thickness of the 1st set (mm)	47.4	46.4	46.4	46.4	46.4
Temperature drop of the 1st set of specimens (K)	50	20	50	50	50
Specimen bowing for the 1st set of specimens(mm)	0.102	0.042	0.089	0.089	0.089 (Specimen 305mm dia.)
Specimen thickness of the 2nd set (mm)	40	40	40	40	40
Temperature drop of the 2nd set of specimens (K)	40	20	40	40	40
Specimen bowing for the 2nd set of specimens(mm)	0.097	0.048	0.083	0.083	0.083 (Specimen 305mm dia.)

6 MEASUREMENT PROCEDURE AND REPORTING

6.1 Inspection upon receiving the RR specimens

The Round-robin specimens will be transferred in individual specimen box. To protect the specimens, each piece of the specimen will be carefully packed and placed in the specimen box which is lined with two layers of thick protecting foams – one layer of rigid foam and another layer of soft foam for shock absorption.

Unpon receiving the RR specimen, please carefully unpack all specimens. Visual check the conditions of each specimen, take photos and report any damage, discolouring and if each piece is labelled correctly and clearly. Send a visual check report to all partners ASAP.

6.2 Reporting data sheet

Participants shall complete the electronic data sheet "EMRP Thermo WP2 RR_D2.3.2.xlsx" by entering data in the "Apparatus" workbook tabs.

6.3 Measurement procedure

Participants determine the specimen characteristics before and after each run according to their internal laboratory protocols following the guidelines below:

- Prior to installing the specimen(s) into the GHPs or HTTCMA, condition the specimen(s) at 23°C ± 1°C, 50% RH ± 10 % RH for 24 h.
- After conditioning, determine the lateral dimensions (diameter or total length and total width), thickness, flatness and mass of each specimen.
- After conditioning, determine the bulk density (ρ) of each specimen.
- Use the example in Annex A as instruction for installing the Round-Robin specimens in HTGHPs or HTTCMA. The example in Annex A is for installing RR specimens in the LNE in-house build HTGHP. **Record the locations of each piece when installing the specimen(s) into the apparatus.**
- Participants conduct thermal conductivity measurements using HTGHP or HTTCMA on each (for single side apparatus) or each pair (for double side apparatus) of the four specimens supplied. Tests shall be carried out by the same operator in each participating institute. For details of the thermal conductivity measurements please see Sections 6.4 and 6.5.
- **It is likely the pencil marks will disappear after the HTGHP tests. Therefore, after the tests in the HTGHP, please use a pencil to re-mark the specimen number and locations before taking them out of the apparatus.**
- After completing the thermal conductivity measurements in the GHPs or HTTCMA, remove the specimen(s) from the apparatus and condition the specimens at 23°C ± 1°C, 50% RH ± 10 % RH for 24 h.
- Repeat the dimensional and mass measurements (above) and re-compute the bulk density.
- Complete the "Specimens" tab in the electronic data sheet "EMRP Thermo WP2 RR_D2.3.2.xlsx" (the up to date version is available on Thermo Share Point).

Important: Each participant (except MKEH as the last lab doing thermal conductivity measurements in the Round-Robin inter-comparison) shall not machine any surface grooves on the Round-Robin specimens or thermocouple holes in the Round-Robin specimens.

6.4 Test conditions for thermal conductivity measurements

Participants conduct thermal conductivity measurements using HTGHP or HTTCMA on each (for single side apparatus) or each pair (for double side apparatus) of the four specimens supplied. The specimens are made of candidate reference material HDCaSi-N14 being developed in the EMRP Thermo project. Tests shall be carried out by the same operator in each participating institute.

The nominal test conditions are summarised in Table 5. The exceptions are that: (1) the temperature points for the NPL LTGHP will be 50 (optional), 100 and 150 °C, and the temperature drop across a specimen is 20 K; (2) the NPL HTGHP and CMI HTGHP will use 30 K temperature drops at 150°C mean specimen temperature.

Table 5 Nominal test conditions for thermal conductivity measurements

Mean Specimens temperature Tm (°C)	Specimen thickness (mm)	Temperature drop across specimen ΔT (K)	No. of runs	Notes
50*	46.4 or 47.4 for LNE	50 or 20 (NPL LTGHP)	1	*optional
150	46.4 or 47.4 for LNE	50 or 20 (NPL LTGHP) or 30 (NPL HTGHP and CMI HTGHP)	1	
250	46.4	50	1	
350	46.4	50	1	
450	46.4	50	1	
550	46.4	50	1	
650	46.4	50	1	
50*	40	40 or 20 (NPL LTGHP)	1	* optional
150	40	40 or 20 (NPL LTGHP), or 30 (NPL HTGHP and CMI HTGHP)	1	
250	40	40	1	

350	40	40	1	
450	40	40	1	
550	40	40	1	
650	40	40	1	

6.5 Thermal conductivity measurements

Participants determine the thermal conductivity of the specimen(s) according to their internal laboratory protocols following the guidelines below:

- Use the same operator in each institute to carry out the thermal conductivity measurements on the RR specimens.
- SPECIMEN THICKNESS: The specimen thickness shall be corrected for thermal expansion effects of the material. The thermal expansion data of the candidate reference material HDCaSi-N14 will be provided separately. Report the in-situ thickness if they are measured.
- THERMAL CONDUCTIVITY MEASUREMENTS: The thermal conductivity measurements are conducted at nominal test conditions specified in Table 5 in ascending order (i.e., from lowest to highest value of T_m) for each specimen or each pair of specimens. The measurements in GHPs are performed according to ISO 8302, EN12667 or EN/TS 15548-1 test methods. The measurements in HTTCMA are performed based on 2-D Axi-symmetric heat transfer model.
- In addition, please also report the temperature imbalance between both sides of the centre-guard gap in the main heater plate, plate flatness and temperature uniformity of the surfaces of the heater plates in contact with specimen(s).
- Complete the “Measurements” tab of electronic data sheet “EMRP Thermo WP2 RR_D2.3.2.xlsx”

6.6 Packing and dispatch of specimens

- After completing the tests on the RR specimens, please take photos of each piece and each specimen before packing.
- Carefully packing each piece of the specimens and place them into each of the specimen boxes. Pack to the standard no worse than when you receive the specimens.
- Label clearly as fragile items for dispatch.
- Send all partners a packing and dispatch report ASAP, including photos and note any damage, discolouring and other anomalies.

7 REPORTING MEASUREMENT DATA

- PTB, as a party not involved in the thermal conductivity measurements in the Round-Robin inter-comparison, is responsible for collecting the measurement results from each participant of the Round-Robin inter-comparison, and make sure all required information are reported. PTB may contact each participant separately in order to clarify the information they reported.

- All participants of the Round-Robin inter-comparison send measurement results to PTB. No discussion on the measurement results is allowed among participants, until all data are reported for the pair of specimen and PTB announce the start of the discussion.
- Please note that the date for completing the tests on the pair of 40 mm thick specimens is expected to be at the end of May 2016 (data from LNE, NPL and CMI); and the date for completing the tests on the pair of 46.4 mm thick specimens is expected to be at the end of June 2016 to also include MKEH.

8 ANALYSIS OF MEASUREMENT RESULTS

The results of this comparison will be analysed by PTB and discussed among all the participants. PTB will send a report on the data analysis to the pilot lab NPL. The results of this comparison will be published only after agreement of all participants of the Round-Robin and PTB.

8.1 Data Input

1) Each individual data set consists of the measured thermal conductivities $\lambda(\vartheta_i)$ at the mean temperatures ϑ_i of 50 (optional), 150, 250, 350, 450, 550 and 650 °C and the expanded uncertainty $\mathrm{ku_c}(\lambda)$ for $k = 2$. The uncertainty may depend on temperature. One should strictly follow the ISO GUM and
2) give a full description of how the measurand $\lambda(\vartheta_i)$ is defined;
3) for each mean temperature ϑ_i state the result of the measurement as $\Lambda(\vartheta_i) = \lambda(\vartheta_i) \pm U$ and give the units of λ, ϑ and U;
4) include the relative expanded uncertainty $U/|\lambda|$, $|\lambda| \neq 0$;
5) give both k and $\mathrm{u_c}(\lambda)$;
6) give the approximate level of confidence associated with the interval $\lambda \pm U$ and state how it was determined;
7) give the information as outlined in section 7.2.7 of ISO GUM.
8) The Round-Robin inter-comparison should be performed under consideration of DIN EN ISO/IEC 17043, 17025, and DIN ISO 5725-1.
9) If any of the thermal conductivity measurement is carried out in a condition deviating from the measurement standards (ISO 8302, EN12667 or EN/TS 15548-1), then the participant shall include the description(s) of the deviation(s) in the report of the data. If any correction have been made for the deviation, then please also include the details of the correction(s) in addition to the original data.
10) In addition to participating in the Round-Robin comparison, all the National Standard apparatus are also participating in a Star-Shape comparison using the HDCaSi-N14 reference specimens assigned to each participant (see Table 2). In the Star-shape intercomparison, each National Standard apparatus is used to measure the thermal conductivity of an independent set of HDCaSi-14 specimens (see Annex 2 for the cutting plan of the star-shape comparison specimens) from 50 or 150 up to 650°C – the same temperature points as shown in Table 5). The tests are repeated independently twice. The total number of tests on each

(pair of) specimens assigned to each participant is three. **The three sets of data reported in the Star-Shape intercomparison for each National Standard apparatus (see Table 1b) will also be used in the data analysis.**

8.2 Procedure

1) In case of deviations of the actual mean temperature(s) from the recommended one(s) the data set $\lambda(\vartheta_i)$ will be approximated by a cubic spline function. Then the thermal conductivities at the recommended temperatures will be interpolated.

2) The comparison reference value (CRV) for the thermal conductivity λ_{ref} and its associated uncertainty $\mathrm{ku_c}(\lambda_{\mathrm{ref}})$ are calculated by the weighted mean method according to Eqs. (1) and (2) from all N data sets for each working temperature and each specimen thickness separately.

$$\lambda_{ref} = \sum_{i=1}^{N} \frac{\lambda_i}{{u_i}^2} \cdot \frac{1}{\sum_{i=1}^{N} \frac{1}{{u_i}^2}} \tag{1}$$

$$U_{95\%}(\lambda_{ref}) = k \cdot u_c(\lambda_{ref}) = 2 \cdot \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{{u_i}^2}}} \tag{2}$$

Here, λ_{i} denotes the measurement result for the thermal conductivity of participant i, $\mathrm{u_i}$ the associated standard measurement uncertainty, and $k = 2$ the coverage factor for 95 % confidence.

3) The degree of equivalence of each participant i is determined by the difference from the CRV

$$d_i = \lambda_i - \lambda_{ref} \,. \tag{3}$$

The associated expanded uncertainty with a coverage factor $k = 2$ for 95 % confidence is defined as

$$U_{95\%}(d_i) = k \cdot u_c(d_i) = 2 \cdot \sqrt{u^2(\lambda_i) - u^2\left(\lambda_{ref}\right)} \,. \tag{4}$$

9 COLLECTING SPECIMENS USED IN THE ROUND-ROBIN

At the end of the inter-comparison, MKEH and CMI will return the Round-Robin specimens back to NPL. NPL is responsible for collecting the Round-Robin specimens. These Round-Robin specimens may be used at NPL for checking measurements.

ACKNOWLEDGEMENTS

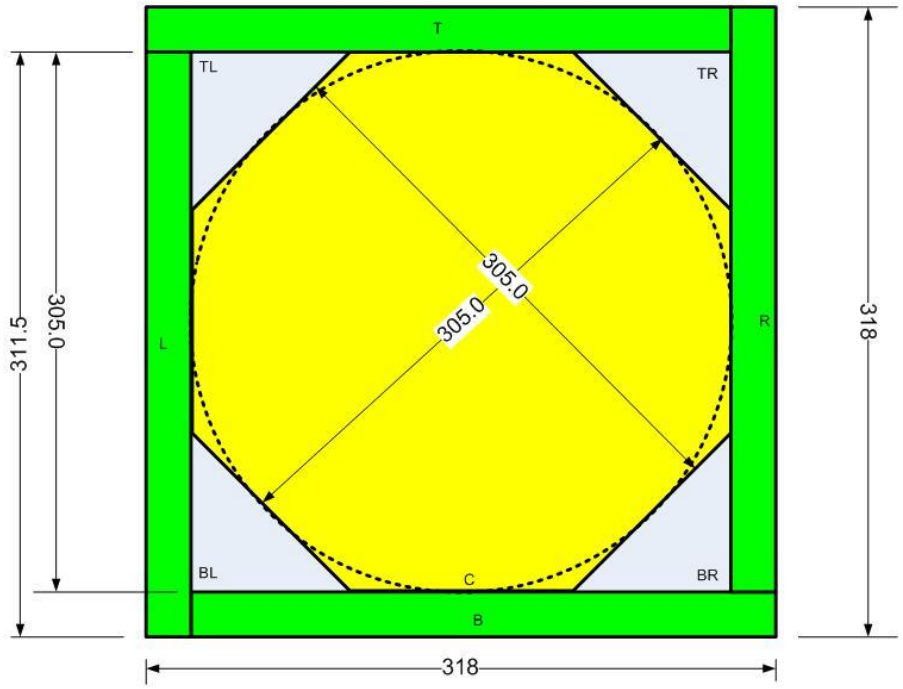
The reporting Spreadsheet of the Round-Robin intercomparison has been mainly based on the spreadsheet used in the bi-lateral comparison of GHPs between the National Institute of Standards and Technology (NIST), United States and the National Physical Laboratory (NPL), United Kingdom. The NIST-NPL bi-lateral comparison is led by NIST. The coordinator would like to take the opportunity to thank the colleague at NIST, Robert Zarr for sharing the reporting spreadsheet with colleagues involved in the Round-Robin inter-comparison.

Annex 1

EMRP Thermo WP2 Instruction for installing the Round-Robin specimens in the LNE in-house build HTGHP

1. There are 4-off HDCaSi-N14 round-robin specimens supplied each consists 9 pieces.
   Thickness: 47.4 mm for 2-off specimens (No. 3 & 4);
   40.0 mm for 2-off specimens (No. 1 & 2).
2. The centre piece and each of the corners and strips have been numbered using a pencil for its position (C, T, B, L, R, TL, TR, BL and BR). The numbers "1", "2", "3" and "4" are round-robin specimen numbers. The side with pencil marks is the top side.
3. Each round-robin specimen need to be assembled into a 318mm by 318mm specimen according to the Figure 1.
4. **Record the locations of each piece when installing the specimen(s) into the HTGHP.**
5. **It is likely the pencil marks will disappear after the HTGHP tests. Therefore, after the tests in the HTGHP, please use a pencil to re-mark the specimen number and locations before taking them out of the apparatus.**

EMRP Thermo WP2 D2.3.2 Round Robin using HDCaSi-N14
Assembly of the RR specimens in LNE in-house build HTGHP



Unit: mm

1. There are 4-off HDCaSi-N14 round-robin specimens supplied each consists 9 pieces.
Thickness: 47.4 mm for 2-off specimens (No. 3 & 4);
40.0 mm for 2-off specimens (No. 1 & 2).
2. The centre piece and each of the corners and strips have been numbered using a pencil for its position (C, T, B, L, R, TL, TR, BL and BR). The numbers "1", "2", "3" and "4" are round-robin specimen numbers. The side with pencil marks is the top side.
3. Each round-robin specimen need to be assembled into a 318mm by 318mm specimen according to the Figure above.
4. Record the locations of each piece when installing the specimen(s) into the HTGHP.
5. It is likely the pencil marks will disappear after the HTGHP tests. Therefore, after the tests in the HTGHP, please use a pencil to re-mark the specimen number and locations before taking them out of the apparatus.

Annex 2

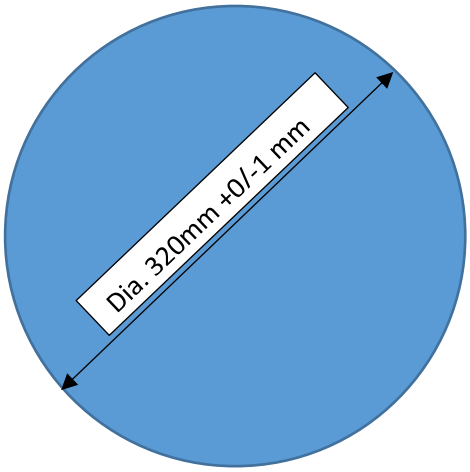
EMRP Thermo Star-shape comparison: Specimen cutting plan for HDCaSi-N14

The **HDCaSi specimens for the Star-shape type inter-comparison** in D3.2.1 will be machined according to the cutting plan specified below.

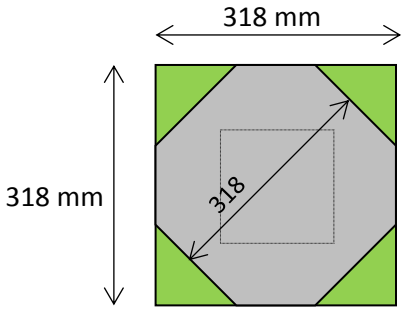
The thickness of each specimen is 48.0 +/- 0.1 mm;
Surface flatness of each specimen within 0.05 mm;
Surface parallelism of each specimen within 0.05mm.

The lateral dimensions & tolerances of each specimen:

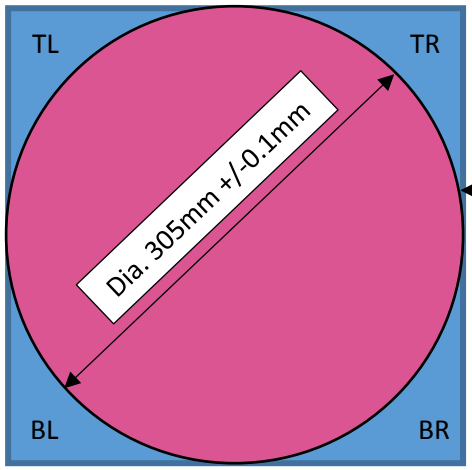
For MKEH HTTCMA:



For LNE in-house built HTGHP (318 x 318 mm, metering section = 152 x 152 mm)**:**



For NPL:
LTGHP (305 by 305mm square)
HTGHP (305mm diameter)



The tips of the 4-off corner pieces will be missing

For CMI in-house build HTGHP: