Supplementary Comparison COOMET.M.P-S4
of gas absolute pressure standards up to 2 MPa, gauge and 7 MPa

Final Report

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Abstract:

This report describes the results of a successful two-phase interlaboratory comparison between Georgian National Agency for Standards and Metrology (GeoSTM), Czech Metrology Institute (CMI) and Slovak Metrology Institute (SMU) denoted as COOMET.M.P-S4. The ranges of the absolute pressure from 0 MPa to 7 MPa and gauge pressure from 0 MPa to 2 MPa were chosen as the most suitable for a mutual comparison. A digital pressure gauge, DHI RPM4 served as a transfer standard in both phases.

Firstly, bilateral interlaboratory comparison (BILC) between two participants, CMI (pilot and reference laboratory) and GeoSTM, started in March 2017 and finished in April 2017. Secondly, interlaboratory comparison (ILC) between three participants, CMI (pilot and reference laboratory), SMU (co-reference laboratory) and GeoSTM, started in October 2018 and finished in February 2019. SMU took part only in the absolute pressure comparison.

PATTERN OF THE COMPARISON

This report describes the results of interlaboratory comparison between Czech Metrology Institute (CMI), Slovak Metrology Institute (SMU) and Georgian National Agency for Standards and Metrology (GeoSTM) in pressure in gas medium denoted as COOMET.M.P-S4. It was carried out to demonstrate the metrological and technical competence, as well as the equivalence of the pressure standards of the Pressure calibration laboratory of GeoSTM with those of CMI and SMU. The ranges of the absolute pressure from 0 MPa to 7 MPa and gauge pressure from 0 MPa to 2 MPa were chosen as the most suitable for a mutual comparison. A digital pressure gauge, Fluke/DHI RPM4, provided by CMI served as a transfer standard for both ranges in all the comparison measurements.

Firstly, a bilateral interlaboratory comparison (BILC) between CMI (pilot and reference laboratory) and GeoSTM was performed from March 2017 to April 2017 within an ILC program of CMI under the EN ISO/IEC 17043:2010 Conformity assessment - General requirements for proficiency testing. That time CMI and GeoSTM had independent traceability and GeoSTM staff performed their measurements in their own premises.

Secondly, GeoSTM asked CMI for a new comparison in the same ranges, because of their new traceability. However, because the new traceability of GeoSTM is to CMI, SMU volunteered to provide a co-reference, but for the schedule restrictions only in the absolute mode. Hence, a follower interlaboratory comparison (ILC) was performed between the participants, CMI (pilot and reference laboratory), SMU (co-reference laboratory) and GeoSTM, from October 2018 to February 2019. Since the same transfer standard was used in the BILC and ILC, its adjustment was changed by CMI between these two comparisons. In the ILC, the laboratory standards of GeoSTM were transported to the CMI and used to calibrate the transfer standard by GeoSTM-staff in the laboratories of CMI. SMU did their measurements in their own premises. GeoSTM laboratory standards are traceable to CMI, and the laboratory standards of the CMI and the SMU have independent traceability.

PARTICIPANTS OF THE COMPARISON

Pilot (reference) laboratory of BILC and ILC

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Participating laboratory of BILC and ILC

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Co-reference laboratory of ILC

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Contact person:	*Ing. Miroslav Chytil*

STANDARDS OF THE COMPARISON

Transfer-standard

Test item: Digital manometer
Manufacturer: DHI
Type: RPM4 A7Ms/A2Ms
Serial number: 184
Range: (0 ÷ 7) MPa absolute; (0 ÷ 2) MPa gauge
Test item owner: CMI, Regional Inspectorate Brno

Laboratory standard of GeoSTM pressure laboratory for 2 MPa, gauge

Type: Digital manometer
Manufacturer: GE Druck
Type: DPI611-13G
Serial №: 3309387
Measuring range: (-0.1 ÷ 2) MPa
Traceability BILC: to Druck Standards Laboratory
Traceability ILC: to CMI
Uncertainty BILC: 0.0003 MPa
Uncertainty ILC: 0.00053 MPa

Laboratory standard of GeoSTM pressure laboratory for 7 MPa, absolute

Type: Digital manometer
Manufacturer: GE Druck
Type: DPI620/PM620
Serial №: 10246352
Measuring range: (0 ÷ 7) MPa
Traceability BILC: to Druck Standards Laboratory
Uncertainty BILC: 0.0007 MPa
Traceability ILC: to CMI
Uncertainty ILC: 0.0018 MPa

Type: Digital barometer
Manufacturer: GE Druck
Serial: PACE1000
Serial №: 10322769
Measuring range: (0.075 ÷ 0.115) MPa
Traceability BILC: to Druck Standards Laboratory
Uncertainty BILC: 0.00001 MPa
Traceability: to CMI
Uncertainty: 0.00001 MPa

Reference standard of CMI pressure laboratory

Type: Piston Gauge
Manufacturer: DH Instruments
Type: PG 7601
Serial №: 0230 (piston-cylinder) / 2189 (mass set) / 127 (stand)
Measuring range: (0.1 ÷ 7.6) MPa, gauge and absolute
Traceability: The reference standard is primary and participated in: EUROMET.M.P.K3a [1], EURAMET.M.P.K8 [2], EUROMET.M.P-S1 [3], EUROMET.M.P-S8 [4] and EURAMET.M.P-S9 [5,6].
Uncertainty: 0.2 Pa + $10^{-5} \cdot p$ + $2 \cdot 10^{-13} \cdot p^2$, gauge, 0.3 Pa + $1.1 \cdot 10^{-5} \cdot p$ + $2 \cdot 10^{-13} \cdot p^2$, absolute, p in Pa, CMCs in the KCDB

Co-reference standard of SMU pressure laboratory

Type: Piston Gauge
Manufacturer: SMU
Type: MPZ
Serial №: A03
Measuring range: (0.02 ÷ 20) MPa, gauge and absolute
Traceability: The reference standard is primary and participated in comparison EURAMET.M.P-K1.c in 2012.
Uncertainty: $2.8 \cdot 10^{-5} \cdot p$, p in Pa

DESCRIPTION OF THE BILC

Time schedule of comparison measurements

Measurements were performed in the scheme CMI – GeoSTM – CMI. The transfer standard was measured at CMI on the 27th and the 28th March 2017. It was transported to GeoSTM and measured there from the 4th till the 6th April 2017. The second measurement at CMI was performed on the 12th and the 20th April 2017. Both laboratories used laboratory standards of different types and of the independent traceability. Transportation of the transfer standard from CMI to GeoSTM and back was performed by CMI staff as an airplane cabin baggage.

Documents with the GeoSTM measurement results

Calibration Certificate №: GE/MI06-00582-17 and GE/MI06-00583-17

Date of issue: 01.06.2017

Measurement procedure: Internal calibration procedure № GE/MI06LP-5.4-06

Documents with the CMI measurement results

Calibration Certificate №: 6013-KL-C0197-17, 6013-KL-C0198-17, 6013-KL-C0251-17 and 6013-KL-C0252-17

Date of issue: 27.03.2017, 28.03.2017, 12.04.2017 and 20.04.2017

Measurement procedure: Internal calibration procedure № 601-MP-C046

Measurement results and uncertainties

In each laboratory, measurements were performed at usual laboratory conditions. Both laboratories measured three series, each in loading and unloading. The following absolute pressure points were used: (0.14; 0.5; 1.0; 1.5; 2.0; 3.0; 4.0; 5.0; 6.0; 7.0) MPa. And these gauge pressure points were used: (0; 0.2; 0.4; 0.6; 0.8; 1.0; 1.2; 1.4; 1.6; 1.8; 2.0) MPa. The pressure medium was dry air. The results had to be stated in the mentioned above calibration certificates. The calibration certificates had to be issued according to principles of EN ISO IEC 17025. The measurement result had to be delivered with associated measurement uncertainties U_{lab} and U_{ref} stated according to EA-4/02 document preferably. All uncertainties in this document are expanded uncertainties for $k = 2$.

The results for 7 MPa range can be seen from Tab. 1a to Tab. 3a. The results for 2 MPa range can be seen from Tab. 1b to Tab. 3b.

Tab. 1a: Results of the participating laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{lab}	x_{lab}	U_{lab}	P_{con}	P_{lab}	x_{lab}	U_{lab}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.14150	0.14138	-0.00012	0.00111	0.14229	0.14241	0.00012	0.00096
0.50000	0.50166	0.50153	-0.00013	0.00186	0.50270	0.50285	0.00015	0.00114
1.00000	1.00218	1.00205	-0.00013	0.00165	1.00314	1.00330	0.00016	0.00322
1.50000	1.50508	1.50490	-0.00018	0.00649	1.50611	1.50627	0.00016	0.00686
2.00000	2.00588	2.00566	-0.00022	0.00168	2.00364	2.00379	0.00015	0.00332
3.00000	3.00233	3.00208	-0.00025	0.00817	2.99822	2.99831	0.00009	0.01631
4.00000	3.99807	3.99778	-0.00029	0.02420	4.00695	4.00692	-0.00003	0.00444
5.00000	5.00259	5.00214	-0.00045	0.01146	5.00684	5.00663	-0.00021	0.00821
6.00000	6.00084	6.00034	-0.00050	0.00392	6.01158	6.01123	-0.00035	0.01755
7.00000	6.99965	6.99913	-0.00052	0.00345	7.00703	7.00654	-0.00049	0.00968

Tab. 2a: The 1st results of the reference laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.14000	0.139809	-0.000191	0.000128	0.14000	0.139887	-0.000113	0.000148
0.50000	0.50000	0.499984	-0.000016	0.000041	0.50000	0.500052	0.000052	0.000016
1.00000	1.00000	1.000010	0.000010	0.000044	1.00000	1.000109	0.000109	0.000024
1.50000	1.50000	1.500018	0.000018	0.000042	1.50000	1.500136	0.000136	0.000022
2.00000	2.00000	2.000010	0.000010	0.000033	2.00000	2.000142	0.000142	0.000025
3.00000	3.00000	3.000031	0.000031	0.000047	3.00000	3.000185	0.000185	0.000036
4.00000	4.00000	4.000007	0.000007	0.000053	4.00000	4.000155	0.000155	0.000048
5.00000	5.00000	4.999943	-0.000057	0.000073	5.00000	5.000076	0.000076	0.000059
6.00000	6.00000	5.999990	-0.000010	0.000069	6.00000	6.000062	0.000062	0.000067
7.00000	7.00000	7.000003	0.000003	0.000094	7.00000	6.999999	-0.000001	0.000088

Tab. 3a: The 2nd results of the reference laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.14000	0.139904	-0.000096	0.000152	0.14000	0.139936	-0.000064	0.000049
0.50000	0.50000	0.500010	0.000010	0.000046	0.50000	0.500072	0.000072	0.000017
1.00000	1.00000	1.000040	0.000040	0.000053	1.00000	1.000126	0.000126	0.000030
1.50000	1.50000	1.500044	0.000044	0.000057	1.50000	1.500151	0.000150	0.000023
2.00000	2.00000	2.000040	0.000040	0.000056	2.00000	2.000156	0.000156	0.000024
3.00000	3.00000	3.000067	0.000067	0.000058	3.00000	3.000191	0.000191	0.000035
4.00000	4.00000	4.000041	0.000041	0.000072	4.00000	4.000162	0.000162	0.000047
5.00000	5.00000	4.999981	-0.000019	0.000070	5.00000	5.000082	0.000082	0.000057
6.00000	6.00000	6.000008	0.000008	0.000081	6.00000	6.000070	0.000070	0.000070
7.00000	7.00000	7.000005	0.000005	0.000102	7.00000	7.000012	0.000012	0.000093

Tab. 1b: Results of the participating laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{lab}	x_{lab}	U_{lab}	P_{con}	P_{lab}	x_{lab}	U_{lab}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.00000	0.00001	0.00000	-0.00001	0.00060	0.00000	0.00000	0.00000	0.00060
0.20000	0.20022	0.20023	0.00001	0.00094	0.20076	0.20080	0.00004	0.00099
0.40000	0.40104	0.40114	0.00010	0.00245	0.40121	0.40134	0.00013	0.00178
0.60000	0.60051	0.60053	0.00002	0.00106	0.60087	0.60094	0.00007	0.00062
0.80000	0.80043	0.80038	-0.00005	0.00089	0.80098	0.80098	0.00000	0.00170
1.00000	1.00363	1.00363	0.00000	0.00850	1.00089	1.00095	0.00006	0.00163
1.20000	1.20459	1.20452	-0.00007	0.00942	1.20085	1.20084	-0.00001	0.00182
1.40000	1.40095	1.40093	-0.00002	0.00125	1.40086	1.40089	0.00003	0.00085
1.60000	1.60105	1.60099	-0.00006	0.00150	1.60157	1.60154	-0.00003	0.00378
1.80000	1.80405	1.80396	-0.00009	0.00715	1.80195	1.80189	-0.00006	0.00322
2.00000	2.00078	2.00070	-0.00008	0.00198	2.00061	2.00056	-0.00005	0.00069

Tab. 2b: The 1st results of the reference laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.000000	0.000000	0.000000	0.000000	0.000006	0.000000	-0.000007	-0.000007	0.000015
0.200000	0.200000	0.200005	0.000005	0.000012	0.200000	0.200011	0.000011	0.000015
0.400000	0.400000	0.399982	-0.000018	0.000033	0.400000	0.400007	0.000007	0.000019
0.600000	0.600000	0.599962	-0.000038	0.000031	0.600000	0.600006	0.000006	0.000021
0.800000	0.800000	0.799955	-0.000045	0.000030	0.800000	0.800008	0.000008	0.000024
1.000000	1.000000	0.999951	-0.000049	0.000033	1.000000	1.000013	0.000013	0.000029
1.200000	1.200000	1.199951	-0.000049	0.000037	1.200000	1.200016	0.000016	0.000027
1.400000	1.400000	1.399974	-0.000026	0.000026	1.400000	1.400040	0.000040	0.000038
1.600000	1.600000	1.599994	-0.000006	0.000038	1.600000	1.600052	0.000052	0.000030
1.800000	1.800000	1.800013	0.000013	0.000037	1.800000	1.800054	0.000054	0.000039
2.000000	2.000000	2.000038	0.000038	0.000041	2.000000	2.000053	0.000053	0.000043

Tab. 3b: The 2nd results of the reference laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.000000	0.000000	0.000000	0.000000	0.000006	0.000000	-0.000003	-0.000003	0.000008
0.200000	0.200000	0.200005	0.000005	0.000007	0.200000	0.200010	0.000010	0.000008
0.400000	0.400000	0.399988	-0.000012	0.000009	0.400000	0.400015	0.000015	0.000010
0.600000	0.600000	0.599970	-0.000030	0.000013	0.600000	0.600008	0.000008	0.000012
0.800000	0.800000	0.799965	-0.000035	0.000013	0.800000	0.800013	0.000013	0.000013
1.000000	1.000000	0.999959	-0.000041	0.000015	1.000000	1.000014	0.000014	0.000015
1.200000	1.200000	1.199957	-0.000043	0.000016	1.200000	1.200015	0.000015	0.000016
1.400000	1.400000	1.399985	-0.000015	0.000018	1.400000	1.400040	0.000040	0.000018
1.600000	1.600000	1.600000	0.000000	0.000020	1.600000	1.600052	0.000052	0.000020
1.800000	1.800000	1.800014	0.000014	0.000023	1.800000	1.800054	0.000054	0.000023
2.000000	2.000000	2.000033	0.000033	0.000033	2.000000	2.000041	0.000041	0.000033

Reference values and uncertainties

The data of GeoSTM for the further evaluation were the differences of the laboratory and transfer standard pressures, x_{lab}, accompanied by the corresponding uncertainty U_{lab} for each nominal pressure point. The data provided by CMI for each pressure point were the corresponding values of x_{ref1} for the first measurement and x_{ref2} for the second measurement, all these accompanied by their corresponding uncertainties U_{ref1} and U_{ref2}. The type-B part of the reference uncertainties consists of the uncertainty of the reference standard and the uncertainty due to the resolution of the transfer standard (the same is valid also for the type-B part of the uncertainty U_{lab}).

As the reference values and their uncertainties, the results of the reference laboratory were used. The average values for the first and the second measurement at the CMI were calculated as (see Tab. 4a and 4b):

$$x_{\mathrm{ref}} = \frac{x_{\mathrm{ref1}} + x_{\mathrm{ref2}}}{2}. \quad (1)$$

Tab. 4a: Reference values for 7 MPa range

	loading		unloading	
P_{nom}	x_{ref}	U_{ref}	x_{ref}	U_{ref}
MPa	MPa	MPa	MPa	MPa
0.14000	-0.000144	0.000162	-0.000089	0.000151
0.50000	-0.000003	0.000048	0.000062	0.000021
1.00000	0.000025	0.000056	0.000118	0.000032
1.50000	0.000031	0.000059	0.000143	0.000024
2.00000	0.000025	0.000059	0.000149	0.000026
3.00000	0.000049	0.000062	0.000188	0.000036
4.00000	0.000024	0.000075	0.000159	0.000048
5.00000	-0.000038	0.000076	0.000079	0.000059
6.00000	-0.000001	0.000082	0.000066	0.000070
7.00000	0.000004	0.000102	0.000006	0.000093

Tab. 4b: Reference values for 2 MPa range

	loading		unloading	
P_{nom}	x_{ref}	U_{ref}	x_{ref}	U_{ref}
MPa	MPa	MPa	MPa	MPa
0.0000	0.000000	0.000006	-0.000005	0.000015
0.2000	0.000005	0.000012	0.000011	0.000015
0.4000	-0.000015	0.000033	0.000011	0.000020
0.6000	-0.000034	0.000031	0.000007	0.000021
0.8000	-0.000040	0.000031	0.000011	0.000024
1.0000	-0.000045	0.000033	0.000014	0.000029
1.2000	-0.000046	0.000037	0.000016	0.000027
1.4000	-0.000021	0.000027	0.000040	0.000038
1.6000	-0.000003	0.000038	0.000052	0.000030
1.8000	0.000014	0.000037	0.000054	0.000039
2.0000	0.000036	0.000041	0.000047	0.000044

Their accompanying uncertainties were taken as the maximum uncertainty of both and adding also the uncertainty due to the long-term stability of the transfer-standard (see Tab. 4a and 4b):

$$U_{\mathrm{ref}} = 2 \cdot \sqrt{\left[\frac{\max(U_{\mathrm{ref1}};U_{\mathrm{ref2}})}{2}\right]^2 + \left[\frac{\max(x_{\mathrm{ref1}};x_{\mathrm{ref2}}) - \min(x_{\mathrm{ref1}};x_{\mathrm{ref2}})}{2\sqrt{3}}\right]^2}. \quad (2)$$

Criteria of evaluation

The evaluation of the measurement results was performed according to EN ISO/IEC 17043:2010 Conformity assessment - General requirements for proficiency testing, using E_n number, which is given by the formula:

$$E_n = \frac{x_{\mathrm{lab}} - x_{\mathrm{ref}}}{\sqrt{{U_{\mathrm{lab}}}^2 + {U_{\mathrm{ref}}}^2}}, \quad (3)$$

where:

x_{lab} means the value measured by the participating laboratory,

x_{ref} means the reference value,

U_{lab} means the uncertainty of the value measured by the participating laboratory,

U_{ref} means the final reference uncertainty

If $|E_n| \leq 1$, the measurement result is considered as satisfactory. If $|E_n| > 1$, the measurement result is considered as unsatisfactory. Tab. 5a and 5b contain the evaluation of the measurement results based on E_n numbers.

Evaluation of the BILC

The organization and evaluation of the ILC program have been made in accordance with the EN ISO/IEC 17043:2010 Conformity assessment - General requirements for proficiency testing. The management system of the ILC Department has been accredited by the Czech Accreditation Institute in accordance with this international standard (as a Proficiency Testing Provider No 7002).

On the basis of the evaluation of BILC results, the participant was successful if the percentage of the satisfactory measurement results of the participating laboratory was equal or greater than 90 %. The GeoSTM has met the requirements stated for this bilateral interlaboratory comparison within the relevant range and so it is issued the certificate on participation in the bilateral interlaboratory comparison №: 0318-OV-A019-17.

Tab. 5a: Evaluation of measurement results for 7 MPa abs. using E_n score

Conventional value of pressure (MPa)	x_{lab} (MPa)	U_{lab} (MPa)	x_{ref} (MPa)	U_{ref} (MPa)	x_{lab}-x_{ref} (MPa)	E_n
0.14000	-0.00012	0.00111	-0.000144	0.000162	0.000024	0.021
0.50000	-0.00013	0.00186	-0.000003	0.000048	-0.000127	-0.068
1.00000	-0.00013	0.00165	0.000025	0.000056	-0.000155	-0.094
1.50000	-0.00018	0.00649	0.000031	0.000059	-0.000211	-0.033
2.00000	-0.00022	0.00168	0.000025	0.000059	-0.000245	-0.146
3.00000	-0.00025	0.00817	0.000049	0.000062	-0.000299	-0.037
4.00000	-0.00029	0.02420	0.000024	0.000075	-0.000314	-0.013
5.00000	-0.00045	0.01146	-0.000038	0.000076	-0.000412	-0.036
6.00000	-0.00050	0.00392	-0.000001	0.000082	-0.000499	-0.127
7.00000	-0.00052	0.00345	0.000004	0.000102	-0.000524	-0.152
7.00000	-0.00049	0.00968	0.000006	0.000093	-0.000496	-0.051
6.00000	-0.00035	0.01755	0.000066	0.000070	-0.000416	-0.024
5.00000	-0.00021	0.00821	0.000079	0.000059	-0.000289	-0.035
4.00000	-0.00003	0.00444	0.000159	0.000048	-0.000189	-0.043
3.00000	0.00009	0.01631	0.000188	0.000036	-0.000098	-0.006
2.00000	0.00015	0.00332	0.000149	0.000026	0.000001	0.000
1.50000	0.00016	0.00686	0.000143	0.000024	0.000017	0.002
1.00000	0.00016	0.00322	0.000118	0.000032	0.000042	0.013
0.50000	0.00015	0.00114	0.000062	0.000021	0.000088	0.077
0.14000	0.00012	0.00096	-0.000089	0.000151	0.000209	0.215

Tab. 5b: Evaluation of measurement results for 2 MPa using E_n score

Conventional value of pressure (MPa)	x_{lab} (MPa)	U_{lab} (MPa)	x_{ref} (MPa)	U_{ref} (MPa)	x_{lab}-x_{ref} (MPa)	E_n
0.00000	-0.00001	0.00060	0.000000	0.000006	-0.000010	-0.017
0.20000	0.00001	0.00094	0.000005	0.000012	0.000005	0.005
0.40000	0.00010	0.00245	-0.000015	0.000033	0.000115	0.047
0.60000	0.00002	0.00106	-0.000034	0.000031	0.000054	0.051
0.80000	-0.00005	0.00089	-0.000040	0.000031	-0.000010	-0.011
1.00000	0.00000	0.00850	-0.000045	0.000033	0.000045	0.005
1.20000	-0.00007	0.00942	-0.000046	0.000037	-0.000024	-0.003
1.40000	-0.00002	0.00125	-0.000021	0.000027	0.000001	0.001
1.60000	-0.00006	0.00150	-0.000003	0.000038	-0.000057	-0.038
1.80000	-0.00009	0.00715	0.000014	0.000037	-0.000104	-0.015
2.00000	-0.00008	0.00198	0.000036	0.000041	-0.000116	-0.059
2.00000	-0.00005	0.00069	0.000047	0.000044	-0.000097	-0.140
1.80000	-0.00006	0.00322	0.000054	0.000039	-0.000114	-0.035
1.60000	-0.00003	0.00378	0.000052	0.000030	-0.000082	-0.022
1.40000	0.00003	0.00085	0.000040	0.000038	-0.000010	-0.012
1.20000	-0.00001	0.00182	0.000016	0.000027	-0.000026	-0.014
1.00000	0.00006	0.00163	0.000014	0.000029	0.000046	0.028
0.80000	0.00000	0.00170	0.000011	0.000024	-0.000011	-0.006
0.60000	0.00007	0.00062	0.000007	0.000021	0.000063	0.102
0.40000	0.00013	0.00178	0.000011	0.000020	0.000119	0.067
0.20000	0.00004	0.00099	0.000011	0.000015	0.000029	0.029
0.00000	0.00000	0.00060	-0.000005	0.000015	0.000005	0.008

DESCRIPTION OF THE ILC

Scheme and time schedule of comparison measurements

Measurements were performed in the scheme CMI – GeoSTM – SMU – CMI. SMU performed measurements only in the absolute mode. The measurement points were the same as in the BILC. The transfer standard was measured at CMI on the 15th and the 16th October 2018. The laboratory standards of GeoSTM were transported to the CMI and used to calibrate the transfer standard there from the 23rd till the 24th October 2018. The transfer standard was transported to the SMU and measured there on the 11th February 2019. The second measurement at CMI was performed on the 18th and the 19th February 2019. All the laboratories used laboratory standards of different types. GeoSTM laboratory standards are traceable to CMI, and the laboratory standards of the CMI and the SMU have independent traceability. Transportation of the transfer standard from CMI to SMU and back was performed by CMI staff.

Documents with the GeoSTM measurement results

Calibration Certificate №: GE/MI06-01375-18 and GE/MI06-01376-18

Date of issue: 05.11.2018

Measurement procedure: Internal calibration procedure № GE/MI06LP-5.4-06

Documents with the CMI measurement results

Calibration Certificate №: 6013-KL-C0805-18, 6013-KL-C0806-18, 6013-KL-C0160-19 and 6013-KL-C0161-19

Date of issue: 23.10.2018, 24.10.2018, 18.02.2019 and 19.02.2019

Measurement procedure: Internal calibration procedure № 601-MP-C046

Documents with the SMU measurement results

Calibration Certificate №: C0014-630-017-18

Date of issue: 05.12.2018

Measurement procedure: Calibration procedure № PP 19-017-15

Measurement results and uncertainties

The results for 7 MPa range can be seen from Tab. 6a to Tab. 9a. The results for 2 MPa range can be seen from Tab. 6b to Tab. 8b.

Tab. 6a: Results of the participating laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{lab}	x_{lab}	U_{lab}	P_{con}	P_{lab}	x_{lab}	U_{lab}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.14029	0.14198	0.00169	0.00176	0.14037	0.14221	0.00184	0.00175
0.50000	0.50035	0.50250	0.00215	0.00176	0.50047	0.50281	0.00234	0.00178
1.00000	1.00095	1.00361	0.00267	0.00194	1.00047	1.00337	0.00290	0.00176
1.50000	1.50017	1.50327	0.00310	0.00175	1.50068	1.50414	0.00346	0.00176
2.00000	2.00032	2.00397	0.00365	0.00181	2.00054	2.00453	0.00398	0.00184
3.00000	2.99895	3.00357	0.00461	0.00286	3.00050	3.00559	0.00510	0.00178
4.00000	4.00013	4.00577	0.00564	0.00175	4.00035	4.00636	0.00601	0.00179
5.00000	5.00016	5.00681	0.00664	0.00176	5.00056	5.00755	0.00699	0.00179
6.00000	6.00013	6.00771	0.00758	0.00177	6.00029	6.00814	0.00785	0.00176
7.00000	7.00015	7.00875	0.00860	0.00175	7.00012	7.00887	0.00875	0.00175

Tab. 7a: The 1st results of the reference laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.140000	0.141752	0.001752	0.000019	0.140000	0.141749	0.001749	0.000004
0.50000	0.500000	0.502110	0.002110	0.000016	0.500000	0.502137	0.002137	0.000007
1.00000	1.000000	1.002618	0.002618	0.000018	1.000000	1.002681	0.002681	0.000017
1.50000	1.500000	1.503111	0.003111	0.000026	1.500000	1.503188	0.003187	0.000038
2.00000	2.000000	2.003590	0.003589	0.000031	2.000000	2.003688	0.003688	0.000036
3.00000	3.000000	3.004562	0.004561	0.000057	3.000000	3.004668	0.004668	0.000051
4.00000	4.000000	4.005517	0.005517	0.000049	4.000000	4.005615	0.005615	0.000053
5.00000	5.000000	5.006424	0.006424	0.000090	5.000000	5.006506	0.006506	0.000070
6.00000	6.000000	6.007394	0.007394	0.000083	6.000000	6.007453	0.007453	0.000085
7.00000	7.000000	7.008403	0.008403	0.000188	7.000000	7.008365	0.008365	0.000088

Tab. 8a: The 2nd results of the reference laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.140000	0.141725	0.001725	0.000163	0.140000	0.141767	0.001767	0.000096
0.50000	0.500000	0.502109	0.002109	0.000087	0.500000	0.502179	0.002179	0.000040
1.00000	1.000000	1.002620	0.002620	0.000079	1.000000	1.002714	0.002714	0.000048
1.50000	1.500000	1.503108	0.003108	0.000079	1.500000	1.503222	0.003222	0.000032
2.00000	2.000000	2.003591	0.003590	0.000089	2.000000	2.003721	0.003721	0.000035
3.00000	3.000000	3.004572	0.004572	0.000096	3.000000	3.004708	0.004708	0.000052
4.00000	4.000000	4.005517	0.005517	0.000113	4.000000	4.005651	0.005651	0.000068
5.00000	5.000000	5.006423	0.006423	0.000125	5.000000	5.006538	0.006538	0.000169
6.00000	6.000000	6.007409	0.007409	0.000111	6.000000	6.007489	0.007489	0.000175
7.00000	7.000000	7.008377	0.008377	0.000103	7.000000	7.008388	0.008388	0.000216

Tab. 9a: The results of the co-reference laboratory for 7 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{cref}	x_{cref}	U_{cref}	P_{con}	P_{cref}	x_{cref}	U_{cref}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.14000	0.137966	0.139674	0.001708	0.000468	0.137966	0.139718	0.001752	0.000387
0.50000	0.498666	0.500725	0.002059	0.000201	0.498666	0.500875	0.002209	0.000198
1.00000	0.998976	1.001510	0.002535	0.000084	0.998975	1.001693	0.002718	0.000120
1.50000	1.499281	1.502312	0.003031	0.000079	1.499281	1.502491	0.003211	0.000062
2.00000	1.999590	2.003129	0.003540	0.000094	1.999589	2.003316	0.003727	0.000057
3.00000	3.000202	3.004774	0.004571	0.000092	3.000202	3.004957	0.004755	0.000075
4.00000	4.000811	4.006378	0.005566	0.000104	4.000810	4.006543	0.005733	0.000101
5.00000	5.001422	5.007984	0.006561	0.000127	5.001421	5.008133	0.006711	0.000127
6.00000	6.002028	6.009631	0.007603	0.000172	6.002028	6.009714	0.007686	0.000158
7.00000	7.002634	7.011285	0.008651	0.000199	7.002634	7.011295	0.008661	0.000199

Tab. 6b: Results of the participating laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{lab}	x_{lab}	U_{lab}	P_{con}	P_{lab}	x_{lab}	U_{lab}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.00000	0.00001	0.00000	-0.00001	0.00063	0.00000	0.00000	0.00000	0.00063
0.20000	0.20030	0.20027	-0.00003	0.00070	0.20038	0.20037	-0.00001	0.00066
0.40000	0.40018	0.40026	0.00008	0.00065	0.40027	0.40039	0.00012	0.00063
0.60000	0.60016	0.60016	0.00000	0.00066	0.60033	0.60038	0.00005	0.00063
0.80000	0.80019	0.80009	-0.00010	0.00063	0.80018	0.80013	-0.00005	0.00063
1.00000	1.00011	1.00005	-0.00006	0.00063	1.00009	1.00008	-0.00001	0.00063
1.20000	1.20018	1.20006	-0.00012	0.00063	1.20021	1.20014	-0.00007	0.00063
1.40000	1.40016	1.40009	-0.00007	0.00063	1.40019	1.40017	-0.00002	0.00063
1.60000	1.60022	1.60008	-0.00014	0.00063	1.60021	1.60010	-0.00011	0.00063
1.80000	1.80017	1.80005	-0.00012	0.00063	1.80021	1.80009	-0.00012	0.00063
2.00000	2.00028	2.00010	-0.00018	0.00063	2.00026	2.00010	-0.00016	0.00063

Tab. 7b: The 1st results of the reference laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}	P_{con}	P_{ref1}	x_{ref1}	U_{ref1}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	-0.000005	-0.000005	0.000012
0.200000	0.200000	0.200007	0.000006	0.000003	0.200000	0.200017	0.000017	0.000003
0.400000	0.400000	0.399982	-0.000018	0.000014	0.400000	0.400010	0.000010	0.000006
0.600000	0.600000	0.599970	-0.000030	0.000008	0.600000	0.600004	0.000004	0.000014
0.800000	0.800000	0.799958	-0.000042	0.000015	0.800000	0.800006	0.000006	0.000010
1.000000	1.000000	0.999961	-0.000039	0.000015	1.000000	1.000011	0.000011	0.000014
1.200000	1.200000	1.199961	-0.000039	0.000017	1.200000	1.200014	0.000014	0.000015
1.400000	1.400000	1.399983	-0.000017	0.000019	1.400000	1.400034	0.000034	0.000019
1.600000	1.600000	1.600007	0.000007	0.000026	1.600000	1.600053	0.000053	0.000021
1.800000	1.800000	1.800022	0.000022	0.000023	1.800000	1.800053	0.000053	0.000023
2.000000	2.000000	2.000052	0.000052	0.000024	2.000000	2.000054	0.000054	0.000025

Tab. 8b: The 2nd results of the reference laboratory for 2 MPa range

			loading				unloading	
P_{nom}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}	P_{con}	P_{ref2}	x_{ref2}	U_{ref2}
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	-0.000004	-0.000004	0.000005
0.200000	0.200000	0.200001	0.000001	0.000003	0.200000	0.200001	0.000001	0.000006
0.400000	0.400000	0.399985	-0.000015	0.000007	0.400000	0.399996	-0.000004	0.000011
0.600000	0.600000	0.599971	-0.000030	0.000008	0.600000	0.599994	-0.000006	0.000011
0.800000	0.800000	0.799966	-0.000035	0.000010	0.800000	0.800000	0.000000	0.000015
1.000000	1.000000	0.999963	-0.000037	0.000012	1.000000	1.000008	0.000008	0.000018
1.200000	1.200000	1.199959	-0.000041	0.000014	1.200000	1.200010	0.000010	0.000018
1.400000	1.400000	1.399976	-0.000024	0.000016	1.400000	1.400026	0.000026	0.000021
1.600000	1.600000	1.599992	-0.000008	0.000021	1.600000	1.600042	0.000042	0.000019
1.800000	1.800000	1.800009	0.000009	0.000025	1.800000	1.800045	0.000045	0.000020
2.000000	2.000000	2.000030	0.000030	0.000026	2.000000	2.000036	0.000035	0.000026

Reference values and uncertainties

The data of GeoSTM for the further evaluation were the differences between the pressures of the laboratory and the transfer standard x_{lab}, accompanied by the corresponding uncertainty U_{lab} for each nominal pressure point. The data provided by CMI for each pressure point were the corresponding values of x_{ref1} for the first measurement and x_{ref2} for the second measurement, all these accompanied by their corresponding uncertainties U_{ref1} and U_{ref2}. The data provided by SMU for each pressure point were the corresponding values of x_{cref}, accompanied by their corresponding uncertainties U_{cref}. The type-B part of the reference uncertainties consists of the uncertainty of the reference standard and the uncertainty due to the resolution of the transfer standard (the same is valid also for the type-B part of the uncertainty U_{lab}). As the reference values and their uncertainties, the results of the reference laboratory were used. The average values for the first and the second measurement at the CMI were calculated according to (1), see Tab. 10a and 10b. Their accompanying uncertainties were calculated using (2). As the co-reference values and their uncertainties, the provided results of the co-reference laboratory were used.

Tab. 10a: Reference values for 7 MPa range

	loading		unloading	
P_{nom}	x_{ref}	U_{ref}	x_{ref}	U_{ref}
MPa	MPa	MPa	MPa	MPa
0.14000	0.001738	0.000164	0.001758	0.000097
0.50000	0.002109	0.000087	0.002158	0.000047
1.00000	0.002619	0.000079	0.002698	0.000052
1.50000	0.003110	0.000079	0.003205	0.000043
2.00000	0.003590	0.000089	0.003705	0.000041
3.00000	0.004567	0.000096	0.004688	0.000057
4.00000	0.005517	0.000113	0.005633	0.000071
5.00000	0.006423	0.000125	0.006522	0.000170
6.00000	0.007402	0.000111	0.007471	0.000176
7.00000	0.008390	0.000189	0.008376	0.000216

Tab. 10b: Reference values for 2 MPa range

	loading		unloading	
P_{nom}	x_{ref}	U_{ref}	x_{ref}	U_{ref}
MPa	MPa	MPa	MPa	MPa
0.0000	0.000000	0.000001	-0.000005	0.000012
0.2000	0.000004	0.000004	0.000009	0.000011
0.4000	-0.000016	0.000014	0.000003	0.000014
0.6000	-0.000030	0.000007	-0.000001	0.000015
0.8000	-0.000038	0.000015	0.000003	0.000016
1.0000	-0.000038	0.000015	0.000009	0.000018
1.2000	-0.000040	0.000017	0.000012	0.000018
1.4000	-0.000021	0.000019	0.000030	0.000022
1.6000	0.000000	0.000027	0.000047	0.000022
1.8000	0.000015	0.000026	0.000049	0.000024
2.0000	0.000041	0.000029	0.000045	0.000028

Criteria of evaluation

The evaluation of the measurement results was again performed using E_n number, which is given by formula (3). Tab. 11a, 12a and 12b contain the evaluation of the measurement results based on E_n numbers.

Tab. 11a: Evaluation of comparison with reference results for 7 MPa range

	loading		unloading	
P_{nom}	$x_{lab} - x_{ref}$	E_n	$x_{lab} - x_{ref}$	E_n
MPa	MPa	-	MPa	-
0.14000	-0.00005	-0.03	0.00009	0.05
0.50000	0.00004	0.02	0.00018	0.10
1.00000	0.00005	0.02	0.00020	0.11
1.50000	-0.00001	-0.01	0.00026	0.14
2.00000	0.00006	0.03	0.00028	0.15
3.00000	0.00005	0.02	0.00041	0.23
4.00000	0.00012	0.07	0.00038	0.21
5.00000	0.00022	0.12	0.00047	0.26
6.00000	0.00018	0.10	0.00038	0.22
7.00000	0.00021	0.12	0.00037	0.21

Tab. 12a: Evaluation of comparison with co-reference results for 7 MPa range

	loading		unloading	
P_{nom}	$x_{lab} - x_{cref}$	E_n	$x_{lab} - x_{cref}$	E_n
MPa	MPa	-	MPa	-
0.14000	-0.00002	-0.01	0.00009	0.05
0.50000	0.00009	0.05	0.00013	0.07
1.00000	0.00013	0.07	0.00018	0.10
1.50000	0.00007	0.04	0.00025	0.14
2.00000	0.00011	0.06	0.00026	0.14
3.00000	0.00004	0.01	0.00034	0.19
4.00000	0.00007	0.04	0.00028	0.15
5.00000	0.00008	0.05	0.00028	0.16
6.00000	-0.00003	-0.01	0.00017	0.09
7.00000	-0.00005	-0.03	0.00009	0.05

Tab. 12b: Evaluation of comparison results for 2 MPa range

	loading		unloading	
P_{nom}	$x_{lab} - x_{ref}$	E_n	$x_{lab} - x_{ref}$	E_n
MPa	MPa	-	MPa	-
0.0000	-0.00001	-0.02	0.00000	0.01
0.2000	-0.00003	-0.05	-0.00002	-0.03
0.4000	0.00010	0.15	0.00012	0.19
0.6000	0.00003	0.05	0.00005	0.08
0.8000	-0.00006	-0.10	-0.00005	-0.08
1.0000	-0.00002	-0.03	-0.00002	-0.03
1.2000	-0.00008	-0.13	-0.00008	-0.13
1.4000	-0.00005	-0.08	-0.00005	-0.08
1.6000	-0.00014	-0.22	-0.00016	-0.25
1.8000	-0.00014	-0.21	-0.00017	-0.27
2.0000	-0.00022	-0.35	-0.00020	-0.32

Evaluation of ILC

The GeoSTM measurement results are equivalent with those of both CMI and the SMU within the claimed uncertainties.

CONCLUSION

These comparisons were carried out to demonstrate the metrological and technical competence, as well as the equivalence of the pressure standard of the Pressure calibration laboratory of GeoSTM with those of CMI and SMU. Agreement between the participants is satisfactory in all cases, all the values agreed within two standard uncertainties.

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APPENDIX

The comparison was neither intended, nor suitable as a CMI versus SMU comparison. Still we provide mutual equivalences for CMI and SMU for the sake of completeness in Tab. A1.

Tab. A1: Evaluation of comparison of reference and co-reference for 7 MPa range

	loading		unloading	
P_{nom}	$x_{lab} - x_{ref}$	E_n	$x_{lab} - x_{ref}$	E_n
MPa	MPa	-	MPa	-
0.14000	0.00003	0.06	0.00001	0.02
0.50000	0.00005	0.23	-0.00005	-0.25
1.00000	0.00008	0.73	-0.00002	-0.16
1.50000	0.00008	0.71	-0.00001	-0.08
2.00000	0.00005	0.39	-0.00002	-0.31
3.00000	0.00000	-0.03	-0.00007	-0.71
4.00000	-0.00005	-0.32	-0.00010	-0.81
5.00000	-0.00014	-0.77	-0.00019	-0.89
6.00000	-0.00020	-0.98	-0.00022	-0.91
7.00000	-0.00026	-0.95	-0.00028	-0.97