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ASIA-PACIFIC METROLOGY PROGRAMME
100 MPa HYDRAULIC PRESSURE INTERLABORATORY COMPARISON
Comparison Identifier: **APMP.M.P-K7**

Final Report on Key Comparison APMP.M.P-K7 in Hydraulic Gauge Pressure from 10 MPa to 100 MPa

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Abstract

This report describes the results of a key comparison of hydraulic high-pressure standards at sixteen National Metrology Institutes (NMIs: NMIJ/AIST, NPLI, CSIR-NML, NIS, KRISS, SCL, SPRING, NMIA, VMI, NML-SIRIM, KIM-LIPI, NSCL, PTB, NIMT, CMS/ITRI and NIM) was carried out during the period October 2002 to July 2004 within the framework of the Asia-Pacific Metrology Programme (APMP) in order to determine their degrees of equivalence at pressures in the range 10 MPa to 100 MPa for gauge mode. The pilot institute was the National Metrology Institute of Japan (NMIJ)/AIST. All participating institutes generally used hydraulic pressure balances as their pressure standards. High-precision pressure transducers were used as transfer standards. The sensing element of the transducer was a precision quartz crystal resonator. To ensure the reliability of the transfer standard, two pressure transducers were used on a transfer standard unit. Three nominally identical transfer packages were circulated independently to reduce the time required for the measurements. During this comparison, the three transfer standards were calibrated simultaneously at the pilot institute eleven times in total. From the calibration results, the behaviors of the transfer standards during the comparison period were well characterized and it was presented that the capabilities of the transfer standards to achieve this key comparison were sufficient. The degrees of equivalence of each national measurement standard were expressed quantitatively by two terms, deviations from the key comparison reference values and pair-wise differences of their deviations. The degrees of equivalence in this comparison were also transferred to the corresponding CCM key comparison, CCM.M.P-K7. The hydraulic pressure standards in the range 10 MPa to 100 MPa for gauge mode of the sixteen participating NMIs were found to be equivalent within their claimed uncertainties.

Contents:

1. Introduction

The National Metrology Institute of Japan (NMIJ)/AIST, Japan, has been agreed by the Technical Committee for Mass and Related Quantities (TCM) in the Asia-Pacific Metrology Programme (APMP) to coordinate an interlaboratory comparison program for high-pressure as a pilot institute. The comparison was identified as **APMP.M.P-K7** by the Consultative Committee for Mass and Related Quantities (CCM) of the International Committee for Weights and Measures (CIPM), the International Bureau of Weights and Measures (BIPM) and APMP. The objective of the comparison was to compare the performance of hydraulic pressure standards in the National Metrology Institutes (NMIs), in the pressure range 10 MPa to 100 MPa for gauge mode using Di(2)-ethyl-Hexyl-Sebacate (DHS) as a transmitting fluid according to the guidelines[1,2,3]. To gain an international acceptance for the pressure standards, this APMP key comparison, APMP.M.P-K7, will be linked to the CCM key comparison, CCM.P.K-7[4], which has the same pressure range as APMP.M.P-K7. All participating institutes have the opportunity to get results in the comparison at a level of uncertainty appropriate for them[5]. The results of this comparison will be included in the Key Comparison Database (KCDB) of BIPM following the rules of CCM and will be used to establish the degree of equivalence of national measurement standard by NMIs[6]. Those are essential supporting evidence for high-pressure calibration and measurement capabilities (CMCs) of NMIs for the Mutual Recognition Arrangement (MRA)[1].

An invitation was distributed to the members of TCM in APMP on 28 June 2002 by the pilot institute, NMIJ/AIST (Japan), and the following NMIs, which were in order of their application, NIS (Egypt), SPRING (Singapore), SCL (Hong Kong), NPLI (India), KRISS (Republic of Korea), NML-SIRIM (Malaysia), CMS/ITRI (Chinese Taipei), CSIR-NML (Republic of South Africa), NIMT (Thailand), KIM-LIPI (Indonesia), NSCL (Syria), NMIA (Australia), NIM (China) and VMI (Viet Nam), responded by 26 July 2002 to participate into this comparison. PTB (Germany), the pilot institute of CCM.P.K-7, was invited to make a firm linkage between APMP.M.P-K7 and CCM.P.K-7.

From a questionnaire survey to the participants, it was decided that high-precision electronic pressure transducers were circulated as the transfer standard for the whole comparison. To ensure the reliability of the transfer standard, two high-precision pressure transducers were used on a transfer standard unit. Three nominally identical transfer packages were circulated independently to reduce the time required to complete all measurements. During the comparison, the three transfer standards were calibrated simultaneously at the pilot institute eleven times in total.

From the calibration results, the behaviors of the transfer standards during the comparison period were well characterized.

A protocol was prepared by the pilot institute, which was an integral part of this comparison[7,8]. The first edition was distributed to the participating institutes on 21 August 2002. After the third edition of the protocol was approved by the participants, the transfer standards were circulated independently from October 2002 to December 2003. All NMIs generally used hydraulic pressure balances as their pressure standards and calibrated the transfer standard against the pressure balance following the protocol[7,8]. The calibration results obtained from each participating institute have been submitted to the pilot institute. The preparation of a report on the comparison and the analysis of data on the basis of the results from the participants have been done by the pilot institute by trying to make a uniform treatment for all participants according to the guidelines[1,2,3].

This report gives the calibration results of the transfer standards carried out at sixteen NMIs. The following sections provide descriptions of the participating institutes and their pressure standards, the transfer standards, the circulation of the transfer standards, the general calibration procedure for the transfer standard, the method for analysis of the calibration data and the comparison results.

2. Participating institutes and their pressure standards

2.1 List of participating institutes

Sixteen National Metrology Institutes (NMIs) participated into this comparison including the pilot institute. The participating institutes are listed in order of their participations in each loop in Table 2.1. The index number in column one is used to identify the participating institute in this report.

One institute, MSL (New Zealand), participated into this comparison and calibrated one transfer standard, but withdrew on 29 June 2004 without reporting the calibration results to the pilot institute. Therefore, MSL was deleted from the list.

Table 2.1: List of participating institutes.

	Institute	Acronym	Country
1	National Metrology Institute of Japan, AIST (Pilot institute)	NMIJ/AIST	Japan
2	National Physical Laboratory	NPLI	India
3	National Metrology Laboratory, CSIR, RSA	CSIR-NML	Republic of South Africa
4	National Institute for Standards	NIS	Egypt
5	Korea Research Institute of Standards and Science	KRISS	Republic of Korea
6	The Government of the Hong Kong Special Administrative Region Standards and Calibration Laboratory	SCL	Hong Kong, China
7	National Metrology Centre, SPRING Singapore	SPRING	Singapore
8	National Measurement Institute Australia	NMIA	Australia
9	Vietnam Metrology Institute	VMI	Vietnam
10	National Metrology Laboratory, SIRIM Berhad	NML-SIRIM	Malaysia
11	KIM-LIPI, Indonesia	KIM-LIPI	Indonesia
12	National Standards & Calibration Laboratory	NSCL	Syria
13	Physikalisch-Technische Bundesanstalt	PTB	Germany
14	National Institute of Metrology, Thailand	NIMT	Thailand
15	Center for Measurement Standards / ITRI	CMS/ITRI	Chinese Taipei
16	National Institute of Metrology	NIM	China

2.2 Pressure standards of participating institutes

The pressure standards of all the participating institutes were generally pressure balances of different manufacture and model. They were equipped with a simple type or a re-entrant type piston-cylinder assembly. Each institute provided to the pilot institute with the information of the institute standard against which the transfer standard was calibrated, including the pressure balance base, the type and material of piston-cylinder assembly, the effective area with associated standard uncertainty, the reference temperature, the pressure distortion coefficient with associated standard uncertainty, the traceability, the method and rotation rate of the piston as listed in Table 2.2. All piston and cylinder materials of the pressure balances used by the participating institutes were tungsten carbide except one of the pressure balances of SCL, Hong Kong, China. For the pressure standard of SCL, two pressure balances were used depending on the pressure range. One was for the pressures of 80 MPa or below and another was for the pressures of 90 MPa and above*. All the institutes assumed linear pressure dependence for the effective area of piston-cylinder assembly. The participants with primary pressure standards directly linked to base SI units were the following six NMIs: NMIJ/AIST, NPLI, KRISS, NMIA, PTB and NIM.

* For pressures of 90 MPa and above at SCL, a Ruska model 7610 pressure controller was used as their pressure standard to calibrate the transfer standard. This pressure controller was calibrated by a pressure balance with details listed in Table 2.2 via a Desgranges model 42055 interfacer. It was because the pressure balance used other oil, instead of Sebacate.

Table 2.2: Details of the pressure standards of the participating institutes. All the uncertainties are expressed as the standard ones.

j	Institute	Country	Pressure balance base		Piston-cylinder		Effective area A_{tr}			Ref. temp	Distortion coefficient λ [MPa^{-1}]		Traceability	Rotation	
			Manufacturer	Model	Type	Material	Value [m^2]	Unc. [m^2]	Unc. [ppm]	t_r [°C]	Value [MPa^{-1}]	Unc.[MPa^{-1}]		Method	[rpm]
1	NMIJ/AIST	Japan	DH	5316-02	Simple	WC/WC	9.805620E-06	1.24E-10	12.6	23	8.38E-07	1.01E-07	Independent	Hand	20 - 30
2	NPLI	India	DH, FRANCE	5306	Simple	WC/WC	9.805937E-06	1.80E-10	18.4	23	8.22E-07	1.50E-07	Independent	Motor	25
3	CSIR-NML	Republic of South Africa	Desgranges et Huot	5403G	Simple	WC/WC	4.902854E-06	3.28E-11	6.7	20	9.09E-07	2.6E-08	BNM-LNE	Motor	20
4	NIS	Egypt	DH-France	5306	Simple	WC/WC	9.804572E-06	7.06E-11	7.2	20	1.03E-06	6.665E-08	BNM-LNE	Hand	20-30
5	KRISS	Republic of Korea	DH	5306	Simple	WC/WC	9.80522E-06	1.8E-10	18.4	23	8.4E-07	9.7E-08	Independent	Hand	25-35
6	SCL	Hong Kong, China	Desgranges Et Huot	5303	Simple	WC/WC	4.90223E-06	7E-11	14.3	20	5E-07	1E-07	NPL, UK	Motor	21
			Budenberg	380H	Simple	Steel/Steel	4.03174E-06	7.5E-11	18.6	20	3.6E-06	1E-07	NPL, UK	Hand	30
7	SPRING	Singapore	RUSKA	2485-950D	Simple	WC/WC	9.80646E-06	1.3E-10	13.3	20	7E-07	1E-07	PTB	Hand	20-30
8	NMIA	Australia	NML	N/A	Simple	WC/WC	9.805178E-06	1.82E-10	18.6	20	8.65E-07	1.10E-07	Independent	Hand	23-27
9	VMI	Vietnam	RUSKA Inc	2485-930D	Simple	WC/WC	9.80932E-06	2.23E-10	22.7	23	1.00E-06	1.00E-07	KRISS	Motor	20
10	NML-SIRIM	Malaysia	Desgranges Et Huot	5301	Simple	WC/WC	5.688389E-06	2.5E-11	4.4	20	1.00E-06	4.2E-08	BNM-LNE	Hand	-
11	KIM-LIPI	Indonesia	Ruska	2485-930S	Simple	WC/WC	9.81882E-06	2.8E-10	28.5	20	7.2E-06	1E-06	PTB	Motor	16
12	NSCL	Syria	NKS	PD66	Simple	WC/WC	5.010995E-06	1.5E-10	30	23	7.44E-07	7.4E-08	NRLM	Hand	30
13	PTB	Germany	PTB	100 MPa	Simple	WC/WC	8.395432E-06	8.4E-11	10	20	7.25E-07	1E-07	Independent	Hand	18-22
14	NIMT	Thailand	Ruska	2485-930D	Simple	WC/WC	7.11111E-06	8.0E-11	11.3	20	6.4E-05	1.05E-07	PTB	Hand	30-40
15	CMS/ITRI	Chinese Taipei	RUSKA	2450	Re-entrant	WC/WC	8.40264E-06	1.89E-10	22.5	23	-2.731E-12	-	NIST	Hand	36
16	NIM	China	Shanhai Minyu Instruments	KY-100	Simple	WC/WC	9.80822E-06	1.1E-10	11	20	7.4E-07	1E-08	Independent	Hand	40-50

3. Transfer standards

As a transfer standard for this APMP comparison, two types of transfer standard were examined before this comparison. One was a piston-cylinder assembly and the other was an electronic pressure transducer. A EUROMET regional comparison (EUROMET PROJECT 389 – 100 MPa Hydraulic Pressure Comparison, EUROMET.M.P-K4) was already done by using a piston-cylinder assembly[9], and a SIM regional comparison (SIM.M.P-K7) by using an electronic pressure transducer[10]. Although the stability of a transducer may be expected not to be better than that of the piston-cylinder assembly, the same type transducer has been used as a transfer standard in some international comparisons with good results[10,11]. To determine the type of transfer standard for this APMP comparison, questionnaires were sent to the participating institutes. From the questionnaire survey, it was decided that high-precision electronic pressure transducers were circulated as the transfer standard for the whole comparison. To ensure the reliability, two transducers were used on each transfer standard.

3.1 Pressure monitors

Two commercially available pressure monitors, which are listed in Table 3.1, were used on the transfer standard. One type is from DH Instruments, Inc. and another type is from Paroscientific Inc. (in alphabetical order)[12,13]. The pressure range of these pressure monitors were up to 100 MPa. Each pressure monitor included a high-precision electronic pressure transducer inside the body. The sensing element of the transducer was a precision quartz crystal resonator and the frequency of oscillation varied with pressure induced stress. The resolution of the transducer was 0.1 kPa.

Table 3.1: Two types of pressure monitors.

Type	a	b
Manufacturer	DH Instruments, Inc.	Paroscientific, Inc.
Model	RPM3 A15000	785 A15000
Specification	See RPM3’s specification*1	See 785’s specification*2
Range	Up to 100 MPa	
Power supply	85 to 264 VAC and 47 to 440 Hz	

*1 http://www.dhinstruments.com//prod1/pdfs/brorpm3a.pdf

*2 http://www.paroscientific.com/pdf/model785.pdf

Each manufacturer listed in Table 3.1 kindly lent two pressure monitors to our APMP pressure group in the period from September 2002 to March 2004. Also NMIJ/AIST purchased one pressure monitor from each manufacturer. In total six pressure monitors were prepared for this comparison and were used to assemble three nominally identical transfer standards. The serial number of each pressure monitor used was listed in Table 3.2.

Table 3.2: Serial number of each pressure monitor.

Type	a	b
Transfer standard A	1477	1651 (88595)
Transfer standard B	1478	1665 (88593)
Transfer standard C	1476	1668 (88609)

Some general information concerning the characteristics of these pressure monitors are given in the operation and maintenance manuals[12, 13] which were enclosed in a transfer package.

To perform a reliable comparison, the effects on the readings of the monitors by setting parameter and environmental condition were evaluated at the pilot institute during the comparison. The important characteristics for the transfer standard such as the long-term stability and the temperature coefficient of the span reading are evaluated quantitatively in section 6.

Effect by power source

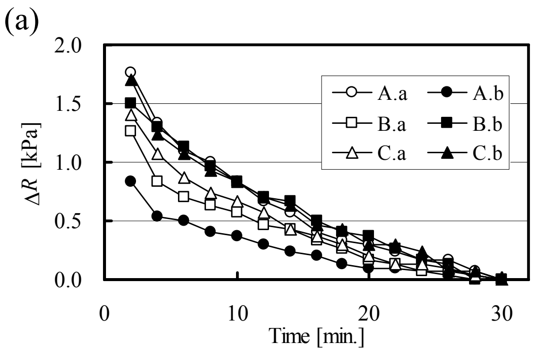
To evaluate the effect on the reading of pressure monitor by a power source, the voltage was changed from 85 V to 264 V and the frequency was varied from 50 Hz to 60 Hz, respectively, using a power supply regulator. From the evaluation performed at pressures 0 MPa, 50 MPa and 100 MPa applied, no systematic effect on the reading by the voltage and the frequency of power source was found. Therefore, the effect on the reading by a power source was considered to be negligible.

Effect by attitude

The effect on the reading by the attitude of pressure monitor was evaluated by inclining the monitor in the range of 0.7 degree. From the results, the change in the reading by inclining the monitor in direction of back or forth was larger than that in direction of right or left. The difference in the change could be understood since the cylindrical transducer was arranged in the direction of back and forth inside the monitor. From the evaluation performed at pressures 0 MPa, 50 MPa and 100 MPa, the maximum effect was evaluated as 0.4 kPa/degree. To keep the water level of the pressure monitors, a sensitive bubble level, whose resolution was 0.1 degree, was installed on each transfer standard. Since the water level could be easily adjusted within 0.1 degree using the level, the effect on the reading by the attitude could be reduced to be less than the resolution of the monitor. Therefore, this effect was not included into the uncertainty estimation.

Effect by transient response

The effect on the reading by a transient response was evaluated. The transient response of each pressure monitor was investigated by generating pressure change (a) from 0 MPa to 100 MPa and (b) from 100 MPa to 0 MPa as a step function. After the change, the reading of each monitor was sampled every two minutes until thirty minutes later. Figure 3.1 shows the results obtained from the measurements. The corrected reading, ΔR, is obtained from $\Delta R = R - R_{30}$, where R is the raw reading and R_{30} is the reading at thirty minutes. In the figures, measurement points at zero minute are removed for retaining the vertical axes narrow.



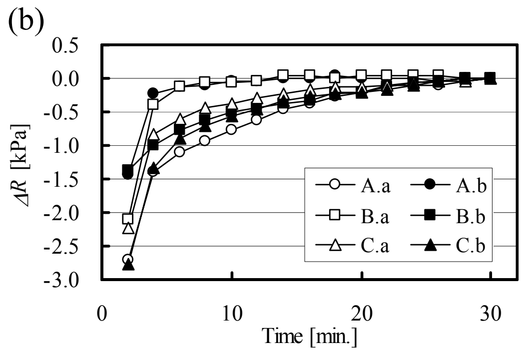


Figure 3.1: (a) Reading change after pressurizing from 0 MPa to 100 MPa, (b) Reading change after depressurizing from 100 MPa to 0 MPa.

When the pressure change from 0 MPa to 100 MPa was applied, the reading was immediately overshot and was gradually decreasing with time exponentially as shown in Figure 3.1 (a). On the other hand, when the pressure change from 100 MPa to 0 MPa was applied, the reading was immediately undershot and was gradually increasing with time exponentially as shown in Figure 3.1 (b). From the results, the reading changes after ten minutes seemed to be relatively slow compared with those obtained before ten minutes. The change in the reading of each pressure monitor between ten minutes to fifteen minutes after applying pressure change of 100 MPa was less than 0.3 kPa at maximum. Therefore, in all calibrations in the comparison, the measurement from ten minutes to fifteen minutes after pressure change was required as described in the technical protocol[7]. The standard uncertainty of the effect was estimated as 0.3 kPa / $2\sqrt{3}$ = 0.087 kPa, which was less than the resolution of pressure monitor. In the case that the participants follow the procedure in the protocol, the effect on the reading by a transient response can be negligible. Therefore, the effect was not included into the uncertainty evaluation.

Effect by temperature on reading at 0 MPa

The effect on the reading at 0 MPa by temperature was evaluated here. If the ambient temperature of the laboratory was not changed during a calibration, the effect would be disregarded because all the readings in the calibration were offset by the reading at 0 MPa in data analysis.

By changing temperature from 20 ℃ to 26 ℃ in separate days, the reading of each pressure monitor at 0 MPa was measured by applying zero pressure using a U-tube on the transfer standard. From the measurements performed at the pilot institute in October 2002 and November 2003, the average temperature dependence on the reading at 0 MPa was evaluated as listed in the following table.

Table 3.3: Average temperature dependence on the reading at 0 MPa.

Monitor	A.a	A.b	B.a	B.b	C.a	C.b
[kPa/℃]	0.63	0.56	0.54	0.37	0.60	0.32

In normal calibrations, the actual temperature was fluctuated and was deviated maximally 0.15 ℃ from the average. Therefore, the standard uncertainty of the effect on the reading at 0 MPa by temperature was estimated using a rectangular distribution as 0.63 kPa/℃ × 0.15 ℃ / $\sqrt{3}$ = 0.055 kPa at maximum, which was less than the resolution of pressure monitor and was disregard. As mentioned previously, the temperature coefficient of the span reading is evaluated quantitatively in section 6.

Long-term shift of reading at 0 MPa

The readings at 0 MPa of pressure monitors on transfer standard C were measured by applying zero pressure using a U-tube on the transfer standard from

October 2002 to February 2004 intermittently. Figure 3.2 present an example of the long-term shifts in readings of pressure monitors C.a and C.b at 0 MPa, which were measured from October 2002 to September 2003. Since the readings were affected by the ambient temperature as mentioned above, some points were deviated irregularly. However, the long-term shifts of the readings at 0 MPa were sufficiently continuous and foreseeable. Since all readings in the respective calibrations were offset by the respective readings at 0 MPa in data analysis as explained in section 6, the effect by the long-term shift of the reading at 0 MPa could be disregarded.

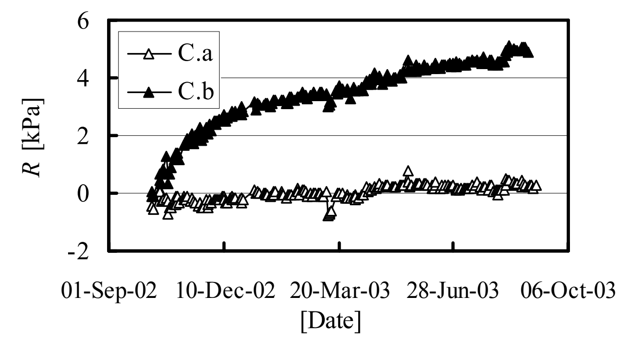


Figure 3.2: Example of long-term shifts in readings at 0 MPa of pressure monitors C.a and C.b.

3.2 Structure of transfer standard

For this APMP comparison, two pressure monitors were used on each transfer standard to ensure the reliability. As shown in Figure 3.3, each transfer standard consisted of two types of pressure monitors, a base-plate, a mercury thermometer, a sensitive bubble level, a reference level bar, an oil pan, a shut-off valve and connecting parts. A mercury thermometer was used to measure the temperature on the base-plate. The tilt orientation of the base-plate was checked using a sensitive bubble level mounted on the base plate and any observed changes were corrected using the leveling screws. The reference level of the transfer standard was represented by a reference level bar on the base-plate. The height of the reference level bar from the top surface of the base-plate was 48 mm. The height of one end of a U-tube was adjusted to the same height as the reference level bar. Two electric thermometers were installed in the transfer standard to check the temperature change during the comparison including the transportation. The temperature measured by the thermometer was recorded into the memory automatically. The data was extracted from the memory at the pilot institute using a special device, which was presented in section 4.3. Through a specified connecting port of the transfer standard, the transfer standard was connected to a participant's pressure balance. A shut-off valve Vi, which was prepared by the participant, was used between the specified connecting port and the participant's pressure balance at the same level of the transfer standard as shown in Figure 3.3. The dimensions of the transfer standard were approximately 600 mm × 360 mm × 150 mm, the total weight was about 18 kg.

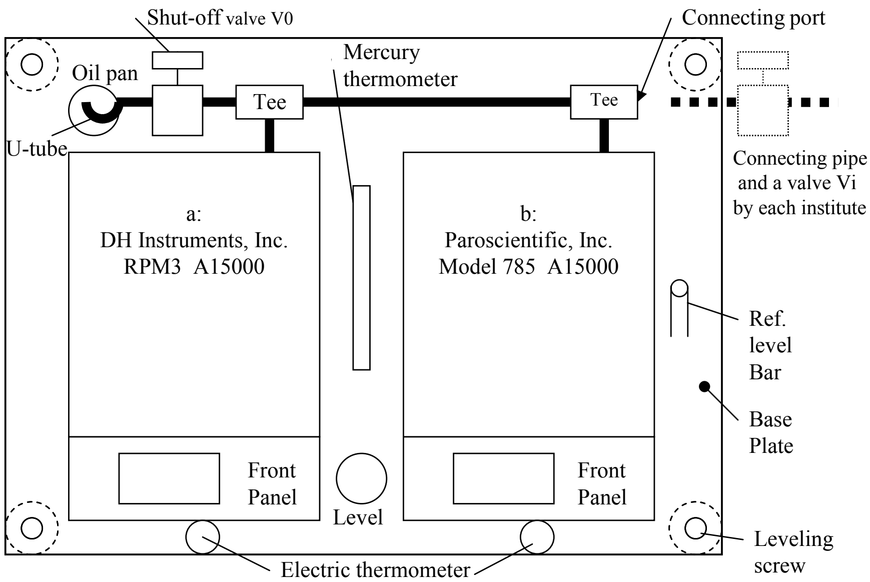


Figure 3.3: Schematic drawing of transfer standard.

3.3 Transfer package

NMIJ/AIST prepared three nominally identical transfer standards from the six pressure monitors as follows:

Transfer standard A: for comparison loop A.

Transfer standard B: for comparison loop B.

Transfer standard C: for comparison loop C.

A single commercial container, which was resistant to mechanical shock and vibration, was used for carrying each transfer standard. The transfer standard was put in the container when it was transferred. The dimensions of the container were approximately 850 mm × 570 mm × 360 mm, the total weight was about 34 kg. Shock meter seals were attached in the box for measuring the condition during transportation.

The contents of the transfer package were a transfer standard, two power cables for both pressure monitors, reserve parts, copies of the manual and the protocol for this comparison as listed in Table 3.4.

Table 3.4: Contents of a transfer package.

Carrying container	(1)	
Transfer standard	(1)	
Power cable	(2) For both pressure monitors	
Oil pan	(2)	
Reserve parts	Tee	CT4440, Number of stock: (1)
	Shut-off valve	60VM4071, Number of stock: (1)
	Color	ACL40, Number of stock: (3)
	Grand nut	AGL40, Number of stock: (3)
Manual	(2) For both pressure monitors[12,13]	
Protocol	(1) Document[7,8]	

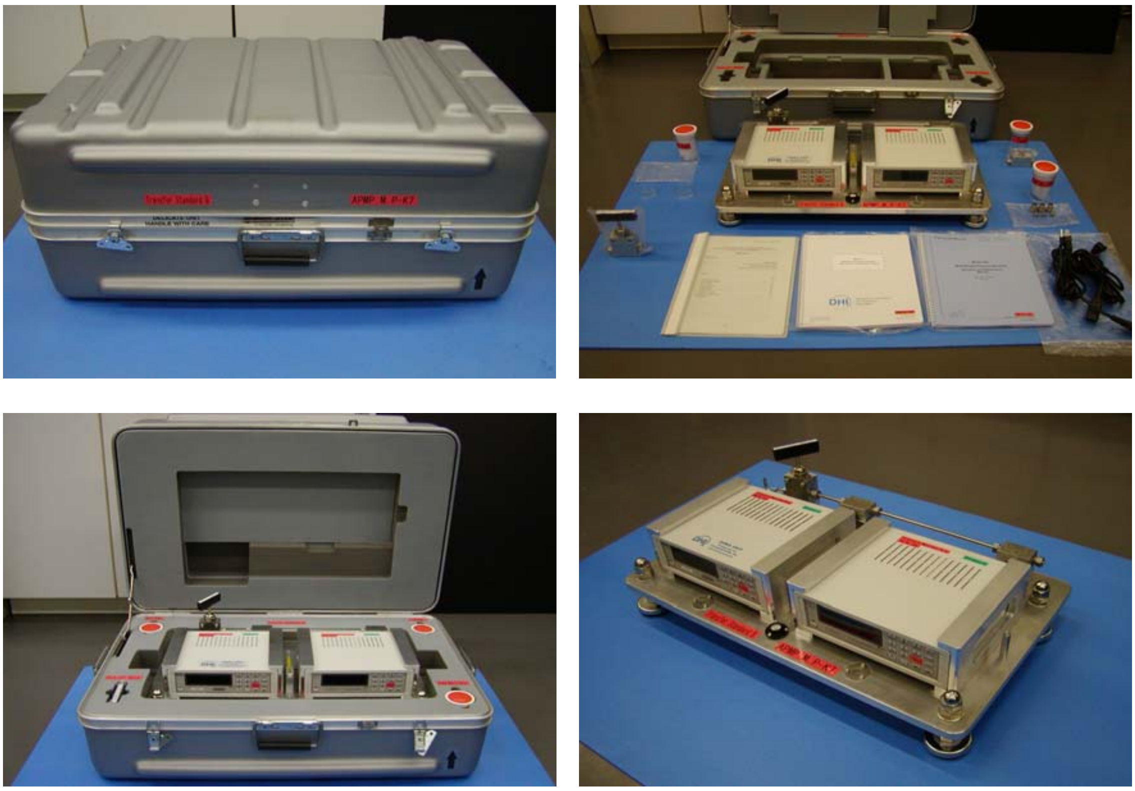


Figure 3.4: Photographs of transfer standard for APMP.M.P-K7.

4. Circulation of the transfer standards

4.1 Chronology of measurements

According to the protocol[7,8], three nominally identical transfer packages were circulated independently during the period October 2002 to December 2003 with calibrations at the pilot institute (NMIJ/AIST) at the start, middle and end of the comparison.

For each circulation, ATA CARNET was prepared by the pilot institute. When the package arrived at the participating institute, the followings procedure was required. The package was unpacked, and an inspection of the appearance was made. Then, the function of the devices was checked. The results were noted on the corresponding paper sheets attached in appendix[8]. The NMIJ/AIST and the institute from where it had been sent were informed about the arrival time and about the result of the inspection. When the package departed from the participating institute to the next institute, all parts were required to be put in the original package appropriately. An inspection of the appearance was made, and the function of the devices was checked. The results were noted on the corresponding paper sheets attached in appendix[8]. The NMIJ/AIST and the institute to where it would be sent were informed about the departure time and about the result of the inspection.

Tables 4.1, 4.2 and 4.3 present the actual chronology of measurements in comparison loops A, B and C with transfer standards A, B and C, respectively. Figures 4.1, 4.2 and 4.3 show the transportations of transfer standards A, B and C on a world map, respectively. Although MSL (New Zealand) withdrew from this comparison, the record of the transportation in comparison loop C was included for reference. The arrival and departure dates, and dates during which calibration data was taken at each participating institute are listed. The comparison was organized on a petal basis with the transfer packages returning periodically to the pilot institute (NMIJ/AIST) for calibrations. Throughout the comparison three transfer standards were calibrated simultaneously eleven times at the pilot institute. The actual sequence of the simultaneous calibrations of the transfer standards at the pilot institute is listed in Table 4.4. The total time required to complete the measurements phase of this comparison was fifteen months.

Table 4.1: Chronology of measurements in comparison loop A with transfer package A.

Petal	Institute	Country	Arrival	Departure	Dates for calibrations
Petal A.1	NMIJ/AIST	Japan	---	2002/11/18	---
	NPLI	India	2002/12/5	2002/12/19	2002/12/11, 12, 13
	CSIR-NML	Republic of South Africa	2003/1/15	2003/2/5	2003/1/21, 22, 24
	NIS	Egypt	2003/3/5	2003/4/1	2003/3/11, 17, 18
	NMIJ/AIST	Japan	2003/4/10	2003/5/30	---
Petal A.2	KRISS	Republic of Korea	2003/6/9	2003/6/30	2003/6/17, 19, 20
	SCL	Hong Kong, China	2003/7/3	2003/7/29	2003/7/8, 9, 10
	SPRING	Singapore	2003/8/5	2003/8/27	2003/8/14, 15, 16
	NMIA	Australia	2003/9/2	2003/9/25	2003/9/16, 18, 19
	VMI	Vietnam	2003/10/8	2003/10/24	2003/10/20, 21, 22
	NMIJ/AIST	Japan	2003/11/1	---	---

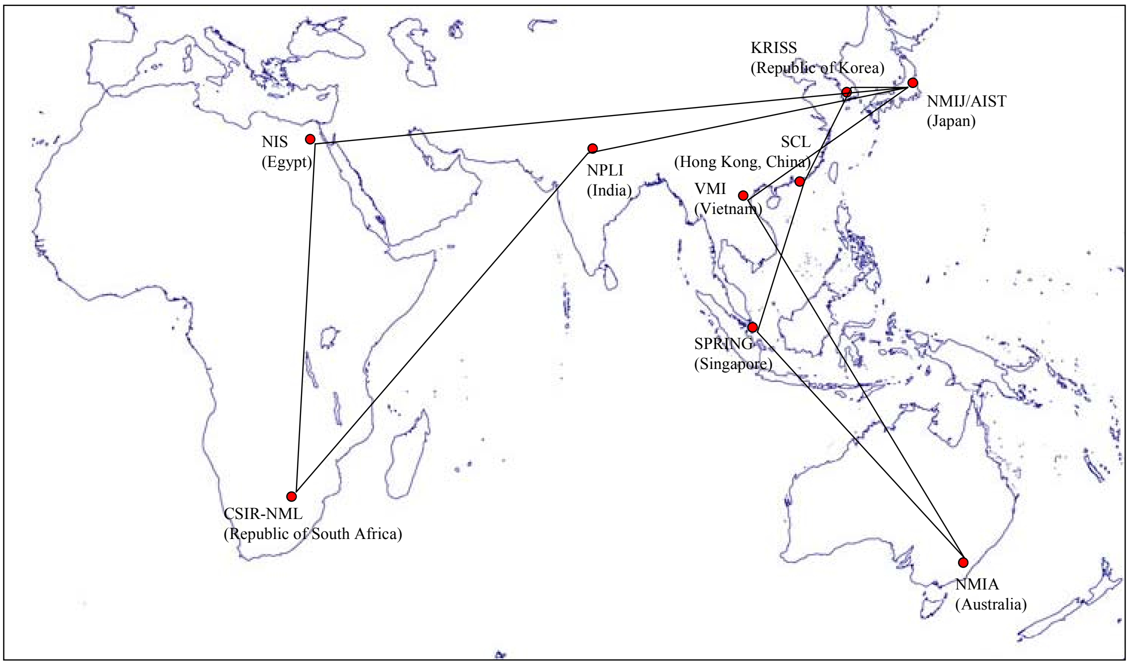


Figure 4.1: Circulation in comparison loop A.

Table 4.2: Chronology of measurements in comparison loop B with transfer package B.

Petal	Institute	Country	Arrival	Departure	Dates for calibrations
Petal B.1	NMIJ/AIST	Japan	---	2002/11/18	---
	NML-SIRIM	Malaysia	2002/11/27	2002/12/28	2002/12/11, 12, 18
	KIM-LIPI	Indonesia	2003/1/8	2003/2/17	2003/1/27
	NSCL	Syria	2003/2/25	2003/3/20	2003/3/9, 10, 11
	NMIJ/AIST	Japan	2003/3/27	2003/5/30	---
Petal B.2	PTB	Germany	2003/6/4	2003/6/30	2003/6/26, 27, 30
	NIMT	Thailand	2003/7/16	2003/7/30	2003/7/26, 27, 28
	CMS/ITRI	Chinese Taipei	2003/8/18	2003/9/12	2003/9/2, 3, 4
	NMIJ/AIST	Japan	2003/9/20	---	---

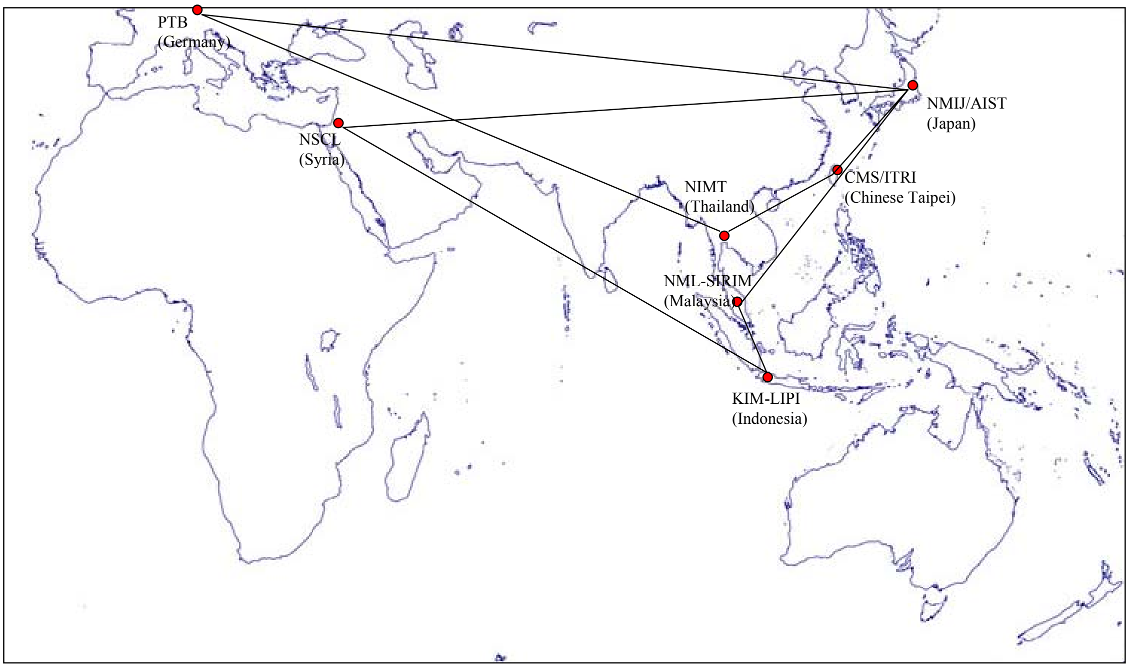


Figure 4.2: Circulation in comparison loop B.

Table 4.3: Chronology of measurements in comparison loop C with transfer package C.

Petal	Institute	Country	Arrival	Departure	Dates for calibrations
Petal C	NMIJ/AIST	Japan	---	2003/9/10	---
	MSLNZ	New Zealand	2003/9/18	2003/10/1	No calibration results reported
	NIM	China	2003/10/21	2003/11/6	2003/10/31, 11/1, 2
	NMIJ/AIST	Japan	2003/11/14	---	---

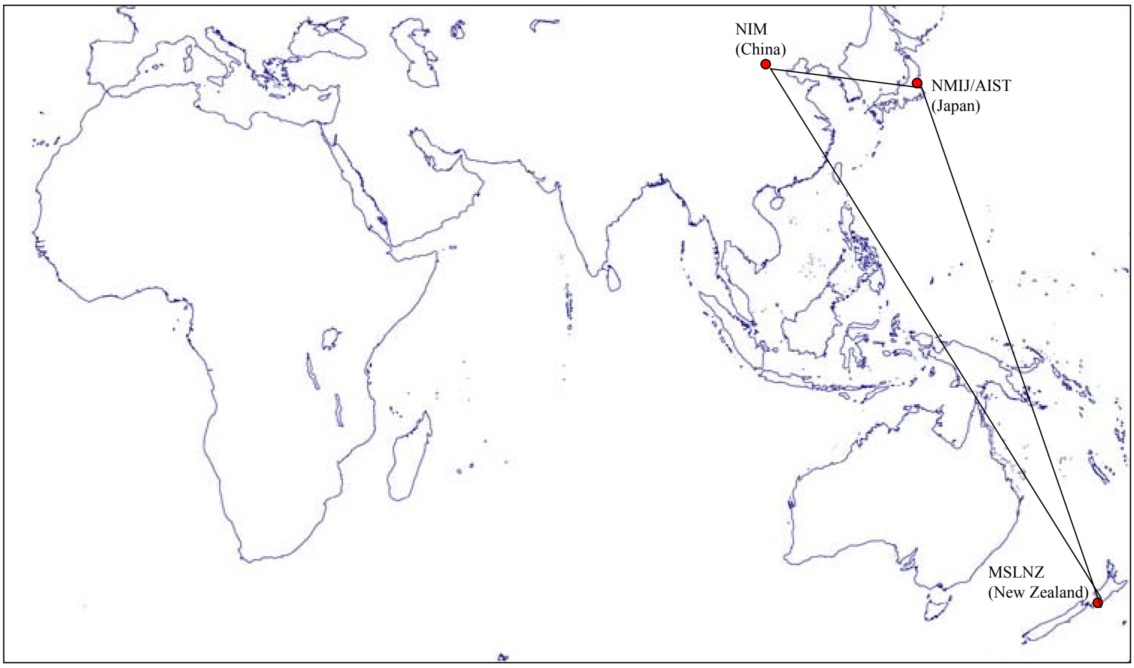


Figure 4.3: Circulation in comparison loop C.

Table 4.4: Simultaneous calibrations performed at the pilot institute (NMIJ/AIST). In temperature column, "Normal", "Lower" and "Higher" mean the temperatures of laboratory, which were around 23 ˚C, 20 ˚C and 26 ˚C, respectively.

Index	Dates for calibrations	Temperature
1	2002/10/9, 10, 11	Normal
2	2002/10/15, 16, 17	Lower
3	2002/10/18, 21, 22	Higher
4	2002/10/29, 30, 31	Normal
5	2002/11/11, 12, 13	Normal
Petal A.1, B.1		
6	2003/4/15, 17, 18	Normal
7	2003/5/16, 20, 22	Normal
Petal A.2, B.2, C		
8	2003/11/17, 19, 20	Normal
9	2003/11/24, 25, 26	Lower
10	2003/11/27, 28, 29	Higher
11	2003/12/1, 2, 3	Normal

4.2 Repair of the transfer standard and rescheduling

Concerning pressure monitor B.a on transfer standard B, the problems to be repaired occurred at KIM-LIPI, Indonesia, NSCL, Syria and CMS/ITRI, Chinese Taipei in comparison loop B. At KIM-LIPI, Indonesia and NSCL, Syria in petal B.1, the problems were solved by the effort and help made by each institute’s people and agents of the manufacture. The problems happened inside the pressure monitor due to an uncommon bad power supply to the input to the board. The problems might be caused by a rough handling of the transfer standard package during shipment between NMIs. However, the problem did not show any unusual change on the characteristic of the pressure transducer inside the monitor, which was confirmed from the evaluation of the calibration results performed before and after the comparison loop. Therefore, both measurement results obtained from pressure monitors B.a and B.b were used for calculating the values of the institutes participated in petals B.1 and B.2 of the comparison loop except CMS/ITRI, Chinese Taipei. At CMS/ITRI, in petal B.2, the effort and help to solve the similar problem were also made in cooperation with the CMS/ITRI people. However, in that case, it was turned out that pressure monitor B.a should be repaired at the pilot institute with an agent of the manufacture. Since there were two pressure monitors on the transfer standard, it was decided that the calibration at CMS/ITRI should be continued using a remaining pressure monitor according to the protocol[7]. CMS/ITRI calibrated pressure monitor B.b on transfer standard B and the result obtained from the pressure monitor was analyzed at the pilot institute to calculate the value of CMS/ITRI. Although the time slots for MSLNZ, New Zealand and NIM, China were originally scheduled after CMS/ITRI in comparison loop B, those were rescheduled as comparison loop C to minimize the time required for completion of this comparison using transfer standard C, which had been calibrated by the pilot institute.

After the transfer standard B arrived at the pilot institute from CMS/ITRI, the failed pressure monitor was checked and was repaired by the pilot institute with an agent of the manufacture. From the check, it was turned out that an element for power supply was cause of the problem, which was not related to the characteristic of the transducer. Again, the characteristic of the pressure transducer was not unusually changed, which was confirmed from the calibration results at the pilot institute.

4.3 Temperature change on the transfer standard during comparison

As explained in section 3, two electric thermometers were installed in each transfer standard to check the temperature change during the whole comparison including the transportation. From outputs obtained from two thermometers, the average temperature on each transfer standard every three hours was obtained as shown in Figure 4.4. The results indicate that the temperature range measured by the thermometers was approximately from in the range from 4 ℃ to 33 ℃ during the whole comparison including the transportation. The temperature range was almost the same as the recommended operating temperature range of 5 ℃ to 35 ℃ by the manufactures. Therefore, it can be stated that the temperature of the transfer standards was maintained in the normal operating range during the whole comparison. It seemed to be sound to keep the characteristics of pressure transducers.

The temperature measured on each transfer standard reported by each participating institute was compared with the temperature described above. There was no clear systematic difference. Therefore, the temperature reported by each participant was used to make a temperature correction on the reading of each pressure monitor.

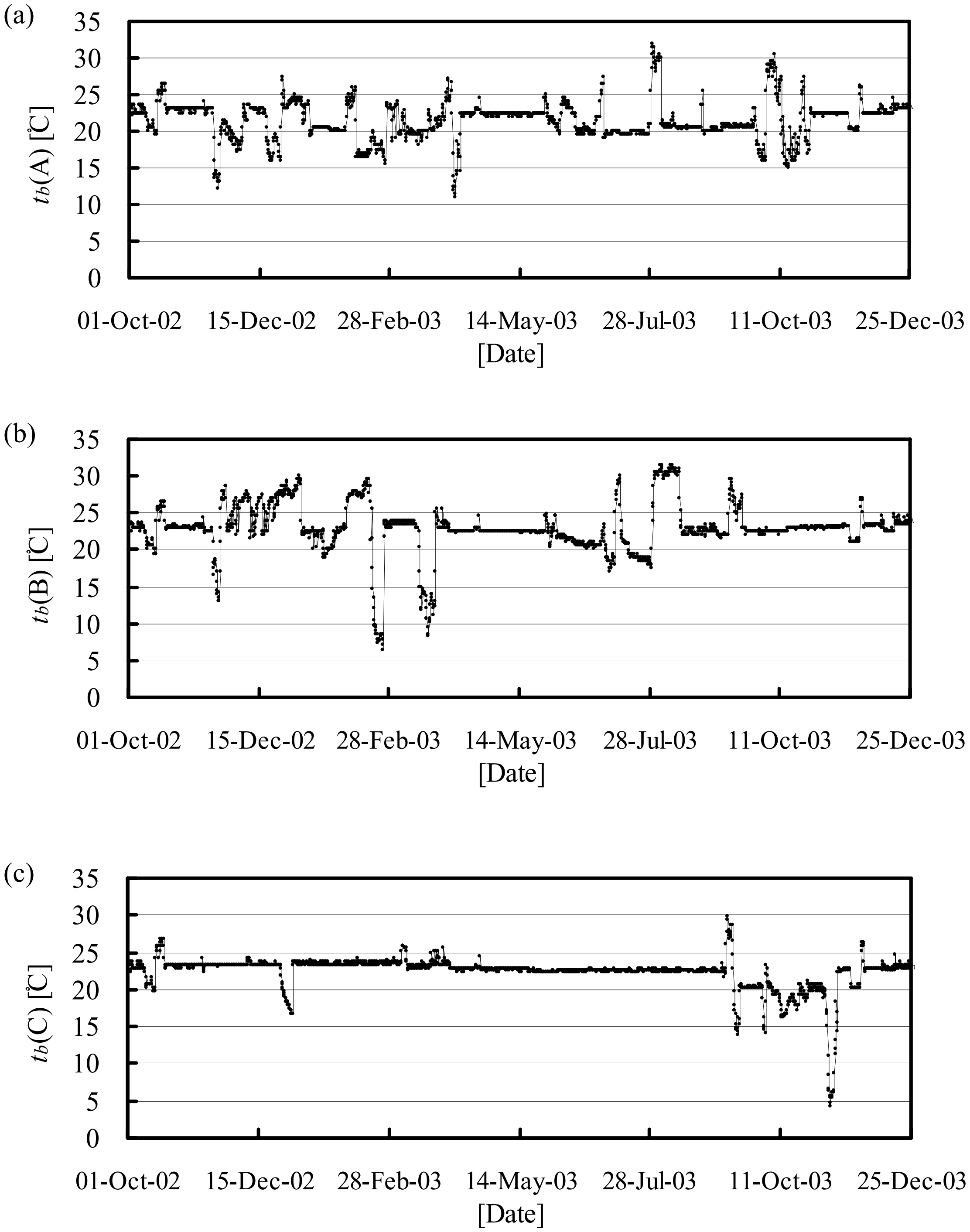


Figure 4.4: Temperature changes on transfer standards (a) A, (b) B and (c) C.

5. Calibration

The general procedure required that each participant calibrated the transfer standard for this comparison was described in the protocol[7,8].

5.1 Preparation

All participants were required to prepare clean Di(2)-ethyl-Hexyl-Sebacate (DHS) as a working fluid. The pressure standard of each participating institute was operated at the normal operating temperature of the institute. The environmental condition, such as atmospheric pressure, ambient temperature and relative humidity, during the calibration was measured using the participant's own devices.

For the preparation of the calibration, the followings were recommended: (i) At latest, twenty-four hours before starting the measurement procedure, pressure monitors should be connected to a power supply and be turned on for warming up and stabilization. (ii) The power supply for the pressure monitors should be maintained during all the calibrations at the participating institute. (iii) Setting parameters of each pressure monitor should be set as follows:

- Range of 100 MPa
- kPa unit
- Gauge mode
- Average measurement mode for twenty readings each twenty seconds
- kPa resolution
- Autozero function ON

(iv) After the installation, the transfer standard system should be pressurized using the system of each participant up to 100 MPa and the function of each pressure monitor and the leak in the test system should be checked. (v) During twelve hours before the start of each calibration cycle, no gauge pressure should be applied to both pressure monitors.

5.2 Head correction by height difference

The pressure generated by a pressure standard at the reference level, P, is represented by the following equation:

$$P = P_{std} + (\rho_f - \rho_a)\cdot g_l\cdot H \qquad (5.1)$$

where, P_{std} is the pressure generated by the participant's pressure standard at its reference level; $(\rho_f - \rho_a)\cdot g\cdot H$, is the head correction, with ρ_f the density of the working fluid, ρ_a the air density, g_l the local acceleration due to gravity, and H the vertical distance between the reference levels of the two intercompared standards (institute standard and transfer standard). *H* is positive if the level of the institute's standard is higher. Each participant should make appropriate corrections for the height difference between the reference levels on the applied pressure to the reference level of the transfer standard, and include their contributions into the uncertainty of the applied pressure.

5.3 Calibration procedure

At nominal target pressures of 0, 10 MPa, 20 MPa, 30 MPa, 40 MPa, 50 MPa, 60 MPa, 70 MPa, 80 MPa, 90 MPa, and 100 MPa, the pressure applied and the readings of the pressure monitors were measured. The values, together with the respective measurement uncertainties, were the main basis of the comparison.

5.3.1 Complete measurement cycle

One complete measurement cycle consists of pressure and temperature recordings obtained from the transfer standard and the pressure standard at twenty-three pressure points of eleven pressure points from 0 MPa to 100 MPa in step of 10 MPa in ascending order, one point 0 MPa, and eleven points from 100 MPa to 0 MPa in step of 10 MPa in descending order as shown in Figure 5.1. The ascending pressure measurement cycle must start from 0 MPa while the descending pressure measurement must start from 100 MPa. The results of the measurement were recorded on the measurement results sheet prepared in appendix[8]. One complete measurement cycle was performed in a day. A total of three calibration cycles were required, with each cycle being on a separate day.

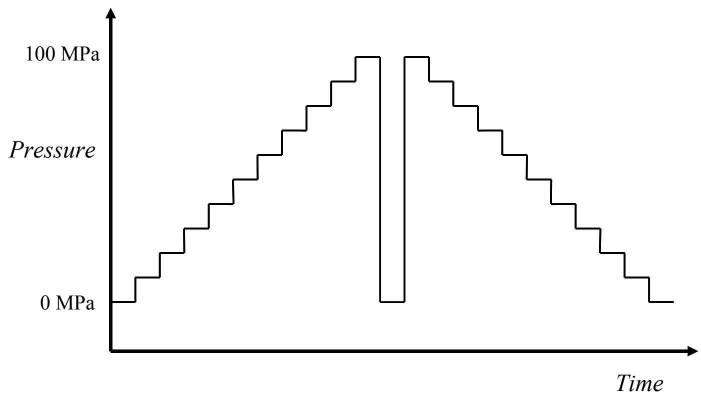


Figure 5.1: One complete measurement cycle.

5.3.2 Calibration at 0 MPa

At the beginning, middle and end of each cycle, zero-pressure readings for the pressure monitors were measured. These data were used to correct calibration data for zero-pressure offsets. To apply zero gauge pressure to the pressure monitors, the valve V0 was opened and the valve Vi was closed. (See Figure 3.3) After the waiting of ten minutes, within five minutes, the readings of each pressure monitor, which were the resulting average for the twenty measurements and its corresponding standard deviation σ, were measured. The temperature on the base-plate, t_b, and the environmental condition were also measured. Those data were recorded in the cell on the forms annexed to the protocol[7,8] as shown in Table 5.1.

Table 5.1: Example of data recording at 0 MPa.

Nom. Pres. [MPa]	Local Time	Atmo Temp. [°C]	Atmo R.H. [%]	Atmo Pres. [kPa]	Temp. Base t_b [°C]	Reading R_a [kPa]		Reading R_b [kPa]		Applied Pressure P [kPa]	$u(P)$ [kPa] (k=1)
						Average	σ	Average	σ		
0	9:30	23.0	45.0	101.2	23.1	3.5	0.2	-5.5	0.1	---	

5.3.3 Calibration at 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 MPa

The pressure generated by the participant's standard was applied to the transfer standard by closing valve V0 and opening valve Vi. The position of the piston of the pressure balance was kept in the floating range to maintain the pressure using the device such as a hand pump. It was required that the difference between actual pressure realized at the transfer standard by the participant's pressure standard and the target pressure should be within a thousandth of the target pressure. After the waiting of ten minutes for stabilizing the pressure, within five minutes, the readings of each pressure monitor, which were the resulting average for the twenty measurements and its corresponding standard deviation σ, were measured. Then, the applied pressure with the associated standard uncertainty at the reference level of the transfer standard was calculated. Any influence quantity for the institute system was taken into account in the uncertainty estimation appropriately by each participant. The correction by the differential height of the reference levels between the participating institute's standard and the transfer standard was considered. These data were recorded in the cell on the forms annexed to the protocol[7,8] as presented in Table 5.2. In the table, P is the pressure applied by the participant's standard at the local gravity g_l and the local air density ρ_a

and calculated at the reference level of the transfer standard using equation (5.1) and $u(P)$ is the standard uncertainty of P.

Table 5.2: Example of data recording at target pressure except 0 MPa.

Nom. Pres. [MPa]	Local Time	Atmo Temp. [°C]	Atmo R.H. [%]	Atmo Pres. [kPa]	Temp. Base t_b [°C]	Reading R_a [kPa]		Reading R_b [kPa]		Applied Pressure P [kPa]	$u(P)$ [kPa] (k=1)
						Average	σ	Average	σ		
100	13:54	23.0	45.0	101.2	23.1	100041.1	0.3	99998.5	0.2	99999.8	5.6

5.3.4 Results to be reported

After the measurements were completed at the participating institute, the calibration results were transmitted to the pilot institute. The pilot institute, NMIJ/AIST, collected the following data and information using the sheets annexed to the protocol[7,8].

(i) Measured and calculated values at the nominal pressures specified, each with an uncertainty in the measurement and the date(s) on which calibration cycle was undertaken [three cycles].

(ii) Details of the participating institute's standard(s) against which the transfer standard was calibrated, including the origin of its traceability to the SI (presented in Table 2.2).

(iii) Details of the parameters used for the comparison, which were local gravity, differential height of the reference levels between the participating institute's standard and the transfer standard, density of working fluid, the voltage and frequency applied to pressure monitors (presented in Table 5.3).

(iv) Uncertainty budget of the pressure generated, which shall be estimated and combined following GUM[5] under the responsibility of the participating institute. The uncertainties were evaluated at a level of one standard uncertainty at the participating institute.

Also, the uncertainty estimation of each pressure monitor calibrated was reported by several institutes optionally.

5.4 Parameters used by each participating institute

Details of the parameters used by each participating institute are listed in Table 5.3. The name of participating institute, the name of country, the local gravity, the height difference, the fluid density with associated standard uncertainties, the voltage and frequency applied to pressure monitors are presented.

Table 5.3: Details of the parameters used by each participating institute. All the uncertainties are expressed as the standard ones.

j	Institute	Country	Local gravity g_l			Height diff. H		ρ_f (DHS)		Voltage	Frequency
			Value [m/s^2]	Unc. [m/s^2]	Unc. [ppm]	Value [mm]	Unc. [mm]	Value [kg/m^3]	Unc. [kg/m^3]	[VAC]	[Hz]
1	NMIJ/AIST	Japan	9.7994804	2.0E-06	0.20	0.0	0.5	Eq.(1)	1%	100	50
2	NPLI	India	9.7912393	9.0E-07	0.09	249	0.5	857.5	0.005	110	50
3	CSIR-NML	Republic of South Africa	9.7860994	1.5E-06	0.15	0	2	920	20	100	50
4	NIS	Egypt	9.792999	4.9E-05	5.00	-5	2	914	50	220	50
5	KRISS	Republic of Korea	9.798321	5.8E-06	0.59	0	0.58	Eq.(1)	0.58%	110	60
6	SCL	Hong Kong, China	9.7872346	2E-06	0.20	0	2.9	946 - 973	29	100	50
7	SPRING	Singapore	9.7805553	1.8E-06	0.18	0.0	0.3	914	20	110	50
8	NMIA	Australia	9.79637612	5E-06	0.51	262	1	914.05	2.5E-02	110	50
9	VMI	Vietnam	9.78668927	2.25E-08	0.00	110	1	913	0.1	100	50
10	NML-SIRIM	Malaysia	9.78056052	1.0E-05	1.02	0	0.6	912.7	12.5	100	50
11	KIM-LIPI	Indonesia	9.78137931	9.8E-05	10.00	178.6	0.58	908.5	0.2	100	50
12	NSCL	Syria	9.79403	7.0E-05	7.15	106	5	Eq.(2)	7.5	100	50
13	PTB	Germany	9.812533	5.3E-06	0.54	-0.13	0.37	Eq.(1)	1%	230	50
14	NIMT	Thailand	9.7829703	5.648E-06	0.58	0	1.15	914	-	100	50
15	CMS/ITRI	Chinese Taipei	9.78913981	8.3E-08	0.01	0	2	913	52.7	110	60
16	NIM	China	9.801260	5.0E-06	0.51	34	1.2	916	1	220	50

Eq.(1) $\rho_f = [912.7 + 0.752\,(p/\text{MPa}) - 1.645\cdot10^{-3}\,(p/\text{MPa})^2 + 1.456\cdot10^{-6}\,(p/\text{MPa})^3] \times [1 - 7.8 \times 10^{-4}\,(t/°\text{C} - 20)]$ kg/m^3.

Eq.(2) $\rho_f = 913 / [1 + 0.000768\,(t/°\text{C} - 25)] + 0.442\,(p/\text{MPa}) - 2.72\times10^{-4}\,(p/\text{MPa})^2$ kg/m^3.

ρ_f: density of Di(2)-ethyl-Hexyl-Sebacate (DHS), p : pressure, t : temperature

6. Analysis of reported data

Data obtained from one complete measurement cycle consist of the recordings of the pressure and temperature obtained from a transfer standard, the pressure applied by a pressure standard and environmental parameters at twenty-three pressure points of eleven pressure points from 0 MPa to 100 MPa in step of 10 MPa in ascending sequence, one point 0 MPa, and eleven points from 100 MPa to 0 MPa in step of 10 MPa in descending sequence. Therefore, the following data sets were obtained from the reported results.

$$\{R(j,k,m,y,w,i,n), P(j,k,y,w,i), t_b(j,k,y,w,i)\}$$

where the meanings of the parameters are as follows:

R [kPa]: Raw reading of pressure monitor,

P [kPa]: Applied pressure at the reference level of each transfer standard by pressure standard j,

t_b [°C]: Temperature measured on each transfer standard,

j : Index for participating institute,

k : Index for transfer standard A – C, $k = 1 - 3$,

m : Index for pressure monitor a or b, $m = 1$ or 2,

y : Index for measurement cycle,

w : Index for indicating ascending or descending measurements, $w = 1$ or 2,

i : Index for indicating pressure, $i \times 10$ MPa, $i = 0 - 10$,

n : Number of days from the beginning date, 1 October 2002, which was defined for purpose of evaluating a long-term shift with time, to the date which the calibration was performed.

In this section, the reduction and analysis of the data are performed by the following procedure:

6.1 Correction for zero-pressure offsets,

6.2 Correction for difference between nominal pressure and actual pressure,

6.3 Correction to reference temperature,

6.4 Correction for long-term shift in characteristics of transducer,

6.5 Normalization of mean ratio of transfer standard,

6.6 Calculation of normalized mean ratio of participating institute,

6.7 Calculation of expected mean pressure of participating institute,

6.8 Estimation of uncertainties.

6.1 Correction for zero-pressure offsets

There were three 0 MPa pressure points in one measurement cycle. From calibration results performed at the pilot institute, it was confirmed that the reproducibility of the reading of pressure monitor at an intermediate 0 MPa point was not better than those at first or last 0 MPa points. The reading at an intermediate 0 MPa point was susceptible to the history suffered at past pressure points. Therefore, in this analysis, the reading at an intermediate 0 MPa point was not used. The readings for ascending and descending pressure points of each cycle are offset by the readings at first and last 0 MPa points of each cycle, respectively. By subtracting the offset from the raw reading R, the corrected reading R_{c0} is obtained as follows:

$$R_{c0}(j,k,m,y,w,i,n) = R(j,k,m,y,w,i,n) - R(j,k,m,y,w,0,n) \tag{6.1}$$

6.2 Correction for difference between nominal pressure and actual pressure

R_{c0} is the reading of pressure monitor when the actual pressure realized at the transfer standard by the participant's pressure standard, P, is applied. Since the readings of pressure monitors are nominally linear and the ratios of the readings of pressure monitors to the actual pressure are generally independent of pressure for the pressure range that the deviation of the actual pressure from the nominal target pressure is small. As described in the protocol[7], the difference between actual pressure applied and the nominal target pressure was adjusted to be within a thousandth of the nominal pressure. The ratios can be used to correct the readings for deviations of the pressure standard from the nominal pressure. When an exact nominal pressure P_n is applied to the pressure monitor, the predicted reading, R_{c1}, is calculated by

$$R_{c1}(j,k,m,y,w,i,n) = \frac{R_{c0}(j,k,m,y,w,i,n)}{P(j,k,y,w,i)} \cdot P_n(i), \tag{6.2}$$

where R_{c0} and P are the simultaneous readings of pressure monitor and the actual pressure applied, respectively.

6.3 Correction to reference temperature

R_{c1} is the reading of each pressure monitor when the base temperature is t_b. Since the reading is affected by the temperature, the reading should be corrected. During the comparison, the effect on the reading by the temperature was evaluated by the pilot institute. Here, the temperature coefficient of each pressure monitor at each target nominal pressure, $\beta(k,m,i)$ [kPa/℃], is calculated by the following equation from calibration data obtained at the pilot institute j = 1:

$$\beta(k,m,i) = \frac{1}{12} \cdot \sum_{q=1}^{2} \sum_{w=1}^{2} \sum_{y=1}^{3} \frac{R_{c1}^{q}(1,k,m,y,w,i,n) - R_{c1}^{0}(1,k,m,y,w,i,n)}{t_b^{q}(1,k,y,w,i) - t_b^{0}(1,k,y,w,i)} \tag{6.3}$$

where t_b^q is the measured temperature on each transfer standard obtained from the calibration results performed at around 23 ℃ for q = 0, 20 ℃ for q = 1 and 26 ℃ for q = 2, respectively, and R_{c1}^q is the corresponding reading of each pressure monitor. The standard uncertainty of the coefficient was estimated as $u\{\beta(k,m,i)\} = u\{\beta(i)\} =$ 0.03 kPa/℃.

Table 6.1 and Figure 6.1 present the calculated temperature coefficients of each pressure monitor for nominal target pressures. Though some points were deviated discontinuously in Figure 6.1, the deviation was not due to lack of measurement points and it came from the actual characteristics of the pressure monitor evaluated. It has been confirmed that the reading of pressure monitor can be corrected sufficiently using the temperature coefficient.

Table 6.1: Temperature coefficients of each pressure monitor.

Org.		Temperature coefficient, β [kPa/C°]					
k		1	1	2	2	3	3
m		1	2	1	2	1	2
Monitor		A.a	A.b	B.a	B.b	C.a	C.b
i	[MPa]	Average	Average	Average	Average	Average	Average
1	10	0.023	-0.056	-0.063	0.021	0.089	0.018
2	20	0.045	0.222	0.041	0.042	0.057	0.013
3	30	0.104	0.073	0.078	0.015	0.136	0.051
4	40	0.102	0.109	0.087	0.004	0.132	0.066
5	50	0.122	0.097	0.106	-0.010	0.160	0.063
6	60	0.114	0.075	0.125	0.094	0.156	0.053
7	70	0.084	0.338	0.150	-0.040	0.171	0.050
8	80	0.132	0.076	0.132	-0.052	0.289	0.059
9	90	0.127	0.058	0.133	-0.068	0.158	-0.032
10	100	0.096	-0.048	0.087	-0.126	0.081	-0.014

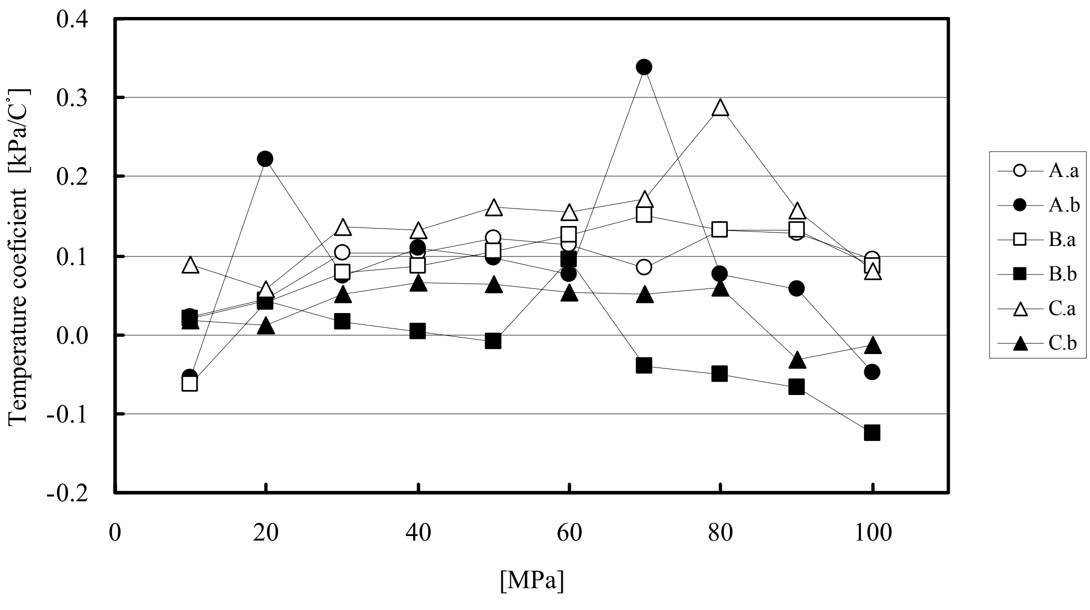


Figure 6.1: Calculated temperature coefficients of each pressure monitor as a function of nominal target pressure.

From the temperature coefficient calculated by equation (6.3), the reading corrected to a reference temperature, R_{c2}, can be calculated as

$$R_{c2}(j,k,m,y,w,i,n) = R_{c1}(j,k,m,y,w,i,n) - \beta(k,m,i)\cdot\left[t_b(j,k,y,w,i) - t_r\right]. \tag{6.4}$$

where t_r is the reference temperature which is determined as stated in the followings.

The average temperature measured on each transfer standard by a mercury thermometer by the participating institutes for nominal target pressure, $\overline{t_b}(j,i)$, is calculated from

$$\overline{t_b}(j,i) = \frac{1}{6}\cdot\sum_{w=1}^{2}\sum_{y=1}^{3} t_b(j,k,y,w,i) \tag{6.5}$$

For the pilot institute, $j = 1$, the average temperature is calculated from

$$\overline{t_b}(1,i) = \frac{1}{198}\cdot\sum_{l=1}^{11}\sum_{k=1}^{3}\sum_{w=1}^{2}\sum_{y=1}^{3} t_b^l(1,k,y,w,i) \tag{6.6}$$

where t_b^l is the temperature on each transfer standard obtained from l-th simultaneous calibration data set (eleven data sets in total) performed at the pilot institute. Table 6.2 and Figure 6.2 present the average temperatures calculated from equations (6.5) and (6.6). Since the reference temperature was not described in the protocol[7], it should be determined to be fair for all participants. The average of all the values in Table 6.2 is 21.33 ℃. Therefore, by rounding the value up slightly, the reference temperature of this comparison was determined as t_r = 21.5 ℃ so that the maximum temperature deviation of the participating institutes from the reference temperature was minimized. Since calibrations were performed at different temperatures, the uncertainty due to the deviation from the reference temperature has been estimated as described in later subsection.

Table 6.2: Average temperatures measured on the transfer standard by the participating institutes for nominal target pressures.

		Average temperature [C˚]															
j		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
0	0	23.37	23.17	20.90	20.19	20.38	20.43	20.71	21.00	18.55	22.53	21.06	23.92	20.87	19.17	23.67	20.70
1	10	23.38	23.17	20.93	20.31	20.42	20.43	20.68	21.00	18.78	22.53	21.23	23.92	20.87	19.17	23.72	20.73
2	20	23.37	23.18	20.95	20.27	20.47	20.42	20.68	21.00	18.97	22.60	21.37	23.88	20.87	19.08	23.72	20.73
3	30	23.37	23.18	20.95	20.17	20.50	20.40	20.67	21.00	19.08	22.62	21.26	23.88	20.90	19.08	23.78	20.75
4	40	23.37	23.18	20.93	20.18	20.53	20.38	20.69	21.00	19.20	22.58	21.35	23.83	20.90	19.08	23.82	20.77
5	50	23.37	23.17	20.93	20.21	20.58	20.37	20.69	21.00	19.20	22.68	21.28	23.83	20.90	19.08	23.83	20.82
6	60	23.37	23.18	20.93	20.19	20.58	20.32	20.68	21.00	19.20	22.67	21.28	23.83	20.90	19.08	23.83	20.83
7	70	23.37	23.18	20.93	20.17	20.63	20.32	20.68	21.00	19.18	22.65	21.37	23.83	20.90	19.17	23.83	20.85
8	80	23.37	23.18	20.93	20.21	20.63	20.28	20.70	21.00	19.17	22.63	21.30	23.83	20.92	19.17	23.85	20.87
9	90	23.37	23.18	20.93	20.31	20.60	20.27	20.69	21.00	19.13	22.73	21.15	23.83	20.92	19.17	23.87	20.85
10	100	23.37	23.17	20.93	20.42	20.62	20.27	20.72	21.00	19.15	22.77	21.25	23.83	20.92	19.17	23.87	20.87
Average		23.37	23.17	20.93	20.24	20.54	20.35	20.69	21.00	19.06	22.64	21.26	23.86	20.90	19.13	23.80	20.80

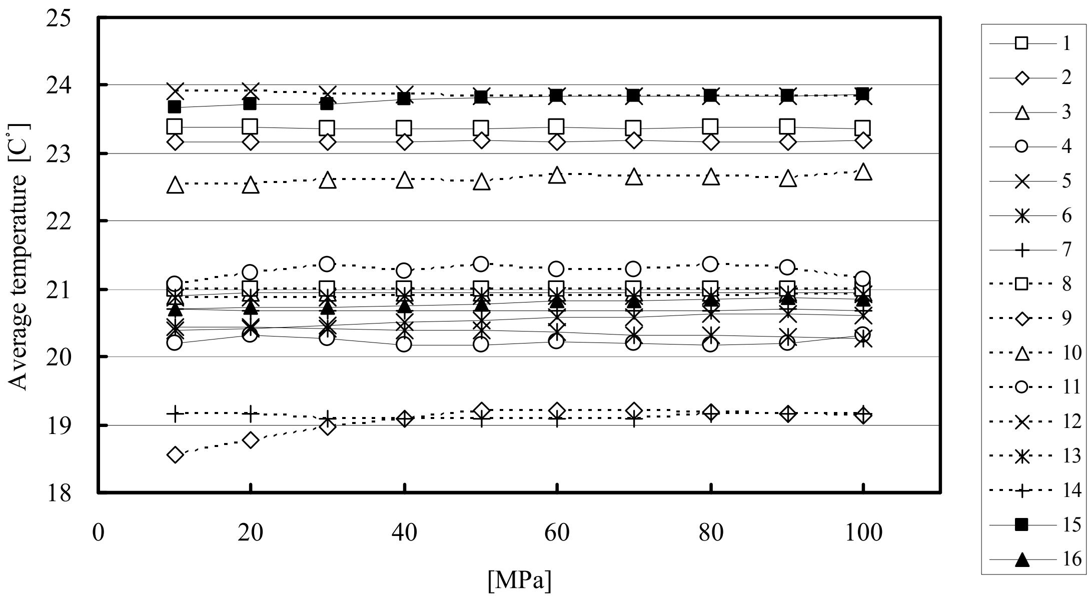


Figure 6.2: Average temperatures measured on each transfer standard by the participating institutes as a function of nominal target pressure.

6.4 Correction for long-term shift in characteristics of transducer

At the pilot institute, three transfer standards were calibrated simultaneously by a primary pressure standard. A calibration set from three cycle measurements were repeated eleven times by changing the calibration date and the temperature of laboratory. In the successive calibration results, a clear long-term shift was observed as a monotonic drift with time in the characteristics of each transducer. It has been confirmed that the shifts were due to the characteristics of the transducers and were not the pressure standard at the pilot institute. The stability of the pressure standard of the pilot institute had been checked by cross-float comparison against other standard pressure balances in the period of this comparison and it was confirmed that there was no systematic shift in the primary pressure standard and the instability was of the order of less than 2×10^{-6}.

In this analysis, the shift was fitted by a least-squares-best-fitting straight line using R_{c2} taken during simultaneous calibrations against the pressure standard at the pilot institute.

$$R_e(k,m,w,i,n) = \alpha_0(k,m,w,i)\cdot n + \alpha_1(k,m,w,i)\,. \tag{6.7}$$

where R_e is the predicted reading at the date which the calibration cycle was performed after n days from the beginning date, 1 October 2002. The predicted reading, once determined by the simultaneous calibrations, could be used to convert all comparison data. Table 6.3 lists the coefficients α_0 and α_1 calculated with the least-squares fit for the long-term shift obtained from eleven simultaneous calibrations at the pilot institute during this comparison. The relationships between the readings of six pressure monitors on three transfer standards can be known using equation (6.7) and the coefficients listed in Table 6.3. Figure 6.3 shows the coefficients α_0 obtained from the ascending sequence.

Table 6.3: Coefficients α_0 and α_1 calculated from the least-squares fit for pressure monitors.

			Coefficients for long-term shift, α_0 [kPa/day], α_1 [kPa]											
k			1		1		2		2		3		3	
m			1		2		1		2		1		2	
Monitor			A.a		A.b		B.a		B.b		C.a		C.b	
w	*i*	[MPa]	α_0	α_1	α_0	α_1	α_0	α_1	α_0	α_1	α_0	α_1	α_0	α_1
1	1	10	1.15E-03	10001.930	2.38E-03	10001.820	-5.14E-05	10000.926	8.76E-04	10002.366	9.44E-04	10001.554	1.53E-03	10000.036
1	2	20	2.20E-03	20003.970	4.61E-03	19999.213	2.31E-03	20003.594	2.11E-03	20002.476	1.49E-03	20003.028	2.51E-03	20000.579
1	3	30	3.41E-03	30006.294	8.54E-03	29998.881	3.65E-03	30004.917	3.96E-03	30002.667	2.17E-03	30003.708	3.70E-03	30000.460
1	4	40	4.71E-03	40008.755	1.38E-02	39999.602	5.18E-03	40007.121	6.10E-03	40002.613	2.90E-03	40005.490	5.08E-03	40000.228
1	5	50	5.67E-03	50011.241	1.96E-02	49999.764	6.50E-03	50008.880	8.33E-03	50002.567	3.42E-03	50007.570	6.62E-03	50000.583
1	6	60	6.97E-03	60013.586	2.60E-02	59999.928	7.66E-03	60011.037	1.04E-02	60001.719	4.03E-03	60010.018	8.21E-03	60000.840
1	7	70	8.33E-03	70017.400	3.21E-02	70002.293	8.98E-03	70013.797	1.32E-02	70003.760	4.56E-03	70012.462	1.01E-02	70001.127
1	8	80	9.01E-03	80020.432	3.88E-02	80003.887	9.39E-03	80016.933	1.54E-02	80003.878	5.26E-03	80017.846	1.20E-02	80001.395
1	9	90	1.01E-02	90023.499	4.51E-02	90003.649	9.79E-03	90019.772	1.78E-02	90004.166	5.68E-03	90020.704	1.31E-02	90003.321
1	10	100	1.03E-02	100026.362	5.15E-02	100000.650	9.68E-03	100021.975	2.00E-02	100004.086	6.02E-03	100020.724	1.51E-02	100002.357
2	10	100	1.02E-02	100027.515	4.91E-02	100000.934	1.01E-02	100022.157	1.88E-02	100005.361	5.93E-03	100021.484	1.37E-02	100003.587
2	9	90	8.83E-03	90025.479	4.29E-02	90005.140	9.36E-03	90020.980	1.66E-02	90005.513	5.20E-03	90021.668	1.19E-02	90004.582
2	8	80	7.33E-03	80023.135	3.71E-02	80006.188	8.58E-03	80018.866	1.45E-02	80005.272	4.79E-03	80018.964	1.12E-02	80002.715
2	7	70	5.99E-03	70020.623	3.09E-02	70005.053	7.70E-03	70016.170	1.26E-02	70005.234	3.75E-03	70013.713	9.43E-03	70002.420
2	6	60	4.95E-03	60016.978	2.60E-02	60002.749	6.45E-03	60013.486	9.95E-03	60003.134	3.32E-03	60011.279	7.98E-03	60002.067
2	5	50	3.66E-03	50014.594	2.08E-02	50002.450	5.29E-03	50011.259	8.58E-03	50003.853	2.71E-03	50008.787	6.67E-03	50001.716
2	4	40	2.73E-03	40011.768	1.64E-02	40001.851	4.11E-03	40009.216	6.85E-03	40003.712	2.21E-03	40006.580	5.28E-03	40001.167
2	3	30	1.96E-03	30008.859	1.17E-02	30000.645	2.86E-03	30006.596	4.90E-03	30003.534	1.69E-03	30004.632	4.00E-03	30001.173
2	2	20	1.55E-03	20005.882	7.42E-03	20000.448	1.80E-03	20004.793	3.17E-03	20003.056	1.17E-03	20003.649	2.87E-03	20001.028
2	1	10	6.29E-04	10002.963	4.17E-03	10002.443	-1.25E-04	10001.581	1.52E-03	10002.666	6.17E-04	10001.906	1.71E-03	10000.242

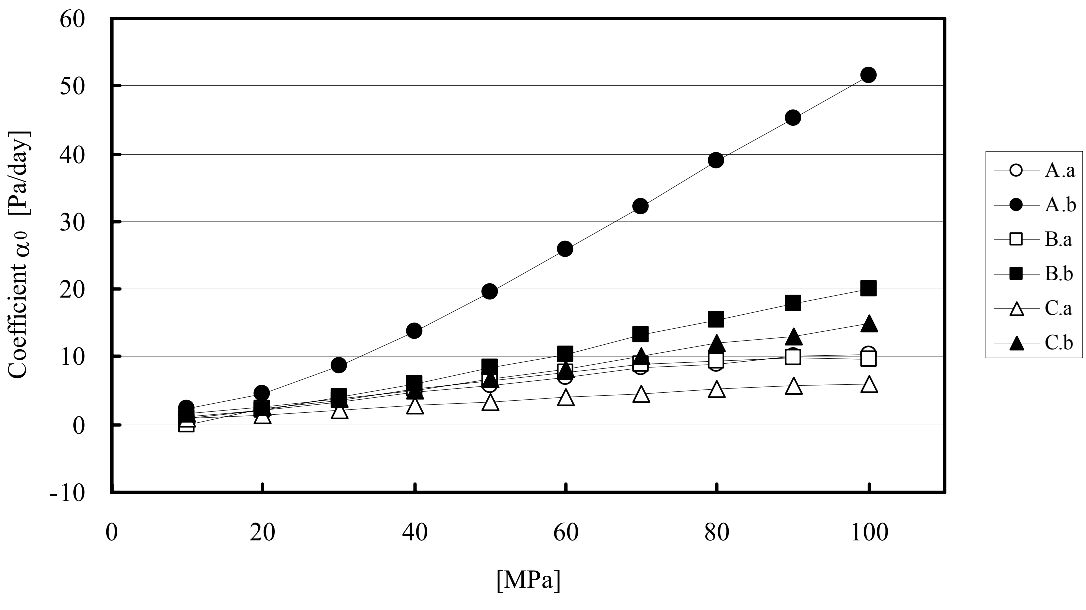


Figure 6.3: Coefficients $\alpha_0(k,m,1,i)$ calculated with the least-squares fit for the long-term shifts as a function of nominal target pressure.

6.5 Normalization of mean ratio of transfer standard

By taking the ratios of R_{c2} to R_e, the normalized mean ratio for each calibration point, s_0, is calculated as

$$s_0(j,k,m,y,w,i) = \frac{R_{c2}(j,k,m,y,w,i,n)}{R_e(k,m,w,i,n)}$$

(6.8)

By taking the average of s_0 for ascending and descending pressures of three cycles, the normalized mean ratio of each pressure monitor, s_1, is calculated as

$$s_1(j,k,m,i) = \frac{1}{6} \cdot \sum_{w=1}^{2} \sum_{y=1}^{3} s_0(j,k,m,y,w,i)$$

(6.9)

There were two pressure monitors on each transfer standard. By taking the average of s_1 for the pressure monitors, the normalized mean ratio of each transfer standard, s_2, is calculated as

$$s_2(j,k,i) = \frac{1}{2} \cdot \sum_{m=1}^{2} s_1(j,k,m,i)$$

(6.10)

From l-th calibration at the pilot institute $j = 1$, the normalized mean ratios, $s_1^l(1,k,m,i)$ and $s_2^l(1,k,i)$, were obtained using equations (6.9) and (6.10). Figures 6.4, 6.5 and 6.6 present the instabilities of transfer standards A, B and C expressed as the deviations of $s_2^l(1,1,i)$, $s_2^l(1,2,i)$ and $s_2^l(1,3,i)$ from unity, respectively.

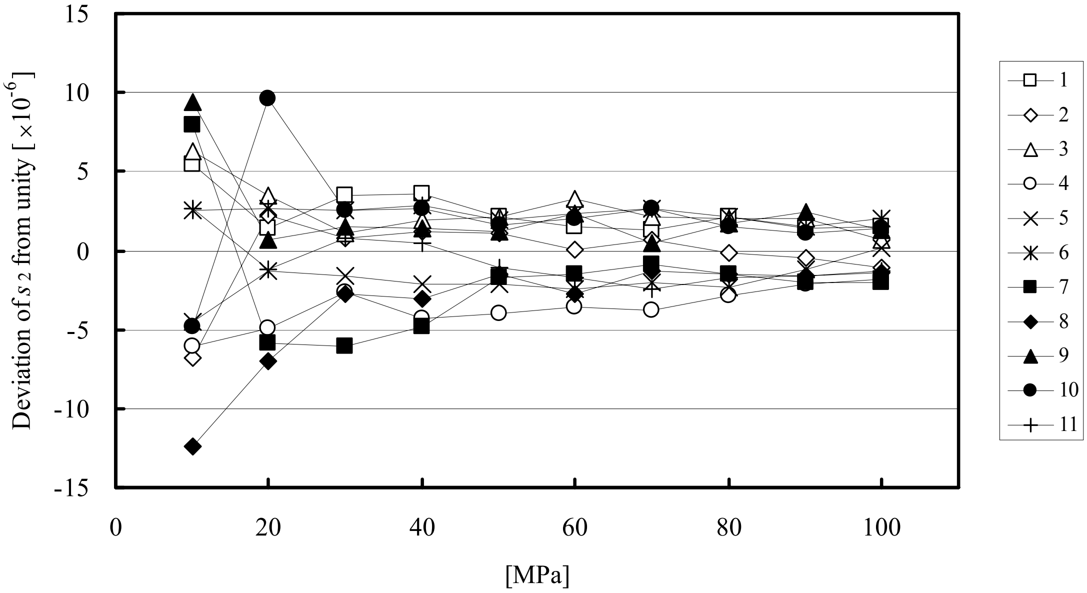


Figure 6.4: Instability of transfer standard A expressed as the deviations of $s_2^l(1,1,i)$ from unity.

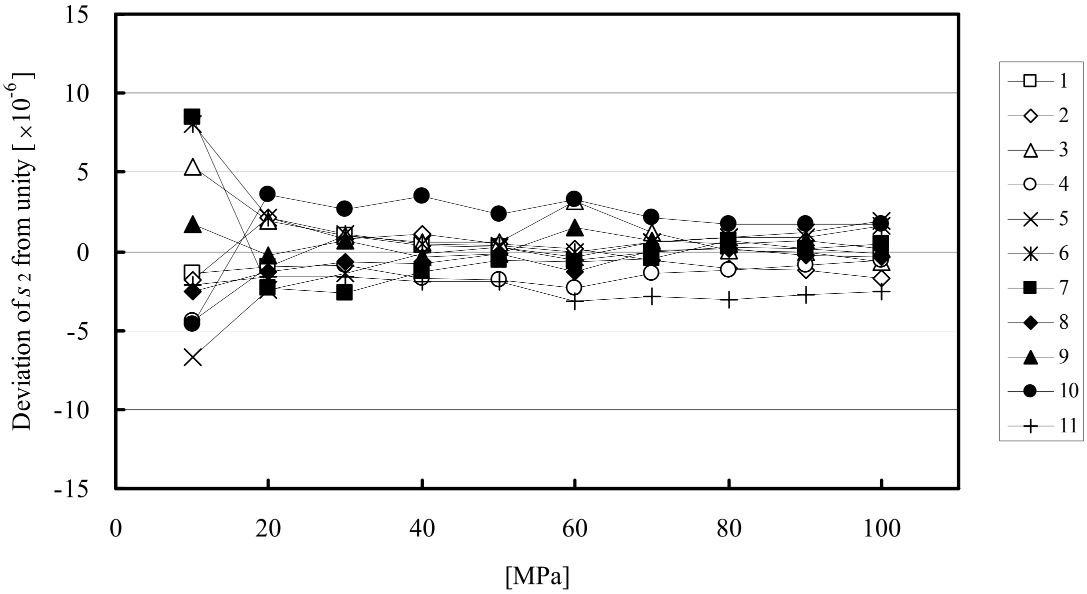


Figure 6.5: Instability of transfer standard B expressed as the deviations of $s_2^l(1,2,i)$ from unity.

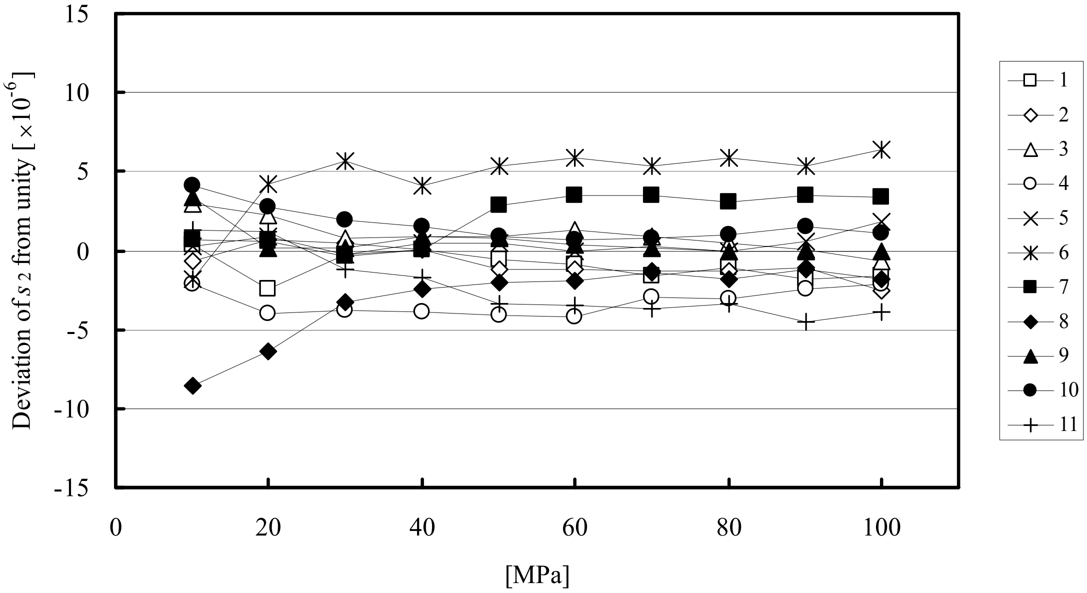


Figure 6.6: Instability of transfer standard C expressed as the deviations of $s_2^l(1,3,i)$ from unity.

Table 6.4 and Figure 6.7 present the instabilities of the transfer standards expressed as the standard deviations, $\sigma\{s_1^l(1,k,m,i)\}$ and $\sigma\{s_2^l(1,k,i)\}$, calculated from eleven values of $s_1^l(1,k,m,i)$ and $s_2^l(1,k,i)$ about their mean, respectively. The standard deviations at each pressure are generally less than 5×10^{-6} in the pressure ranges between 30 MPa and 100 MPa and 11×10^{-6} at maximum for each pressure monitor and each transfer standard. It should be noted that despite the problems of transfer standard B at three institutes due to an uncommon bad power supply to the input of the board inside the pressure monitor B.a, the deviations in the results obtained from transfer standard B were not unusual and were similar to the results obtained from other transfer standards. From these results, it can be stated that the stability of each transfer standard was enough to compare the pressure standards established by the participating institutes. The instabilities of the transfer standards have been incorporated into the uncertainty evaluation as described in later subsection.

Table 6.4: Instabilities of the transfer standards expressed as the standard deviations, $\sigma\{s_1^l(1,k,m,i)\}$ and $\sigma\{s_2^l(1,k,i)\}$, which are the standard deviations of eleven values of $s_1^l(1,k,m,i)$ and $s_2^l(1,k,i)$ about their mean, respectively. $s_1^l(1,k,m,i)$ and $s_2^l(1,k,i)$ were the normalized mean ratios obtained from *l*-th simultaneous calibration data set (eleven sets in total) performed at the pilot institute.

		Standard deviations of normalized mean ratios, $\sigma(s_1^{\,l})$ and $\sigma(s_2^{\,l})$ [$\times 10^{-6}$]								
$\sigma(s^l)$		$\sigma(s_1^{\,l})$	$\sigma(s_1^{\,l})$	$\sigma(s_2^{\,l})$	$\sigma(s_1^{\,l})$	$\sigma(s_1^{\,l})$	$\sigma(s_2^{\,l})$	$\sigma(s_1^{\,l})$	$\sigma(s_1^{\,l})$	$\sigma(s_2^{\,l})$
k		1	1	1	2	2	2	3	3	3
m		1	2		1	2		1	2	
i	[MPa]	A.a	A.b	A	B.a	B.b	B	C.a	C.b	C
1	10	10.5	8.4	9.5	10.5	8.0	9.3	7.4	7.3	7.3
2	20	6.3	7.0	6.6	4.4	4.6	4.5	3.9	6.4	5.3
3	30	4.2	4.9	4.6	3.5	4.0	3.8	3.3	4.6	4.0
4	40	3.7	4.6	4.2	3.8	3.3	3.6	3.0	4.1	3.6
5	50	3.8	4.6	4.2	4.0	3.9	3.9	2.5	5.0	4.0
6	60	3.9	4.6	4.3	4.0	4.3	4.2	2.5	5.2	4.1
7	70	3.9	4.3	4.1	4.6	4.4	4.5	2.3	4.8	3.8
8	80	3.8	4.4	4.1	4.1	4.7	4.4	1.9	4.9	3.7
9	90	3.1	4.2	3.7	4.3	4.7	4.5	2.2	4.8	3.7
10	100	3.5	3.7	3.6	4.2	5.1	4.7	2.1	5.4	4.1

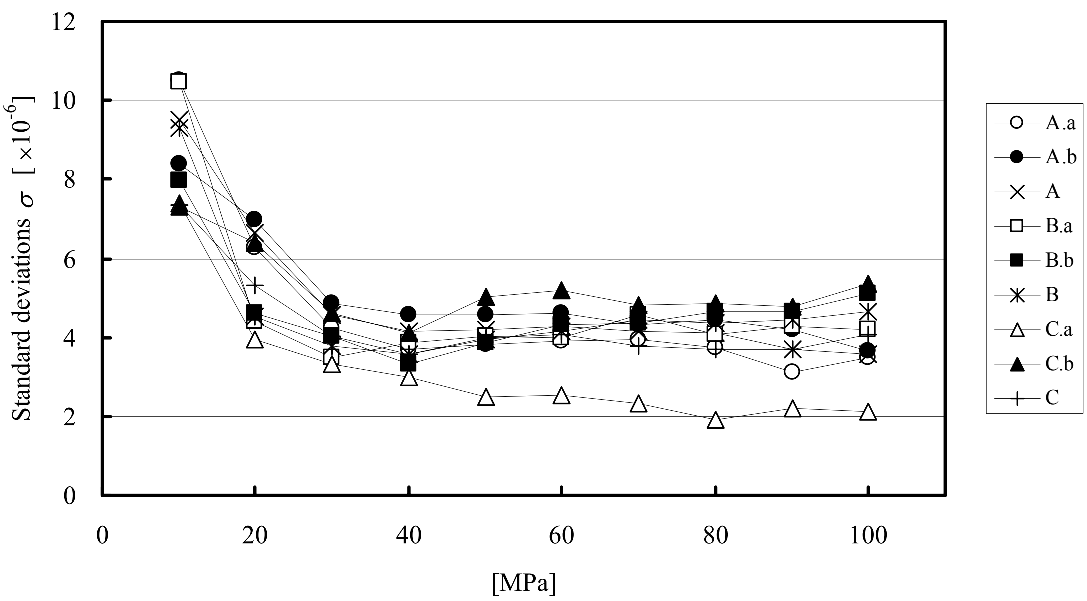


Figure 6.7: Instabilities of the transfer standards expressed as the standard deviations, $\sigma\{s_1^l(1,k,m,i)\}$ and $\sigma\{s_2^l(1,k,i)\}$, as a function of nominal target pressure.

6.6 Calculation of normalized mean ratio of participating institute

Since the predicted reading R_e was determined by the least-squares method using data obtained from eleven simultaneous calibrations at the pilot institute j = 1, the following relation can be derived for each transfer standard,

$$\frac{1}{11} \cdot \sum_{l=1}^{11} \left[s_2^l (1, k, i) \right] = 1$$

(6.11)

where s_2^l is the normalized mean ratio of each transfer standard obtained from l-th calibration performed at the pilot institute. Therefore, the relationships between the normalized mean ratios obtained from six pressure monitors on three transfer standards were already compensated to compare pressure standards used to calibrate different transfer standards.

For j-th non-pilot participating institute, the normalized mean ratio of the institute, S, is obtained from

$$S(j, i) = s_2(j, k, i).$$

(6.12)

where k is selected from 1 to 3 depending on the transfer standard that j-th institute calibrated. Ratio S provides a common basis for comparing the results reported by participants.

For the pilot institute j = 1, S is calculated from

$$S(1, i) = \frac{1}{33} \cdot \sum_{k=1}^{3} \sum_{l=1}^{11} \left[s_2^l (1, k, i) \right].$$

(6.13)

As understood from equation (6.11), $S(1,i)$ = 1.

Table 6.5 and Figure 6.8 present the deviations from the normalized mean ratios of the institutes from unity, $S(j,i) - 1$, obtained from calibrations at the pilot institute and other participating institutes as a function of nominal target pressure.

Table 6.5: Deviations of the normalized mean ratios of the institutes from unity, $S-1$, for nominal target pressures.

		Deviation of normalized mean ratio from unity, $\{S(j,i)-1\}$ [$\times 10^{-6}$]															
j		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
k		1, 2, 3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	0.0	-30.5	-9.5	-40.5	-13.2	-2.0	-21.4	-37.9	-15.3	-25.0	31.5	18.7	6.0	12.3	21.6	-19.6
2	20	0.0	-11.6	-14.6	-24.5	-6.5	3.8	-12.4	-23.2	37.0	-15.3	20.5	3.3	0.3	6.5	17.4	-11.8
3	30	0.0	-13.8	-10.7	-11.9	-2.4	3.5	-6.6	-17.3	47.6	-18.6	19.7	0.2	0.1	9.7	14.8	-9.1
4	40	0.0	-11.9	-8.0	-10.3	0.5	2.3	-6.1	-16.9	34.7	-22.4	17.2	-1.1	0.3	2.0	18.4	-10.0
5	50	0.0	-4.8	-8.5	-7.9	1.0	0.0	-5.7	-16.4	31.0	-27.0	10.7	-2.6	0.6	-1.6	18.6	-9.3
6	60	0.0	-2.0	-9.4	-8.3	1.4	-5.4	-5.7	-17.1	23.8	-30.9	11.4	-5.2	2.7	2.2	15.5	-11.0
7	70	0.0	3.6	-6.1	-4.6	4.0	-7.2	-2.9	-17.2	14.2	-27.6	11.7	-6.0	0.3	-3.5	18.5	-11.4
8	80	0.0	3.2	-6.7	-2.6	4.3	-9.7	-3.6	-19.1	15.9	-26.4	8.8	-7.1	0.9	-2.7	18.4	-14.0
9	90	0.0	2.9	-6.1	-1.0	5.2	44.2	-2.6	-20.3	5.6	-26.6	9.1	-8.8	1.2	-2.2	16.2	-16.2
10	100	0.0	3.0	-7.5	-3.0	5.8	54.1	-3.2	-23.3	6.1	-28.9	9.4	-8.0	1.5	-2.5	16.4	-20.2

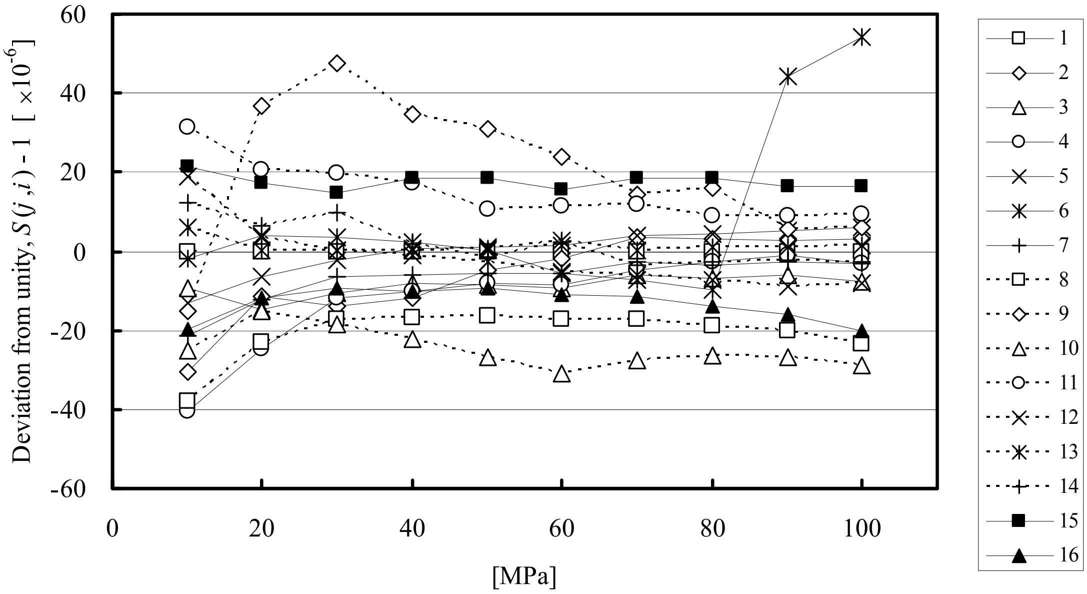


Figure 6.8: Deviations of the normalized mean ratios of the institutes from unity, $S-1$, as a function of nominal target pressure.

6.7 Calculation of expected mean pressure of participating institute

Expected mean pressure of participating institute, $p(j,i)$, is calculated by

$$p(j,i) = S(j,i) \cdot P_n(i). \tag{6.14}$$

where $P_n(i)$ is the nominal target pressure.

$p(j,i)$ is taken as an indicator of the expected pressure actually generated by the pressure standard of the participating institute when the institute claims the nominal target pressure. The results for $p(j,i)$ from individual institutes are presented in Table 6.6.

Table 6.6: Expected mean pressures of the institutes for nominal target pressures.

		Mean pressure, $p(j,i)$ [MPa]															
j		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
k		1, 2, 3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	10.00000	9.99969	9.99990	9.99960	9.99987	9.99998	9.99979	9.99962	9.99985	9.99975	10.00031	10.00019	10.00006	10.00012	10.00022	9.99980
2	20	20.00000	19.99977	19.99971	19.99951	19.99987	20.00008	19.99975	19.99954	20.00074	19.99969	20.00041	20.00007	20.00001	20.00013	20.00035	19.99976
3	30	30.00000	29.99958	29.99968	29.99964	29.99993	30.00010	29.99980	29.99948	30.00143	29.99944	30.00059	30.00001	30.00000	30.00029	30.00044	29.99973
4	40	40.00000	39.99952	39.99968	39.99959	40.00002	40.00009	39.99976	39.99932	40.00139	39.99910	40.00069	39.99996	40.00001	40.00008	40.00074	39.99960
5	50	50.00000	49.99976	49.99958	49.99961	50.00005	50.00000	49.99971	49.99918	50.00155	49.99865	50.00054	49.99987	50.00003	49.99992	50.00093	49.99954
6	60	60.00000	59.99988	59.99943	59.99950	60.00008	59.99967	59.99966	59.99897	60.00143	59.99814	60.00068	59.99969	60.00016	60.00013	60.00093	59.99934
7	70	70.00000	70.00025	69.99957	69.99968	70.00028	69.99950	69.99980	69.99880	70.00099	69.99807	70.00082	69.99958	70.00002	69.99976	70.00130	69.99920
8	80	80.00000	80.00025	79.99946	79.99979	80.00035	79.99922	79.99971	79.99847	80.00127	79.99789	80.00070	79.99943	80.00008	79.99978	80.00147	79.99888
9	90	90.00000	90.00026	89.99945	89.99991	90.00047	90.00398	89.99977	89.99817	90.00051	89.99760	90.00082	89.99921	90.00011	89.99980	90.00146	89.99854
10	100	100.00000	100.00030	99.99925	99.99970	100.00058	100.00541	99.99968	99.99767	100.00061	99.99711	100.00094	99.99920	100.00015	99.99975	100.00164	99.99798

6.8 Estimation of uncertainties

In this subsection, all the uncertainties are expressed as the standard ones. The relative combined standard uncertainty in the normalized mean ratio of j-th participating institute, $S(j,i)$, may be estimated from the root-sum-square of four component uncertainties.

$$u_c\{S(j,i)\} = \sqrt{u_{std}^2\{S(j,i)\} + u_{tem}^2\{S(j,i)\} + u_{rdm}^2\{S(j,i)\} + u_{lts}^2\{S(j,i)\}} \tag{6.15}$$

where $u_{std}\{S\}$ is the uncertainty in S due to systematic effects in pressure standard j, $u_{tem}\{S\}$ is the uncertainty in correcting the readings to equivalent values at the reference temperature, $u_{rdm}\{S\}$ is the uncertainty due to combined effect of short-term random errors of transfer standard used and pressure standard j during calibration and $u_{lts}\{S\}$ is the uncertainty arising from long-term shift in the characteristics of the transducers on the transfer standard calibrated at j-th institute.

6.8.1 Uncertainty due to systematic effect in pressure standard

The relative standard uncertainty due to systematic effect in pressure standard j, $u\{S_{std}(j,i)\}$, can be estimated from

$$u_{std}\{S(j,i)\} = \frac{u\{P_{std}(j,i)\}}{P_n(i)} \tag{6.16}$$

where $P_n(i)$ is the nominal target pressure.

Table 6.7 and Figure 6.9 present the estimated relative standard uncertainties arising from systematic effects in the pressure standards used in the comparison, as reported by the participating institutes for nominal target pressures. The uncertainty due to the hydrostatic head correction was considered as included in the uncertainty of the pressure standard. The main contributions in this uncertainty came from the effective area and the pressure distortion coefficient of the pressure standard of the participating institute.

Table 6.7: Relative standard uncertainties, as claimed by the participants, due to systematic effects in their pressure standards. All the uncertainties are expressed as the standard ones.

		Relative standard uncertainty of applied pressure reported by participating institute, $u_{std}\{S(j,i)\}$ [$\times10^{-6}$]															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	13.1	25.0	11.0	15.0	20.0	20.0	15.0	19.5	25.0	12.0	32.0	40.0	11.0	25.1	30.0	15.0
2	20	13.0	25.0	11.0	15.0	20.5	16.5	15.5	19.0	24.5	12.0	32.5	35.0	10.5	25.1	25.0	15.0
3	30	13.2	25.0	11.0	15.0	20.7	17.0	15.3	19.0	24.3	12.3	33.7	33.3	10.7	25.1	26.7	14.7
4	40	13.4	24.8	11.3	15.0	21.3	17.9	15.8	19.3	24.5	12.3	34.5	32.5	11.0	25.1	25.0	14.5
5	50	13.8	25.0	11.2	15.2	21.0	18.8	16.0	19.4	24.8	12.2	35.4	32.0	11.4	25.1	24.0	14.2
6	60	14.2	25.0	11.2	15.2	21.2	20.0	16.3	20.0	25.0	12.3	36.5	31.7	11.8	25.1	25.0	14.2
7	70	14.6	25.0	11.3	15.1	21.4	21.4	16.7	20.0	25.3	12.4	37.4	32.9	12.3	25.1	24.3	14.1
8	80	15.1	25.0	11.4	15.3	21.8	22.5	17.1	20.0	25.6	12.6	38.4	32.5	12.9	25.1	25.0	14.0
9	90	15.7	25.0	11.3	15.4	22.1	47.8	17.6	21.1	26.0	12.7	39.4	32.2	13.6	25.1	24.4	14.0
10	100	16.3	25.0	11.4	15.4	22.5	51.7	18.1	22.0	26.4	12.8	40.4	32.0	14.2	25.1	24.0	13.9

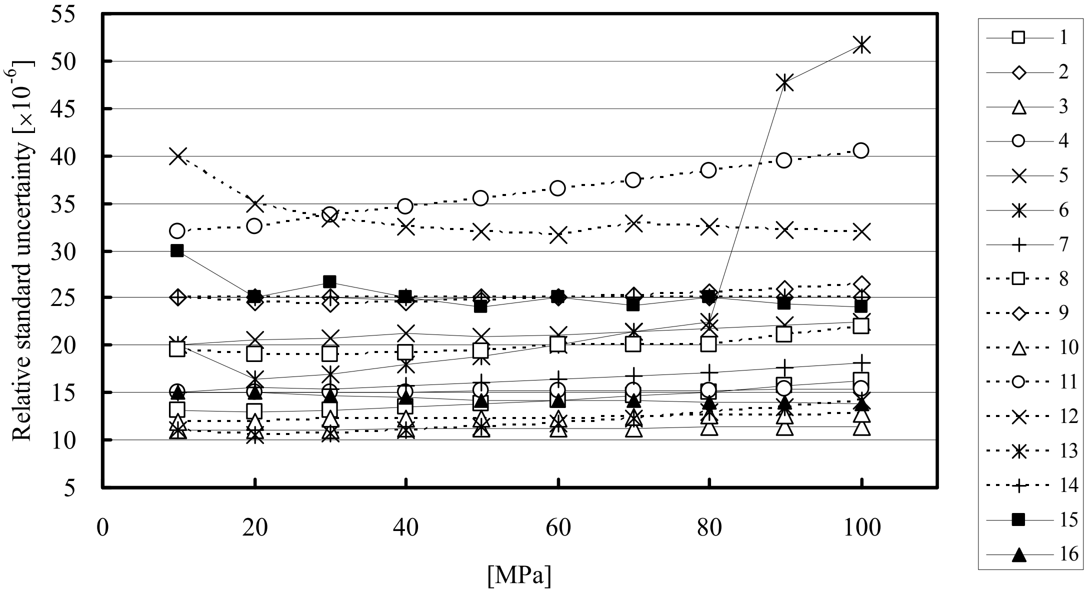


Figure 6.9: Relative standard uncertainties, as claimed by the participants, due to systematic effects in their pressure standards as a function of nominal target pressure.

6.8.2 Uncertainty due to deviation from reference temperature

The uncertainty in correcting the reading at the temperature realized at *j*-th participating institute to equivalent value at the reference temperature, $u\{S_{tem}\}$, can be estimated from

$$u_{tem}\{S(j,i)\} = \frac{u\{\beta(i)\}}{P_n(i)} \cdot \left|\overline{t_b}(j,i) - t_r\right| \tag{6.17}$$

where $u\{\beta(i)\}$ is the calculated standard uncertainty in the temperature coefficient, which was estimated as $u\{\beta(i)\}$= 0.03 kPa/℃ in the previous subsection. $\overline{t_b}(j,i)$ is the average temperature measured on each transfer standard by the participating institutes for nominal target pressures calculated from equations (6.5) or (6.6), t_r is the reference temperature of this comparison determined as t_r = 21.5 ℃. The uncertainty in $\overline{t_b}(j,i)$ may also contribute an uncertainty to $u\{S_{tem}\}$. However this systematic contribution was so small that the uncertainty made a negligible contribution to the uncertainty evaluated by equation (6.17). Table 6.8 and Figure 6.10 present the estimated standard uncertainties, $u\{S_{tem}\}$, calculated from equations (6.17).

Table 6.8: Standard uncertainties in correcting the readings to equivalent values at the reference temperature. All the uncertainties are expressed as the standard ones.

		Relative standard uncertainty due to deviation from reference temperature, $u_{tem}\{S(j,i)\}$ [$\times10^{-6}$]															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	5.6	5.0	1.8	3.9	3.4	3.2	2.4	1.5	8.9	3.1	1.3	7.2	1.9	7.0	6.5	2.4
2	20	2.8	2.5	0.8	1.8	1.6	1.6	1.2	0.8	4.1	1.6	0.4	3.6	0.9	3.5	3.3	1.2
3	30	1.9	1.7	0.6	1.2	1.0	1.1	0.8	0.5	2.5	1.1	0.1	2.4	0.6	2.4	2.2	0.8
4	40	1.4	1.3	0.4	1.0	0.8	0.8	0.6	0.4	1.8	0.8	0.2	1.8	0.5	1.8	1.7	0.6
5	50	1.1	1.0	0.3	0.8	0.6	0.7	0.5	0.3	1.4	0.6	0.1	1.4	0.4	1.5	1.4	0.4
6	60	0.9	0.8	0.3	0.6	0.5	0.6	0.4	0.3	1.2	0.6	0.1	1.2	0.3	1.2	1.2	0.3
7	70	0.8	0.7	0.2	0.6	0.4	0.5	0.4	0.2	1.0	0.5	0.1	1.0	0.3	1.0	1.0	0.3
8	80	0.7	0.6	0.2	0.5	0.3	0.4	0.3	0.2	0.9	0.4	0.1	0.9	0.2	0.9	0.9	0.2
9	90	0.6	0.6	0.2	0.4	0.3	0.4	0.3	0.2	0.8	0.4	0.1	0.8	0.2	0.8	0.8	0.2
10	100	0.6	0.5	0.2	0.4	0.3	0.4	0.2	0.2	0.7	0.4	0.1	0.7	0.2	0.7	0.7	0.2

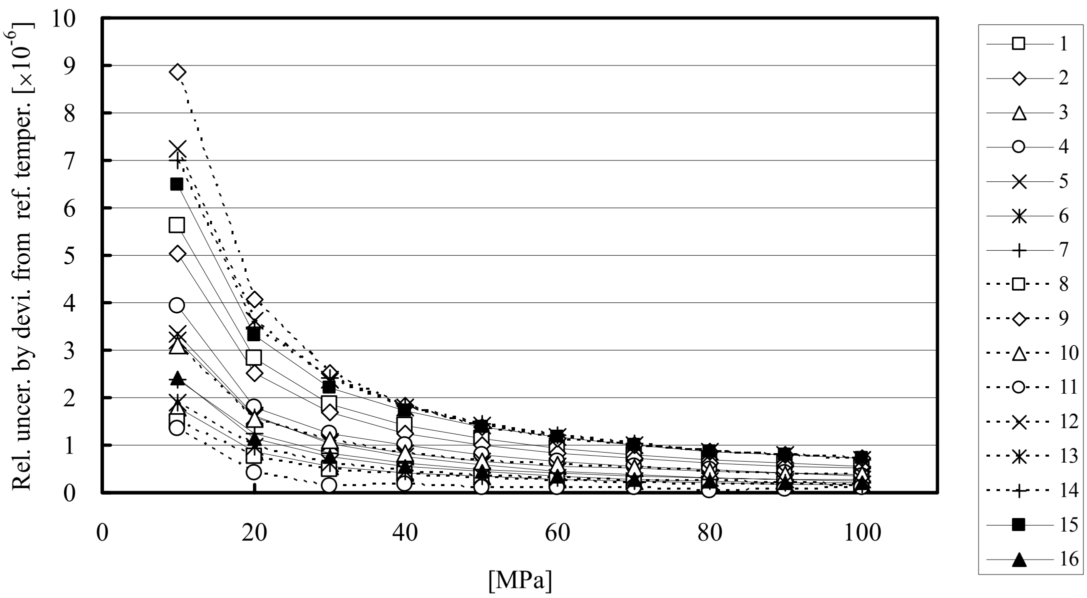


Figure 6.10: Standard uncertainties in correcting the readings to equivalent values at the reference temperature as a function of nominal target pressure.

6.8.3 Uncertainty due to combined effect of short-term random errors

The standard uncertainty in S due to combined effect of short-term random errors of the transfer standard calibrated, $u\{S_{rdm}\}$, can be estimated from the corresponding uncertainties in the normalized mean ratios by statistical methods.

For j-th non-pilot participating institute, the uncertainty is obtained from

$$u_{rdm}^2\{S(j,i)\} = \sigma^2\{s_0(j,k,m,y,w,i)\}/12 \tag{6.18}$$

where $\sigma\{s_0(j,k,m,y,w,i)\}$ is the standard deviation of twelve values of $s_0(j,k,m,y,w,i)$ about its mean.

For the pilot institute j = 1, the uncertainty is calculated from

$$u_{rdm}^2\{S(1,i)\} = \frac{1}{33}\cdot\sum_{k=1}^{3}\sum_{l=1}^{11}\left[\sigma^2\{s_0^l(1,k,m,y,w,i)\}/12\right] \tag{6.19}$$

where $s_0^l(1,k,m,y,w,i)$ is the normalized mean ratio obtained from l-th simultaneous calibration set (eleven sets in total) performed at the pilot institute, $\sigma\{s_0^l(1,k,m,y,w,i)\}$ is the standard deviation of twelve values of $s_0^l(1,k,m,y,w,i)$ about its mean. The multiple calibrations at the pilot institute tend to reduce the influence of uncorrelated uncertainties arising from short-term variability for the pilot institute[14].

Table 6.9 and Figure 6.11 present the estimated standard uncertainties due to combined effect of short-term random errors calculated from equations (6.18) and (6.19).

Table 6.9: Standard uncertainties in the normalized mean ratios due to combined effects of short-term random errors. All the uncertainties are expressed as the standard ones.

		Standard uncertainty due to combined effects of short-term random effects, $u_{rdm}\{S(j,i)\}$ [$\times10^{-6}$]															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	3.4	6.2	2.0	8.3	5.8	5.8	5.7	2.9	24.6	24.7	6.8	4.7	2.6	3.8	2.9	4.6
2	20	2.1	5.6	2.7	4.9	1.8	2.8	3.7	1.6	27.0	15.7	6.2	2.7	1.9	2.1	2.7	2.8
3	30	1.5	7.2	3.2	4.2	2.2	1.8	2.1	1.5	25.6	8.5	5.2	2.9	1.4	6.4	1.8	2.0
4	40	1.2	6.9	2.2	5.4	1.9	1.8	1.6	1.2	18.3	8.5	5.2	2.6	1.7	2.1	1.3	1.6
5	50	1.3	4.5	2.8	3.1	2.4	1.0	0.6	0.6	17.4	5.9	3.7	2.4	1.9	2.1	0.9	1.2
6	60	1.3	3.2	2.5	2.8	2.7	1.2	0.3	0.7	12.9	3.6	6.5	2.1	2.3	2.5	0.6	0.8
7	70	1.3	2.3	2.2	3.6	2.5	1.0	1.2	0.8	10.2	4.9	7.4	2.2	2.3	2.1	0.6	0.6
8	80	1.3	2.6	2.4	3.8	2.7	1.0	0.7	0.7	8.2	4.4	5.9	2.0	2.3	1.9	0.6	0.8
9	90	1.2	2.3	2.2	2.7	2.3	4.9	1.0	0.9	6.8	3.8	4.8	2.1	2.2	1.7	0.4	1.0
10	100	1.3	2.5	2.2	2.2	2.1	6.9	0.8	0.9	6.9	2.9	5.5	1.9	2.2	1.6	0.9	1.3

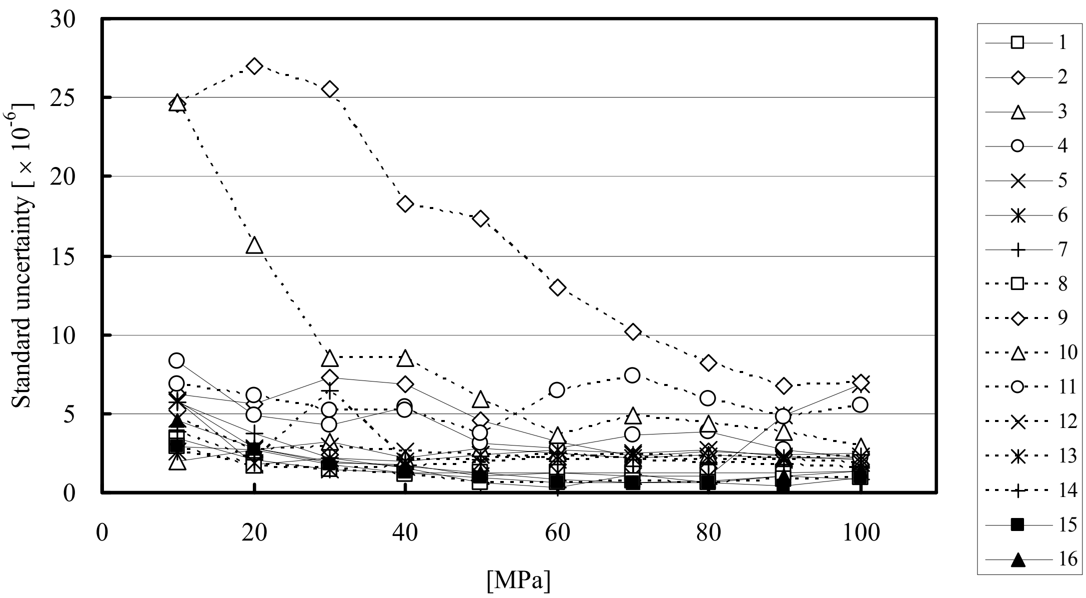


Figure 6.11: Standard uncertainties in the normalized mean ratios due to short-term random errors as a function of nominal target pressure.

6.8.4 Uncertainty arising from the long-term shift

The long-term shift of a pressure transducer between calibrations should be considered in the uncertainties. The deviations from unity of $s_1(j,k,m,i)$ and $s_2(j,k,i)$ obtained from the eleven calibrations seemed to be almost random at each nominal target pressure as presented in Figure 6.4 to 6.6. Therefore, the relative standard uncertainty in the normalized mean ratio of *j*-th participating institute due to long-term shift, $u_{lts}\{S(j,i)\}$, was estimated as follows:

In the case that two monitors on *k*-th transfer standard were calibrated at *j*-th participating institute,

$$u_{lts}^2\{S(j,i)\} = \sigma^2\{s_2^l(1,k,i)\} \tag{6.20}$$

and in the case that *m*-th monitor on *k*-th transfer standard was calibrated at *j*-th participating institute,

$$u_{lts}^2\{S(j,i)\} = \sigma^2\{s_1^l(1,k,m,i)\} \tag{6.21}$$

where $\sigma\{s_1^l(1,k,m,i)\}$ and $\sigma\{s_2^l(1,k,i)\}$ are the standard deviations of eleven values of $s_1^l(1,k,m,i)$ and $s_2^l(1,k,i)$ about their mean, respectively, which are listed in Table 6.4.

At the pilot institute $j = 1$, three transfer standards were calibrated simultaneously eleven times. The relative uncertainty arising from long-term shifts of the transfer standards for the pilot institute, $u_{lts}\{S(1,i)\}$, is estimated as follows:

$$u_{lts}^2\{S(1,i)\} = \frac{1}{33}\cdot\sum_{k=1}^{3}\sum_{l=1}^{11}\left[\sigma^2\{s_2^l(1,k,i)\}\right] \tag{6.22}$$

6.8.5 Combined uncertainty in normalized mean ratio of institute

The combined standard uncertainty in the normalized mean ratio of the institute is estimated by combining the component uncertainties using the "root-sum-squares" method according to equation (6.15) and is presented in Table 6.10 and Figure 6.12.

Table 6.10: Combined standard uncertainties in normalized mean ratios of institutes, $u_c\{S\}$. All the uncertainties are expressed as the standard ones.

		Combined standard uncertainty, $u_c\{S(j,i)\}$ [$\times 10^{-6}$]															
j		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
k		1, 2, 3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	14.9	27.9	14.8	20.0	23.1	23.1	18.8	21.9	37.4	29.2	34.0	42.0	14.8	27.9	31.9	17.5
2	20	13.6	26.3	12.5	16.7	21.3	17.6	16.8	19.8	37.1	20.5	33.5	35.7	12.0	25.9	25.8	16.2
3	30	13.4	26.4	12.1	16.1	21.2	17.6	16.0	19.5	35.6	15.6	34.3	33.8	11.5	26.3	27.1	15.4
4	40	13.6	26.0	12.0	16.4	21.7	18.4	16.2	19.6	30.8	15.4	35.1	32.8	11.7	25.5	25.3	15.0
5	50	13.9	25.7	12.2	16.0	21.5	19.3	16.5	19.8	30.6	14.1	35.8	32.4	12.2	25.5	24.4	14.8
6	60	14.3	25.5	12.2	16.0	21.7	20.5	16.8	20.4	28.5	13.5	37.3	32.0	12.7	25.5	25.4	14.8
7	70	14.7	25.4	12.1	16.0	21.9	21.8	17.2	20.4	27.5	13.9	38.3	33.2	13.1	25.4	24.7	14.7
8	80	15.2	25.4	12.2	16.2	22.2	22.8	17.5	20.4	27.2	13.9	39.0	32.8	13.6	25.4	25.5	14.5
9	90	15.8	25.4	12.1	16.1	22.5	48.2	18.0	21.5	27.1	13.7	39.9	32.5	14.2	25.4	24.9	14.5
10	100	16.4	25.5	12.3	16.1	23.0	52.3	18.6	22.4	27.6	13.8	41.0	32.3	14.9	25.4	24.6	14.5

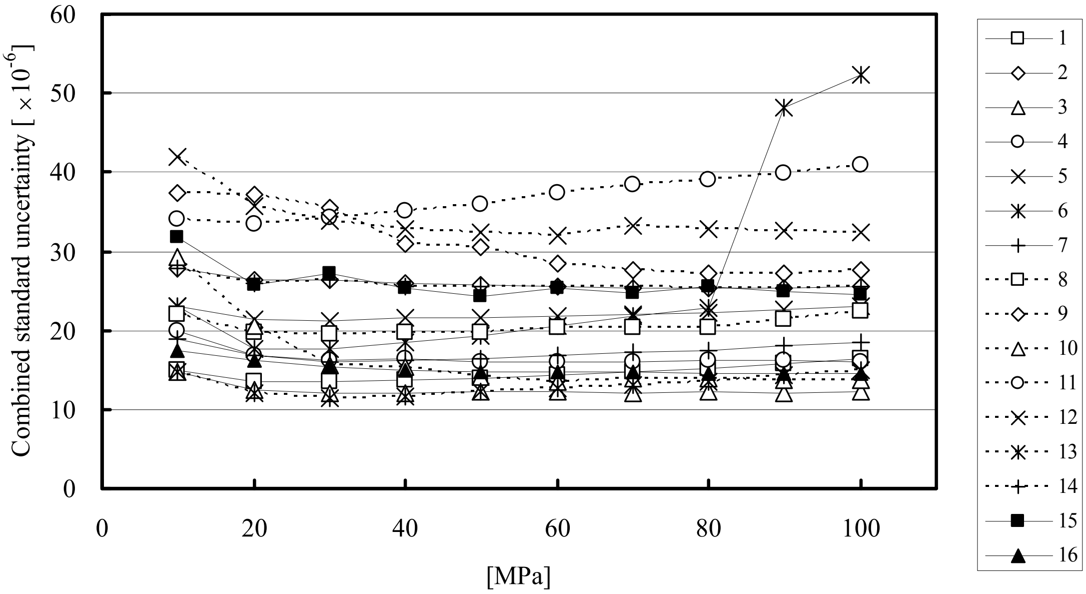


Figure 6.12: Combined standard uncertainties in normalized mean ratios of institutes as a function of nominal target pressure.

6.8.6 Combined uncertainty in expected mean pressure of institute

The combined standard uncertainty of the expected mean pressure of participating institute, $u_c\{p(j,i)\}$, is calculated from $u_c\{S(j,i)\}$ by

$$u_c\{p(j,i)\} = u_c\{S(j,i)\} \cdot P_n(i). \tag{6.23}$$

where $P_n(i)$ is the nominal target pressure. $u_c\{p(j,i)\}$ is presented in Table 6.11 and Figure 6.13.

Table 6.11: Combined standard uncertainties in expected mean pressures of institutes, $u_c\{p\}$. All the uncertainties are expressed as the standard ones.

		Combined standard uncertainty, $u_c\{p(j,i)\}$ [kPa]															
j		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
k		1, 2, 3	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	0.149	0.279	0.148	0.200	0.231	0.231	0.188	0.219	0.374	0.292	0.340	0.420	0.148	0.279	0.319	0.175
2	20	0.272	0.526	0.251	0.335	0.426	0.353	0.337	0.396	0.742	0.411	0.670	0.714	0.239	0.519	0.516	0.324
3	30	0.403	0.791	0.364	0.484	0.636	0.528	0.480	0.584	1.068	0.467	1.029	1.014	0.345	0.788	0.814	0.461
4	40	0.544	1.039	0.480	0.655	0.866	0.735	0.650	0.785	1.234	0.614	1.403	1.314	0.468	1.018	1.012	0.601
5	50	0.696	1.287	0.611	0.802	1.076	0.963	0.825	0.991	1.528	0.707	1.791	1.618	0.611	1.275	1.218	0.740
6	60	0.857	1.533	0.729	0.958	1.304	1.227	1.010	1.225	1.708	0.810	2.237	1.921	0.764	1.532	1.524	0.886
7	70	1.032	1.778	0.847	1.122	1.533	1.525	1.203	1.426	1.928	0.971	2.684	2.321	0.915	1.781	1.729	1.026
8	80	1.219	2.033	0.976	1.293	1.778	1.826	1.403	1.628	2.173	1.109	3.120	2.623	1.087	2.033	2.036	1.160
9	90	1.420	2.285	1.091	1.451	2.028	4.336	1.618	1.931	2.442	1.237	3.591	2.926	1.280	2.286	2.241	1.307
10	100	1.638	2.546	1.231	1.608	2.297	5.229	1.857	2.240	2.760	1.376	4.098	3.232	1.494	2.544	2.456	1.455

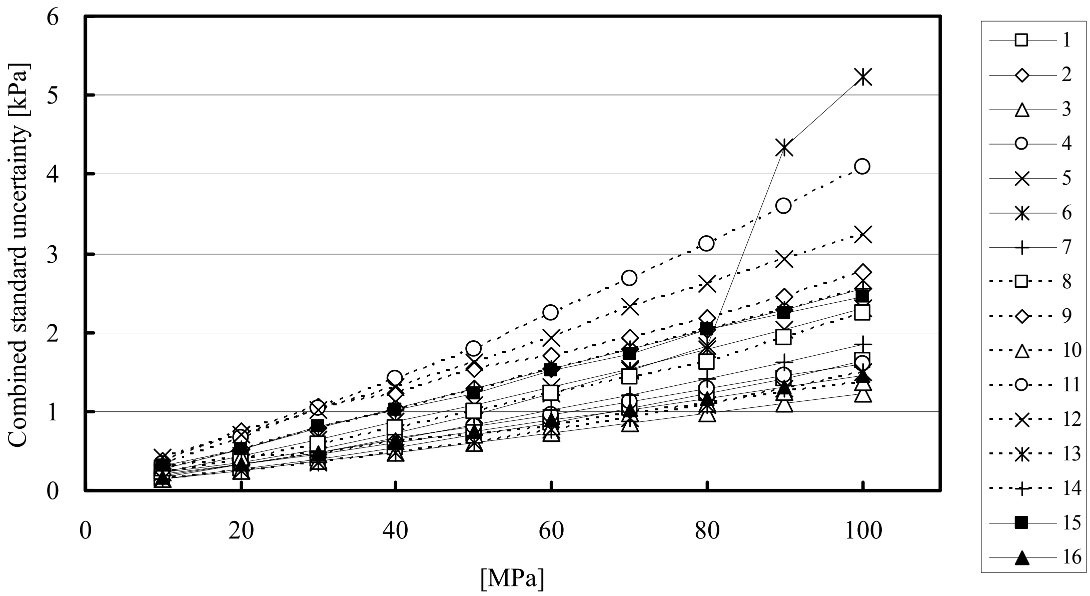


Figure 6.13: Combined standard uncertainties in expected mean pressures of institutes as a function of nominal target pressure.

7. Results for key comparison APMP.M.P-K7

The results for key comparison APMP.M.P-K7 are processed by the following procedure:

7.1 Calculation of Key Comparison Reference Values (KCRVs),

7.2 Evaluation of degrees of equivalence.

7.1 Calculation of APMP Key Comparison Reference Values

The key comparison reference value (KCRV) is interpreted as an estimate of the measurand on the basis of the measurements provided by the participating institutes. In the guidelines[2], it is described that "In calculating the KCRV, the pilot institute will use the method considered most appropriate for the particular comparison." Several methods for defining a KCRV have been proposed[15]. The typical methods are (i) the simple mean method, (ii) the weighted mean method and (iii) the median method. Each method has some advantages and disadvantages. However, the simple mean values are known to lack stability against the effect of "outliers" [16]. For this APMP comparison, three transfer standards were circulated independently using petal patterns. The circulation was different from the simple circulation of a single transfer standard around all the participants. Also several pressure standards in the participating institutes were secondary and some of them were not independent. In this case, an analysis method based on the use of the median may be expected to be more appropriate than the weighted mean method[15]. The advantage of using the median method rather than the weighted mean method is that the weighted means are not statistically robust because they can be easily influenced by individual results[9].

From the consideration above, the median value of the expected mean pressure obtained from all participating institutes is calculated at the nominal target pressure as the KCRV for this key comparison, $p(KCRV, i)$, using similar ways as given in the key comparisons EUROMET Project 389 and CCM.P-K1.c [9,17].

According to the method of Müller, the uncertainty of the median can be estimated by taking *MAD*, which is the median of absolute deviations from the median of the results, multiplying by 1.858 and dividing the square root of one less than the number of participating institute contributing to the reference value [16].

$$u\{p(KCRV, i)\} = \frac{1.858 \cdot MAD}{\sqrt{n-1}} \tag{7.1}$$

where $u\{p(KCRV,i)\}$ is the standard uncertainty of $p(KCRV,i)$.

Table 7.1 presents the KCRVs and their combined standard uncertainties calculated for the expected mean pressures.

Table 7.1: APMP Key comparison reference values and their combined standard uncertainties calculated for the expected mean pressures. All the uncertainties are expressed as the standard ones.

	Nom. Tar. Pressure	$p(KCRV,i)$	$u\{p(KCRV,i)\}$
i	[MPa]	[MPa]	[kPa]
1	10	9.999886	0.074
2	20	19.999935	0.091
3	30	29.999964	0.145
4	40	39.999978	0.162
5	50	49.999895	0.113
6	60	59.999784	0.168
7	70	69.999778	0.181
8	80	79.999787	0.246
9	90	89.999956	0.255
10	100	99.999874	0.331

7.2 Evaluation of degrees of equivalence

In the MRA the term "degree of equivalence of the measurement standards" is taken to mean the degree to which a standard is consistent with a Key Comparison Reference Value (KCRV) or with a measurement standard at another institute[1].

Therefore, the degrees of equivalence of the pressure standards for this comparison are expressed using the expected mean pressures quantitatively in two ways:

(1) Deviations of participating institute's values from KCRVs,

(2) Differences between deviations for pairs of participating institutes.

7.2.1 Deviation of institute's value from APMP KCRV

By comparing the expected mean pressure of *j*-th participating institute relative to a KCRV, the relative deviation from the reference value, $\Delta(j,i)$, is calculated by the following equation:

$$\Delta(j,i) = \frac{p(j,i) - p(KCRV,i)}{p(KCRV,i)} \tag{7.2}$$

and the relative expanded uncertainty of $\Delta(j,i)$, $U\{\Delta(j,i)\}$, is estimated from

$$U\{\Delta(j,i)\} = k \cdot u_c\{\Delta(j,i)\} = k \cdot \frac{\sqrt{u^2\{p(j,i)\} + u^2\{p(KCRV,i)\}}}{p(KCRV,i)} \tag{7.3}$$

where $u_c\{\Delta(j,i)\}$ is the combined standard uncertainty of the relative deviation, *k* is the coverage factor and *k* = 2 is adopted, $u\{p(j,i)\}$ and $u\{p(KCRV,i)\}$ are the combined uncertainties in the expected mean pressure of the institute and the reference value.

Table 7.2 presents the relative deviations from reference values, $\Delta(j,i)$, the expanded (*k* = 2) uncertainties of the relative deviations, $U\{\Delta(j,i)\}$, and the degrees of equivalence expressed by the ratios, $\Delta(j,i)/U\{\Delta(j,i)\}$, for individual NMIs. Figures 7.1 presents $\Delta(j,i)$ with $U\{\Delta(j,i)\}$ graphically for the participating institutes as a function of nominal target pressure. Figures 7.2 provides a measure of the degree of equivalence by the relative magnitude of the deviation, $\Delta(j,i)/U\{\Delta(j,i)\}$. For the present comparison, the condition $|\Delta(j,i)/U\{\Delta(j,i)\}| \leq 1$ was established for all the participating institutes at all nominal target pressures.

Table 7.2: Deviations from the APMP KCRVs, $\Delta(j,i)$ [upper], the expanded (k = 2) uncertainties of the deviations, $U\{\Delta(j,i)\}$ [middle] and the degrees of equivalence as expressed by the ratios, $\Delta(j,i)/U\{\Delta(j,i)\}$ [lower].

		Relative deviation of normalized mean pressure from KCRV, $\Delta(j,i) = \{p(j,i) - p(KCRV,i)\} / p(KCRV,i)$ [×10^{-6}]															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	11.4	-19.1	1.8	-29.1	-1.8	9.4	-10.1	-26.5	-3.9	-13.6	42.8	30.1	17.4	23.7	33.0	-8.2
2	20	3.3	-8.3	-11.4	-21.3	-3.3	7.0	-9.1	-19.9	40.2	-12.0	23.8	6.6	3.5	9.8	20.6	-8.5
3	30	1.2	-12.6	-9.5	-10.7	-1.2	4.7	-5.4	-16.0	48.8	-17.3	21.0	1.5	1.3	10.9	16.0	-7.9
4	40	0.5	-11.4	-7.4	-9.7	1.0	2.9	-5.5	-16.3	35.3	-21.9	17.7	-0.5	0.8	2.5	18.9	-9.4
5	50	2.1	-2.7	-6.4	-5.8	3.1	2.1	-3.6	-14.3	33.1	-24.9	12.8	-0.5	2.7	0.5	20.7	-7.2
6	60	3.6	1.6	-5.8	-4.7	5.0	-1.8	-2.1	-13.5	27.4	-27.3	15.0	-1.6	6.3	5.8	19.1	-7.3
7	70	3.2	6.8	-2.9	-1.4	7.2	-4.0	0.3	-14.0	17.3	-24.4	14.9	-2.8	3.4	-0.3	21.7	-8.2
8	80	2.7	5.8	-4.1	0.0	7.0	-7.1	-0.9	-16.4	18.5	-23.8	11.4	-4.5	3.6	0.0	21.1	-11.4
9	90	0.5	3.4	-5.6	-0.5	5.7	44.7	-2.1	-19.8	6.1	-26.1	9.6	-8.3	1.7	-1.7	16.7	-15.7
10	100	1.3	4.3	-6.2	-1.7	7.1	55.3	-1.9	-22.1	7.4	-27.6	10.6	-6.7	2.8	-1.3	17.7	-18.9

		Expanded uncertainty, $U\{\Delta(j,i)\}$ [×10^{-6}] (k = 2)															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	33.3	57.8	33.1	42.7	48.6	48.6	40.4	46.3	76.2	60.2	69.7	85.2	33.1	57.8	65.4	38.0
2	20	28.6	53.3	26.7	34.7	43.6	36.4	34.9	40.6	74.7	42.0	67.6	72.0	25.6	52.7	52.4	33.6
3	30	28.6	53.6	26.1	33.7	43.5	36.5	33.5	40.1	71.9	32.6	69.3	68.3	25.0	53.4	55.1	32.2
4	40	28.4	52.6	25.3	33.7	44.1	37.6	33.5	40.1	62.2	31.8	70.6	66.2	24.8	51.6	51.3	31.1
5	50	28.2	51.7	24.8	32.4	43.3	38.8	33.3	39.9	61.3	28.6	71.8	64.9	24.9	51.2	48.9	30.0
6	60	29.1	51.4	24.9	32.4	43.8	41.3	34.1	41.2	57.2	27.6	74.8	64.3	26.1	51.4	51.1	30.1
7	70	29.9	51.0	24.8	32.5	44.1	43.9	34.7	41.1	55.3	28.2	76.8	66.5	26.6	51.1	49.7	29.8
8	80	31.1	51.2	25.2	32.9	44.9	46.1	35.6	41.2	54.7	28.4	78.2	65.9	27.9	51.2	51.3	29.7
9	90	32.1	51.1	24.9	32.7	45.4	96.5	36.4	43.3	54.6	28.1	80.0	65.3	29.0	51.1	50.1	29.6
10	100	33.4	51.3	25.5	32.8	46.4	104.8	37.7	45.3	55.6	28.3	82.2	65.0	30.6	51.3	49.6	29.8

		$\Delta(j,i) / U\{\Delta(j,i)\}$															
	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
1	10	0.34	-0.33	0.06	-0.68	-0.04	0.19	-0.25	-0.57	-0.05	-0.23	0.61	0.35	0.53	0.41	0.50	-0.22
2	20	0.11	-0.16	-0.43	-0.61	-0.08	0.19	-0.26	-0.49	0.54	-0.29	0.35	0.09	0.14	0.19	0.39	-0.25
3	30	0.04	-0.24	-0.36	-0.32	-0.03	0.13	-0.16	-0.40	0.68	-0.53	0.30	0.02	0.05	0.20	0.29	-0.25
4	40	0.02	-0.22	-0.29	-0.29	0.02	0.08	-0.17	-0.41	0.57	-0.69	0.25	-0.01	0.03	0.05	0.37	-0.30
5	50	0.07	-0.05	-0.26	-0.18	0.07	0.05	-0.11	-0.36	0.54	-0.87	0.18	-0.01	0.11	0.01	0.42	-0.24
6	60	0.12	0.03	-0.23	-0.15	0.11	-0.04	-0.06	-0.33	0.48	-0.99	0.20	-0.03	0.24	0.11	0.37	-0.24
7	70	0.11	0.13	-0.12	-0.04	0.16	-0.09	0.01	-0.34	0.31	-0.87	0.19	-0.04	0.13	-0.01	0.44	-0.28
8	80	0.09	0.11	-0.16	0.00	0.16	-0.15	-0.03	-0.40	0.34	-0.84	0.15	-0.07	0.13	0.00	0.41	-0.38
9	90	0.02	0.07	-0.22	-0.01	0.13	0.46	-0.06	-0.46	0.11	-0.93	0.12	-0.13	0.06	-0.03	0.33	-0.53
10	100	0.04	0.08	-0.24	-0.05	0.15	0.53	-0.05	-0.49	0.13	-0.98	0.13	-0.10	0.09	-0.02	0.36	-0.63

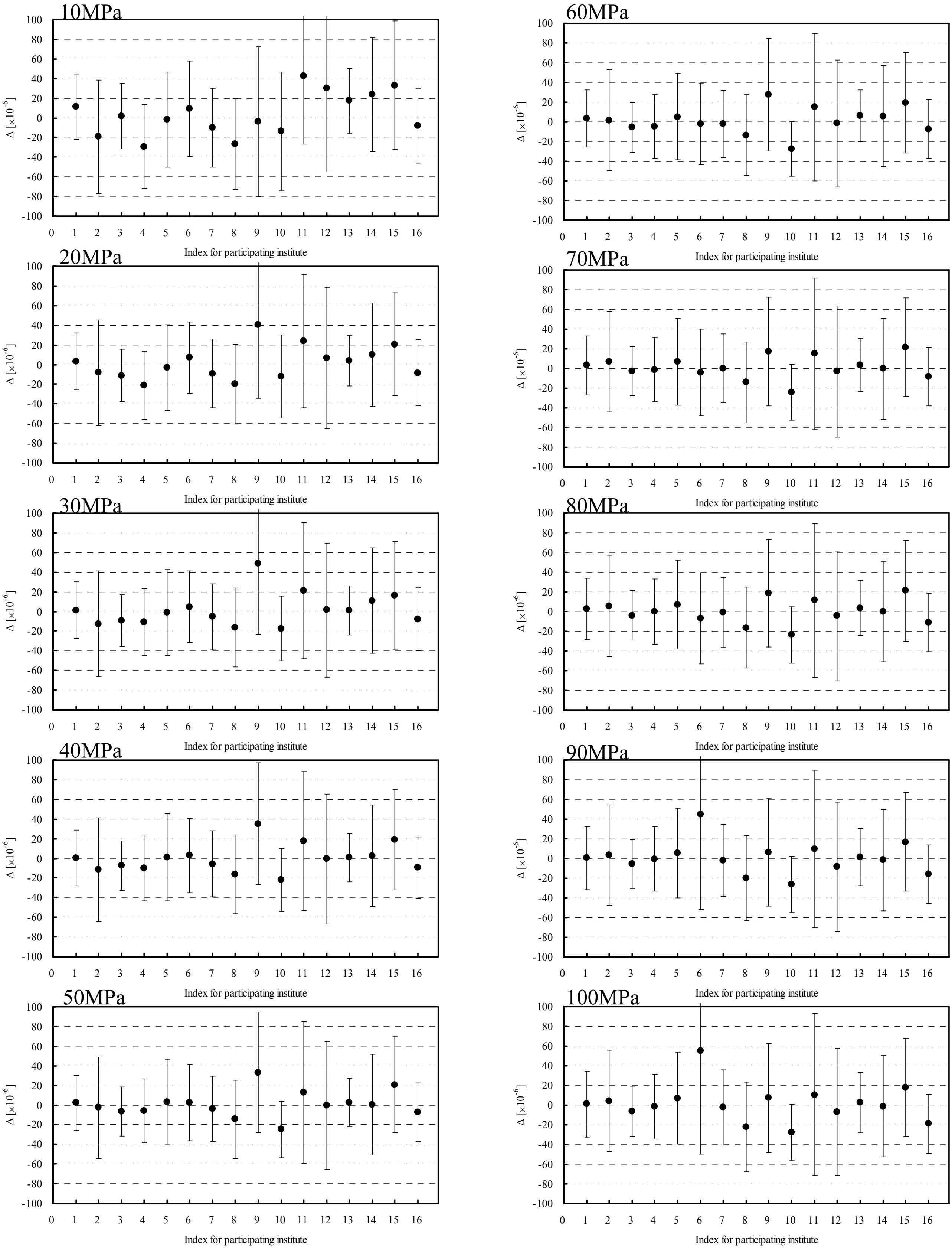


Figure 7.1: Deviations from the APMP KCRVs, $\Delta(j,i)$, and the expanded uncertainties of $\Delta(j,i)$, $U\{\Delta(j,i)\}$. The black points show deviations $\Delta(j,i)$ and the error bars refer to expanded ($k = 2$) uncertainties $U\{\Delta(j,i)\}$.

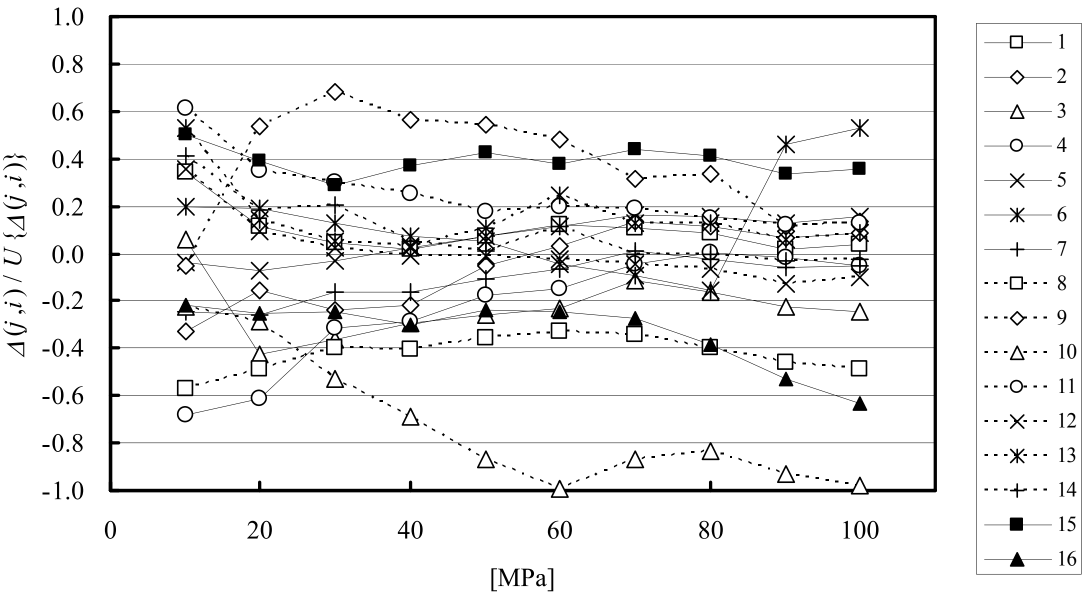


Figure 7.2: Degrees of equivalence of the participating institutes with respect to key comparison reference values. Ratios $\Delta(j,i)/U\{\Delta(j,i)\}$ for the participating institutes are plotted as a function of nominal target pressure.

7.2.2 Difference between deviations for pairs of institutes

The degree of equivalence between pairs of pressure standards *j* and *j'* is calculated by the following equation:

$$\delta(j, j', i) = \Delta(j, i) - \Delta(j', i) = \frac{p(j,i) - p(j',i)}{p(KCRV, i)}$$

(7.4)

where $\delta(j, j', i)$ is the relative difference of their deviations from the reference values, and the relative expanded uncertainty of the difference, $U\{\delta(j, j', i)\}$, is estimated from

$$U\{\delta(j, j', i)\} = k \cdot u_c\{\delta(j, j', i)\} = k \cdot \frac{\sqrt{u^2\{p(j,i)\} + u^2\{p(j',i)\}}}{p(KCRV, i)}$$

(7.5)

where $u_c\{\delta(j, j', i)\}$ is the combined standard uncertainty of the difference, *k* is the coverage factor and *k* = 2 is adopted, $u\{p(j,i)\}$ and $u\{p(j',i)\}$ are the combined uncertainties in the normalized mean ratio of *j*-th and *j'*-th institutes, respectively.

Tables 7.3, 7.4 and 7.5 present a summary of results of the differences, $\delta(j, j', i)$, the expanded (*k* = 2) uncertainties of the differences, $U\{\delta(j, j', i)\}$, and the degrees of equivalence expressed by the ratios, $\delta(j, j', i)/U\{\delta(j, j', i)\}$, for the participating institutes. A measure of the degree of equivalence is provided by the relative magnitude of the deviation as $\delta(j, j', i)/U\{\delta(j, j', i)\} \leq 1$. For the present comparison, the condition was established for all the pairs of the participating institutes at all nominal target pressures.

Table 7.3: Differences, $\delta(j, j', i) = \Delta(j, i) - \Delta(j', i)$.

j	Institute			Differences between deviations, $\delta(j,j',i) = \Delta(j,i) - \Delta(j',i)$ [$\times 10^{-6}$]															
		j'		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10		30.5	9.5	40.5	13.2	2.0	21.4	37.9	15.3	25.0	-31.5	-18.7	-6.0	-12.3	-21.6	19.6
		2	20		11.6	14.6	24.5	6.5	-3.8	12.4	23.2	-37.0	15.3	-20.5	-3.3	-0.3	-6.5	-17.4	11.8
		3	30		13.8	10.7	11.9	2.4	-3.5	6.6	17.3	-47.6	18.6	-19.7	-0.2	-0.1	-9.7	-14.8	9.1
		4	40		11.9	8.0	10.3	-0.5	-2.3	6.1	16.9	-34.7	22.4	-17.2	1.1	-0.3	-2.0	-18.4	10.0
1	NMIJ/AIST	5	50		4.8	8.5	7.9	-1.0	0.0	5.7	16.4	-31.0	27.0	-10.7	2.6	-0.6	1.6	-18.6	9.3
		6	60		2.0	9.4	8.3	-1.4	5.4	5.7	17.1	-23.8	30.9	-11.4	5.2	-2.7	-2.2	-15.5	11.0
		7	70		-3.6	6.1	4.6	-4.0	7.2	2.9	17.2	-14.2	27.6	-11.7	6.0	-0.3	3.5	-18.5	11.4
		8	80		-3.2	6.7	2.6	-4.3	9.7	3.6	19.1	-15.9	26.4	-8.8	7.1	-0.9	2.7	-18.4	14.0
		9	90		-2.9	6.1	1.0	-5.2	-44.2	2.6	20.3	-5.6	26.6	-9.1	8.8	-1.2	2.2	-16.2	16.2
		10	100		-3.0	7.5	3.0	-5.8	-54.1	3.2	23.3	-6.1	28.9	-9.4	8.0	-1.5	2.5	-16.4	20.2
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-30.5		-21.0	9.9	-17.3	-28.6	-9.1	7.4	-15.3	-5.6	-62.0	-49.3	-36.6	-42.9	-52.1	-10.9
		2	20	-11.6		3.1	13.0	-5.0	-15.3	0.8	11.7	-48.5	3.7	-32.1	-14.9	-11.8	-18.1	-28.9	0.2
		3	30	-13.8		-3.1	-2.0	-11.4	-17.3	-7.2	3.4	-61.5	4.7	-33.6	-14.1	-14.0	-23.5	-28.6	-4.7
		4	40	-11.9		-3.9	-1.7	-12.4	-14.2	-5.8	5.0	-46.6	10.5	-29.1	-10.8	-12.2	-13.9	-30.3	-1.9
2	NPLI	5	50	-4.8		3.7	3.1	-5.9	-4.8	0.9	11.6	-35.8	22.2	-15.5	-2.3	-5.5	-3.2	-23.5	4.4
		6	60	-2.0		7.5	6.4	-3.3	3.5	3.8	15.1	-25.8	29.0	-13.3	3.2	-4.7	-4.2	-17.5	9.0
		7	70	3.6		9.7	8.2	-0.4	10.8	6.5	20.8	-10.5	31.2	-8.1	9.6	3.4	7.1	-14.9	15.0
		8	80	3.2		9.9	5.8	-1.2	12.9	6.7	22.2	-12.7	29.6	-5.6	10.3	2.2	5.9	-15.2	17.2
		9	90	2.9		8.9	3.9	-2.3	-41.3	5.4	23.2	-2.8	29.5	-6.2	11.7	1.7	5.1	-13.4	19.0
		10	100	3.0		10.5	6.0	-2.8	-51.1	6.2	26.3	-3.1	31.9	-6.4	11.0	1.5	5.5	-13.4	23.2
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-9.5	21.0		30.9	3.7	-7.6	11.9	28.3	5.7	15.4	-41.0	-28.3	-15.6	-21.9	-31.1	10.0
		2	20	-14.6	-3.1		9.9	-8.1	-18.4	-2.3	8.6	-51.6	0.6	-35.2	-18.0	-14.9	-21.2	-32.0	-2.9
		3	30	-10.7	3.1		1.2	-8.3	-14.2	-4.1	6.5	-58.3	7.8	-30.5	-11.0	-10.8	-20.4	-25.5	-1.6
		4	40	-8.0	3.9		2.3	-8.4	-10.3	-1.9	8.9	-42.7	14.4	-25.2	-6.9	-8.3	-10.0	-26.4	2.0
3	CSIR-NML	5	50	-8.5	-3.7		-0.6	-9.5	-8.5	-2.8	7.9	-39.5	18.5	-19.2	-5.9	-9.1	-6.8	-27.1	0.8
		6	60	-9.4	-7.5		-1.1	-10.8	-4.0	-3.7	7.7	-33.2	21.5	-20.8	-4.2	-12.2	-11.7	-25.0	1.5
		7	70	-6.1	-9.7		-1.5	-10.1	1.1	-3.2	11.1	-20.2	21.5	-17.8	-0.1	-6.3	-2.6	-24.6	5.3
		8	80	-6.7	-9.9		-4.1	-11.1	3.0	-3.2	12.3	-22.6	19.7	-15.5	0.4	-7.7	-4.0	-25.1	7.3
		9	90	-6.1	-8.9		-5.1	-11.3	-50.3	-3.5	14.2	-11.7	20.6	-15.2	2.7	-7.3	-3.9	-22.3	10.1
		10	100	-7.5	-10.5		-4.5	-13.3	-61.6	-4.3	15.8	-13.6	21.4	-16.9	0.5	-9.0	-5.0	-23.9	12.7
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-40.5	-9.9	-30.9		-27.2	-38.5	-19.0	-2.6	-25.2	-15.5	-71.9	-59.2	-46.5	-52.8	-62.1	-20.9
		2	20	-24.5	-13.0	-9.9		-18.0	-28.3	-12.2	-1.3	-61.5	-9.3	-45.1	-27.9	-24.8	-31.1	-41.9	-12.8
		3	30	-11.9	2.0	-1.2		-9.4	-15.3	-5.2	5.4	-59.5	6.7	-31.6	-12.1	-12.0	-21.6	-26.7	-2.7
		4	40	-10.3	1.7	-2.3		-10.7	-12.6	-4.2	6.6	-45.0	12.1	-27.4	-9.2	-10.5	-12.3	-28.6	-0.3
4	NIS	5	50	-7.9	-3.1	0.6		-8.9	-7.9	-2.2	8.5	-38.9	19.1	-18.6	-5.3	-8.5	-6.3	-26.5	1.4
		6	60	-8.3	-6.4	1.1		-9.7	-2.9	-2.6	8.8	-32.1	22.6	-19.7	-3.1	-11.1	-10.6	-23.9	2.6
		7	70	-4.6	-8.2	1.5		-8.6	2.6	-1.7	12.6	-18.8	23.0	-16.3	1.4	-4.9	-1.2	-23.1	6.8
		8	80	-2.6	-5.8	4.1		-7.0	7.1	0.9	16.4	-18.5	23.8	-11.4	4.5	-3.6	0.1	-21.0	11.4
		9	90	-1.0	-3.9	5.1		-6.2	-45.2	1.6	19.3	-6.6	25.6	-10.1	7.8	-2.2	1.2	-17.2	15.2
		10	100	-3.0	-6.0	4.5		-8.8	-57.0	0.2	20.3	-9.1	25.9	-12.3	5.0	-4.5	-0.5	-19.4	17.2
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-13.2	17.3	-3.7	27.2		-11.3	8.2	24.7	2.0	11.7	-44.7	-32.0	-19.3	-25.6	-34.8	6.4
		2	20	-6.5	5.0	8.1	18.0		-10.3	5.8	16.7	-43.5	8.7	-27.1	-9.9	-6.8	-13.1	-23.9	5.2
		3	30	-2.4	11.4	8.3	9.4		-5.9	4.2	14.8	-50.0	16.1	-22.2	-2.7	-2.6	-12.1	-17.2	6.7
		4	40	0.5	12.4	8.4	10.7		-1.9	6.5	17.3	-34.3	22.9	-16.7	1.5	0.2	-1.5	-17.9	10.4
5	KRISS	5	50	1.0	5.9	9.5	8.9		1.0	6.7	17.5	-30.0	28.0	-9.7	3.6	0.4	2.7	-17.6	10.3
		6	60	1.4	3.3	10.8	9.7		6.8	7.1	18.5	-22.4	32.3	-10.0	6.6	-1.4	-0.9	-14.2	12.3
		7	70	4.0	0.4	10.1	8.6		11.2	6.9	21.2	-10.2	31.6	-7.7	10.0	3.7	7.5	-14.5	15.4
		8	80	4.3	1.2	11.1	7.0		14.1	7.9	23.4	-11.5	30.7	-4.5	11.5	3.4	7.0	-14.1	18.3
		9	90	5.2	2.3	11.3	6.2		-39.0	7.8	25.5	-0.4	31.8	-3.9	14.0	4.0	7.4	-11.0	21.4
		10	100	5.8	2.8	13.3	8.8		-48.2	9.0	29.2	-0.3	34.7	-3.5	13.8	4.3	8.4	-10.6	26.0
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-2.0	28.6	7.6	38.5	11.3		19.5	35.9	13.3	23.0	-33.4	-20.7	-8.0	-14.3	-23.6	17.6
		2	20	3.8	15.3	18.4	28.3	10.3		16.1	27.0	-33.2	19.0	-16.8	0.4	3.5	-2.8	-13.6	15.5
		3	30	3.5	17.3	14.2	15.3	5.9		10.1	20.7	-44.1	22.0	-16.3	3.2	3.3	-6.2	-11.3	12.6
		4	40	2.3	14.2	10.3	12.6	1.9		8.4	19.2	-32.4	24.7	-14.9	3.4	2.0	0.3	-16.1	12.3
6	SCL	5	50	0.0	4.8	8.5	7.9	-1.0		5.7	16.4	-31.0	27.0	-10.7	2.6	-0.6	1.7	-18.6	9.3
		6	60	-5.4	-3.5	4.0	2.9	-6.8		0.3	11.7	-29.2	25.5	-16.8	-0.2	-8.2	-7.7	-21.0	5.5
		7	70	-7.2	-10.8	-1.1	-2.6	-11.2		-4.3	10.0	-21.3	20.4	-18.9	-1.2	-7.4	-3.7	-25.7	4.2
		8	80	-9.7	-12.9	-3.0	-7.1	-14.1		-6.2	9.3	-25.6	16.7	-18.5	-2.6	-10.7	-7.0	-28.1	4.3
		9	90	44.2	41.3	50.3	45.2	39.0		46.8	64.5	38.6	70.8	35.1	53.0	43.0	46.4	28.0	60.4
		10	100	54.1	51.1	61.6	57.0	48.2		57.2	77.4	47.9	83.0	44.7	62.0	52.6	56.6	37.6	74.2
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-21.4	9.1	-11.9	19.0	-8.2	-19.5		16.4	-6.2	3.5	-52.9	-40.2	-27.5	-33.8	-43.0	-1.9
		2	20	-12.4	-0.8	2.3	12.2	-5.8	-16.1		10.8	-49.3	2.9	-32.9	-15.7	-12.7	-18.9	-29.7	-0.6
		3	30	-6.6	7.2	4.1	5.2	-4.2	-10.1		10.6	-54.2	11.9	-26.4	-6.9	-6.8	-16.3	-21.4	2.5
		4	40	-6.1	5.8	1.9	4.2	-6.5	-8.4		10.8	-40.8	16.3	-23.3	-5.0	-6.4	-8.1	-24.5	3.9
7	SPRING	5	50	-5.7	-0.9	2.8	2.2	-6.7	-5.7		10.7	-36.7	21.3	-16.4	-3.2	-6.3	-4.1	-24.3	3.5
		6	60	-5.7	-3.8	3.7	2.6	-7.1	-0.3		11.4	-29.5	25.2	-17.1	-0.5	-8.5	-8.0	-21.3	5.2
		7	70	-2.9	-6.5	3.2	1.7	-6.9	4.3		14.3	-17.1	24.7	-14.6	3.1	-3.2	0.6	-21.4	8.5
		8	80	-3.6	-6.7	3.2	-0.9	-7.9	6.2		15.5	-19.4	22.9	-12.3	3.6	-4.5	-0.9	-22.0	10.4
		9	90	-2.6	-5.4	3.5	-1.6	-7.8	-46.8		17.7	-8.2	24.0	-11.7	6.2	-3.8	-0.4	-18.8	13.6
		10	100	-3.2	-6.2	4.3	-0.2	-9.0	-57.2		20.2	-9.3	25.7	-12.5	4.8	-4.7	-0.6	-19.6	17.0
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-37.9	-7.4	-28.3	2.6	-24.7	-35.9	-16.4		-22.6	-12.9	-69.3	-56.6	-43.9	-50.2	-59.5	-18.3
		2	20	-23.2	-11.7	-8.6	1.3	-16.7	-27.0	-10.8		-60.2	-7.9	-43.7	-26.5	-23.5	-29.7	-40.6	-11.4
		3	30	-17.3	-3.4	-6.5	-5.4	-14.8	-20.7	-10.6		-64.9	1.3	-37.0	-17.5	-17.4	-27.0	-32.1	-8.1
		4	40	-16.9	-5.0	-8.9	-6.6	-17.3	-19.2	-10.8		-51.6	5.5	-34.1	-15.8	-17.2	-18.9	-35.3	-6.9
8	NMIA	5	50	-16.4	-11.6	-7.9	-8.5	-17.5	-16.4	-10.7		-47.4	10.6	-27.1	-13.9	-17.1	-14.8	-35.1	-7.2
		6	60	-17.1	-15.1	-7.7	-8.8	-18.5	-11.7	-11.4		-40.9	13.8	-28.5	-11.9	-19.8	-19.4	-32.7	-6.2
		7	70	-17.2	-20.8	-11.1	-12.6	-21.2	-10.0	-14.3		-31.4	10.4	-28.9	-11.2	-17.5	-13.8	-35.7	-5.8
		8	80	-19.1	-22.2	-12.3	-16.4	-23.4	-9.3	-15.5		-34.9	7.4	-27.8	-11.9	-20.0	-16.4	-37.5	-5.1
		9	90	-20.3	-23.2	-14.2	-19.3	-25.5	-64.5	-17.7		-25.9	6.3	-29.4	-11.5	-21.5	-18.1	-36.5	-4.1
		10	100	-23.3	-26.3	-15.8	-20.3	-29.2	-77.4	-20.2		-29.5	5.6	-32.7	-15.4	-24.8	-20.8	-39.8	-3.2

Table 7.3: Differences, $\delta(j, j', i) = \Delta(j, i) - \Delta(j', i)$ (Continued.).

j	Institute			Differences between deviations, $\delta(j,j',i) = \Delta(j,i) - \Delta(j',i)$ [$\times 10^{-6}$]															
		j'		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
9	VMI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-15.3	15.3	-5.7	25.2	-2.0	-13.3	6.2	22.6		9.7	-46.7	-34.0	-21.3	-27.6	-36.9	4.3
		2	20	37.0	48.5	51.6	61.5	43.5	33.2	49.3	60.2		52.2	16.4	33.6	36.7	30.4	19.6	48.7
		3	30	47.6	61.5	58.3	59.5	50.0	44.1	54.2	64.9		66.2	27.9	47.4	47.5	37.9	32.8	56.8
		4	40	34.7	46.6	42.7	45.0	34.3	32.4	40.8	51.6		57.1	17.5	35.8	34.4	32.7	16.3	44.7
		5	50	31.0	35.8	39.5	38.9	30.0	31.0	36.7	47.4		58.0	20.3	33.6	30.4	32.6	12.4	40.3
		6	60	23.8	25.8	33.2	32.1	22.4	29.2	29.5	40.9		54.7	12.4	29.0	21.1	21.5	8.2	34.7
		7	70	14.2	10.5	20.2	18.8	10.2	21.3	17.1	31.4		41.8	2.5	20.2	13.9	17.6	-4.4	25.5
		8	80	15.9	12.7	22.6	18.5	11.5	25.6	19.4	34.9		42.3	7.1	23.0	14.9	18.6	-2.5	29.9
		9	90	5.6	2.8	11.7	6.6	0.4	-38.6	8.2	25.9		32.2	-3.5	14.4	4.4	7.8	-10.6	21.8
		10	100	6.1	3.1	13.6	9.1	0.3	-47.9	9.3	29.5		35.0	-3.2	14.1	4.6	8.7	-10.3	26.3
10	NML-SIRIM	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-25.0	5.6	-15.4	15.5	-11.7	-23.0	-3.5	12.9	-9.7		-56.4	-43.7	-31.0	-37.3	-46.6	-5.4
		2	20	-15.3	-3.7	-0.6	9.3	-8.7	-19.0	-2.9	7.9	-52.2		-35.8	-18.6	-15.5	-21.8	-32.6	-3.5
		3	30	-18.6	-4.7	-7.8	-6.7	-16.1	-22.0	-11.9	-1.3	-66.2		-38.3	-18.8	-18.7	-28.3	-33.3	-9.4
		4	40	-22.4	-10.5	-14.4	-12.1	-22.9	-24.7	-16.3	-5.5	-57.1		-39.6	-21.3	-22.7	-24.4	-40.8	-12.4
		5	50	-27.0	-22.2	-18.5	-19.1	-28.0	-27.0	-21.3	-10.6	-58.0		-37.7	-24.4	-27.6	-25.4	-45.6	-17.7
		6	60	-30.9	-29.0	-21.5	-22.6	-32.3	-25.5	-25.2	-13.8	-54.7		-42.3	-25.7	-33.7	-33.2	-46.5	-20.0
		7	70	-27.6	-31.2	-21.5	-23.0	-31.6	-20.4	-24.7	-10.4	-41.8		-39.3	-21.6	-27.9	-24.1	-46.1	-16.2
		8	80	-26.4	-29.6	-19.7	-23.8	-30.7	-16.7	-22.9	-7.4	-42.3		-35.2	-19.3	-27.4	-23.7	-44.8	-12.4
		9	90	-26.6	-29.5	-20.6	-25.6	-31.8	-70.8	-24.0	-6.3	-32.2		-35.7	-17.8	-27.8	-24.4	-42.8	-10.4
		10	100	-28.9	-31.9	-21.4	-25.9	-34.7	-83.0	-25.7	-5.6	-35.0		-38.3	-20.9	-30.4	-26.4	-45.3	-8.7
11	KIM-LIPI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	31.5	62.0	41.0	71.9	44.7	33.4	52.9	69.3	46.7	56.4		12.7	25.4	19.1	9.9	51.0
		2	20	20.5	32.1	35.2	45.1	27.1	16.8	32.9	43.7	-16.4	35.8		17.2	20.3	14.0	3.2	32.3
		3	30	19.7	33.6	30.5	31.6	22.2	16.3	26.4	37.0	-27.9	38.3		19.5	19.6	10.0	5.0	28.9
		4	40	17.2	29.1	25.2	27.4	16.7	14.9	23.3	34.1	-17.5	39.6		18.3	16.9	15.2	-1.2	27.2
		5	50	10.7	15.5	19.2	18.6	9.7	10.7	16.4	27.1	-20.3	37.7		13.3	10.1	12.3	-7.9	20.0
		6	60	11.4	13.3	20.8	19.7	10.0	16.8	17.1	28.5	-12.4	42.3		16.6	8.6	9.1	-4.2	22.3
		7	70	11.7	8.1	17.8	16.3	7.7	18.9	14.6	28.9	-2.5	39.3		17.7	11.4	15.2	-6.8	23.1
		8	80	8.8	5.6	15.5	11.4	4.5	18.5	12.3	27.8	-7.1	35.2		15.9	7.8	11.5	-9.6	22.8
		9	90	9.1	6.2	15.2	10.1	3.9	-35.1	11.7	29.4	3.5	35.7		17.9	7.9	11.3	-7.1	25.3
		10	100	9.4	6.4	16.9	12.3	3.5	-44.7	12.5	32.7	3.2	38.3		17.3	7.9	11.9	-7.1	29.5
12	NSCL	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	18.7	49.3	28.3	59.2	32.0	20.7	40.2	56.6	34.0	43.7	-12.7		12.7	6.4	-2.9	38.3
		2	20	3.3	14.9	18.0	27.9	9.9	-0.4	15.7	26.5	-33.6	18.6	-17.2		3.1	-3.2	-14.0	15.1
		3	30	0.2	14.1	11.0	12.1	2.7	-3.2	6.9	17.5	-47.4	18.8	-19.5		0.1	-9.5	-14.5	9.4
		4	40	-1.1	10.8	6.9	9.2	-1.5	-3.4	5.0	15.8	-35.8	21.3	-18.3		-1.4	-3.1	-19.5	8.9
		5	50	-2.6	2.3	5.9	5.3	-3.6	-2.6	3.2	13.9	-33.6	24.4	-13.3		-3.2	-0.9	-21.2	6.7
		6	60	-5.2	-3.2	4.2	3.1	-6.6	0.2	0.5	11.9	-29.0	25.7	-16.6		-7.9	-7.5	-20.8	5.7
		7	70	-6.0	-9.6	0.1	-1.4	-10.0	1.2	-3.1	11.2	-20.2	21.6	-17.7		-6.3	-2.5	-24.5	5.4
		8	80	-7.1	-10.3	-0.4	-4.5	-11.5	2.6	-3.6	11.9	-23.0	19.3	-15.9		-8.1	-4.4	-25.5	6.9
		9	90	-8.8	-11.7	-2.7	-7.8	-14.0	-53.0	-6.2	11.5	-14.4	17.8	-17.9		-10.0	-6.6	-25.0	7.4
		10	100	-8.0	-11.0	-0.5	-5.0	-13.8	-62.0	-4.8	15.4	-14.1	20.9	-17.3		-9.5	-5.4	-24.4	12.2
13	PTB	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	6.0	36.6	15.6	46.5	19.3	8.0	27.5	43.9	21.3	31.0	-25.4	-12.7		-6.3	-15.6	25.6
		2	20	0.3	11.8	14.9	24.8	6.8	-3.5	12.7	23.5	-36.7	15.5	-20.3	-3.1		-6.2	-17.1	12.1
		3	30	0.1	14.0	10.8	12.0	2.6	-3.3	6.8	17.4	-47.5	18.7	-19.6	-0.1		-9.6	-14.7	9.3
		4	40	0.3	12.2	8.3	10.5	-0.2	-2.0	6.4	17.2	-34.4	22.7	-16.9	1.4		-1.7	-18.1	10.3
		5	50	0.6	5.5	9.1	8.5	-0.4	0.6	6.3	17.1	-30.4	27.6	-10.1	3.2		2.3	-18.0	9.9
		6	60	2.7	4.7	12.2	11.1	1.4	8.2	8.5	19.8	-21.1	33.7	-8.6	7.9		0.5	-12.8	13.7
		7	70	0.3	-3.4	6.3	4.9	-3.7	7.4	3.2	17.5	-13.9	27.9	-11.4	6.3		3.7	-18.3	11.6
		8	80	0.9	-2.2	7.7	3.6	-3.4	10.7	4.5	20.0	-14.9	27.4	-7.8	8.1		3.6	-17.4	15.0
		9	90	1.2	-1.7	7.3	2.2	-4.0	-43.0	3.8	21.5	-4.4	27.8	-7.9	10.0		3.4	-15.0	17.4
		10	100	1.5	-1.5	9.0	4.5	-4.3	-52.6	4.7	24.8	-4.6	30.4	-7.9	9.5		4.0	-14.9	21.7
14	NIMT	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	12.3	42.9	21.9	52.8	25.6	14.3	33.8	50.2	27.6	37.3	-19.1	-6.4	6.3		-9.3	31.9
		2	20	6.5	18.1	21.2	31.1	13.1	2.8	18.9	29.7	-30.4	21.8	-14.0	3.2	6.2		-10.8	18.3
		3	30	9.7	23.5	20.4	21.6	12.1	6.2	16.3	27.0	-37.9	28.3	-10.0	9.5	9.6		-5.1	18.9
		4	40	2.0	13.9	10.0	12.3	1.5	-0.3	8.1	18.9	-32.7	24.4	-15.2	3.1	1.7		-16.4	12.0
		5	50	-1.6	3.2	6.8	6.3	-2.7	-1.7	4.1	14.8	-32.6	25.4	-12.3	0.9	-2.3		-20.3	7.6
		6	60	2.2	4.2	11.7	10.6	0.9	7.7	8.0	19.4	-21.5	33.2	-9.1	7.5	-0.5		-13.3	13.2
		7	70	-3.5	-7.1	2.6	1.2	-7.5	3.7	-0.6	13.8	-17.6	24.1	-15.2	2.5	-3.7		-22.0	7.9
		8	80	-2.7	-5.9	4.0	-0.1	-7.0	7.0	0.9	16.4	-18.6	23.7	-11.5	4.4	-3.6		-21.1	11.3
		9	90	-2.2	-5.1	3.9	-1.2	-7.4	-46.4	0.4	18.1	-7.8	24.4	-11.3	6.6	-3.4		-18.4	14.0
		10	100	-2.5	-5.5	5.0	0.5	-8.4	-56.6	0.6	20.8	-8.7	26.4	-11.9	5.4	-4.0		-19.0	17.6
15	CMS/ITRI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	21.6	52.1	31.1	62.1	34.8	23.6	43.0	59.5	36.9	46.6	-9.9	2.9	15.6	9.3		41.2
		2	20	17.4	28.9	32.0	41.9	23.9	13.6	29.7	40.6	-19.6	32.6	-3.2	14.0	17.1	10.8		29.1
		3	30	14.8	28.6	25.5	26.7	17.2	11.3	21.4	32.1	-32.8	33.3	-5.0	14.5	14.7	5.1		23.9
		4	40	18.4	30.3	26.4	28.6	17.9	16.1	24.5	35.3	-16.3	40.8	1.2	19.5	18.1	16.4		28.4
		5	50	18.6	23.5	27.1	26.5	17.6	18.6	24.3	35.1	-12.4	45.6	7.9	21.2	18.0	20.3		27.9
		6	60	15.5	17.5	25.0	23.9	14.2	21.0	21.3	32.7	-8.2	46.5	4.2	20.8	12.8	13.3		26.5
		7	70	18.5	14.9	24.6	23.1	14.5	25.7	21.4	35.7	4.4	46.1	6.8	24.5	18.3	22.0		29.9
		8	80	18.4	15.2	25.1	21.0	14.1	28.1	22.0	37.5	2.5	44.8	9.6	25.5	17.4	21.1		32.4
		9	90	16.2	13.4	22.3	17.2	11.0	-28.0	18.8	36.5	10.6	42.8	7.1	25.0	15.0	18.4		32.4
		10	100	16.4	13.4	23.9	19.4	10.6	-37.6	19.6	39.8	10.3	45.3	7.1	24.4	14.9	19.0		36.6
16	NIM	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-19.6	10.9	-10.0	20.9	-6.4	-17.6	1.9	18.3	-4.3	5.4	-51.0	-38.3	-25.6	-31.9	-41.2	
		2	20	-11.8	-0.2	2.9	12.8	-5.2	-15.5	0.6	11.4	-48.7	3.5	-32.3	-15.1	-12.1	-18.3	-29.1	
		3	30	-9.1	4.7	1.6	2.7	-6.7	-12.6	-2.5	8.1	-56.8	9.4	-28.9	-9.4	-9.3	-18.9	-23.9	
		4	40	-10.0	1.9	-2.0	0.3	-10.4	-12.3	-3.9	6.9	-44.7	12.4	-27.2	-8.9	-10.3	-12.0	-28.4	
		5	50	-9.3	-4.4	-0.8	-1.4	-10.3	-9.3	-3.5	7.2	-40.3	17.7	-20.0	-6.7	-9.9	-7.6	-27.9	
		6	60	-11.0	-9.0	-1.5	-2.6	-12.3	-5.5	-5.2	6.2	-34.7	20.0	-22.3	-5.7	-13.7	-13.2	-26.5	
		7	70	-11.4	-15.0	-5.3	-6.8	-15.4	-4.2	-8.5	5.8	-25.5	16.2	-23.1	-5.4	-11.6	-7.9	-29.9	
		8	80	-14.0	-17.2	-7.3	-11.4	-18.3	-4.3	-10.4	5.1	-29.9	12.4	-22.8	-6.9	-15.0	-11.3	-32.4	
		9	90	-16.2	-19.0	-10.1	-15.2	-21.4	-60.4	-13.6	4.1	-21.8	10.4	-25.3	-7.4	-17.4	-14.0	-32.4	
		10	100	-20.2	-23.2	-12.7	-17.2	-26.0	-74.2	-17.0	3.2	-26.3	8.7	-29.5	-12.2	-21.7	-17.6	-36.6	

Table 7.4: Expanded (k = 2) uncertainties of differences, $U\{\delta(j, j', i)\}$.

j	Institute			Expanded uncertainty of δ, $U\{\delta(j,j',i)\}$ [$\times 10^{-6}$]															
		j'		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10		63.3	42.0	49.9	55.0	55.0	48.0	53.0	80.5	65.5	74.3	89.1	41.9	63.3	70.3	45.9
		2	20		59.2	37.0	43.1	50.5	44.5	43.3	48.0	79.0	49.2	72.3	76.4	36.2	58.6	58.3	42.3
		3	30		59.2	36.2	42.0	50.2	44.3	41.8	47.3	76.1	41.1	73.7	72.7	35.4	59.0	60.5	40.8
		4	40		58.6	36.3	42.6	51.1	45.7	42.4	47.7	67.4	41.0	75.2	71.1	35.9	57.7	57.5	40.5
1	NMIJ/AIST	5	50		58.5	37.0	42.5	51.2	47.5	43.2	48.4	67.2	39.7	76.8	70.5	37.0	58.1	56.1	40.6
		6	60		58.5	37.5	42.8	52.0	49.9	44.2	49.9	63.7	39.3	79.9	70.1	38.3	58.5	58.3	41.1
		7	70		58.7	38.1	43.5	52.8	52.6	45.3	50.3	62.5	40.5	82.1	72.6	39.4	58.8	57.5	41.6
		8	80		59.3	39.0	44.4	53.9	54.9	46.5	50.8	62.3	41.2	83.7	72.3	40.8	59.3	59.3	42.1
		9	90		59.8	39.8	45.1	55.0	101.4	47.8	53.3	62.8	41.9	85.8	72.3	42.5	59.8	59.0	42.9
		10	100		60.6	41.0	45.9	56.4	109.6	49.5	55.5	64.2	42.8	88.3	72.5	44.4	60.5	59.1	43.8
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	63.3		63.2	68.7	72.5	72.5	67.3	71.0	93.3	80.8	88.0	100.8	63.1	78.9	84.7	65.9
		2	20	59.2		58.2	62.3	67.7	63.3	62.4	65.8	90.9	66.7	85.2	88.6	57.7	73.8	73.6	61.7
		3	30	59.2		58.1	61.9	67.7	63.4	61.7	65.6	88.6	61.2	86.5	85.7	57.6	74.5	75.7	61.0
		4	40	58.6		57.2	61.4	67.6	63.6	61.3	65.1	80.6	60.4	87.3	83.8	57.0	72.7	72.5	60.0
2	NPLI	5	50	58.5		57.0	60.7	67.1	64.3	61.1	65.0	79.9	58.7	88.2	82.7	57.0	72.4	70.9	59.4
		6	60	58.5		56.6	60.2	67.1	65.4	61.2	65.4	76.5	57.8	90.4	81.9	57.1	72.2	72.1	59.0
		7	70	58.7		56.3	60.1	67.1	66.9	61.3	65.1	74.9	57.9	92.0	83.5	57.1	71.9	70.9	58.6
		8	80	59.3		56.4	60.2	67.5	68.3	61.7	65.1	74.4	57.9	93.1	83.0	57.6	71.9	71.9	58.5
		9	90	59.8		56.3	60.2	67.9	108.9	62.2	66.5	74.3	57.7	94.6	82.5	58.2	71.8	71.1	58.5
		10	100	60.6		56.6	60.2	68.6	116.3	63.0	67.8	75.1	57.9	96.5	82.3	59.0	72.0	70.8	58.6
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	42.0	63.2		49.7	54.9	54.9	47.8	52.9	80.4	65.4	74.2	89.0	41.8	63.2	70.2	45.8
		2	20	37.0	58.2		41.8	49.4	43.3	42.0	46.9	78.3	48.1	71.5	75.7	34.6	57.6	57.3	41.0
		3	30	36.2	58.1		40.4	48.9	42.8	40.2	45.9	75.2	39.5	72.8	71.8	33.5	57.9	59.4	39.2
		4	40	36.3	57.2		40.6	49.5	43.9	40.4	46.0	66.2	39.0	74.1	69.9	33.5	56.3	56.0	38.5
3	CSIR-NML	5	50	37.0	57.0		40.3	49.5	45.6	41.1	46.6	65.8	37.4	75.7	69.2	34.6	56.5	54.5	38.4
		6	60	37.5	56.6		40.1	49.8	47.6	41.5	47.5	61.9	36.3	78.4	68.5	35.2	56.6	56.3	38.3
		7	70	38.1	56.3		40.2	50.0	49.8	42.0	47.4	60.2	36.8	80.4	70.6	35.6	56.3	55.0	38.0
		8	80	39.0	56.4		40.5	50.7	51.8	42.7	47.5	59.6	36.9	81.7	70.0	36.5	56.4	56.5	37.9
		9	90	39.8	56.3		40.3	51.2	99.4	43.4	49.3	59.4	36.7	83.4	69.4	37.4	56.3	55.4	37.8
		10	100	41.0	56.6		40.5	52.1	107.4	44.6	51.1	60.4	36.9	85.6	69.2	38.7	56.5	55.0	38.1
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	49.9	68.7	49.7		61.2	61.1	54.9	59.4	84.8	70.7	79.0	93.0	49.7	68.7	75.2	53.1
		2	20	43.1	62.3	41.8		54.2	48.6	47.5	51.9	81.4	53.0	74.9	78.8	41.2	61.7	61.5	46.6
		3	30	42.0	61.9	40.4		53.3	47.8	45.5	50.6	78.2	44.8	75.8	74.9	39.6	61.7	63.1	44.6
		4	40	42.6	61.4	40.6		54.3	49.2	46.1	51.1	69.8	44.9	77.4	73.4	40.3	60.5	60.3	44.5
4	NIS	5	50	42.5	60.7	40.3		53.7	50.1	46.0	51.0	69.0	42.8	78.5	72.2	40.3	60.2	58.3	43.7
		6	60	42.8	60.2	40.1		53.9	51.9	46.4	51.8	65.3	41.8	81.1	71.5	40.8	60.2	60.0	43.5
		7	70	43.5	60.1	40.2		54.3	54.1	47.0	51.8	63.7	42.4	83.1	73.7	41.4	60.1	58.9	43.4
		8	80	44.4	60.2	40.5		55.0	55.9	47.7	52.0	63.2	42.6	84.4	73.1	42.2	60.2	60.3	43.4
		9	90	45.1	60.2	40.3		55.4	101.6	48.3	53.7	63.1	42.4	86.1	72.6	43.0	60.2	59.3	43.4
		10	100	45.9	60.2	40.5		56.1	109.4	49.1	55.1	63.9	42.3	88.0	72.2	43.9	60.2	58.7	43.4
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	55.0	72.5	54.9	61.2		65.4	59.6	63.8	87.9	74.5	82.3	95.8	54.9	72.5	78.7	58.0
		2	20	50.5	67.7	49.4	54.2		55.3	54.3	58.2	85.6	59.2	79.4	83.1	48.9	67.1	66.9	53.5
		3	30	50.2	67.7	48.9	53.3		55.1	53.1	57.6	82.9	52.6	80.6	79.8	48.2	67.5	68.8	52.3
		4	40	51.1	67.6	49.5	54.3		56.8	54.1	58.4	75.4	53.1	82.4	78.7	49.2	66.8	66.6	52.7
5	KRISS	5	50	51.2	67.1	49.5	53.7		57.7	54.2	58.5	74.8	51.5	83.6	77.7	49.5	66.7	65.0	52.2
		6	60	52.0	67.1	49.8	53.9		59.7	55.0	59.6	71.6	51.2	86.3	77.4	50.4	67.1	66.9	52.5
		7	70	52.8	67.1	50.0	54.3		61.8	55.7	59.8	70.4	51.9	88.3	79.5	51.0	67.1	66.0	52.7
		8	80	53.9	67.5	50.7	55.0		63.7	56.6	60.3	70.2	52.4	89.8	79.2	52.1	67.5	67.6	53.1
		9	90	55.0	67.9	51.2	55.4		106.4	57.6	62.2	70.5	52.8	91.7	79.1	53.3	67.9	67.2	53.6
		10	100	56.4	68.6	52.1	56.1		114.2	59.1	64.2	71.8	53.5	94.0	79.3	54.8	68.5	67.3	54.4
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	55.0	72.5	54.9	61.1	65.4		59.6	63.7	87.9	74.4	82.3	95.8	54.8	72.5	78.7	58.0
		2	20	44.5	63.3	43.3	48.6	55.3		48.8	53.0	82.1	54.1	75.7	79.6	42.6	62.7	62.5	47.9
		3	30	44.3	63.4	42.8	47.8	55.1		47.6	52.5	79.4	47.0	77.1	76.2	42.0	63.3	64.7	46.7
		4	40	45.7	63.6	43.9	49.2	56.8		49.1	53.8	71.8	47.9	79.2	75.3	43.6	62.8	62.6	47.5
6	SCL	5	50	47.5	64.3	45.6	50.1	57.7		50.7	55.3	72.2	47.8	81.3	75.3	45.6	63.9	62.1	48.6
		6	60	49.9	65.4	47.6	51.9	59.7		53.0	57.8	70.1	49.0	85.1	76.0	48.2	65.4	65.2	50.5
		7	70	52.6	66.9	49.8	54.1	61.8		55.5	59.6	70.2	51.7	88.2	79.4	50.8	67.0	65.9	52.5
		8	80	54.9	68.3	51.8	55.9	63.7		57.6	61.2	71.0	53.4	90.4	79.9	53.1	68.3	68.4	54.1
		9	90	101.4	108.9	99.4	101.6	106.4		102.8	105.5	110.6	100.2	125.1	116.2	100.5	108.9	108.5	100.6
		10	100	109.6	116.3	107.4	109.4	114.2		111.0	113.8	118.2	108.1	132.9	122.9	108.8	116.3	115.5	108.5
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	48.0	67.3	47.8	54.9	59.6	59.6		57.8	83.7	69.4	77.8	92.0	47.8	67.3	74.0	51.3
		2	20	43.3	62.4	42.0	47.5	54.3	48.8		52.0	81.5	53.1	75.0	78.9	41.3	61.8	61.6	46.7
		3	30	41.8	61.7	40.2	45.5	53.1	47.6		50.4	78.1	44.6	75.7	74.8	39.4	61.6	63.0	44.4
		4	40	42.4	61.3	40.4	46.1	54.1	49.1		50.9	69.7	44.7	77.3	73.3	40.0	60.4	60.1	44.3
7	SPRING	5	50	43.2	61.1	41.1	46.0	54.2	50.7		51.6	69.5	43.5	78.9	72.7	41.1	60.7	58.9	44.3
		6	60	44.2	61.2	41.5	46.4	55.0	53.0		52.9	66.1	43.2	81.8	72.4	42.2	61.2	61.0	44.8
		7	70	45.3	61.3	42.0	47.0	55.7	55.5		53.3	64.9	44.2	84.0	74.7	43.2	61.4	60.2	45.2
		8	80	46.5	61.7	42.7	47.7	56.6	57.6		53.7	64.7	44.7	85.5	74.4	44.4	61.7	61.8	45.5
		9	90	47.8	62.2	43.4	48.3	57.6	102.8		56.0	65.1	45.3	87.5	74.3	45.8	62.2	61.4	46.2
		10	100	49.5	63.0	44.6	49.1	59.1	111.0		58.2	66.5	46.2	90.0	74.6	47.7	63.0	61.6	47.2
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	53.0	71.0	52.9	59.4	63.8	63.7	57.8		86.7	73.0	81.0	94.7	52.9	71.0	77.4	56.1
		2	20	48.0	65.8	46.9	51.9	58.2	53.0	52.0		84.1	57.1	77.8	81.6	46.3	65.3	65.0	51.2
		3	30	47.3	65.6	45.9	50.6	57.6	52.5	50.4		81.2	49.9	78.9	78.0	45.3	65.4	66.8	49.6
		4	40	47.7	65.1	46.0	51.1	58.4	53.8	50.9		73.1	49.8	80.4	76.5	45.7	64.3	64.0	49.4
8	NMIA	5	50	48.4	65.0	46.6	51.0	58.5	55.3	51.6		72.8	48.7	81.9	75.9	46.6	64.6	62.8	49.5
		6	60	49.9	65.4	47.5	51.8	59.6	57.8	52.9		70.1	49.0	85.0	76.0	48.1	65.4	65.2	50.4
		7	70	50.3	65.1	47.4	51.8	59.8	59.6	53.3		68.5	49.3	86.8	77.8	48.4	65.2	64.0	50.2
		8	80	50.8	65.1	47.5	52.0	60.3	61.2	53.7		67.9	49.3	88.0	77.2	48.9	65.1	65.2	50.0
		9	90	53.3	66.5	49.3	53.7	62.2	105.5	56.0		69.2	51.0	90.6	77.9	51.5	66.5	65.7	51.8
		10	100	55.5	67.8	51.1	55.1	64.2	113.8	58.2		71.1	52.6	93.4	78.6	53.8	67.8	66.5	53.4

Table 7.4: Expanded (k = 2) uncertainties of differences, $U\{\delta(j, j', i)\}$ (Continued.).

j	Institute			Expanded uncertainty of δ, $U\{\delta(j, j', i)\}$ [$\times 10^{-6}$]															
		j'		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	80.5	93.3	80.4	84.8	87.9	87.9	83.7	86.7		94.8	101.1	112.4	80.4	93.3	98.2	82.5
		2	20	79.0	90.9	78.3	81.4	85.6	82.1	81.5	84.1		84.8	100.0	103.0	77.9	90.5	90.4	81.0
		3	30	76.1	88.6	75.2	78.2	82.9	79.4	78.1	81.2		77.7	98.9	98.2	74.8	88.5	89.5	77.5
		4	40	67.4	80.6	66.2	69.8	75.4	71.8	69.7	73.1		68.9	93.4	90.1	66.0	80.0	79.8	68.6
9	VMI	5	50	67.2	79.9	65.8	69.0	74.8	72.2	69.5	72.8		67.4	94.2	89.0	65.8	79.6	78.2	67.9
		6	60	63.7	76.5	61.9	65.3	71.6	70.1	66.1	70.1		63.0	93.8	85.7	62.4	76.5	76.3	64.1
		7	70	62.5	74.9	60.2	63.7	70.4	70.2	64.9	68.5		61.7	94.4	86.2	61.0	75.0	74.0	62.4
		8	80	62.3	74.4	59.6	63.2	70.2	71.0	64.7	67.9		61.0	95.1	85.2	60.8	74.4	74.5	61.6
		9	90	62.8	74.3	59.4	63.1	70.5	110.6	65.1	69.2		60.8	96.5	84.7	61.3	74.3	73.6	61.5
		10	100	64.2	75.1	60.4	63.9	71.8	118.2	66.5	71.1		61.7	98.8	85.0	62.8	75.1	73.9	62.4
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	65.5	80.8	65.4	70.7	74.5	74.4	69.4	73.0	94.8		89.7	102.2	65.4	80.7	86.4	68.0
		2	20	49.2	66.7	48.1	53.0	59.2	54.1	53.1	57.1	84.8		78.6	82.3	47.5	66.1	65.9	52.3
		3	30	41.1	61.2	39.5	44.8	52.6	47.0	44.6	49.9	77.7		75.3	74.4	38.7	61.1	62.5	43.7
		4	40	41.0	60.4	39.0	44.9	53.1	47.9	44.7	49.8	68.9		76.6	72.5	38.6	59.5	59.2	43.0
10	NML-SIRIM	5	50	39.7	58.7	37.4	42.8	51.5	47.8	43.5	48.7	67.4		77.0	70.6	37.4	58.3	56.3	40.9
		6	60	39.3	57.8	36.3	41.8	51.2	49.0	43.2	49.0	63.0		79.3	69.5	37.1	57.8	57.5	40.0
		7	70	40.5	57.9	36.8	42.4	51.9	51.7	44.2	49.3	61.7		81.5	71.9	38.1	58.0	56.7	40.4
		8	80	41.2	57.9	36.9	42.6	52.4	53.4	44.7	49.3	61.0		82.8	71.2	38.8	57.9	58.0	40.1
		9	90	41.9	57.7	36.7	42.4	52.8	100.2	45.3	51.0	60.8		84.4	70.6	39.6	57.8	56.9	40.0
		10	100	42.8	57.9	36.9	42.3	53.5	108.1	46.2	52.6	61.7		86.5	70.3	40.6	57.8	56.3	40.0
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	74.3	88.0	74.2	79.0	82.3	82.3	77.8	81.0	101.1	89.7		108.1	74.2	88.0	93.2	76.5
		2	20	72.3	85.2	71.5	74.9	79.4	75.7	75.0	77.8	100.0	78.6		97.9	71.1	84.7	84.6	74.4
		3	30	73.7	86.5	72.8	75.8	80.6	77.1	75.7	78.9	98.9	75.3		96.3	72.3	86.4	87.4	75.2
		4	40	75.2	87.3	74.1	77.4	82.4	79.2	77.3	80.4	93.4	76.6		96.1	73.9	86.7	86.5	76.3
11	KIM-LIPI	5	50	76.8	88.2	75.7	78.5	83.6	81.3	78.9	81.9	94.2	77.0		96.5	75.7	87.9	86.6	77.5
		6	60	79.9	90.4	78.4	81.1	86.3	85.1	81.8	85.0	93.8	79.3		98.3	78.8	90.4	90.2	80.2
		7	70	82.1	92.0	80.4	83.1	88.3	88.2	84.0	86.8	94.4	81.5		101.4	81.0	92.0	91.2	82.1
		8	80	83.7	93.1	81.7	84.4	89.8	90.4	85.5	88.0	95.1	82.8		101.9	82.6	93.1	93.1	83.2
		9	90	85.8	94.6	83.4	86.1	91.7	125.1	87.5	90.6	96.5	84.4		102.9	84.7	94.6	94.1	84.9
		10	100	88.3	96.5	85.6	88.0	94.0	132.9	90.0	93.4	98.8	86.5		104.4	87.2	96.5	95.6	87.0
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	89.1	100.8	89.0	93.0	95.8	95.8	92.0	94.7	112.4	102.2	108.1		89.0	100.8	105.4	90.9
		2	20	76.4	88.6	75.7	78.8	83.1	79.6	78.9	81.6	103.0	82.3	97.9		75.3	88.2	88.1	78.4
		3	30	72.7	85.7	71.8	74.9	79.8	76.2	74.8	78.0	98.2	74.4	96.3		71.4	85.6	86.6	74.2
		4	40	71.1	83.8	69.9	73.4	78.7	75.3	73.3	76.5	90.1	72.5	96.1		69.7	83.1	82.9	72.2
12	NSCL	5	50	70.5	82.7	69.2	72.2	77.7	75.3	72.7	75.9	89.0	70.6	96.5		69.2	82.4	81.0	71.2
		6	60	70.1	81.9	68.5	71.5	77.4	76.0	72.4	76.0	85.7	69.5	98.3		68.9	81.9	81.7	70.5
		7	70	72.6	83.5	70.6	73.7	79.5	79.4	74.7	77.8	86.2	71.9	101.4		71.3	83.6	82.7	72.5
		8	80	72.3	83.0	70.0	73.1	79.2	79.9	74.4	77.2	85.2	71.2	101.9		71.0	83.0	83.0	71.7
		9	90	72.3	82.5	69.4	72.6	79.1	116.2	74.3	77.9	84.7	70.6	102.9		71.0	82.5	81.9	71.2
		10	100	72.5	82.3	69.2	72.2	79.3	122.9	74.6	78.6	85.0	70.3	104.4		71.2	82.3	81.2	70.9
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	41.9	63.1	41.8	49.7	54.9	54.8	47.8	52.9	80.4	65.4	74.2	89.0		63.1	70.2	45.8
		2	20	36.2	57.7	34.6	41.2	48.9	42.6	41.3	46.3	77.9	47.5	71.1	75.3		57.1	56.8	40.3
		3	30	35.4	57.6	33.5	39.6	48.2	42.0	39.4	45.3	74.8	38.7	72.3	71.4		57.4	58.9	38.4
		4	40	35.9	57.0	33.5	40.3	49.2	43.6	40.0	45.7	66.0	38.6	73.9	69.7		56.0	55.8	38.1
13	PTB	5	50	37.0	57.0	34.6	40.3	49.5	45.6	41.1	46.6	65.8	37.4	75.7	69.2		56.5	54.5	38.4
		6	60	38.3	57.1	35.2	40.8	50.4	48.2	42.2	48.1	62.4	37.1	78.8	68.9		57.1	56.8	39.0
		7	70	39.4	57.1	35.6	41.4	51.0	50.8	43.2	48.4	61.0	38.1	81.0	71.3		57.2	55.9	39.3
		8	80	40.8	57.6	36.5	42.2	52.1	53.1	44.4	48.9	60.8	38.8	82.6	71.0		57.6	57.7	39.8
		9	90	42.5	58.2	37.4	43.0	53.3	100.5	45.8	51.5	61.3	39.6	84.7	71.0		58.2	57.4	40.7
		10	100	44.4	59.0	38.7	43.9	54.8	108.8	47.7	53.8	62.8	40.6	87.2	71.2		59.0	57.5	41.7
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	63.3	78.9	63.2	68.7	72.5	72.5	67.3	71.0	93.3	80.7	88.0	100.8	63.1		84.7	65.9
		2	20	58.6	73.8	57.6	61.7	67.1	62.7	61.8	65.3	90.5	66.1	84.7	88.2	57.1		73.1	61.2
		3	30	59.0	74.5	57.9	61.7	67.5	63.3	61.6	65.4	88.5	61.1	86.4	85.6	57.4		75.5	60.9
		4	40	57.7	72.7	56.3	60.5	66.8	62.8	60.4	64.3	80.0	59.5	86.7	83.1	56.0		71.8	59.1
14	NIMT	5	50	58.1	72.4	56.5	60.2	66.7	63.9	60.7	64.6	79.6	58.3	87.9	82.4	56.5		70.5	59.0
		6	60	58.5	72.2	56.6	60.2	67.1	65.4	61.2	65.4	76.5	57.8	90.4	81.9	57.1		72.0	59.0
		7	70	58.8	71.9	56.3	60.1	67.1	67.0	61.4	65.2	75.0	58.0	92.0	83.6	57.2		70.9	58.7
		8	80	59.3	71.9	56.4	60.2	67.5	68.3	61.7	65.1	74.4	57.9	93.1	83.0	57.6		71.9	58.5
		9	90	59.8	71.8	56.3	60.2	67.9	108.9	62.2	66.5	74.3	57.8	94.6	82.5	58.2		71.1	58.5
		10	100	60.5	72.0	56.5	60.2	68.5	116.3	63.0	67.8	75.1	57.8	96.5	82.3	59.0		70.7	58.6
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT		NIM
		1	10	70.3	84.7	70.2	75.2	78.7	78.7	74.0	77.4	98.2	86.4	93.2	105.4	70.2	84.7		72.7
		2	20	58.3	73.6	57.3	61.5	66.9	62.5	61.6	65.0	90.4	65.9	84.6	88.1	56.8	73.1		60.9
		3	30	60.5	75.7	59.4	63.1	68.8	64.7	63.0	66.8	89.5	62.5	87.4	86.6	58.9	75.5		62.3
		4	40	57.5	72.5	56.0	60.3	66.6	62.6	60.1	64.0	79.8	59.2	86.5	82.9	55.8	71.8		58.9
15	CMS/ITRI	5	50	56.1	70.9	54.5	58.3	65.0	62.1	58.9	62.8	78.2	56.3	86.6	81.0	54.5	70.5		57.0
		6	60	58.3	72.1	56.3	60.0	66.9	65.2	61.0	65.2	76.3	57.5	90.2	81.7	56.8	72.0		58.8
		7	70	57.5	70.9	55.0	58.9	66.0	65.9	60.2	64.0	74.0	56.7	91.2	82.7	55.9	70.9		57.4
		8	80	59.3	71.9	56.5	60.3	67.6	68.4	61.8	65.2	74.5	58.0	93.1	83.0	57.7	71.9		58.6
		9	90	59.0	71.1	55.4	59.3	67.2	108.5	61.4	65.7	73.6	56.9	94.1	81.9	57.4	71.1		57.6
		10	100	59.1	70.8	55.0	58.7	67.3	115.5	61.6	66.5	73.9	56.3	95.6	81.2	57.5	70.7		57.1
		i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	45.9	65.9	45.8	53.1	58.0	58.0	51.3	56.1	82.5	68.0	76.5	90.9	45.8	65.9	72.7	
		2	20	42.3	61.7	41.0	46.6	53.5	47.9	46.7	51.2	81.0	52.3	74.4	78.4	40.3	61.2	60.9	
		3	30	40.8	61.0	39.2	44.6	52.3	46.7	44.4	49.6	77.5	43.7	75.2	74.2	38.4	60.9	62.3	
		4	40	40.5	60.0	38.5	44.5	52.7	47.5	44.3	49.4	68.6	43.0	76.3	72.2	38.1	59.1	58.9	
16	NIM	5	50	40.6	59.4	38.4	43.7	52.2	48.6	44.3	49.5	67.9	40.9	77.5	71.2	38.4	59.0	57.0	
		6	60	41.1	59.0	38.3	43.5	52.5	50.5	44.8	50.4	64.1	40.0	80.2	70.5	39.0	59.0	58.8	
		7	70	41.6	58.6	38.0	43.4	52.7	52.5	45.2	50.2	62.4	40.4	82.1	72.5	39.3	58.7	57.4	
		8	80	42.1	58.5	37.9	43.4	53.1	54.1	45.5	50.0	61.6	40.1	83.2	71.7	39.8	58.5	58.6	
		9	90	42.9	58.5	37.8	43.4	53.6	100.6	46.2	51.8	61.5	40.0	84.9	71.2	40.7	58.5	57.6	
		10	100	43.8	58.6	38.1	43.4	54.4	108.5	47.2	53.4	62.4	40.0	87.0	70.9	41.7	58.6	57.1	

Table 7.5: Degrees of equivalence expressed by ratios, $\delta(j, j', i)/U\{\delta(j, j', i)\}$.

j	Institute		j'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
				$\delta(j,j',i)$ / $U\{\delta(j,j',i)\}$															
1	NMIJ/AIST	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10		0.48	0.23	0.81	0.24	0.04	0.45	0.71	0.19	0.38	-0.42	-0.21	-0.14	-0.19	-0.31	0.43
		2	20		0.20	0.40	0.57	0.13	-0.08	0.29	0.48	-0.47	0.31	-0.28	-0.04	-0.01	-0.11	-0.30	0.28
		3	30		0.23	0.30	0.28	0.05	-0.08	0.16	0.36	-0.63	0.45	-0.27	0.00	0.00	-0.16	-0.24	0.22
		4	40		0.20	0.22	0.24	-0.01	-0.05	0.14	0.35	-0.52	0.55	-0.23	0.02	-0.01	-0.03	-0.32	0.25
		5	50		0.08	0.23	0.19	-0.02	0.00	0.13	0.34	-0.46	0.68	-0.14	0.04	-0.02	0.03	-0.33	0.23
		6	60		0.03	0.25	0.19	-0.03	0.11	0.13	0.34	-0.37	0.79	-0.14	0.07	-0.07	-0.04	-0.27	0.27
		7	70		-0.06	0.16	0.11	-0.08	0.14	0.06	0.34	-0.23	0.68	-0.14	0.08	-0.01	0.06	-0.32	0.27
		8	80		-0.05	0.17	0.06	-0.08	0.18	0.08	0.37	-0.25	0.64	-0.10	0.10	-0.02	0.05	-0.31	0.33
		9	90		-0.05	0.15	0.02	-0.09	-0.44	0.05	0.38	-0.09	0.64	-0.11	0.12	-0.03	0.04	-0.28	0.38
		10	100		-0.05	0.18	0.06	-0.10	-0.49	0.06	0.42	-0.10	0.68	-0.11	0.11	-0.03	0.04	-0.28	0.46
2	NPLI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.48		-0.33	0.14	-0.24	-0.39	-0.14	0.10	-0.16	-0.07	-0.70	-0.49	-0.58	-0.54	-0.62	-0.17
		2	20	-0.20		0.05	0.21	-0.07	-0.24	0.01	0.18	-0.53	0.06	-0.38	-0.17	-0.20	-0.24	-0.39	0.00
		3	30	-0.23		-0.05	-0.03	-0.17	-0.27	-0.12	0.05	-0.69	0.08	-0.39	-0.16	-0.24	-0.32	-0.38	-0.08
		4	40	-0.20		-0.07	-0.03	-0.18	-0.22	-0.10	0.08	-0.58	0.17	-0.33	-0.13	-0.21	-0.19	-0.42	-0.03
		5	50	-0.08		0.06	0.05	-0.09	-0.08	0.01	0.18	-0.45	0.38	-0.18	-0.03	-0.10	-0.04	-0.33	0.07
		6	60	-0.03		0.13	0.11	-0.05	0.05	0.06	0.23	-0.34	0.50	-0.15	0.04	-0.08	-0.06	-0.24	0.15
		7	70	0.06		0.17	0.14	-0.01	0.16	0.11	0.32	-0.14	0.54	-0.09	0.12	0.06	0.10	-0.21	0.26
		8	80	0.05		0.18	0.10	-0.02	0.19	0.11	0.34	-0.17	0.51	-0.06	0.12	0.04	0.08	-0.21	0.29
		9	90	0.05		0.16	0.06	-0.03	-0.38	0.09	0.35	-0.04	0.51	-0.07	0.14	0.03	0.07	-0.19	0.33
		10	100	0.05		0.19	0.10	-0.04	-0.44	0.10	0.39	-0.04	0.55	-0.07	0.13	0.03	0.08	-0.19	0.40
3	CSIR-NML	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.23	0.33		0.62	0.07	-0.14	0.25	0.54	0.07	0.24	-0.55	-0.32	-0.37	-0.35	-0.44	0.22
		2	20	-0.40	-0.05		0.24	-0.16	-0.43	-0.05	0.18	-0.66	0.01	-0.49	-0.24	-0.43	-0.37	-0.56	-0.07
		3	30	-0.30	0.05		0.03	-0.17	-0.33	-0.10	0.14	-0.78	0.20	-0.42	-0.15	-0.32	-0.35	-0.43	-0.04
		4	40	-0.22	0.07		0.06	-0.17	-0.23	-0.05	0.19	-0.65	0.37	-0.34	-0.10	-0.25	-0.18	-0.47	0.05
		5	50	-0.23	-0.06		-0.01	-0.19	-0.19	-0.07	0.17	-0.60	0.50	-0.25	-0.09	-0.26	-0.12	-0.50	0.02
		6	60	-0.25	-0.13		-0.03	-0.22	-0.08	-0.09	0.16	-0.54	0.59	-0.27	-0.06	-0.35	-0.21	-0.44	0.04
		7	70	-0.16	-0.17		-0.04	-0.20	0.02	-0.08	0.24	-0.34	0.58	-0.22	0.00	-0.18	-0.05	-0.45	0.14
		8	80	-0.17	-0.18		-0.10	-0.22	0.06	-0.07	0.26	-0.38	0.53	-0.19	0.01	-0.21	-0.07	-0.45	0.19
		9	90	-0.15	-0.16		-0.13	-0.22	-0.51	-0.08	0.29	-0.20	0.56	-0.18	0.04	-0.19	-0.07	-0.40	0.27
		10	100	-0.18	-0.19		-0.11	-0.26	-0.57	-0.10	0.31	-0.23	0.58	-0.20	0.01	-0.23	-0.09	-0.44	0.33
4	NIS	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.81	-0.14	-0.62		-0.45	-0.63	-0.35	-0.04	-0.30	-0.22	-0.91	-0.64	-0.94	-0.77	-0.83	-0.39
		2	20	-0.57	-0.21	-0.24		-0.33	-0.58	-0.26	-0.03	-0.76	-0.18	-0.60	-0.35	-0.60	-0.50	-0.68	-0.27
		3	30	-0.28	0.03	-0.03		-0.18	-0.32	-0.12	0.11	-0.76	0.15	-0.42	-0.16	-0.30	-0.35	-0.42	-0.06
		4	40	-0.24	0.03	-0.06		-0.20	-0.26	-0.09	0.13	-0.64	0.27	-0.35	-0.12	-0.26	-0.20	-0.48	-0.01
		5	50	-0.19	-0.05	0.01		-0.17	-0.16	-0.05	0.17	-0.56	0.45	-0.24	-0.07	-0.21	-0.10	-0.45	0.03
		6	60	-0.19	-0.11	0.03		-0.18	-0.06	-0.06	0.17	-0.49	0.54	-0.24	-0.04	-0.27	-0.18	-0.40	0.06
		7	70	-0.11	-0.14	0.04		-0.16	0.05	-0.04	0.24	-0.29	0.54	-0.20	0.02	-0.12	-0.02	-0.39	0.16
		8	80	-0.06	-0.10	0.10		-0.13	0.13	0.02	0.32	-0.29	0.56	-0.14	0.06	-0.08	0.00	-0.35	0.26
		9	90	-0.02	-0.06	0.13		-0.11	-0.44	0.03	0.36	-0.10	0.60	-0.12	0.11	-0.05	0.02	-0.29	0.35
		10	100	-0.06	-0.10	0.11		-0.16	-0.52	0.00	0.37	-0.14	0.61	-0.14	0.07	-0.10	-0.01	-0.33	0.40
5	KRISS	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.24	0.24	-0.07	0.45		-0.17	0.14	0.39	0.02	0.16	-0.54	-0.33	-0.35	-0.35	-0.44	0.11
		2	20	-0.13	0.07	0.16	0.33		-0.19	0.11	0.29	-0.51	0.15	-0.34	-0.12	-0.14	-0.19	-0.36	0.10
		3	30	-0.05	0.17	0.17	0.18		-0.11	0.08	0.26	-0.60	0.31	-0.28	-0.03	-0.05	-0.18	-0.25	0.13
		4	40	0.01	0.18	0.17	0.20		-0.03	0.12	0.30	-0.45	0.43	-0.20	0.02	0.00	-0.02	-0.27	0.20
		5	50	0.02	0.09	0.19	0.17		0.02	0.12	0.30	-0.40	0.54	-0.12	0.05	0.01	0.04	-0.27	0.20
		6	60	0.03	0.05	0.22	0.18		0.11	0.13	0.31	-0.31	0.63	-0.12	0.09	-0.03	-0.01	-0.21	0.23
		7	70	0.08	0.01	0.20	0.16		0.18	0.12	0.35	-0.14	0.61	-0.09	0.13	0.07	0.11	-0.22	0.29
		8	80	0.08	0.02	0.22	0.13		0.22	0.14	0.39	-0.16	0.59	-0.05	0.14	0.06	0.10	-0.21	0.35
		9	90	0.09	0.03	0.22	0.11		-0.37	0.14	0.41	-0.01	0.60	-0.04	0.18	0.08	0.11	-0.16	0.40
		10	100	0.10	0.04	0.26	0.16		-0.42	0.15	0.45	0.00	0.65	-0.04	0.17	0.08	0.12	-0.16	0.48
6	SCL	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.04	0.39	0.14	0.63	0.17		0.33	0.56	0.15	0.31	-0.41	-0.22	-0.15	-0.20	-0.30	0.30
		2	20	0.08	0.24	0.43	0.58	0.19		0.33	0.51	-0.40	0.35	-0.22	0.01	0.08	-0.04	-0.22	0.32
		3	30	0.08	0.27	0.33	0.32	0.11		0.21	0.39	-0.56	0.47	-0.21	0.04	0.08	-0.10	-0.18	0.27
		4	40	0.05	0.22	0.23	0.26	0.03		0.17	0.36	-0.45	0.52	-0.19	0.05	0.05	0.01	-0.26	0.26
		5	50	0.00	0.08	0.19	0.16	-0.02		0.11	0.30	-0.43	0.57	-0.13	0.03	-0.01	0.03	-0.30	0.19
		6	60	-0.11	-0.05	0.08	0.06	-0.11		0.01	0.20	-0.42	0.52	-0.20	0.00	-0.17	-0.12	-0.32	0.11
		7	70	-0.14	-0.16	-0.02	-0.05	-0.18		-0.08	0.17	-0.30	0.40	-0.21	-0.01	-0.15	-0.06	-0.39	0.08
		8	80	-0.18	-0.19	-0.06	-0.13	-0.22		-0.11	0.15	-0.36	0.31	-0.20	-0.03	-0.20	-0.10	-0.41	0.08
		9	90	0.44	0.38	0.51	0.44	0.37		0.45	0.61	0.35	0.71	0.28	0.46	0.43	0.43	0.26	0.60
		10	100	0.49	0.44	0.57	0.52	0.42		0.52	0.68	0.41	0.77	0.34	0.50	0.48	0.49	0.33	0.68
7	SPRING	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.45	0.14	-0.25	0.35	-0.14	-0.33		0.28	-0.07	0.05	-0.68	-0.44	-0.57	-0.50	-0.58	-0.04
		2	20	-0.29	-0.01	0.05	0.26	-0.11	-0.33		0.21	-0.61	0.05	-0.44	-0.20	-0.31	-0.31	-0.48	-0.01
		3	30	-0.16	0.12	0.10	0.12	-0.08	-0.21		0.21	-0.69	0.27	-0.35	-0.09	-0.17	-0.27	-0.34	0.06
		4	40	-0.14	0.10	0.05	0.09	-0.12	-0.17		0.21	-0.59	0.36	-0.30	-0.07	-0.16	-0.13	-0.41	0.09
		5	50	-0.13	-0.01	0.07	0.05	-0.12	-0.11		0.21	-0.53	0.49	-0.21	-0.04	-0.15	-0.07	-0.41	0.08
		6	60	-0.13	-0.06	0.09	0.06	-0.13	-0.01		0.22	-0.45	0.58	-0.21	-0.01	-0.20	-0.13	-0.35	0.12
		7	70	-0.06	-0.11	0.08	0.04	-0.12	0.08		0.27	-0.26	0.56	-0.17	0.04	-0.07	0.01	-0.36	0.19
		8	80	-0.08	-0.11	0.07	-0.02	-0.14	0.11		0.29	-0.30	0.51	-0.14	0.05	-0.10	-0.01	-0.36	0.23
		9	90	-0.05	-0.09	0.08	-0.03	-0.14	-0.45		0.32	-0.13	0.53	-0.13	0.08	-0.08	-0.01	-0.31	0.29
		10	100	-0.06	-0.10	0.10	0.00	-0.15	-0.52		0.35	-0.14	0.56	-0.14	0.06	-0.10	-0.01	-0.32	0.36
8	NMIA	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.71	-0.10	-0.54	0.04	-0.39	-0.56	-0.28		-0.26	-0.18	-0.86	-0.60	-0.83	-0.71	-0.77	-0.33
		2	20	-0.48	-0.18	-0.18	0.03	-0.29	-0.51	-0.21		-0.72	-0.14	-0.56	-0.33	-0.51	-0.46	-0.62	-0.22
		3	30	-0.36	-0.05	-0.14	-0.11	-0.26	-0.39	-0.21		-0.80	0.03	-0.47	-0.22	-0.38	-0.41	-0.48	-0.16
		4	40	-0.35	-0.08	-0.19	-0.13	-0.30	-0.36	-0.21		-0.71	0.11	-0.42	-0.21	-0.38	-0.29	-0.55	-0.14
		5	50	-0.34	-0.18	-0.17	-0.17	-0.30	-0.30	-0.21		-0.65	0.22	-0.33	-0.18	-0.37	-0.23	-0.56	-0.14
		6	60	-0.34	-0.23	-0.16	-0.17	-0.31	-0.20	-0.22		-0.58	0.28	-0.34	-0.16	-0.41	-0.30	-0.50	-0.12
		7	70	-0.34	-0.32	-0.24	-0.24	-0.35	-0.17	-0.27		-0.46	0.21	-0.33	-0.14	-0.36	-0.21	-0.56	-0.12
		8	80	-0.37	-0.34	-0.26	-0.32	-0.39	-0.15	-0.29		-0.51	0.15	-0.32	-0.15	-0.41	-0.25	-0.57	-0.10
		9	90	-0.38	-0.35	-0.29	-0.36	-0.41	-0.61	-0.32		-0.37	0.12	-0.32	-0.15	-0.42	-0.27	-0.56	-0.08
		10	100	-0.42	-0.39	-0.31	-0.37	-0.45	-0.68	-0.35		-0.41	0.11	-0.35	-0.20	-0.46	-0.31	-0.60	-0.06

Table 7.5: Degrees of equivalence expressed by ratios $\delta(j, j',i)/U\{\delta(j, j',i)\}$ (Continued.).

j	Institute		j'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
				$\delta(j,j',i)$ / $U\{\delta(j,j',i)\}$															
9	VMI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.19	0.16	-0.07	0.30	-0.02	-0.15	0.07	0.26		0.10	-0.46	-0.30	-0.26	-0.30	-0.38	0.05
		2	20	0.47	0.53	0.66	0.76	0.51	0.40	0.61	0.72		0.62	0.16	0.33	0.47	0.34	0.22	0.60
		3	30	0.63	0.69	0.78	0.76	0.60	0.56	0.69	0.80		0.85	0.28	0.48	0.63	0.43	0.37	0.73
		4	40	0.52	0.58	0.65	0.64	0.45	0.45	0.59	0.71		0.83	0.19	0.40	0.52	0.41	0.20	0.65
		5	50	0.46	0.45	0.60	0.56	0.40	0.43	0.53	0.65		0.86	0.22	0.38	0.46	0.41	0.16	0.59
		6	60	0.37	0.34	0.54	0.49	0.31	0.42	0.45	0.58		0.87	0.13	0.34	0.34	0.28	0.11	0.54
		7	70	0.23	0.14	0.34	0.29	0.14	0.30	0.26	0.46		0.68	0.03	0.23	0.23	0.23	-0.06	0.41
		8	80	0.25	0.17	0.38	0.29	0.16	0.36	0.30	0.51		0.69	0.07	0.27	0.25	0.25	-0.03	0.49
		9	90	0.09	0.04	0.20	0.10	0.01	-0.35	0.13	0.37		0.53	-0.04	0.17	0.07	0.11	-0.14	0.35
		10	100	0.10	0.04	0.23	0.14	0.00	-0.41	0.14	0.41		0.57	-0.03	0.17	0.07	0.12	-0.14	0.42
10	NML-SIRIM	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.38	0.07	-0.24	0.22	-0.16	-0.31	-0.05	0.18	-0.10		-0.63	-0.43	-0.47	-0.46	-0.54	-0.08
		2	20	-0.31	-0.06	-0.01	0.18	-0.15	-0.35	-0.05	0.14	-0.62		-0.46	-0.23	-0.33	-0.33	-0.49	-0.07
		3	30	-0.45	-0.08	-0.20	-0.15	-0.31	-0.47	-0.27	-0.03	-0.85		-0.51	-0.25	-0.48	-0.46	-0.53	-0.22
		4	40	-0.55	-0.17	-0.37	-0.27	-0.43	-0.52	-0.36	-0.11	-0.83		-0.52	-0.29	-0.59	-0.41	-0.69	-0.29
		5	50	-0.68	-0.38	-0.50	-0.45	-0.54	-0.57	-0.49	-0.22	-0.86		-0.49	-0.35	-0.74	-0.43	-0.81	-0.43
		6	60	-0.79	-0.50	-0.59	-0.54	-0.63	-0.52	-0.58	-0.28	-0.87		-0.53	-0.37	-0.91	-0.57	-0.81	-0.50
		7	70	-0.68	-0.54	-0.58	-0.54	-0.61	-0.40	-0.56	-0.21	-0.68		-0.48	-0.30	-0.73	-0.42	-0.81	-0.40
		8	80	-0.64	-0.51	-0.53	-0.56	-0.59	-0.31	-0.51	-0.15	-0.69		-0.43	-0.27	-0.70	-0.41	-0.77	-0.31
		9	90	-0.64	-0.51	-0.56	-0.60	-0.60	-0.71	-0.53	-0.12	-0.53		-0.42	-0.25	-0.70	-0.42	-0.75	-0.26
		10	100	-0.68	-0.55	-0.58	-0.61	-0.65	-0.77	-0.56	-0.11	-0.57		-0.44	-0.30	-0.75	-0.46	-0.80	-0.22
11	KIM-LIPI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	0.42	0.70	0.55	0.91	0.54	0.41	0.68	0.86	0.46	0.63		0.12	0.34	0.22	0.11	0.67
		2	20	0.28	0.38	0.49	0.60	0.34	0.22	0.44	0.56	-0.16	0.46		0.18	0.28	0.17	0.04	0.43
		3	30	0.27	0.39	0.42	0.42	0.28	0.21	0.35	0.47	-0.28	0.51		0.20	0.27	0.12	0.06	0.38
		4	40	0.23	0.33	0.34	0.35	0.20	0.19	0.30	0.42	-0.19	0.52		0.19	0.23	0.18	-0.01	0.36
		5	50	0.14	0.18	0.25	0.24	0.12	0.13	0.21	0.33	-0.22	0.49		0.14	0.13	0.14	-0.09	0.26
		6	60	0.14	0.15	0.27	0.24	0.12	0.20	0.21	0.34	-0.13	0.53		0.17	0.11	0.10	-0.05	0.28
		7	70	0.14	0.09	0.22	0.20	0.09	0.21	0.17	0.33	-0.03	0.48		0.17	0.14	0.16	-0.07	0.28
		8	80	0.10	0.06	0.19	0.14	0.05	0.20	0.14	0.32	-0.07	0.43		0.16	0.09	0.12	-0.10	0.27
		9	90	0.11	0.07	0.18	0.12	0.04	-0.28	0.13	0.32	0.04	0.42		0.17	0.09	0.12	-0.08	0.30
		10	100	0.11	0.07	0.20	0.14	0.04	-0.34	0.14	0.35	0.03	0.44		0.17	0.09	0.12	-0.07	0.34
12	NSCL	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	0.21	0.49	0.32	0.64	0.33	0.22	0.44	0.60	0.30	0.43	-0.12		0.14	0.06	-0.03	0.42
		2	20	0.04	0.17	0.24	0.35	0.12	-0.01	0.20	0.33	-0.33	0.23	-0.18		0.04	-0.04	-0.16	0.19
		3	30	0.00	0.16	0.15	0.16	0.03	-0.04	0.09	0.22	-0.48	0.25	-0.20		0.00	-0.11	-0.17	0.13
		4	40	-0.02	0.13	0.10	0.12	-0.02	-0.05	0.07	0.21	-0.40	0.29	-0.19		-0.02	-0.04	-0.23	0.12
		5	50	-0.04	0.03	0.09	0.07	-0.05	-0.03	0.04	0.18	-0.38	0.35	-0.14		-0.05	-0.01	-0.26	0.09
		6	60	-0.07	-0.04	0.06	0.04	-0.09	0.00	0.01	0.16	-0.34	0.37	-0.17		-0.12	-0.09	-0.25	0.08
		7	70	-0.08	-0.12	0.00	-0.02	-0.13	0.01	-0.04	0.14	-0.23	0.30	-0.17		-0.09	-0.03	-0.30	0.07
		8	80	-0.10	-0.12	-0.01	-0.06	-0.14	0.03	-0.05	0.15	-0.27	0.27	-0.16		-0.11	-0.05	-0.31	0.10
		9	90	-0.12	-0.14	-0.04	-0.11	-0.18	-0.46	-0.08	0.15	-0.17	0.25	-0.17		-0.14	-0.08	-0.31	0.10
		10	100	-0.11	-0.13	-0.01	-0.07	-0.17	-0.50	-0.06	0.20	-0.17	0.30	-0.17		-0.13	-0.07	-0.30	0.17
13	PTB	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	0.14	0.58	0.37	0.94	0.35	0.15	0.57	0.83	0.26	0.47	-0.34	-0.14		-0.10	-0.22	0.56
		2	20	0.01	0.20	0.43	0.60	0.14	-0.08	0.31	0.51	-0.47	0.33	-0.28	-0.04		-0.11	-0.30	0.30
		3	30	0.00	0.24	0.32	0.30	0.05	-0.08	0.17	0.38	-0.63	0.48	-0.27	0.00		-0.17	-0.25	0.24
		4	40	0.01	0.21	0.25	0.26	0.00	-0.05	0.16	0.38	-0.52	0.59	-0.23	0.02		-0.03	-0.32	0.27
		5	50	0.02	0.10	0.26	0.21	-0.01	0.01	0.15	0.37	-0.46	0.74	-0.13	0.05		0.04	-0.33	0.26
		6	60	0.07	0.08	0.35	0.27	0.03	0.17	0.20	0.41	-0.34	0.91	-0.11	0.12		0.01	-0.23	0.35
		7	70	0.01	-0.06	0.18	0.12	-0.07	0.15	0.07	0.36	-0.23	0.73	-0.14	0.09		0.07	-0.33	0.30
		8	80	0.02	-0.04	0.21	0.08	-0.06	0.20	0.10	0.41	-0.25	0.70	-0.09	0.11		0.06	-0.30	0.38
		9	90	0.03	-0.03	0.19	0.05	-0.08	-0.43	0.08	0.42	-0.07	0.70	-0.09	0.14		0.06	-0.26	0.43
		10	100	0.03	-0.03	0.23	0.10	-0.08	-0.48	0.10	0.46	-0.07	0.75	-0.09	0.13		0.07	-0.26	0.52
14	NIMT	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	0.19	0.54	0.35	0.77	0.35	0.20	0.50	0.71	0.30	0.46	-0.22	-0.06	0.10		-0.11	0.48
		2	20	0.11	0.24	0.37	0.50	0.19	0.04	0.31	0.46	-0.34	0.33	-0.17	0.04	0.11		-0.15	0.30
		3	30	0.16	0.32	0.35	0.35	0.18	0.10	0.27	0.41	-0.43	0.46	-0.12	0.11	0.17		-0.07	0.31
		4	40	0.03	0.19	0.18	0.20	0.02	-0.01	0.13	0.29	-0.41	0.41	-0.18	0.04	0.03		-0.23	0.20
		5	50	-0.03	0.04	0.12	0.10	-0.04	-0.03	0.07	0.23	-0.41	0.43	-0.14	0.01	-0.04		-0.29	0.13
		6	60	0.04	0.06	0.21	0.18	0.01	0.12	0.13	0.30	-0.28	0.57	-0.10	0.09	-0.01		-0.18	0.22
		7	70	-0.06	-0.10	0.05	0.02	-0.11	0.06	-0.01	0.21	-0.23	0.42	-0.16	0.03	-0.07		-0.31	0.13
		8	80	-0.05	-0.08	0.07	0.00	-0.10	0.10	0.01	0.25	-0.25	0.41	-0.12	0.05	-0.06		-0.29	0.19
		9	90	-0.04	-0.07	0.07	-0.02	-0.11	-0.43	0.01	0.27	-0.11	0.42	-0.12	0.08	-0.06		-0.26	0.24
		10	100	-0.04	-0.08	0.09	0.01	-0.12	-0.49	0.01	0.31	-0.12	0.46	-0.12	0.07	-0.07		-0.27	0.30
15	CMS/ITRI	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	0.31	0.62	0.44	0.83	0.44	0.30	0.58	0.77	0.38	0.54	-0.11	0.03	0.22	0.11		0.57
		2	20	0.30	0.39	0.56	0.68	0.36	0.22	0.48	0.62	-0.22	0.49	-0.04	0.16	0.30	0.15		0.48
		3	30	0.24	0.38	0.43	0.42	0.25	0.18	0.34	0.48	-0.37	0.53	-0.06	0.17	0.25	0.07		0.38
		4	40	0.32	0.42	0.47	0.48	0.27	0.26	0.41	0.55	-0.20	0.69	0.01	0.23	0.32	0.23		0.48
		5	50	0.33	0.33	0.50	0.45	0.27	0.30	0.41	0.56	-0.16	0.81	0.09	0.26	0.33	0.29		0.49
		6	60	0.27	0.24	0.44	0.40	0.21	0.32	0.35	0.50	-0.11	0.81	0.05	0.25	0.23	0.18		0.45
		7	70	0.32	0.21	0.45	0.39	0.22	0.39	0.36	0.56	0.06	0.81	0.07	0.30	0.33	0.31		0.52
		8	80	0.31	0.21	0.45	0.35	0.21	0.41	0.36	0.57	0.03	0.77	0.10	0.31	0.30	0.29		0.55
		9	90	0.28	0.19	0.40	0.29	0.16	-0.26	0.31	0.56	0.14	0.75	0.08	0.31	0.26	0.26		0.56
		10	100	0.28	0.19	0.44	0.33	0.16	-0.33	0.32	0.60	0.14	0.80	0.07	0.30	0.26	0.27		0.64
16	NIM	i	[MPa]	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	PTB	NIMT	CMS/ITRI	NIM
		1	10	-0.43	0.17	-0.22	0.39	-0.11	-0.30	0.04	0.33	-0.05	0.08	-0.67	-0.42	-0.56	-0.48	-0.57	
		2	20	-0.28	0.00	0.07	0.27	-0.10	-0.32	0.01	0.22	-0.60	0.07	-0.43	-0.19	-0.30	-0.30	-0.48	
		3	30	-0.22	0.08	0.04	0.06	-0.13	-0.27	-0.06	0.16	-0.73	0.22	-0.38	-0.13	-0.24	-0.31	-0.38	
		4	40	-0.25	0.03	-0.05	0.01	-0.20	-0.26	-0.09	0.14	-0.65	0.29	-0.36	-0.12	-0.27	-0.20	-0.48	
		5	50	-0.23	-0.07	-0.02	-0.03	-0.20	-0.19	-0.08	0.14	-0.59	0.43	-0.26	-0.09	-0.26	-0.13	-0.49	
		6	60	-0.27	-0.15	-0.04	-0.06	-0.23	-0.11	-0.12	0.12	-0.54	0.50	-0.28	-0.08	-0.35	-0.22	-0.45	
		7	70	-0.27	-0.26	-0.14	-0.16	-0.29	-0.08	-0.19	0.12	-0.41	0.40	-0.28	-0.07	-0.30	-0.13	-0.52	
		8	80	-0.33	-0.29	-0.19	-0.26	-0.35	-0.08	-0.23	0.10	-0.49	0.31	-0.27	-0.10	-0.38	-0.19	-0.55	
		9	90	-0.38	-0.33	-0.27	-0.35	-0.40	-0.60	-0.29	0.08	-0.35	0.26	-0.30	-0.10	-0.43	-0.24	-0.56	
		10	100	-0.46	-0.40	-0.33	-0.40	-0.48	-0.68	-0.36	0.06	-0.42	0.22	-0.34	-0.17	-0.52	-0.30	-0.64	

8. Linking key comparison APMP.M.P-K7 to key comparison CCM.P-K7

According to the MRA the linking should be established by means of the linking institutes taking part in both the International Committee for Weights and Measures (CIPM) and the Regional Metrology Organization (RMO) key comparisons[1]. A procedure for linking the results of a RMO key comparison to those of a related CIPM key comparison has been proposed[18,19].

This APMP key comparison, APMP.M.P-K7, is linked to the corresponding CCM key comparison, CCM.P.K-7, which has the same pressure range as APMP.M.P-K7. The final report of CCM.P.K-7 has been approved[4]. Although the type of transfer standards for both comparisons were different since the transfer standard of CCM.P.K-7 was a complete pressure balance, the pressure points at which both comparisons were carried out were the same within a thousandth of the target nominal pressure.

8.1 Weighted mean calculated from linking institutes

The values for the linkage are calculated by using the combined differences, which are calculated by a <u>weighted mean method</u> using the results of the corresponding differences of the linking institutes in the both comparisons CCM.P.K-7 and APMP.M.P-K7, in the same way as given in the linkage between the key comparisons, CCM.P-K1.c and APMP.M.P-K1.c, or CCM.P-K1.c and EUROMET.M.P-K2[17,20,21,22].

In the present case, the results obtained from three linking institutes, NMIJ, PTB and NPLI, which participated into both comparisons CCM.P.K-7 and APMP.M.P-K7, were used to establish the linkage.

The weighted mean obtained from the linking institutes for CCM.P-K7, $X_{CCM}(i)$, is

$$X_{CCM}(i) = \frac{x(NMIJ,i)/u_c^2\{x(NMIJ,i)\} + x(PTB,i)/u_c^2\{x(PTB,i)\} + x(NPLI,i)/u_c^2\{x(NPLI,i)\}}{1/u_c^2\{x(NMIJ,i)\} + 1/u_c^2\{x(PTB,i)\} + 1/u_c^2\{x(NPLI,i)\}} \tag{8.1}$$

where $x(J,i)$ and $u_c\{x(J,i)\}$ are respectively the <u>relative</u> deviations form the reference values and their combined standard uncertainties of *J*-th institute calculated from the <u>claiming effective area</u> related to the CCM comparison.

Table 8.1 and Figure 8.1 present the results of the linking institutes and the weighted mean obtained from the linking institutes for CCM.P-K7 as a function of nominal target pressure.

Table 8.1: Weighted mean calculated from the linking institutes for CCM.P-K7.

		Results in CCM.P-K7						
		NMIJ/AIST		PTB		NPLI		Weighted mean
i	[MPa]	x(NMIJ,i)	$u\{x$(NMIJ,i)$\}$	x(PTB,i)	u$\{x$(PTB,i)$\}$	x(NPLI,i)	$u\{x$(NPLI,i)$\}$	$X_{CCM}(i)$
1	10	0.0	13.5	2.5	11.0	-11.5	30.5	0.6
2	20	-1.6	13.5	1.1	11.0	-9.7	28.5	-0.8
3	30	-0.7	13.5	0.3	11.0	-7.9	24.5	-0.9
4	40	-1.1	13.5	0.0	11.5	-7.6	24.5	-1.3
5	50	-0.5	14.0	0.6	12.5	-5.2	24.5	-0.6
6	60	-1.3	14.5	0.0	13.5	-4.5	24.5	-1.1
7	70	-0.6	15.0	0.0	14.5	-3.2	24.5	-0.7
8	80	-0.5	15.5	0.0	15.5	-1.8	24.5	-0.5
9	90	0.0	16.5	-0.1	16.5	-0.8	24.5	-0.2
10	100	0.0	17.0	-0.1	18.0	-0.8	24.5	-0.2

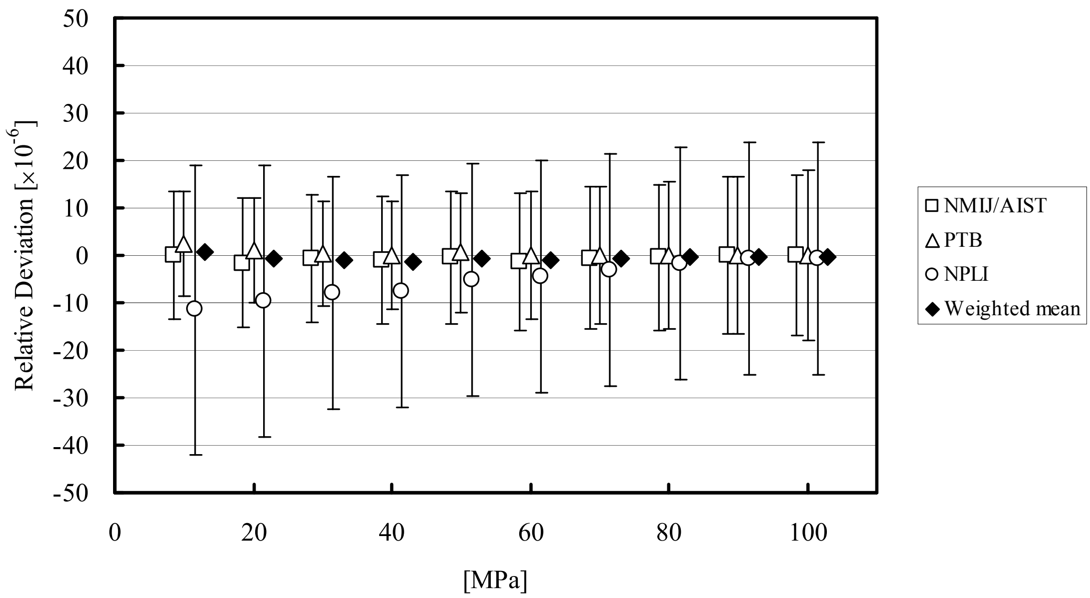


Figure 8.1: Results of the linking institutes and the weighted mean calculated from the linking institutes for CCM.P-K7 as a function of nominal target pressure.

In the same way, the weighted mean obtained from the linking institutes for APMP.M.P-K7, $Y_{APMP}(i)$, is

$$Y_{APMP}(i) = \frac{y(NMIJ,i)/u_c^2\{y(NMIJ,i)\} + y(PTB,i)/u_c^2\{y(PTB,i)\} + y(NPLI,i)/u_c^2\{y(NPLI,i)\}}{1/u_c^2\{y(NMIJ,i)\} + 1/u_c^2\{y(PTB,i)\} + 1/u_c^2\{y(NPLI,i)\}} \tag{8.2}$$

where $y(l,i)$ and $u_c\{y(l,i)\}$ are respectively the <u>relative</u> deviations from the reference values and their combined standard uncertainties of *j*-th institute calculated from the <u>expected mean pressure</u> related to the APMP comparison.

Table 8.2 and Figure 8.2 present the results of the linking institutes and the weighted mean obtained from the linking institutes for APMP.M.P-K7 as a function of nominal target pressure.

Table 8.2: Weighted mean calculated from the linking institutes for APMP.M.P-K7.

		Results in APMP.M.P-K7						
		NMIJ/AIST		PTB		NPLI		Weighted mean
i	[MPa]	y(NMIJ,i)	$u\{y$(NMIJ,i)$\}$	y(PTB,i)	$u\{y$(PTB,i)$\}$	y(NPLI,i)	$u\{y$(NPLI,i)$\}$	$Y_{APMP}(i)$
1	10	11.4	16.6	17.4	16.5	-19.1	28.9	9.7
2	20	3.3	14.3	3.5	12.8	-8.3	26.7	2.1
3	30	1.2	14.3	1.3	12.5	-12.6	26.8	-0.2
4	40	0.5	14.2	0.8	12.4	-11.4	26.3	-0.7
5	50	2.1	14.1	2.7	12.4	-2.7	25.8	1.9
6	60	3.6	14.6	6.3	13.0	1.6	25.7	4.7
7	70	3.2	15.0	3.4	13.3	6.8	25.5	3.8
8	80	2.7	15.5	3.6	13.9	5.8	25.6	3.6
9	90	0.5	16.0	1.7	14.5	3.4	25.5	1.5
10	100	1.3	16.7	2.8	15.3	4.3	25.7	2.4

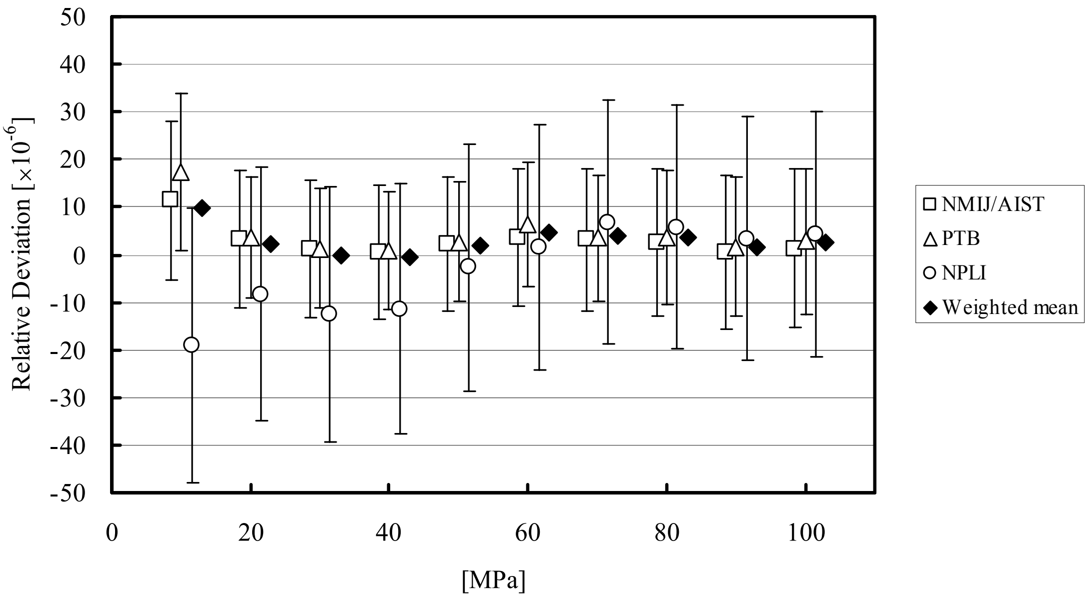


Figure 8.2: Results of the linking institutes and the weighted mean calculated from the linking institutes for APMP.M.P-K7 as a function of nominal target pressure.

8.2 Evaluation of degrees of equivalence

8.2.1 Deviation of institute's value from CCM KCRV

As mentioned above, the measurands in CCM.P-K7 and APMP.M.P-K7 were the claiming effective area and the expected mean pressure, respectively. The following relationship is established:

(Claiming effective area)/(Actual effective area)
≈ (Expected mean pressure)/(Claiming pressure).

By considering the relationship of both quantities, the degrees of equivalence of participating institutes in APMP.M.P-K7 comparison can be transferred to CCM.P-K7 comparison as follows:

$$D(J,i) = X_{CCM}(i) - Y_{APMP}(i) + y(j,i) \tag{8.3}$$

where $D(J,i)$ is the relative deviation from the CCM.P-K7 reference value of J-th institute participated into APMP.M.P-K7 and $y(j,i)$ is the relative deviation from the APMP.M.P-K7 reference value of j-th participating institute.

The relative deviation from the CCM.P-K7 reference value for the institutes participated into CCM.P-K7, $D(J,i)$, is simply transferred for convenience as follows:

$$D(J,i) = x(J,i) \tag{8.4}$$

Table 8.3 shows the differences of the weighted mean values, $X_{CCM}(i) - Y_{APMP}(i)$, calculated from equations (8.1) and (8.2) as a function of nominal target pressure.

Table 8.3: Differences of the weighted mean values, $X_{CCM}(i)-Y_{APMP}(i)$.

i	[MPa]	$X_{CCM}(i)$-$Y_{\mathrm{APMP}}(i)$
1	10	-9.1
2	20	-2.9
3	30	-0.7
4	40	-0.6
5	50	-2.4
6	60	-5.8
7	70	-4.5
8	80	-4.1
9	90	-1.7
10	100	-2.6

The differences listed in Table 8.3 are considerably smaller than the expanded uncertainties claimed by the participating institutes in APMP.M.P-K7 and the results of the linking institutes in both comparisons are comparable. Therefore, in the same way as given in the linkage between the key comparisons, CCM.P-K1.c and APMP.M.P-K1.c, or CCM.P-K1.c and EUROMET.M.P-K2[17,20,21,22], the relative expanded uncertainty of $D(J,i)$ for the institutes participated into APMP.M.P-K7 is estimated from

$$U\{D(J,i)\} = k \cdot u_c\{y(j,i)\} \tag{8.5}$$

where k is the coverage factor and k = 2 is adopted.

The relative expanded uncertainty for the institutes participated into CCM.P-K7 is simply transferred for convenience as follows:

$$U\{D(J,i)\} = k \cdot u_c\{x(J,i)\} \tag{8.6}$$

Table 8.4 presents respectively the relative deviations from the CCM KCRVs, $D(J,i)$, the expanded (k = 2) uncertainties of the relative deviations, $U\{D(J,i)\}$, and the degrees of equivalence expressed by the ratios, $D(J,i)/U\{D(J,i)\}$, for individual NMIs at all nominal target pressures. A measure of the degree of equivalence is provided by the relative magnitude of the deviation as $|D(J,i)/U\{D(J,i)\}| \le 1$. Only a few results from

NML-SIRIM were marginal and would satisfy the condition if the results were rounded to one significant figure.

Figures 8.3 presents $D(J,i)$ with $U\{D(J,i)\}$ graphically for the participating institutes as a function of nominal target pressure.

Table 8.4: Deviations from the CCM KCRVs, $D(J,i)$ [upper], the expanded (k = 2) uncertainties of the deviations, $U\{D(J,i)\}$ [middle] and the degrees of equivalence as expressed by the ratios, $D(J,i)/U\{D(J,i)\}$ [lower].

		Relative deviation from CCM KCRV, $D(J,i)$ [×10^{-6}]																					
	J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
i	[MPa]	PTB	IMGC-CNR	BNM-LNE	NPL	CENAM	NIST	INMS/NRC	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM
1	10	2.5	8.5	-3.7	-3.5	5.3	31.9	-1.6	0.0	-11.5	-7.3	-38.2	-11.0	0.3	-19.2	-35.6	-13.0	-22.7	33.7	21.0	14.6	23.9	-17.3
2	20	1.1	1.1	-5.0	-1.7	3.3	20.9	0.0	-1.6	-9.7	-14.3	-24.1	-6.2	4.2	-12.0	-22.8	37.4	-14.9	20.9	3.7	6.9	17.8	-11.4
3	30	0.3	0.0	-5.5	-1.6	1.9	15.1	0.3	-0.7	-7.9	-10.2	-11.4	-1.9	4.0	-6.1	-16.8	48.1	-18.0	20.3	0.8	10.2	15.3	-8.6
4	40	0.0	0.5	-6.2	-1.3	0.0	9.6	2.2	-1.1	-7.6	-8.1	-10.3	0.4	2.2	-6.2	-17.0	34.6	-22.5	17.1	-1.2	1.9	18.3	-10.1
5	50	0.6	2.4	-5.3	0.0	-2.8	7.0	4.6	-0.5	-5.2	-8.8	-8.2	0.7	-0.3	-6.0	-16.7	30.7	-27.3	10.4	-2.9	-1.9	18.3	-9.6
6	60	0.0	2.1	-6.0	0.4	-4.5	4.1	5.9	-1.3	-4.5	-11.7	-10.6	-0.9	-7.7	-8.0	-19.3	21.6	-33.2	9.1	-7.5	0.0	13.3	-13.2
7	70	0.0	4.3	-5.7	2.6	-6.2	3.5	7.6	-0.6	-3.2	-7.4	-6.0	2.7	-8.5	-4.2	-18.6	12.8	-28.9	10.4	-7.3	-4.8	17.2	-12.7
8	80	0.0	4.5	-5.9	4.5	-7.0	3.6	7.8	-0.5	-1.8	-8.1	-4.0	2.9	-11.1	-5.0	-20.5	14.5	-27.8	7.4	-8.5	-4.1	17.0	-15.4
9	90	-0.1	5.2	-5.9	6.5	-8.5	4.4	8.0	0.0	-0.8	-7.2	-2.2	4.0	43.0	-3.7	-21.5	4.5	-27.8	7.9	-10.0	-3.4	15.1	-17.3
10	100	-0.1	7.2	-5.9	8.3	-9.5	4.7	7.2	0.0	-0.8	-8.9	-4.3	4.5	52.7	-4.5	-24.7	4.8	-30.3	8.0	-9.3	-3.9	15.1	-21.5

		Expanded uncertainty, $U\{D(J,i)\}$ [×10^{-6}] (k = 2)																					
	J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
i	[MPa]	PTB	IMGC-CNR	BNM-LNE	NPL	CENAM	NIST	INMS/NRC	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM
1	10	22.0	23.0	16.0	23.0	32.0	39.0	35.0	27.0	61.0	33.1	42.7	48.6	48.6	40.4	46.3	76.2	60.2	69.7	85.2	57.8	65.4	38.0
2	20	22.0	22.0	14.0	22.0	31.0	38.0	36.0	27.0	57.0	26.7	34.7	43.6	36.4	34.9	40.6	74.7	42.0	67.6	72.0	52.7	52.4	33.6
3	30	22.0	22.0	14.0	23.0	32.0	37.0	37.0	27.0	49.0	26.1	33.7	43.5	36.5	33.5	40.1	71.9	32.6	69.3	68.3	53.4	55.1	32.2
4	40	23.0	22.0	14.0	23.0	32.0	37.0	37.0	27.0	49.0	25.3	33.7	44.1	37.6	33.5	40.1	62.2	31.8	70.6	66.2	51.6	51.3	31.1
5	50	25.0	22.0	15.0	23.0	33.0	37.0	39.0	28.0	49.0	24.8	32.4	43.3	38.8	33.3	39.9	61.3	28.6	71.8	64.9	51.2	48.9	30.0
6	60	27.0	23.0	16.0	24.0	34.0	38.0	41.0	29.0	49.0	24.9	32.4	43.8	41.3	34.1	41.2	57.2	27.6	74.8	64.3	51.4	51.1	30.1
7	70	29.0	22.0	16.0	24.0	35.0	38.0	42.0	30.0	49.0	24.8	32.5	44.1	43.9	34.7	41.1	55.3	28.2	76.8	66.5	51.1	49.7	29.8
8	80	31.0	23.0	17.0	24.0	36.0	38.0	43.0	31.0	49.0	25.2	32.9	44.9	46.1	35.6	41.2	54.7	28.4	78.2	65.9	51.2	51.3	29.7
9	90	33.0	23.0	18.0	25.0	37.0	38.0	45.0	33.0	49.0	24.9	32.7	45.4	96.5	36.4	43.3	54.6	28.1	80.0	65.3	51.1	50.1	29.6
10	100	36.0	23.0	19.0	25.0	38.0	38.0	46.0	34.0	49.0	25.5	32.8	46.4	104.8	37.7	45.3	55.6	28.3	82.2	65.0	51.3	49.6	29.8

		$D(J,i)$ / $U\{D(J,i)\}$																					
	J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
i	[MPa]	PTB	IMGC-CNR	BNM-LNE	NPL	CENAM	NIST	INMS/NRC	NMIJ/AIST	NPLI	CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM
1	10	0.11	0.37	-0.23	-0.15	0.17	0.82	-0.05	0.00	-0.19	-0.22	-0.90	-0.23	0.01	-0.47	-0.77	-0.17	-0.38	0.48	0.25	0.25	0.36	-0.46
2	20	0.05	0.05	-0.36	-0.08	0.11	0.55	0.00	-0.06	-0.17	-0.53	-0.70	-0.14	0.11	-0.34	-0.56	0.50	-0.35	0.31	0.05	0.13	0.34	-0.34
3	30	0.01	0.00	-0.39	-0.07	0.06	0.41	0.01	-0.03	-0.16	-0.39	-0.34	-0.04	0.11	-0.18	-0.42	0.67	-0.55	0.29	0.01	0.19	0.28	-0.27
4	40	0.00	0.02	-0.44	-0.06	0.00	0.26	0.06	-0.04	-0.16	-0.32	-0.31	0.01	0.06	-0.18	-0.42	0.56	-0.71	0.24	-0.02	0.04	0.36	-0.32
5	50	0.02	0.11	-0.35	0.00	-0.08	0.19	0.12	-0.02	-0.11	-0.35	-0.25	0.02	-0.01	-0.18	-0.42	0.50	-0.95	0.14	-0.04	-0.04	0.37	-0.32
6	60	0.00	0.09	-0.38	0.02	-0.13	0.11	0.14	-0.04	-0.09	-0.47	-0.33	-0.02	-0.19	-0.23	-0.47	0.38	-1.20	0.12	-0.12	0.00	0.26	-0.44
7	70	0.00	0.20	-0.36	0.11	-0.18	0.09	0.18	-0.02	-0.07	-0.30	-0.18	0.06	-0.19	-0.12	-0.45	0.23	-1.03	0.13	-0.11	-0.09	0.35	-0.43
8	80	0.00	0.20	-0.35	0.19	-0.19	0.09	0.18	-0.02	-0.04	-0.32	-0.12	0.06	-0.24	-0.14	-0.50	0.26	-0.98	0.09	-0.13	-0.08	0.33	-0.52
9	90	0.00	0.23	-0.33	0.26	-0.23	0.12	0.18	0.00	-0.02	-0.29	-0.07	0.09	0.45	-0.10	-0.50	0.08	-0.99	0.10	-0.15	-0.07	0.30	-0.59
10	100	0.00	0.31	-0.31	0.33	-0.25	0.12	0.16	0.00	-0.02	-0.35	-0.13	0.10	0.50	-0.12	-0.55	0.09	-1.07	0.10	-0.14	-0.08	0.30	-0.72

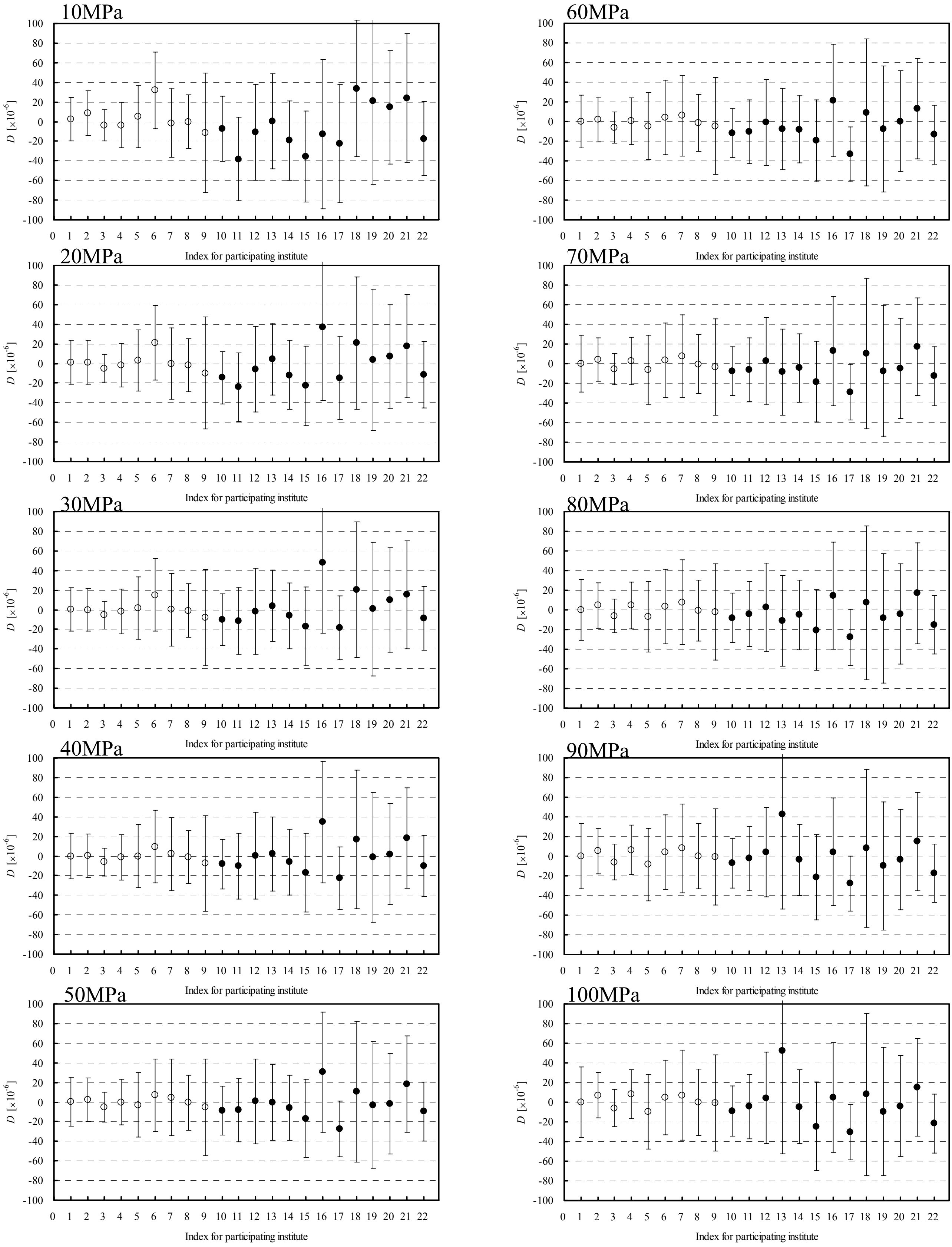


Figure 8.3: Deviations from the CCM KCRVs, $D(J,i)$, and the expanded uncertainties of $D(J,i)$, $U\{D(J,i)\}$. The black points show deviations $D(J,i)$ and the error bars refer to expanded ($k = 2$) uncertainties $U\{D(J,i)\}$.

8.2.2 Difference between deviations for pairs of institutes

The degree of equivalence between pairs of pressure standards *J* and *J'* is calculated by the following equation:

$$d(J,J',i) = D(J,i) - D(J',i) \tag{8.7}$$

where $d(J,J',i)$ is the relative difference of their deviations, and the relative expanded uncertainty of the difference, $U\{d(J,J',i)\}$, is estimated from

$$U\{d(J,J',i)\} = \sqrt{U^2\{D(J,i)\} + U^2\{D(J',i)\}} \tag{8.8}$$

where $U\{D(J,i)\}$ and $U\{D(J',i)\}$ are the expanded (k = 2) uncertainties of the relative deviation of *J*-th and *J'*-th institutes, respectively.

Tables 8.5, 8.6 and 8.7 present the results of the differences, $d(J,J',i)$, the expanded (k = 2) uncertainties of the differences, $U\{d(J,J',i)\}$, and the degrees of equivalence expressed by the ratios, $D(J,J',i)/U\{D(J,J',i)\}$, for the participating institutes in CCM.P-K7 and APMP.M.P-K7 at 10 MPa, 50 MPa and 100 MPa, respectively.

A measure of the degree of equivalence is provided by the relative magnitude of the deviation as $D(J,J',i)/U\{D(J,J',i)\} \le 1$. Only a few results obtained at 10 MPa and 100 MPa were marginal, however they would satisfy the condition if the results were rounded to one significant figure.

Table 8.5: Results of the differences, $d(J,J',i)$ [upper], the expanded (k = 2) uncertainties of the differences, $U\{d(J,J',i)\}$ [middle], and the degrees of equivalence expressed by the ratios, $D(J,J',i)/U\{D(J,J',i)\}$ [lower] at 10 MPa.

i = 1		Differences between deviations, $d(J, J', i) = D(J, i) - D(J', i)$ [$\times 10^{-6}$]													
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22	$D(J, i)$
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM	
1	PTB	9.8	40.7	13.5	2.2	21.7	38.1	15.5	25.2	-31.2	-18.5	-12.1	-21.4	19.8	2.5
2	IMGC-CNR	15.8	46.7	19.5	8.2	27.7	44.1	21.5	31.2	-25.2	-12.5	-6.1	-15.4	25.8	8.5
3	BNM-LNE	3.6	34.5	7.3	-4.0	15.5	31.9	9.3	19.0	-37.4	-24.7	-18.3	-27.6	13.6	-3.7
4	NPL	3.8	34.7	7.5	-3.8	15.7	32.1	9.5	19.2	-37.2	-24.5	-18.1	-27.4	13.8	-3.5
5	CENAM	12.6	43.5	16.3	5.0	24.5	40.9	18.3	28.0	-28.4	-15.7	-9.3	-18.6	22.6	5.3
6	NIST	39.2	70.1	42.9	31.6	51.1	67.5	44.9	54.6	-1.8	10.9	17.3	8.0	49.2	31.9
7	INMS/NRC	5.7	36.6	9.4	-1.9	17.6	34.0	11.4	21.1	-35.3	-22.6	-16.2	-25.5	15.7	-1.6
8	NMIJ/AIST	7.3	38.2	11.0	-0.3	19.2	35.6	13.0	22.7	-33.7	-21.0	-14.6	-23.9	17.3	0.0
9	NPLI	-4.2	26.7	-0.5	-11.8	7.7	24.1	1.5	11.2	-45.2	-32.5	-26.1	-35.4	5.8	-11.5
$D(J', i)$		-7.3	-38.2	-11.0	0.3	-19.2	-35.6	-13.0	-22.7	33.7	21.0	14.6	23.9	-17.3	

i = 1		Expanded uncertainty of d, $U\{d(J, J', i)\}$ [$\times 10^{-6}$]													
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22	$U\{D(J, i)\}$
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM	
1	PTB	39.7	48.0	53.3	53.3	46.0	51.3	79.3	64.1	73.1	88.0	61.8	69.0	43.9	22.0
2	IMGC-CNR	40.3	48.5	53.8	53.7	46.5	51.7	79.6	64.5	73.4	88.3	62.2	69.3	44.4	23.0
3	BNM-LNE	36.8	45.6	51.2	51.1	43.5	49.0	77.9	62.3	71.5	86.7	59.9	67.3	41.2	16.0
4	NPL	40.3	48.5	53.8	53.7	46.5	51.7	79.6	64.5	73.4	88.3	62.2	69.3	44.4	23.0
5	CENAM	46.0	53.3	58.2	58.2	51.6	56.3	82.7	68.2	76.7	91.0	66.0	72.8	49.7	32.0
6	NIST	51.1	57.8	62.3	62.3	56.2	60.6	85.6	71.7	79.9	93.7	69.7	76.2	54.5	39.0
7	INMS/NRC	48.2	55.2	59.9	59.9	53.5	58.1	83.9	69.7	78.0	92.1	67.5	74.2	51.7	35.0
8	NMIJ/AIST	42.7	50.5	55.6	55.6	48.6	53.6	80.9	66.0	74.7	89.4	63.8	70.8	46.6	27.0
9	NPLI	69.4	74.4	78.0	78.0	73.2	76.6	97.6	85.7	92.6	104.8	84.0	89.4	71.9	61.0
$U\{D(J', i)\}$		33.1	42.7	48.6	48.6	40.4	46.3	76.2	60.2	69.7	85.2	57.8	65.4	38.0	

i = 1		$d(J, J', i) / U\{d(J, J', i)\}$												
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM
1	PTB	0.25	0.85	0.25	0.04	0.47	0.74	0.20	0.39	-0.43	-0.21	-0.20	-0.31	0.45
2	IMGC-CNR	0.39	0.96	0.36	0.15	0.59	0.85	0.27	0.48	-0.34	-0.14	-0.10	-0.22	0.58
3	BNM-LNE	0.10	0.76	0.14	-0.08	0.36	0.65	0.12	0.30	-0.52	-0.28	-0.31	-0.41	0.33
4	NPL	0.09	0.72	0.14	-0.07	0.34	0.62	0.12	0.30	-0.51	-0.28	-0.29	-0.39	0.31
5	CENAM	0.27	0.82	0.28	0.09	0.47	0.73	0.22	0.41	-0.37	-0.17	-0.14	-0.25	0.46
6	NIST	0.77	1.21	0.69	0.51	0.91	1.11	0.52	0.76	-0.02	0.12	0.25	0.11	0.90
7	INMS/NRC	0.12	0.66	0.16	-0.03	0.33	0.59	0.14	0.30	-0.45	-0.25	-0.24	-0.34	0.30
8	NMIJ/AIST	0.17	0.76	0.20	-0.01	0.39	0.66	0.16	0.34	-0.45	-0.23	-0.23	-0.34	0.37
9	NPLI	-0.06	0.36	-0.01	-0.15	0.10	0.31	0.02	0.13	-0.49	-0.31	-0.31	-0.40	0.08

Table 8.6: Results of the differences, $d(J,J',i)$ [upper], the expanded (k = 2) uncertainties of the differences, $U\{d(J,J',i)\}$ [middle], and the degrees of equivalence expressed by the ratios, $D(J,J',i)/U\{D(J,J',i)\}$ [lower] at 50 MPa.

$i = 5$		Differences between deviations, $d(J, J', i) = D(J, i) - D(J', i)$ [$\times 10^{-6}$]													
	$J \setminus J'$	10 CSIR-NML	11 NIS	12 KRISS	13 SCL	14 SPRING	15 NMIA	16 VMI	17 NML-SIRIM	18 KIM-LIPI	19 NSCL	20 NIMT	21 CMS/ITRI	22 NIM	$D(J, i)$
1	PTB	9.4	8.8	-0.1	0.9	6.6	17.3	-30.1	27.9	-9.8	3.5	2.5	-17.7	10.2	0.6
2	IMGC-CNR	11.2	10.6	1.7	2.7	8.4	19.1	-28.3	29.7	-8.0	5.3	4.3	-15.9	12.0	2.4
3	BNM-LNE	3.5	2.9	-6.0	-5.0	0.7	11.4	-36.0	22.0	-15.7	-2.4	-3.4	-23.6	4.3	-5.3
4	NPL	8.8	8.2	-0.7	0.3	6.0	16.7	-30.7	27.3	-10.4	2.9	1.9	-18.3	9.6	0.0
5	CENAM	6.0	5.4	-3.5	-2.5	3.2	13.9	-33.5	24.5	-13.2	0.1	-0.9	-21.1	6.8	-2.8
6	NIST	15.8	15.2	6.3	7.3	13.0	23.7	-23.7	34.3	-3.4	9.9	8.9	-11.3	16.6	7.0
7	INMS/NRC	13.4	12.8	3.9	4.9	10.6	21.3	-26.1	31.9	-5.8	7.5	6.5	-13.7	14.2	4.6
8	NMIJ/AIST	8.3	7.7	-1.2	-0.2	5.5	16.2	-31.2	26.8	-10.9	2.4	1.4	-18.8	9.1	-0.5
9	NPLI	3.6	3.0	-5.9	-4.9	0.8	11.5	-35.9	22.1	-15.6	-2.3	-3.3	-23.5	4.4	-5.2
$D(J', i)$		-8.8	-8.2	0.7	-0.3	-6.0	-16.7	30.7	-27.3	10.4	-2.9	-1.9	18.3	-9.6	

$i = 5$		Expanded uncertainty of d, $U\{d(J, J', i)\}$ [$\times 10^{-6}$]													
	$J \setminus J'$	10 CSIR-NML	11 NIS	12 KRISS	13 SCL	14 SPRING	15 NMIA	16 VMI	17 NML-SIRIM	18 KIM-LIPI	19 NSCL	20 NIMT	21 CMS/ITRI	22 NIM	$U\{D(J, i)\}$
1	PTB	35.2	40.9	50.0	46.1	41.7	47.1	66.2	38.0	76.0	69.5	57.0	55.0	39.0	25.0
2	IMGC-CNR	33.2	39.2	48.5	44.6	39.9	45.6	65.1	36.1	75.1	68.5	55.7	53.7	37.2	22.0
3	BNM-LNE	29.0	35.7	45.8	41.6	36.5	42.6	63.1	32.3	73.3	66.6	53.3	51.2	33.5	15.0
4	NPL	33.9	39.7	49.0	45.1	40.5	46.0	65.5	36.7	75.4	68.8	56.1	54.1	37.8	23.0
5	CENAM	41.3	46.2	54.4	50.9	46.9	51.8	69.6	43.7	79.0	72.8	60.9	59.0	44.6	33.0
6	NIST	44.6	49.2	56.9	53.6	49.8	54.4	71.6	46.8	80.8	74.7	63.2	61.4	47.6	37.0
7	INMS/NRC	46.2	50.7	58.2	55.0	51.3	55.8	72.6	48.4	81.7	75.7	64.3	62.6	49.2	39.0
8	NMIJ/AIST	37.4	42.8	51.5	47.8	43.5	48.7	67.4	40.1	77.0	70.7	58.3	56.4	41.0	28.0
9	NPLI	54.9	58.7	65.4	62.5	59.3	63.2	78.5	56.8	86.9	81.3	70.9	69.3	57.4	49.0
$U\{D(J', i)\}$		24.8	32.4	43.3	38.8	33.3	39.9	61.3	28.6	71.8	64.9	51.2	48.9	30.0	

$i = 5$		$d(J, J', i) / U\{d(J, J', i)\}$												
	$J \setminus J'$	10 CSIR-NML	11 NIS	12 KRISS	13 SCL	14 SPRING	15 NMIA	16 VMI	17 NML-SIRIM	18 KIM-LIPI	19 NSCL	20 NIMT	21 CMS/ITRI	22 NIM
1	PTB	0.27	0.22	0.00	0.02	0.16	0.37	-0.45	0.73	-0.13	0.05	0.04	-0.32	0.26
2	IMGC-CNR	0.34	0.27	0.03	0.06	0.21	0.42	-0.43	0.82	-0.11	0.08	0.08	-0.30	0.32
3	BNM-LNE	0.12	0.08	-0.13	-0.12	0.02	0.27	-0.57	0.68	-0.21	-0.04	-0.06	-0.46	0.13
4	NPL	0.26	0.21	-0.01	0.01	0.15	0.36	-0.47	0.74	-0.14	0.04	0.03	-0.34	0.25
5	CENAM	0.15	0.12	-0.06	-0.05	0.07	0.27	-0.48	0.56	-0.17	0.00	-0.01	-0.36	0.15
6	NIST	0.35	0.31	0.11	0.14	0.26	0.44	-0.33	0.73	-0.04	0.13	0.14	-0.18	0.35
7	INMS/NRC	0.29	0.25	0.07	0.09	0.21	0.38	-0.36	0.66	-0.07	0.10	0.10	-0.22	0.29
8	NMIJ/AIST	0.22	0.18	-0.02	0.00	0.13	0.33	-0.46	0.67	-0.14	0.03	0.02	-0.33	0.22
9	NPLI	0.07	0.05	-0.09	-0.08	0.01	0.18	-0.46	0.39	-0.18	-0.03	-0.05	-0.34	0.08

Table 8.7: Results of the differences, $d(J,J',i)$ [upper], the expanded (k = 2) uncertainties of the differences, $U\{d(J,J',i)\}$ [middle], and the degrees of equivalence expressed by the ratios, $D(J,J',i)/U\{D(J,J',i)\}$ [lower] at 100 MPa.

i = 10		Differences between deviations, $d(J, J', i) = D(J, i) - D(J', i)$ [$\times 10^{-6}$]													
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22	$D(J, i)$
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM	
1	PTB	8.8	4.2	-4.6	-52.8	4.4	24.6	-4.9	30.2	-8.1	9.2	3.8	-15.2	21.4	-0.1
2	IMGC-CNR	16.1	11.5	2.7	-45.5	11.7	31.9	2.4	37.5	-0.8	16.5	11.1	-7.9	28.7	7.2
3	BNM-LNE	3.0	-1.6	-10.4	-58.6	-1.4	18.8	-10.7	24.4	-13.9	3.4	-2.0	-21.0	15.6	-5.9
4	NPL	17.2	12.6	3.8	-44.4	12.8	33.0	3.5	38.6	0.3	17.6	12.2	-6.8	29.8	8.3
5	CENAM	-0.6	-5.2	-14.0	-62.2	-5.0	15.2	-14.3	20.8	-17.5	-0.2	-5.6	-24.6	12.0	-9.5
6	NIST	13.6	9.0	0.2	-48.0	9.2	29.4	-0.1	35.0	-3.3	14.0	8.6	-10.4	26.2	4.7
7	INMS/NRC	16.1	11.5	2.7	-45.5	11.7	31.9	2.4	37.5	-0.8	16.5	11.1	-7.9	28.7	7.2
8	NMIJ/AIST	8.9	4.3	-4.5	-52.7	4.5	24.7	-4.8	30.3	-8.0	9.3	3.9	-15.1	21.5	0.0
9	NPLI	8.1	3.5	-5.3	-53.5	3.7	23.9	-5.6	29.5	-8.8	8.5	3.1	-15.9	20.7	-0.8
$D(J', i)$		-8.9	-4.3	4.5	52.7	-4.5	-24.7	4.8	-30.3	8.0	-9.3	-3.9	15.1	-21.5	

i = 10		Expanded uncertainty of d, $U\{d(J, J', i)\}$ [$\times 10^{-6}$]													
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22	$U\{D(J, i)\}$
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM	
1	PTB	44.1	48.7	58.7	110.8	52.2	57.8	66.2	45.8	89.8	74.3	62.7	61.3	46.8	36.0
2	IMGC-CNR	34.3	40.1	51.8	107.3	44.2	50.8	60.2	36.5	85.4	68.9	56.2	54.6	37.7	23.0
3	BNM-LNE	31.8	37.9	50.1	106.5	42.2	49.1	58.8	34.1	84.4	67.7	54.7	53.1	35.4	19.0
4	NPL	35.7	41.3	52.7	107.7	45.3	51.7	61.0	37.8	85.9	69.6	57.1	55.5	38.9	25.0
5	CENAM	45.8	50.2	60.0	111.5	53.6	59.1	67.3	47.4	90.6	75.3	63.8	62.5	48.3	38.0
6	NIST	45.8	50.2	60.0	111.5	53.6	59.1	67.3	47.4	90.6	75.3	63.8	62.5	48.3	38.0
7	INMS/NRC	52.6	56.5	65.3	114.4	59.5	64.5	72.2	54.0	94.2	79.6	68.9	67.6	54.8	46.0
8	NMIJ/AIST	42.5	47.3	57.5	110.2	50.8	56.6	65.2	44.2	89.0	73.3	61.6	60.1	45.2	34.0
9	NPLI	55.2	59.0	67.5	115.7	61.8	66.7	74.1	56.6	95.7	81.4	70.9	69.7	57.4	49.0
$U\{D(J', i)\}$		25.5	32.8	46.4	104.8	37.7	45.3	55.6	28.3	82.2	65.0	51.3	49.6	29.8	

i = 10		$d(J, J', i) / U\{d(J, J', i)\}$												
$J \setminus J'$		10	11	12	13	14	15	16	17	18	19	20	21	22
		CSIR-NML	NIS	KRISS	SCL	SPRING	NMIA	VMI	NML-SIRIM	KIM-LIPI	NSCL	NIMT	CMS/ITRI	NIM
1	PTB	0.20	0.09	-0.08	-0.48	0.08	0.43	-0.07	0.66	-0.09	0.12	0.06	-0.25	0.46
2	IMGC-CNR	0.47	0.29	0.05	-0.42	0.27	0.63	0.04	1.03	-0.01	0.24	0.20	-0.14	0.76
3	BNM-LNE	0.09	-0.04	-0.21	-0.55	-0.03	0.38	-0.18	0.71	-0.16	0.05	-0.04	-0.39	0.44
4	NPL	0.48	0.31	0.07	-0.41	0.28	0.64	0.06	1.02	0.00	0.25	0.21	-0.12	0.77
5	CENAM	-0.01	-0.10	-0.23	-0.56	-0.09	0.26	-0.21	0.44	-0.19	0.00	-0.09	-0.39	0.25
6	NIST	0.30	0.18	0.00	-0.43	0.17	0.50	0.00	0.74	-0.04	0.19	0.13	-0.17	0.54
7	INMS/NRC	0.31	0.20	0.04	-0.40	0.20	0.49	0.03	0.69	-0.01	0.21	0.16	-0.12	0.52
8	NMIJ/AIST	0.21	0.09	-0.08	-0.48	0.09	0.44	-0.07	0.68	-0.09	0.13	0.06	-0.25	0.48
9	NPLI	0.15	0.06	-0.08	-0.46	0.06	0.36	-0.08	0.52	-0.09	0.10	0.04	-0.23	0.36

9. Discussions

Although there were unanticipated problems, all the participating institutes could get almost equal opportunity to participate in this key comparison. It was entirely thanks to all the participating institutes that the circulations were successful. The results presented in this report are based on data originally submitted to the pilot institute for preparation of the draft A report. From the calibration data of each participating institute, the expected mean pressures for each participating institute were calculated with associated uncertainties.

All the participants generally calibrated two pressure monitors on the transfer standard against the pressure balance following the protocol[7,8]. However, in comparison loop B.1, CMS/ITRI calibrated only pressure monitor B.b on transfer standard B because of the problem happened in pressure monitor B.a due to bad power supply element. In the same loop, KIM-LIPI performed only one cycle calibration though three cycles were required in the protocol. The reason was explained that it was due to the lack of the calibration time since pressure monitor B.b was also repaired at KIM-LIPI. The irregular data submitted from those institutes were also analyzed in this report by examining the analytical method.

Despite of the problem occurred on transfer standard B, it has been confirmed that the problem did not make any systematic change on the characteristics of the pressure transducers on the transfer standard.

In this report, the APMP.M.P-K7 reference values were calculated using the median method and the degrees of equivalence with respect to the APMP.M.P-K7 reference values and the degrees of equivalence between pairs of participating institutes in APMP.M.P-K7 were presented first.

Finally the results of the participating institutes in APMP.M.P-K7 were linked to CCM.P-K7 using the weighted mean method and the degrees of equivalence with respect to the CCM.P-K7 reference values and the degrees of equivalence between pairs of participating institutes in APMP.M.P-K7 and CCM.P-K7 were presented at 10 MPa, 50 MPa and 100 MPa.

10. Conclusions

Sixteen National Metrology Institutes (NMIs) participated into this APMP key comparison of hydraulic high-pressure standards from 10 MPa to 100 MPa for gauge mode. High-precision electronic pressure transducers were circulated as the transfer standards for the whole comparison. In order to ensure the reliability of the transfer standard, two high-precision pressure transducers were used on a transfer standard unit.

During this comparison, three transfer standards were calibrated simultaneously at the pilot institute eleven times in total. From the calibration results, the behaviors of the transfer standards during the comparison period were well characterized and it was confirmed that the capabilities of the transfer standards to achieve this key comparison were sufficient.

The degrees of equivalence of national hydraulic pressure standards at sixteen participating NMIs were obtained. They were expressed quantitatively by two terms, deviations from the key comparison reference values and pair-wise differences between deviations of participating institutes. The degrees of equivalence in this comparison were also transferred to the corresponding CCM key comparison, CCM.M.P-K7.

The hydraulic pressure standards in the range 10 MPa to 100 MPa for gauge mode of the sixteen participating NMIs (NMIJ/AIST, NPLI, CSIR-NML, NIS, KRISS, SCL, SPRING, NMIA, VMI, NML-SIRIM, KIM-LIPI, NSCL, PTB, NIMT, CMS/ITRI and NIM) were found to be equivalent compared with their claimed expanded uncertainties. The results of this APMP comparison were satisfactory.

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References

1. Mutual recognition of national measurements standards and of calibration and measurement certificates issued by national metrology institutes (MRA), Technical Report, International Committee for Weights and Measures, 1999 (http://www.bipm.org/pdf/mra.pdf)
2. Guidelines for CIPM key comparisons, Appendix F to Mutual recognition of national measurements standards and of calibration and measurement certificates issued by national metrology institutes, Technical Report, International Committee for Weights and Measures, 1999 (http://www.bipm.org/pdf/guidelines.pdf)
3. Formalities required for the CCM key comparisons (2nd revised draft), 2001.
4. Wladimir Sabuga, etc., Final Report on Key Comparison CCM.P-K7 in the Range 10 MPa to 100 MPa of Hydraulic Gauge Pressure, Version 1 of 19.01.2005.
5. Guide to the Expression of Uncertainty in Measurement (GUM), 2nd ed., Geneva, International Organization for Standardization, 1995.
6. Entering the details and results of RMO key and supplementary comparisons into the BIPM key comparison database, 2000.
7. Tokihiko Kobata, Protocol of "Asia-Pacific Metrology Program 100 MPa Hydraulic Pressure Interlaboratory Comparison, APMP.M.P-K7, Edition 3.2, 10 September 2003.
8. Tokihiko Kobata, Appendix of Protocol of "Asia-Pacific Metrology Program 100 MPa Hydraulic Pressure Interlaboratory Comparison, APMP.M.P-K7, Edition 3.0, 1 November 2002.
9. Michael Perkin, Report on a comparison of pressure standards in the range 10 MPa to 100 MPa (EUROMET PROJECT 389), May 2000.
10. Jorge C. Torres Guzmán, etc., Pressure standards comparison within the Interamerican Metrology System (SIM), up to 100 MPa, NCSL International, Proceedings of the 2001 Workshop & Symposium, 2001.
11. M. P. Fitzgerald, etc., Pressure comparison from 25 MPa to 260 MPa between the MSL and the NML, Metrologia, **36**, 669-672, 1999.
12. DH Instruments, Inc., RPM3 Operation and Maintenance Manual, 2000. (http://www.dhinstruments.com//supp1/man.htm)
13. Paroscientific, Inc., Model 785 Multi-Range Pressure Standard Operation and Maintenance Manual, 2001. (http://www.paroscientific.com/software.htm#manuals)
14. A.P. Miiller, etc., Final Report on Key Comparison CCM.P-K4 in Absolute Pressure from 1 Pa to 1000 Pa, Metrologia, **39**, Tech. Suppl., 07001, 2002.
15. M. G. Cox, The evaluation of key comparison data, Metrologia, **39**, 589-595, 2002.
16. J. W. Müller, Possible advantage of a robust evaluation of comparisons, Rapport

BIPM-1995/2, 1995.

17. G. Molinar, etc., Final report, CCM key comparison 7 MPa, Phase B (CCM.P-K1.c), October 2000.
18. C. Elster, etc., Proposal for linking the results of CIPM and RMO key comparisons, Metrologia, **40**, 189-194, 2003.
19. J. C. Legras, How to link regional comparisons to a CIPM key comparison? Example based on the CCM.P-K1.c pressure comparison, CCM High Pressure Working Group, 2003.
20. A. K. Bandyopadhyay, etc., Final report of APMP key comparison (APMP.M.P-K1.c), 2003.
21. S. Ban, etc., Final report of regional key comparison EUROMET.M.P-K2 within the pressure range 1 MPa to 4 MPa, 2002.
22. The BIPM key comparison database, Summary results of CCM.P-K1.c, September 2003.