FINAL REPORT

SIM Key Comparison in Pneumatic Gauge Pressure for High Accuracy Pressure Balances up to 7 MPa

SIM.M.P-K1

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Contents

I. ABSTRACT

This report describes the results of a pneumatic pressure standards key comparison among eleven SIM National Metrology Institutes to determine their degree of equivalence in the pressure range from 0.6 MPa to 7 MPa in gauge mode. The pilot laboratory was the Centro Nacional de Metrología (CENAM, Mexico). All participating institutes used pneumatic pressure balances as their pressure standard. The transfer standard was a complete system including a pressure balance with a free-deformational piston-cylinder assembly and a set of masses. Eleven participants completed their measurements, although only ten laboratories reported the pressure-dependent effective areas of the transfer standard at specified pressures with the associated uncertainties; NRC/Canada withdrew the comparison by not sending their measurements. To link the results of the ten laboratories that sent their results to the CCM.P-K1.c comparison NIST, USA provided the reference values. To evaluate the compatibility of results of the participants their relative deviations from those obtained by NIST results were analyzed. The results of seven participating NMIs agree with the NIST reference values within their expanded uncertainties (k=2) in the entire pressure range from 0.6 MPa to 7 MPa according to the error equation method.

II. INTRODUCTION

This comparison aimed to obtain the equivalence statements into SIM region derived from CCM key Comparison CCM.P-K1.c, in the range from 0.6 MPa to 7 MPa, in pneumatic gauge pressure. This comparison will provide the means to the laboratories to support their uncertainty statements given in their CMC Tables. The number of participants was eleven, three NMI from NORAMET, two from CAMET, one from CARIMET, two from ANDIMET and three from SURAMET. NRC/Canada withdrew the comparison by not sending their measurements. The Pressure and Vacuum Section of the Centro Nacional de Metrología (CENAM), Mexico, was the pilot laboratory in this comparison. The Technical Protocol used specified the procedures followed for the comparison and was prepared in accordance with the Guidelines for CIPM Key Comparisons.

III. COMPARISON PURPOSE

This key regional comparison is to confirm the measurement and calibration capabilities (CMCs) for pneumatic gauge pressure in the range from 0.6 MPa to 7 MPa; also, it allows setting the level of agreement among the participant National Metrology Institutes (NMI) and providing a link to the CIPM Key Comparison CCM.P-K1.c.

IV. PARTICIPATING LABORATORIES

Table 1 shows the list of the participating laboratories with their delivery addresses for the transfer standard (TS), as well as the names of the contact persons.

Table 1. Participating laboratories.

Participating laboratory name and TS delivery address	Contact person
Centro Nacional de Metrología, CENAM (pilot laboratory) Pressure and Vacuum Group km 4.5 Carretera a los Cues 76241 El Marqués Queretaro. Mexico	Comparison coordinator: Dr Jorge C. Torres-Guzman Phone: +52 442 211 0500 ext. 3741 Fax: +52 442 211 0578 E-mail: jorge.torres@cenam.mx
National Institute of Standards and Technology, NIST Pressure and Vacuum Group Building 220/A56. 100 Bureau Drive Stop 8364 Gaithersburg, MD 20899-8364. USA	Dr Douglas Olson/ Dr Jay Hendricks Phone: 301 975 2956 Fax: 301 208 6962 E-mail: douglas.olson@nist.gov
Institute for National Measurement Standards, National Research Council. (INMS / NRC) Building M-36, Room 203 Ottawa, Ontario K1A-0R6. Canada	Anil Agarwal Phone: 613-991-0615 Fax: 613-952-1394 E-mail: anil.agarwal@nrc.ca
Bureau of Standards of Jamaica (BSJ) 6 Winchester Road Kingston 10 Jamaica, West Indies.	Allan Foreman† / Tarik Nembhard Phone: 1-876-926-3140 (to 3145) Fax: 1-876-929-4736 E-mail: tnembhard@bsj.org.jm
Centro Nacional de Metrología de Panamá (CENAMEP) Edificio 215, Ciudad del Saber, Antiguo fuerte Clayton, Panama City Panama. Apdo. 1736	Saul Garcia / Ozmir Ortega Phone: +(507) 517 - 0081 Fax: +(507) 507 – 0019 E-mail: sgarcia@cenamep.org.pa
Laboratorio Costarricense de Metrología. Lacomet. Ciudad de la Investigación de la UCR, Apdo. 1736−2050, San Pedro de Montes de Oca. Costa Rica	Adrián Solano / Róger Irías Phone: (506)2836580, (506)2805387 Fax: (506) 283 5133 E-mail: asolano@lacomet.go.cr
Instituto Nacional de Metrología, INM. Before - Superintendencia de Industria y Comercio. SIC Avenida Carrera 50 # 26-55, Int 2. CAN. Bogota D. C. Colombia	Catalina Neira / Roberto Calderón Phone: +(57) (1) 3153265 / 3153266 Fax: +(57) (1) 3153266 / 3153267 E-mail: mneira@inm.gov.co
Instituto Nacional de Calidad, INACAL. Before - INDECOPI Laboratorio de metrología de presión Calle De la Prosa N° 150, San Borja, Lima 41. Peru	Leonardo de la Cruz García Phone: +51-1-6408820 ext. 1517 E-mail: ldelacruz@inacal.gob.pe
Laboratorio Custodio de Patrones Nacionales de Presión (LCPN-P) Laboratorio de metrología de presión Empresa Nacional de Aeronáutica, ENAER, Avenida José Miguel Carrera 11087 Paradero 36 ½. Comuna El Bosque. Santiago. Chile	José Palma / Marcial Espinoza Phone: +56-2 383 1966 Fax: +56-2 3831 707 E-mail: marcial.espinoza@enaer.cl
Instituto Nacional de Tecnología Industrial (INTI) INTI - Fisica y Metrología	Juan Forastieri / Víctor Miranda Phone: +54-11-47525402

Colectora de Avenida General Paz 5445 entre Albarellos y Avenida de los Constituyentes Casilla de correo 157 B1650KNA, San Martin. Argentina	Fax: +54-11-47134140 E-mail: jaforast@inti.gov.ar, victorm@inti.gob.ar
National Institute of Metrology, Standardization and Industrial Quality. INMETRO Laboratório de Pressão. Inmetro - Dimci/Dimec/Lapre Rio de Janeiro - RJ – Brazil	Paulo Roberto Guimarães Couto Phone: +55 212679-9046/2679-9042 Fax: +55 21 2679-1505 E-mail: prcouto@inmetro.gov.br

V. TRANSFER STANDARD AND PARTICIPATING LABORATORIES´ STANDARDS USED

The transfer standard was a piston-cylinder assembly of 0.5 cm^2 nominal effective area with serial number 1150. It is part of a pressure balance equipped with a set of masses; Fluke (DH Instruments), USA, manufactured all parts. This piston-cylinder assembly was considered new since was manufactured in 2008, the pilot laboratory checked during the period of the comparison the drift of its effective area. The TS drift was checked by comparing the results obtained on the calibrations performed by CENAM at the beginning and at the end of the comparison (graph 1 shows the first and last calibrations of the TS made by CENAM, were it can be shown that the TS has no drift). The worst reproducibility calculated for the TS (at 5 300 kPa) was $7.0 \cdot 10^{-11}$ m^2. This uncertainty, due to reproducibility, combined with the area uncertainty was the one used.

The mass pieces to be put on the carrying bell of the TS to generate the nominal pressures are given in the next table (nominal pressure in kPa mass pieces).

Nominal pressure in kPa	Nominal mass pieces in kg
600	(2(1) + 0.5)
700	(2(1) + 1)
1 100	(4.5 + 0.5)
1 800	(4.5 + 2(1 to 2))
3 000	(4.5 + 5(1 to 2))
4 100	(4.5 + 5(1 to 3) + 0.5)
5 300	(4.5 + 5(1 to 4) + 1 + 0.5)
6 400	(4.5 + 5(1 to 5 + 2(1))
7 000	(4.5 + 5(1 to 5) + 2(1 to 2) + 1)

The mass of the mass set pieces is given in Annex 1.

The standards used by the participating laboratories for the calibration of the transfer standard of the comparison are shown in Table 2.

Table 2. Participating laboratories standards used for the comparison.

Country	Argentina	Brazil	Chile	Colombia	Costa Rica	Jamaica	Mexico	Peru	USA
NMI	INTI	INMETRO	ENAER	INM	LACOMET	JBS	CENAM	INACAL	NIST
Contact	Juan Angel Forastieri jaforast@inti.gob.ar	Paulo Couto prcouto@inmetro.gov.br	Marcial Espinoza mespinoza@enaer.cl	Maria Neira mneira@inm.gov.co	Adrián Solano asolano@lacomet.go.cr	Tarik Nembhard tnembhard@bsj.org.jm	Jorge Torres Guzman jtorres@cenam.mx	Leonardo De la Cruz ldelacruz@inacal.gob.pe	Douglas Olson Dolson@nist.gov
Fluid	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Standard used	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance
Maker	RUSKA	RUSKA	RUSKA	DH Instruments	DH Instruments	RUSKA	DH Instruments	DH Instruments	RUSKA
Model	2465-729	2465A - 754	2465-A	PG-7601	PG-7601	2465	PG-7601	PG-7601	2465
Serial N°	Piston: V-1327	Base: 54874 Piston: V-1551	Base: 53860; Piston: V-1518	Base: 584; Piston: 1143	Base: 583; Piston: 1152	Base:64420 Piston: V1665	Base: 107; Piston: 228	Base: 716; Piston: 1390	Piston: V-373
Range	14 kPa to 7 000 kPa	14 kPa to 7 000 kPa	14 kPa to 7 000 kPa	40 kPa to 7 000 kPa	700 kPa a 7 000 kPa	345 kPa to 7 000 kPa	40 kPa to 7 000 kPa	40 kPa to 7 000 kPa	350 kPa to 7 000 kPa
Accuracy Class	0.005 %R	0.003 5 %R	0.005 %R	0.002 %R	0.0025 %R	0.005 %R	10 Pa or 0.005 %R or greater	0.003 %R	0.0035 %R or greater
Cylinder Material	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide
Piston Material	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide
Effective area (A_0) at zero pressure in m^2	8.39E-06	8.39347E-06	8.38702E-06	4.901870E-05	4.90E-05	8.39E-06	4.90267E-05	4.9019147E-05	8.39E-06
Relative Expanded Uncertainty of A_0, in 10^{-6}	18	23	18	32	26	1.30E-07	19	21	note 1
Elastic deformation coefficient b, in Pa^{-1}	2.00E-12	0	1.20E-12	-2.35E-12	-1.50E-12	1.61E-12	2.10E-14	-2.30E-13	2.66E-12
Expanded Uncertainty b, in Pa^{-1}	7.00E-13	1.00E-12	1.00E-12	6.00E-13	2.7E-13	2.00E-18	4.90E-13	5.4E-13	note 1
Traceability	PTB - Germany	PTB - Germany	PTB - Germany	PTB - Germany	CENAM - Mexico	NIST - USA	CENAM - Mexico	CENAM - Mexico	NIST - USA

Note 1: The uncertainty statement for the effective area of the NIST standard combines the uncertainty in A_0 and b. The expanded uncertainty is given by the following, with p in Pa,

$$\frac{U(A)}{A} = \left[\left(\frac{0.34}{p}\right)^2 + (11.6 \times 10^{-6})^2 + \left(2.24 \times 10^{-12} * (p - 830\,000)\right)^2\right]$$

Note 2: Canada and Panama did not send the information of the standards used.

VI. MEASUREMENTS PROCEDURE

The measuring method is by cross float between the TS and the standard pressure balance of the participant laboratory. The transfer standard and the piston-cylinder assembly were mounted in accordance with the instructions given in the User's Manual Pressure Balance, Model 7601. The comparison procedure was approved by the participant NMIs as document: SIM Key Comparison for 7 MPa Range of Pneumatic Gauge Pressure - Technical Protocol SIM.P-7.40 (7 MPa).

The most important information is:

a) The reference temperature of the comparison was 20 °C.
b) The time between a comparison target pressure level change and the acquisition of data, for the laboratory standard and the TS cross-floating equilibrium, was no less than 10 minutes.
c) The direction of the piston rotation is clockwise. The rotation, at the equilibrium between the reference standard and TS, should be equal to 20 rpm.
d) The measurements included three cycles, each with nominal pressures in the following order (600, 700, 1 100, 1 800, 3 000, 4 100, 5 300, 6 400, 7 000, 7 000, 6 400, 5 300, 4 100, 3 000, 1 800, 1 100, 700, 600) kPa. 54 measurements were performed by each laboratory.
e) Each cycle of measurement was to be completed in one day.
f) The masses were calibrated, and these values used by all NMIs.
g) Laboratories used a table with mass identification to generate the nominal pressures.

VII. COMPARISON ROUND

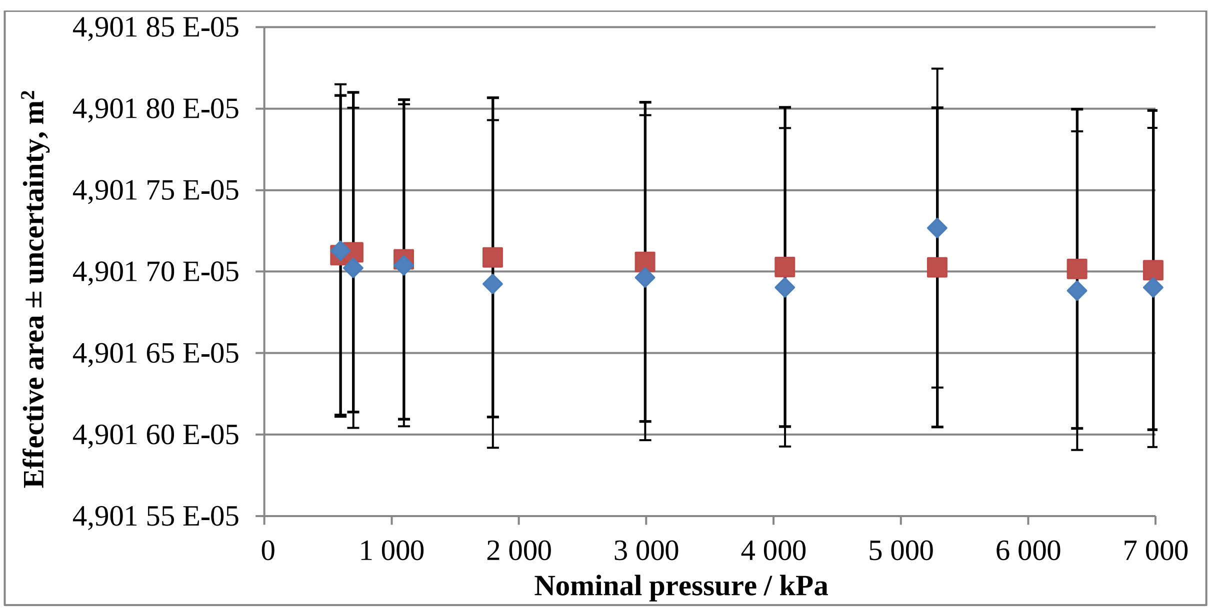
In Table 3 it is presented the delivery date of the TS and the participant laboratory that received the TS.

Table 3. Comparison round of participating laboratories.

Start of Measurement date and Participant
August 1st, 2008. CENAM, TS initial calibration
October 1st, 2008. NIST
November 25th, 2008. NRC
January 10th, 2009. CENAM, TS intermediate check
February 15th, 2009. BSJ
April 1st, 2009. CENAMEP
May 15th, 2009. LACOMET
July 1st, 2009. CENAM, TS intermediate check
August 15th, 2009. INM
October 1st, 2009. INACAL
November 15th, 2009. ENAER
January 2nd, 2010. INTI
February 15th, 2010. INMETRO
June 1st, 2010. CENAM, TS final calibration

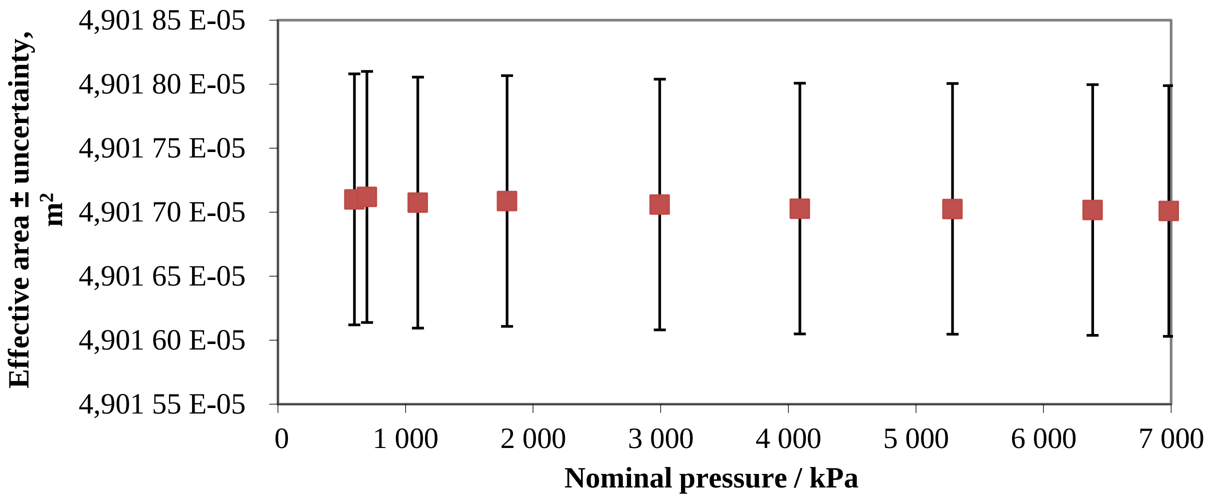
VIII. RESULTS

Graph 1 shows the first and last calibrations of the TS made by CENAM. The intermediate checks fall in between these two. The TS showed no drift, as well as no mayor dispersion.



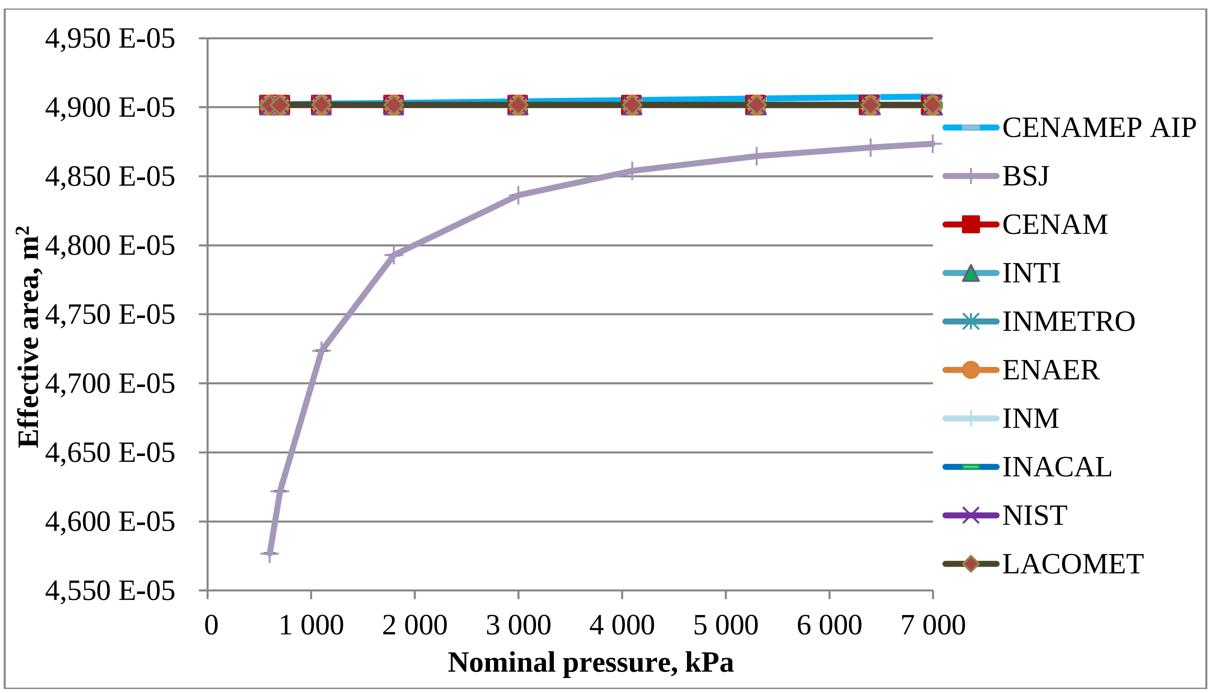
Graph 1. TS effective area and uncertainty as obtained by CENAM, first and last calibrations (at the beginning and at the end of the comparison), m^2.

As shown in graph 2, CENAM used for the comparison the last calibration performed.

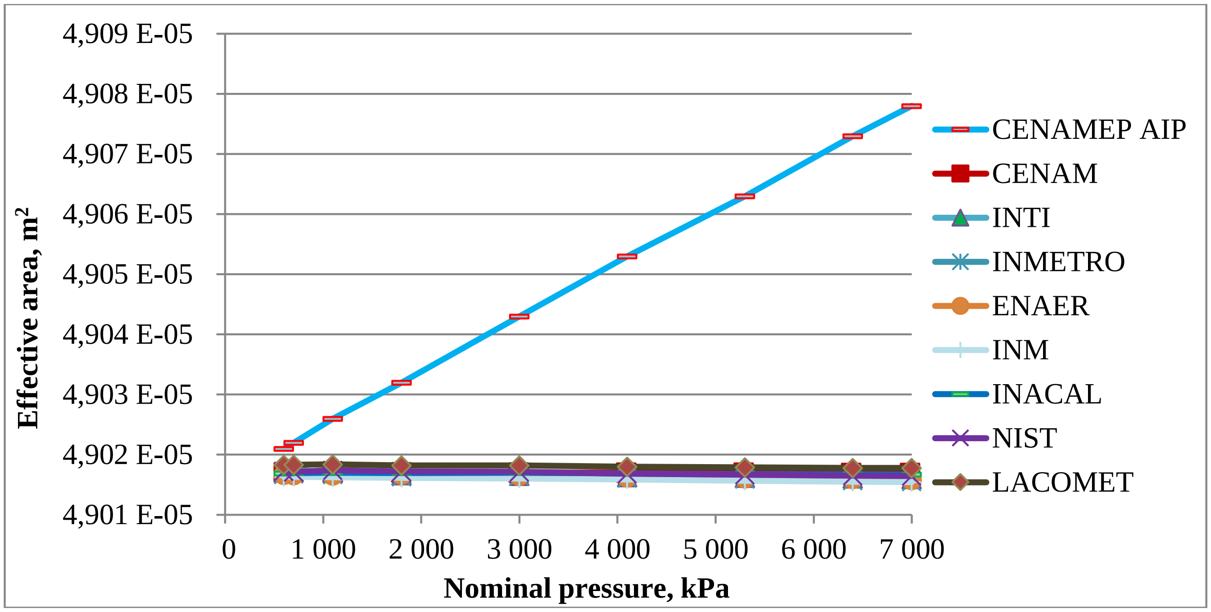


Graph 2. TS effective area and uncertainty used by CENAM, m^2.

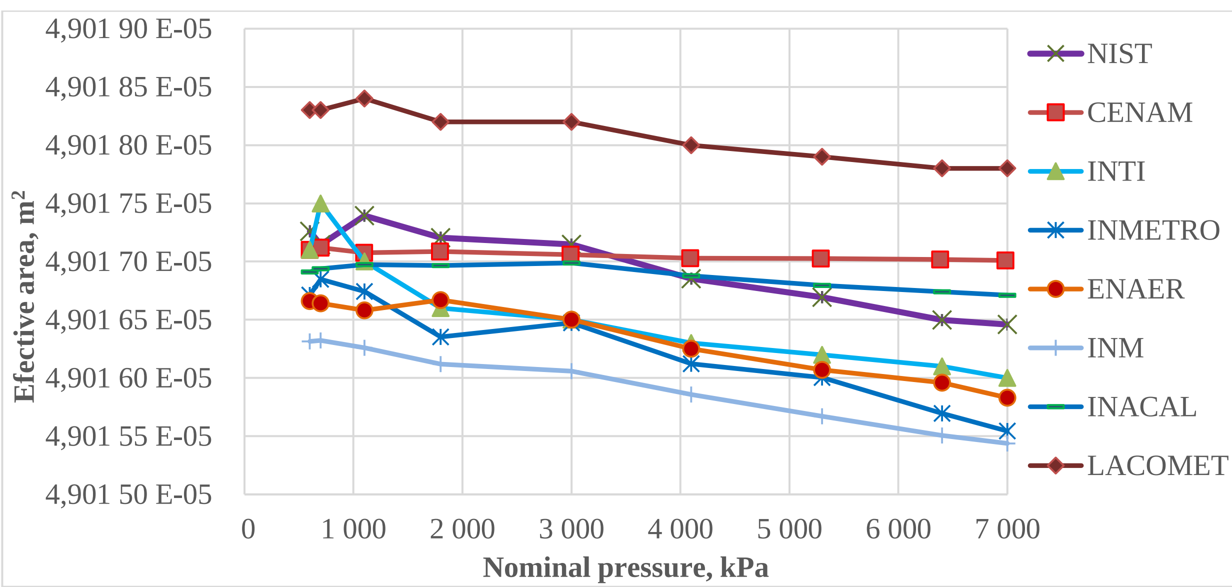
In graphs 3 to 5, the effective area calculated for the TS from each NMI (in m^2) are shown.



Graph 3. TS effective area as obtained by each NMI, m^2.

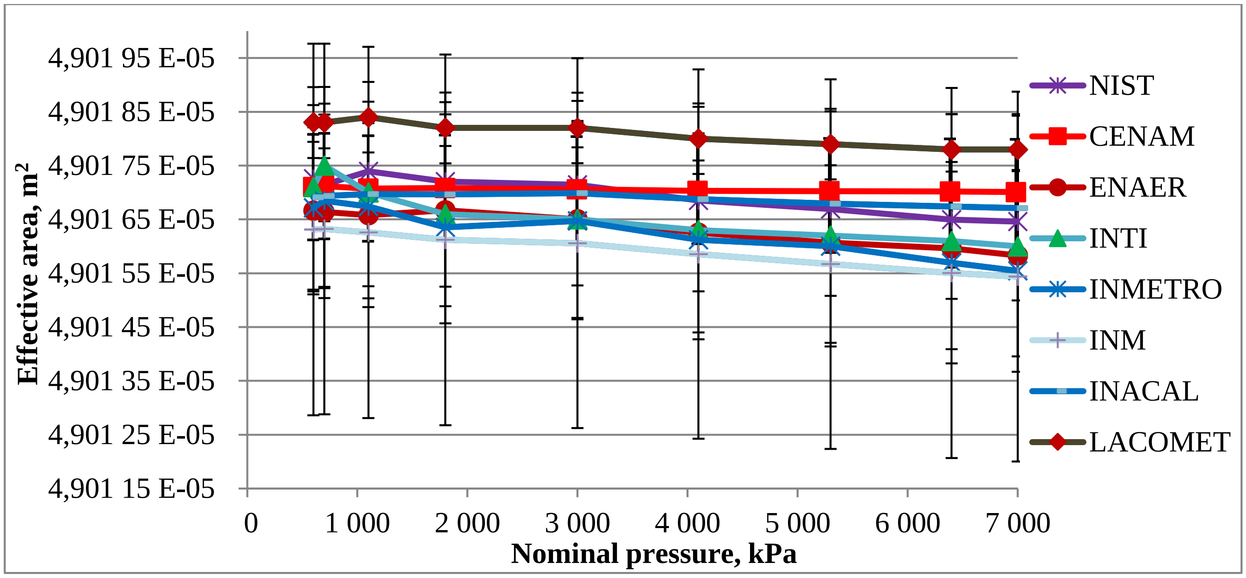


Graph 4. TS effective area and its uncertainty as obtained by each NMI without BSJ, m^2.



Graph 5. TS effective area as obtained by each NMI without BSJ and CENAMEP AIP, m^2.

Graph 6 presents the effective area of the TS and its corresponding expanded uncertainty for each NMI, without BSJ and CENAMEP. In tables 4 and 5, the values for effective area and its corresponding uncertainty as obtained by each participating laboratory are included.



Graph 6. TS effective area and its uncertainty as obtained by each NMI without BSJ and CENAMEP, m^2.

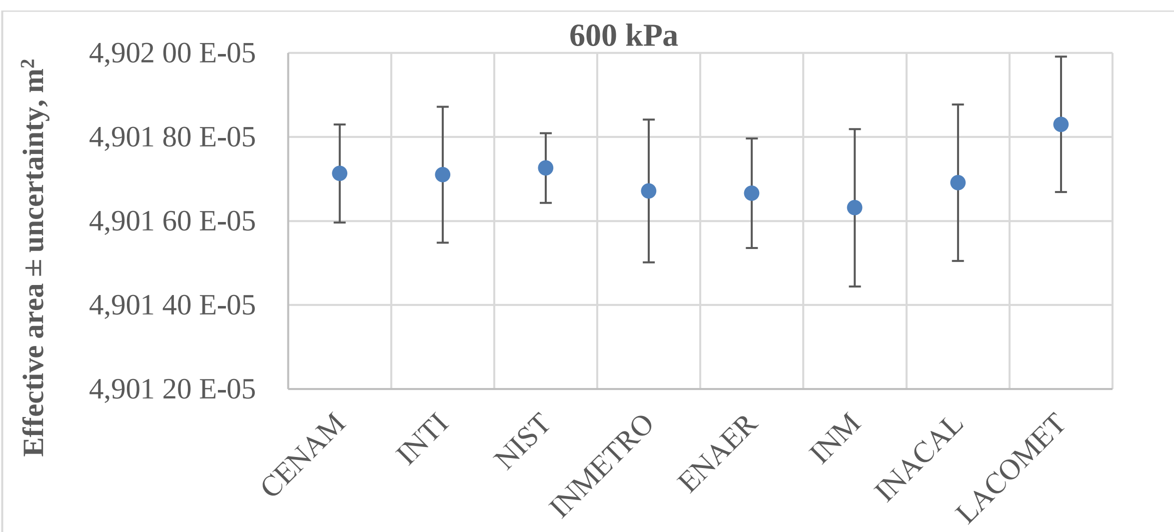
Table 4. TS effective area and its uncertainty as obtained by each NMI, m^2.

	CENAM		INTI		NIST		INMETRO		ENAER	
Nom Press (kPa)	Area TS m^2	*U* Area m^2	Area TS m^2	*U* Area m^2	Area TS m^2	*U* Area m^2	Area TS m^2	*U* Area m^2	Area TS m^2	*U* Area m^2
600	4.901 71 E-05	1.2E-09	4.901 71 E-05	1.6E-09	4.901 73 E-05	8.3E-10	4.901 67 E-05	1.7E-09	4.901 67 E-05	1.3E-09
700	4.901 70 E-05	1.1E-09	4.901 75 E-05	1.6E-09	4.901 71 E-05	8.2E-10	4.901 68 E-05	1.7E-09	4.901 66 E-05	1.3E-09
1 100	4.901 70 E-05	1.1E-09	4.901 70 E-05	1.6E-09	4.901 74 E-05	8.1E-10	4.901 67 E-05	1.9E-09	4.901 66 E-05	1.3E-09
1 800	4.901 69 E-05	1.2E-09	4.901 66 E-05	1.6E-09	4.901 72 E-05	8.1E-10	4.901 64 E-05	1.9E-09	4.901 67 E-05	1.3E-09
3 000	4.901 70 E-05	1.1E-09	4.901 65 E-05	1.6E-09	4.901 71 E-05	8.4E-10	4.901 65 E-05	2.0E-09	4.901 65 E-05	1.3E-09
4 100	4.901 69 E-05	1.1E-09	4.901 63 E-05	1.6E-09	4.901 69 E-05	8.9E-10	4.901 61 E-05	2.0E-09	4.901 63 E-05	1.3E-09
5 300	4.901 73 E-05	1.1E-09	4.901 62 E-05	1.6E-09	4.901 67 E-05	9.6E-10	4.901 60 E-05	2.0E-09	4.901 61 E-05	1.3E-09
6 400	4.901 69 E-05	1.1E-09	4.901 61 E-05	1.6E-09	4.901 65 E-05	1.0E-09	4.901 57 E-05	2.0E-09	4.901 60 E-05	1.3E-09
7 000	4.901 70 E-05	1.1E-09	4.901 60 E-05	1.6E-09	4.901 65 E-05	1.1E-09	4.901 55 E-05	2.0E-09	4.901 58 E-05	1.3E-09

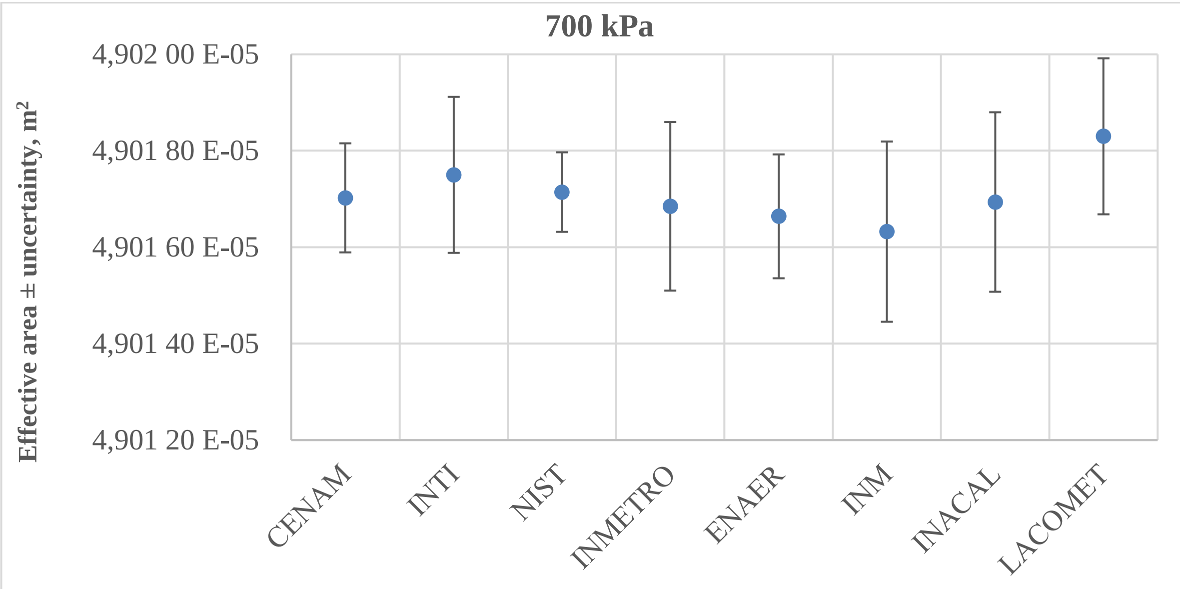
Table 5. Continued. TS effective area and its uncertainty as obtained by each NMI, m^2.

	INM		BSJ		CENAMEP AIP		INACAL		LACOMET	
Nom	Area	*U*	Area	*U*	Area	*U*	Area	*U*	Area	*U*
Press	TS	Area	TS	Area	TS	Area	TS	Area	TS	Area
(kPa)	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2
600	4.901 63 E-05	1.9E-09	4.576 72 E-05	1.5E-09	4.902 10 E-05	1.5E-10	4.901 69 E-05	1.9E-09	4.901 83 E-05	1.6E-09
700	4.901 63 E-05	1.9E-09	4.621 90 E-05	1.5E-09	4.902 20 E-05	1.5E-10	4.901 69 E-05	1.9E-09	4.901 83 E-05	1.6E-09
1 100	4.901 63 E-05	1.9E-09	4.723 66 E-05	1.5E-09	4.902 60 E-05	1.5E-10	4.901 70 E-05	1.9E-09	4.901 84 E-05	1.6E-09
1 800	4.901 61 E-05	1.9E-09	4.792 91 E-05	1.5E-09	4.903 20 E-05	1.5E-10	4.901 70 E-05	1.9E-09	4.901 82 E-05	1.6E-09
3 000	4.901 61 E-05	1.9E-09	4.836 40 E-05	1.5E-09	4.904 30 E-05	1.5E-10	4.901 70 E-05	1.9E-09	4.901 82 E-05	1.6E-09
4 100	4.901 59 E-05	1.9E-09	4.853 89 E-05	1.5E-09	4.905 30 E-05	1.5E-10	4.901 69 E-05	1.9E-09	4.901 80 E-05	1.6E-09
5 300	4.901 57 E-05	1.9E-09	4.864 69 E-05	1.5E-09	4.906 30 E-05	1.5E-10	4.901 68 E-05	1.9E-09	4.901 79 E-05	1.6E-09
6 400	4.901 55 E-05	1.9E-09	4.871 00 E-05	1.5E-09	4.907 30 E-05	1.5E-10	4.901 67 E-05	1.9E-09	4.901 78 E-05	1.6E-09
7 000	4.901 54 E-05	1.9E-09	4.873 59 E-05	1.5E-09	4.907 80 E-05	1.5E-10	4.901 67 E-05	1.9E-09	4.901 78 E-05	1.6E-09

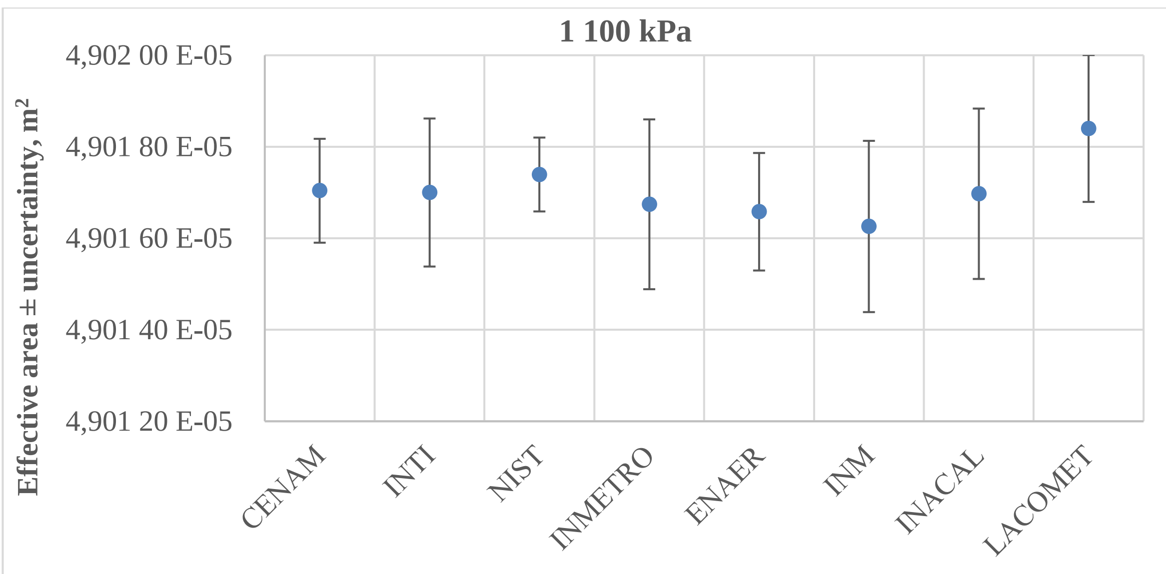
Graph 7 to graph 15, show the effective area and its corresponding expanded uncertainty as calculated by each NMI for each applied pressure. BSJ and CENAMEP are not included.



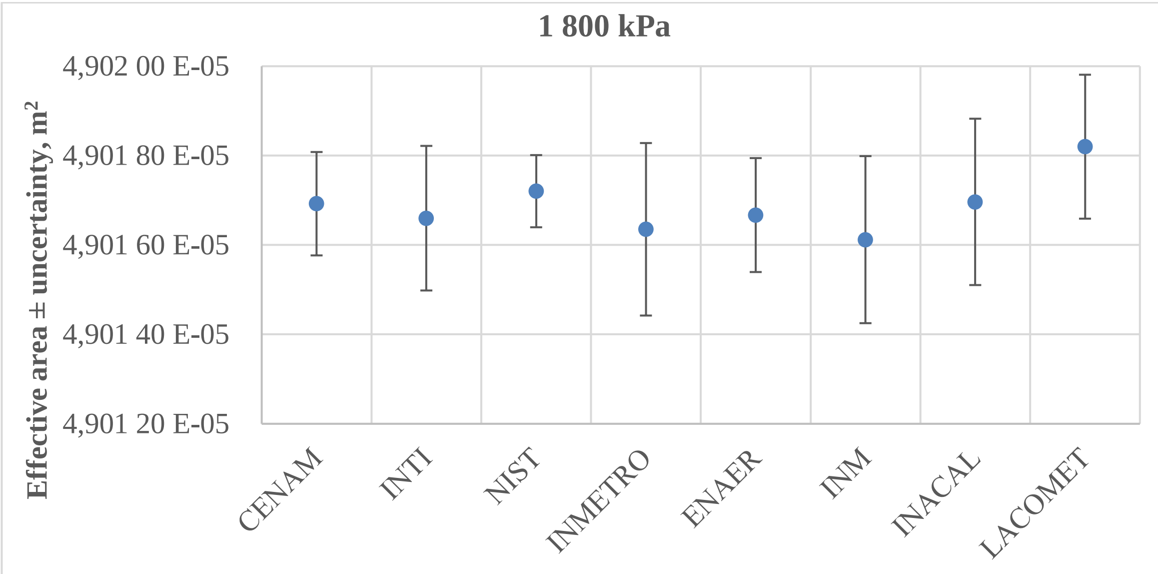
Graph 7. TS effective area and its expanded uncertainty as obtained by each NMI, for 600 kPa, m^2.



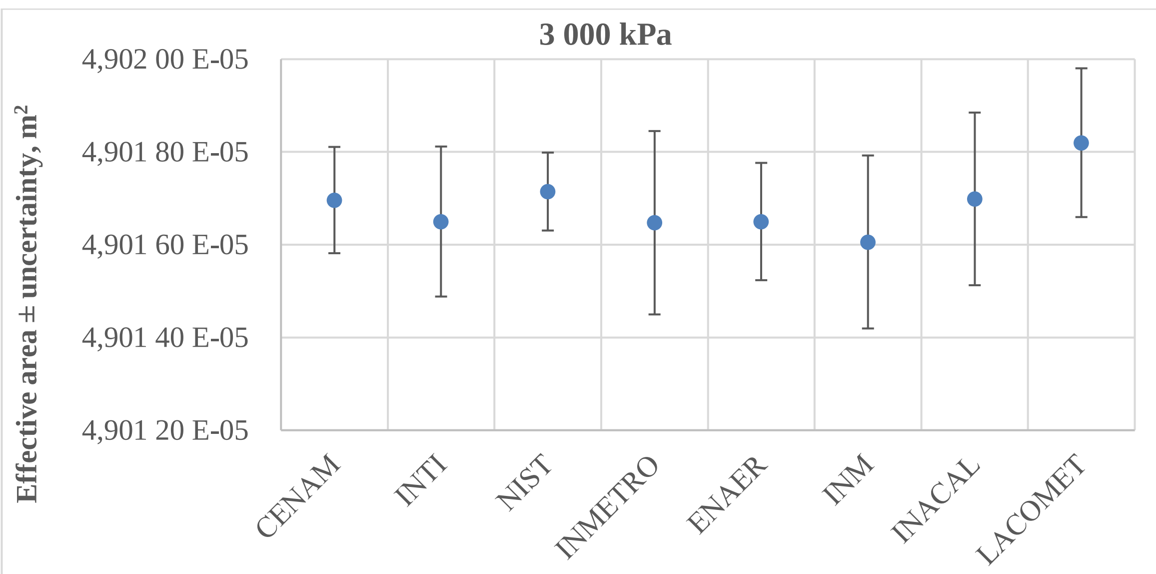
Graph 8. TS effective area and its expanded uncertainty as obtained by each NMI, for 700 kPa, m^2.



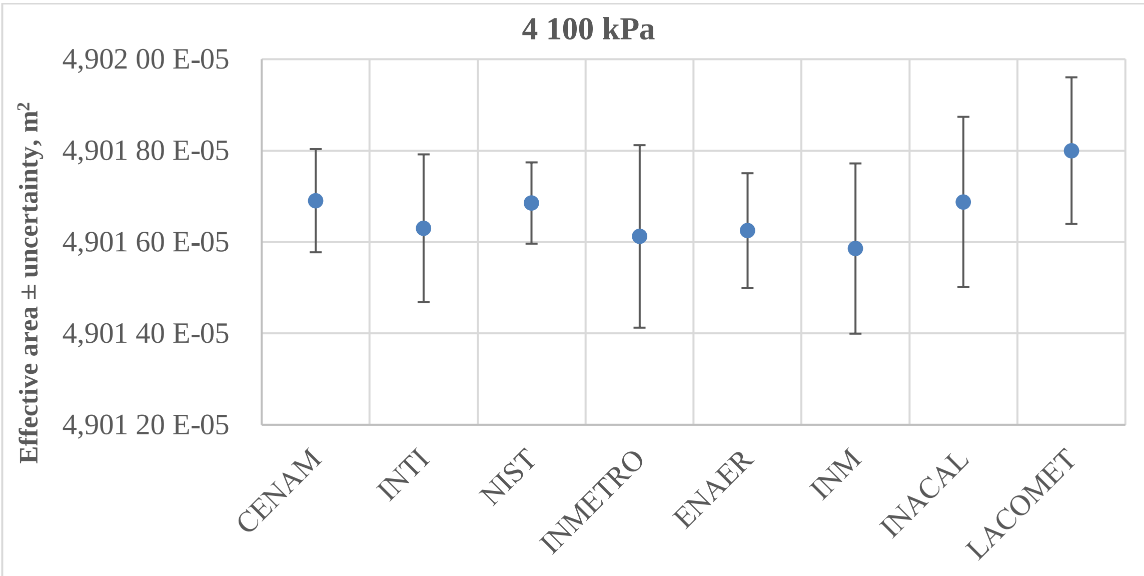
Graph 9. TS effective area and its expanded uncertainty as obtained by each NMI, for 1 100 kPa, m^2.



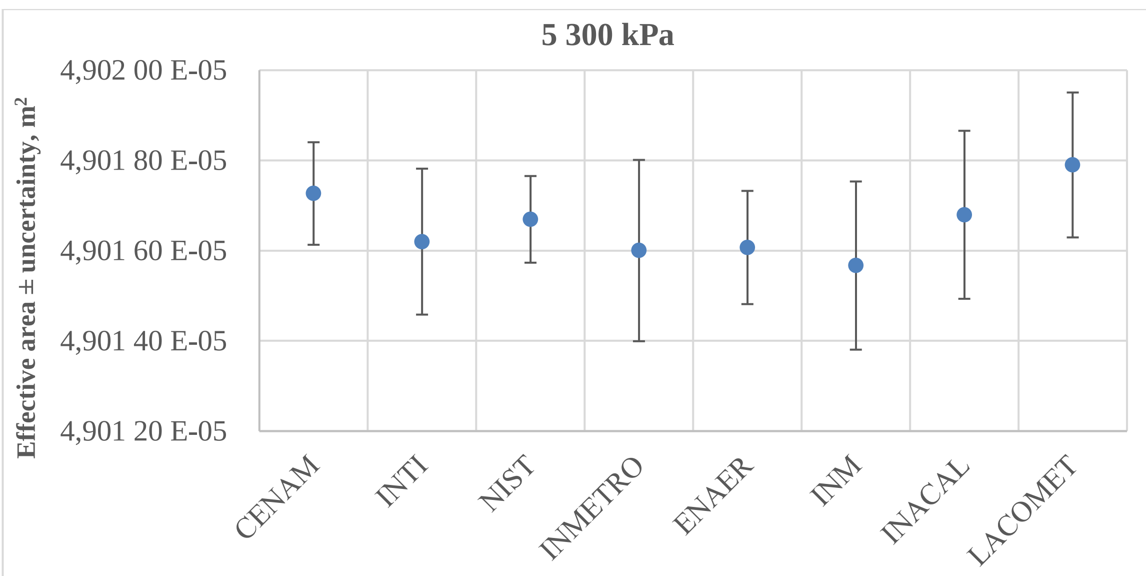
Graph 10. TS effective area and its expanded uncertainty as obtained by each NMI, for 1 800 kPa, m^2.



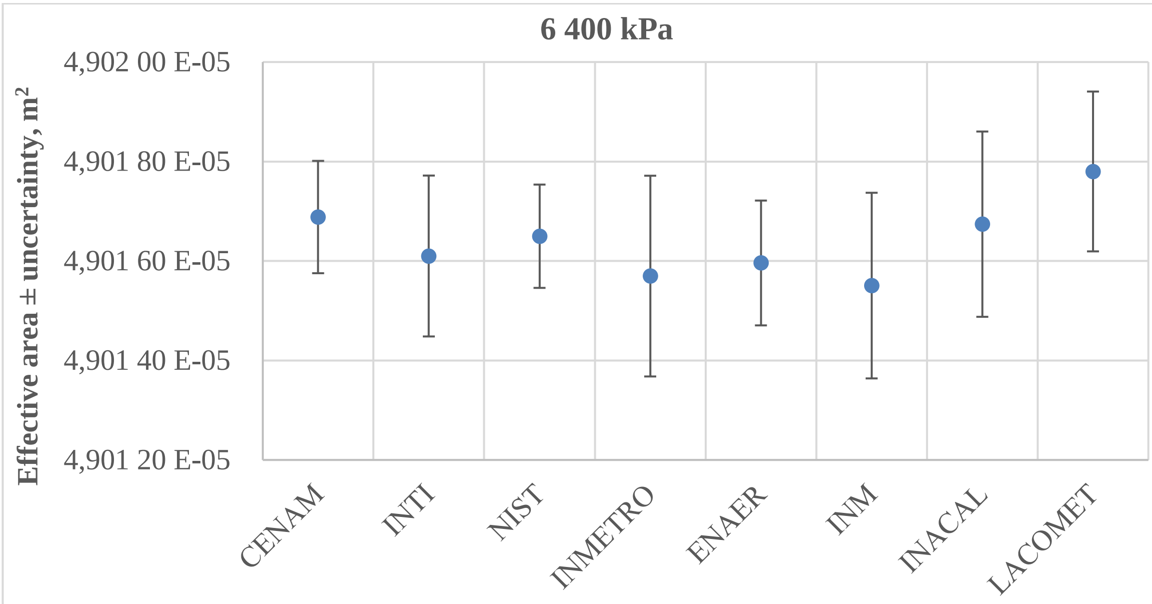
Graph 11. TS effective area and its expanded uncertainty as obtained by each NMI, for 3 000 kPa, m^2.



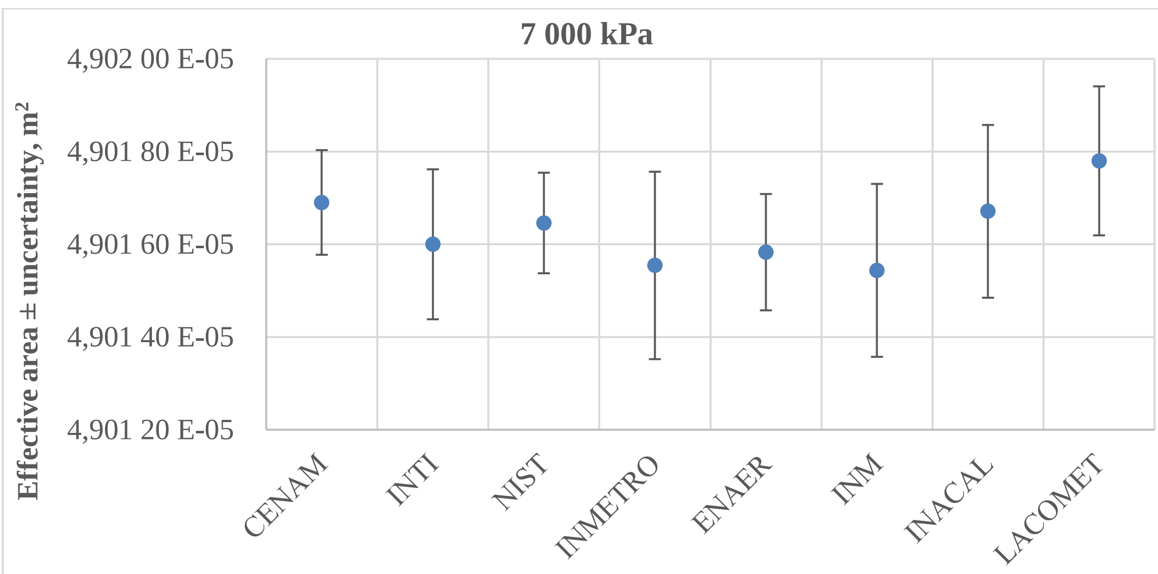
Graph 12. TS effective area and its expanded uncertainty as obtained by each NMI, for 4 100 kPa, m^2.



Graph 13. TS effective area and its expanded uncertainty as obtained by each NMI, for 5 300 kPa, m^2.



Graph 14. TS effective area and its expanded uncertainty as obtained by each NMI, for 6 400 kPa, m^2.

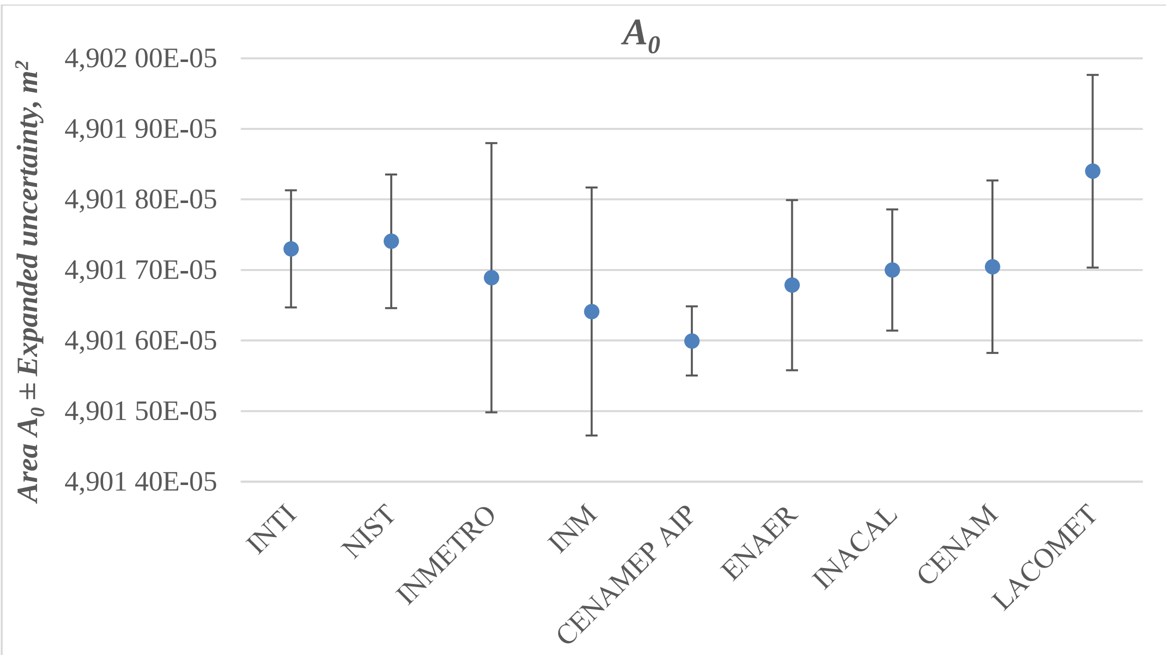


Graph 15. TS effective area and its expanded uncertainty as obtained by each NMI, for 7 000 kPa, m^2.

Table 6 and graph 16 present the results for A_0 and its corresponding expanded uncertainty for each participating NMI, m^2. In table 6, laboratories in italics did not calculated A_0 (INMETRO, INM and CENAMEP). To compare results CENAM made the calculations by means of the lineal regression method. To compare the results for the laboratories, a temperature correction was used to transfer their results to 20 °C reference temperature, as outlined in the Comparison Protocol.

Table 6. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2.

NMI	A_0 / m^2	UA_0 / m^2	*b* / 1/Pa	*Ub* / 1/Pa
INTI	4.901 73E-05	8.3E-10	-3.9E-12	2.0E-13
NIST	4.901 74E-05	9.5E-10	-2.7E-12	6.1E-13
INMETRO	4.901 69E-05	1.9E-09	-3.8E-12	6.5E-13
INM	4.901 64E-05	1.8E-09	-2.8E-12	1.8E-13
CENAMEP AIP	4.901 60E-05	4.9E-10	1.8E-10	1.8E-12
ENAER	4.901 68E-05	1.2E-09	-2.7E-12	3.5E-13
INACAL	4.901 70E-05	8.6E-10	-7.6E-13	3.4E-13
CENAM	4.901 70E-05	1.2E-09	-2.6E-13	7.7E-13
LACOMET	4.901 84E-05	1.4E-09	-1.8E-12	3.3E-13
BSJ	4.650 27E-05	7.4E-07	8.3E-09	4.1E-09



Graph 16. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2. For clarity, BSJ is not included.

IX. EVALUATION OF RESULTS AND CONCLUSIONS

A) SIM

For evaluation of the NMIs performance the normalized error equation (*En*) criteria was applied to their TS effective area results, according to the following equation (1).

$$E_n = \frac{\bar{a} - \bar{A}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \tag{1}$$

Where:

E_n : Normalized error.

$\bar{a}$: Effective area of the TS as obtained by each participating laboratory.

$\bar{A}$: Effective area of the TS as obtained by NIST, TS reference area.

U_{lab}^2 : Expanded uncertainty assigned to the TS effective area as obtained by each participating laboratory.

U_{ref}^2 : Expanded uncertainty assigned to the TS effective area as obtained by NIST, TS effective area reference uncertainty.

The normalized error equation results have the following criteria:

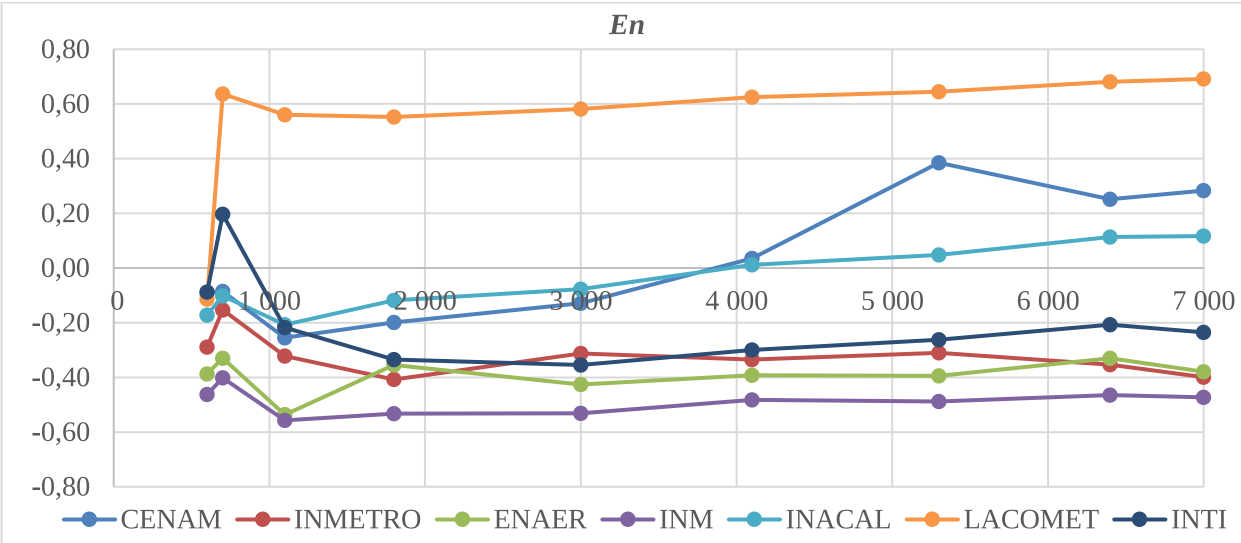
$|E_n| \leq 1.0$ Satisfactory result.

$|E_n| > 1.0$ Non-satisfactory result.

Table 7. Normalized error (E_n) according to equation (1), of participating NMIs with respect to the reference laboratory (NIST) values for effective area.

NMI	600 kPa	700 kPa	1 100 kPa	1 800 kPa	3 000 kPa	4 100 kPa	5 300 kPa	6 400 kPa	7 000 kPa
INTI	-0.09	0.20	-0.22	-0.33	-0.35	-0.30	-0.26	-0.21	-0.24
CENAM	-0.09	-0.09	-0.25	-0.20	-0.13	0.04	0.4	0.3	0.3
INMETRO	-0.29	-0.15	-0.32	-0.41	-0.31	-0.33	-0.31	-0.35	-0.40
ENAER	-0.39	-0.33	-0.54	-0.35	-0.43	-0.39	-0.39	-0.33	-0.38
INM	-0.46	-0.40	-0.56	-0.53	-0.53	-0.48	-0.49	-0.46	-0.47
INACAL	-0.17	-0.10	-0.21	-0.12	-0.08	0.01	0.05	0.11	0.12
LACOMET	-0.11	0.64	0.56	0.55	0.58	0.63	0.64	0.68	0.69
CENAMEP	4	6	10	18	30	40	48	54	56
BSJ	-1 902	-1 651	-1 049	-639	-372	-274	-207	-168	-151

In this SIM comparison, 11 laboratories participated. From those, one did not send their measurement results (NRC/Canada). As it can be seen in graphs from 7 to 15 as well as for the normalized error results shown in table 7 and graph 17, from the 10 laboratories which sent their results, seven laboratories have compatibility of their results with those of the references values provided by NIST. Two laboratories (CENAMEP and BSJ) have no compatibility with the reference values or with those results of the other participating laboratories.



Graph 17. Normalized error (E_n) according to equation (1) with respect to the reference laboratory (NIST) values for effective area.

B) SIM.M.P-K1 with CCM.P-K1

For evaluation of the NMIs performance the normalized error equation ($E_{n\ lab}$) criteria was applied to their TS effective area results, according to the following equation (2).

$$E_{n\ \ lab} = \frac{\left(x_{lab} - x_{NIST}\right)_{SIM} - (X_{NIST} - X_{VR})_{CIPM}}{\sqrt[2]{U_{lab\ SIM}{}^2 + U_{NIST\ SIM}{}^2 + U_{NIST\ CIPM}{}^2 + U_{VR}{}^2}} \qquad (2)$$

Where,

$E_{n\ lab}$: Normalized error.
X_{lab} : Effective area of the TS as obtained by each participating laboratory, in SIM.
x_{NIST} : Effective area of the TS as obtained by NIST, TS reference area in SIM.
X_{NIST} : Effective area of the TS as obtained by NIST, TS reference area in CIPM.
x_{VR} : Effective area of the TS as reference area in CIPM.
$U^2_{lab\ SIM}$: Expanded uncertainty assigned to the TS effective area as obtained by each participating laboratory, in SIM.
$U^2_{NIST\ SIM}$: Expanded uncertainty assigned to the TS effective area as obtained by NIST, TS effective area reference uncertainty in SIM.
$U^2_{NIST\ CIPM}$: Expanded uncertainty assigned to the TS effective area as obtained by NIST, TS effective area reference uncertainty in CIPM.
U^2_{VR} : Expanded uncertainty assigned to the TS effective area, TS effective area reference uncertainty in CIPM.

The normalized error equation results have the following criteria:

$|E_{n\ lab}| \leq 1.0$ Satisfactory result.

$|E_{n\ lab}| > 1.0$ Non-satisfactory result.

To obtain the reference value, all the transfer standard data in the final report of the CCM.P-K1 were fit to the linear function.

Ap (20°C, p) = f(p) = Ao (1 + $\lambda\, p$) where Ao is the effective area at atmospheric pressure and 20 °C and λ is the distortion coefficient.

The resulting value is:

Ap /mm^2 = 8.388 516 5 + 3.947 10^{-8} p /kPa

which is equivalent to Ao = 8.388 516 5 mm^2 and a distortion coefficient λ = 4.71 10^{-9} kPa^{-1} with a standard deviation of the linear fit of 6.075 10^{-5} mm^2 equivalent to 7.2 ppm.

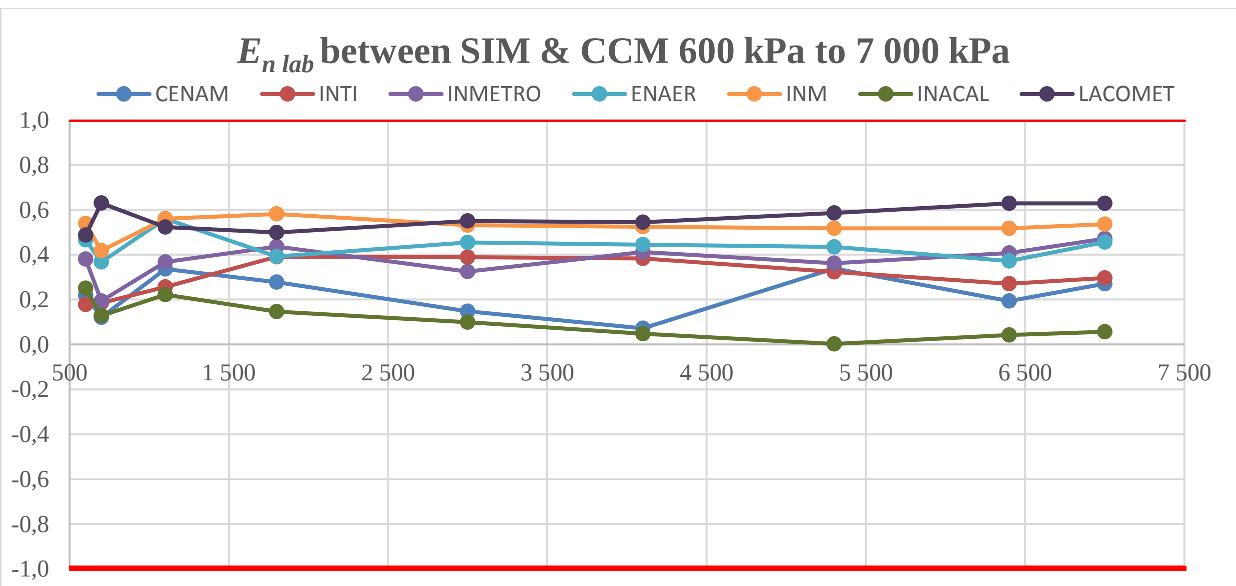
Table 8. TS effective area of the TS as obtained by NIST, TS reference area in SIM, effective area of the TS as obtained by NIST, TS reference area in CIPM & reference value for de piston-cylinder in de CCM.P-K1, m^2.

	NIST / SIM.M.P-K1		**NIST / CCM.P-K1**		**Reference Value CCM.P-K1**	
Nom	Area	*U*	Area	*U*	Area	*U*
Press	TS	Area	TS	Area	TS	Area
(kPa)	m^2	m^2	m^2	m^2	m^2	m^2
600	4.901 73E-05	8.3E-10	8.388 660E-06	8.70E-12	8.388 540 2E-06	1.2E-10
700	4.901 71E-05	8.2E-10	8.388 610E-06	8.80E-12	8.388 544 1E-06	1.2E-10
1 100	4.901 74E-05	8.1E-10	8.388 620E-06	8.80E-12	8.388 559 9E-06	1.2E-10
1 800	4.901 72E-05	8.1E-10	8.388 690E-06	9.00E-12	8.388 587 5E-06	1.2E-10
3 000	4.901 71E-05	8.4E-10	8.388 740E-06	9.80E-12	8.388 634 9E-06	1.2E-10
4 100	4.901 69E-05	8.9E-10	8.388 780E-06	1.10E-11	8.388 678 3E-06	1.2E-10
5 300	4.901 67E-05	9.6E-10	8.388 830E-06	1.26E-11	8.388 725 7E-06	1.2E-10
6 400	4.901 65E-05	1.0E-09	8.388 880E-06	1.44E-11	8.388 769 1E-06	1.2E-10
7 000	4.901 65E-05	1.1E-09	8.388 870E-06	1.50E-11	8.388 792 8E-06	1.2E-10

Table 9. Normalized error ($E_{n\ lab}$) according to equation (2) of participating NMIs with respect to the reference CIPM values for effective area.

NMI	600 kPa	700 kPa	1 100 kPa	1 800 kPa	3 000 kPa	4 100 kPa	5 300 kPa	6 400 kPa	7 000 kPa
INTI	0.18	0.19	0.26	0.39	0.39	0.38	0.32	0.27	0.30
CENAM	0.22	0.12	0.34	0.28	0.15	0.07	0.34	0.19	0.27
INMETRO	0.38	0.19	0.37	0.44	0.32	0.41	0.36	0.41	0.47
ENAER	0.47	0.37	0.56	0.39	0.45	0.44	0.43	0.37	0.46
INM	0.54	0.42	0.56	0.58	0.53	0.52	0.52	0.52	0.54
INACAL	0.25	0.13	0.22	0.15	0.10	0.05	0.00	0.04	0.06
LACOMET	0.49	0.63	0.52	0.50	0.55	0.54	0.59	0.63	0.63
CENAMEP	4	6	10	18	30	40	47	55	55
BSJ	1 891	1 633	1 042	637	379	273	207	170	151

In this SIM comparison, 11 laboratories participated. From those, one did not send their measurement results (NRC/Canada). As it can be seen in graphs from 7 to 15 as well as for the normalized error results shown in table 9 and graph 18, from the 10 laboratories which sent their results, seven laboratories have compatibility of their results with those of the references values provided by NIST. Two laboratories (CENAMEP and BSJ) have no compatibility with the reference values or with those results of the other participating laboratories.



Graph 18. Normalized error ($E_{n\ lab}$) according to equation (2) with respect to the reference CIPM values for effective area.

ANNEX 1

Mass values, as calibrated at CENAM.

Mass set

The mass set consists of (all pieces being identified by serial number 2467):
Five mass pieces of 5 kg nominal mass, marked by numbers from 1 to 5,
One mass piece of 4.5 kg nominal mass,
Two mass pieces of 2 kg marked by numbers from 1 to 2,
One mass piece of 1 kg nominal mass,
One mass piece of 0.5 kg nominal mass,
Two mass pieces of 0.2 kg marked by numbers from 1 to 2 and
One mass piece of 0.1 kg nominal mass.

The material density of the mass pieces is:
ρ_m = (7 900 ± 79) kg/m^3

The mass of the mass pieces, as calibrated at CENAM, are given in the next table.

IDENTIFICATION N.S.: 2467	**MASS** kg	***U* MASS** *k* =2 kg
100 g	0.099 999 45	1.25E-07
200 g 1	0.199 999 18	2.50E-07
200 g 2	0.200 000 78	2.50E-07
500 g	0.500 005 60	6.00E-07
1 kg	1.000 011 3	1.25E-06
2 kg 1	2.000 029 1	2.50E-06
2 kg 2	2.000 024 8	2.50E-06
4.5 kg	4.500 065 0	5.50E-06
5 kg 1	5.000 035	6.00E-06
5 kg 2	5.000 015	6.00E-06
5 kg 3	5.000 033	6.00E-06
5 kg 4	5.000 041	6.00E-06
5 kg 5	5.000 044	6.00E-06