FINAL REPORT

SIM Key Comparison in Pneumatic Gauge Pressure for High Accuracy Pressure Balances up to 120 kPa

SIM.M.P-K6

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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 10 kPa to 120 kPa 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-deformation piston-cylinder assembly and a set of masses. Eleven participants completed their measurements and reported the pressure-dependent effective areas of the transfer standard at specified pressures with the associated uncertainties. NRC/Canada and BSJ/Jamaica withdrew the comparison by not sending their measurements. To link the results of the nine laboratories that sent their results to the CCM.P- 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 six participating NMIs agree with the NIST reference values within their expanded uncertainties (k = 2) in the entire pressure range from 10 kPa to 120 kPa according to the normalized error equation method.

II. INTRODUCTION

This comparison aimed to obtain the equivalence statements into SIM region derived from CCM key Comparison CCM.P-K6, in the range from 10 kPa to 120 kPa, 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 and BSJ/Jamaica 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 10 kPa to 120 kPa; 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-K6.

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 / Jesus Aranzolo S. 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 150, San Borja, Lima 41. Perú	Leonardo de la Cruz 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	Marcial Espinoza / José Palma 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 Colectora de Avenida General Paz 5445 entre Albarellos y Avenida de los Constituyentes Casilla de correo 157 B1650KNA, San Martin. Argentina	Juan Forastieri / Víctor Miranda Phone: +54-11-47525402 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 10 cm^2 nominal effective area with serial number 1192. 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 manufactured in 2008. The pilot laboratory checked during the period of the comparison for drift (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 10 kPa) was $8.9 \cdot 10^{-9}$ 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 table 2. The mass of the mass set pieces are given in Annex 1

Table 2. Mass pieces to be put on the carrying bell of the TS to generate the nominal pressures.

Nominal pressure in kPa	Nominal mass pieces in kg
10	(0.2)
20	(1+ 0.2)
30	(2 + 0.2)
40	(1+2 + 0.2)
50	(2(1 to 2) + 0.2)
60	(4 +1 + 0.2)
70	(5(1) + 1 + 0.2)
80	(5(1) + 2(1) + 0.2)
90	(5 + 2(1) + 1 + 0.2)
100	(5 + 2(1 to 2) + 0.2)
110	(5(1 to 2) + 0.2)
120	(5(1 to 2) + 1 + 0.2)

The standards used by the participating laboratories for the calibration of the transfer standard of the comparison are shown in Table 3.

Table 3. Participating laboratories standards used for the comparison (Canada, Jamaica and Panama did not send their information).

Country	**Argentina**	**Brazil**	**Chile**	**Colombia**	**Costa Rica**	**Mexico**	**Peru**	**USA**
NMI	INTI	INMETRO	ENAER	INM	LACOMET	CENAM	INACAL	NIST
Contact	Juan Angel Forastieri jaforast@inti.gob.ar	Paulo Couto prcouto@inmetro.gov.br	Marcial Espinoza mespinoza@enaer.cl	Catalina Neira mneira@inm.gov.co	Adrián Solano asolano@lacomet.go.cr	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
Standard used	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance
Maker	RUSKA	RUSKA	RUSKA	DH Instruments	DH Instruments	DH Instruments	DH Instruments	RUSKA
Model	2465-729	2465A -754	2465A-754	PG-7601	PG-7601	PGA-7601	PG-7601	2465
Serial N°	Piston: TL-1426	Base: 54874 Piston: TL1505	Base: 53860; Piston: TL1596	Base: 584; Piston: 0806	Base: 583; Piston: 1099	Base: 107; Piston: 108A	Base: 716; Piston: 1388	TL-613
Range	1.38 kPa to 180 kPa	1.5 kPa to 180 kPa	1.5 kPa to 350 kPa	5 kPa to 350 kPa	5 kPa to 350 kPa	10 kPa to 350 kPa	2 kPa to 350 kPa	10 kPa to 200 kPa
Accuracy Class	0.0035 %R	0.003 5 %R	0.005 %R	0.002 %R	0.0025 %R	0.002 %R	0.003 %R	0.0035 %R
Cylinder Material	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Ceramic	Tungsten carbide	Tungsten carbide
Piston Material	Steel	Steel	Steel	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Stainless steel
Effective area (A_0) at zero pressure in m^2	3.357139E-4	3.35730 E-04	3.35622E-4	9.80533E-4	9.805 46E-4	9.804986E-4	9.80505E-4	3.357388E-4
Relative Expanded Uncertainty of A_0, in 10^{-6}	20	17	15	18.4	19.4	8.9	17.8	5.1 (see note 1)
Elastic deformation coefficient *b*, in Pa^{-1}	0	0	0	4.20E-12	2.7E-12	5.38E-12	7.1E-14	0.0
Expanded Uncertainty *b*, in Pa^{-1}	0	0	0	1.10E-12	2.7E-12	2.69E-13	8.2E-12	1.12E-12
Traceability	PTB - Germany	PTB -Germany	PTB -Germany	PTB - Germany	CENAM - Mexico	CENAM - Mexico	CENAM - Mexico	NIST - USA

Note 1. The laboratory standard used at NIST, (TL-613 known as PG36), has an uncertainty term proportional to 1/*p*. The full expression for the relative standard uncertainty in effective area is

$$\frac{u(A_e)}{A_e} = \left[\left(\frac{0.11Pa}{p} \right)^2 + \left(5.11x10^{-6} \right)^2 + \left(1.12x10^{-12}\, Pa^{-1} \cdot p \right)^2 \right]^{1/2}$$

p in Pa.

The number quoted in the table above is the constant term in the uncertainty expression. Even though the distortion coefficient, *b*, is zero, its uncertainty is not. Its relative significance is small but it is included for completeness. A_0 and *b*, along with their uncertainties, were determined by cross float to two NIST primary standard piston gauges. The primary standard piston gauges are described in *Metrologia* **43** (2006) 53-59.

VI. MEASUREMENTS PROCEDURE

Cross float, between the TS and the laboratory standard, was the measuring method. The transfer standard and the piston-cylinder assembly were mounted in accordance with the instructions given in the User's Manual Pressure Balance, DHI Model 7601. The comparison procedure was approved by the participant NMIs in a document named: SIM Key Comparison for 120 kPa Range of Pneumatic Gauge Pressure - Technical Protocol SIM.M.P-K6 (120 kPa).

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 cross-floating equilibrium of the laboratory standard and the TS, 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 (10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120) kPa. In total 72 measurements.
e) Each cycle of measurement was to be completed in one day.
f) The masses were calibrated at CENAM and these values used by all NMIs.
g) To generate the nominal pressures laboratories used a table with mass identification.

VII. COMPARISON ROUND

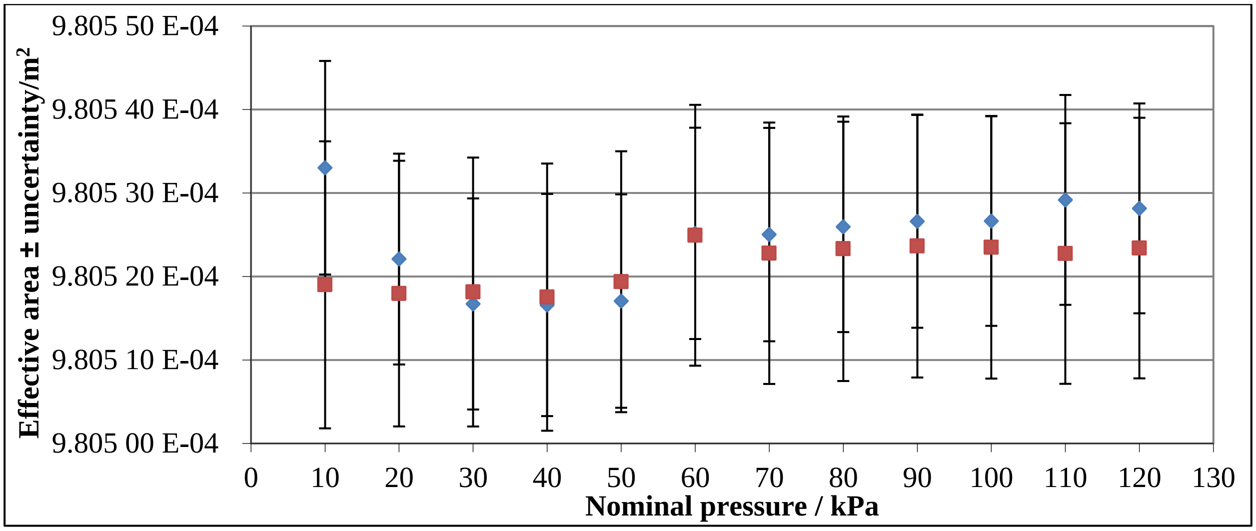
Table 4 presents the delivery date of the TS and the participant laboratory that was to receive the TS. During the comparison, no mayor delay or anomaly happen to the TS or in any laboratory site.

Table 4. Participating laboratories comparison round.

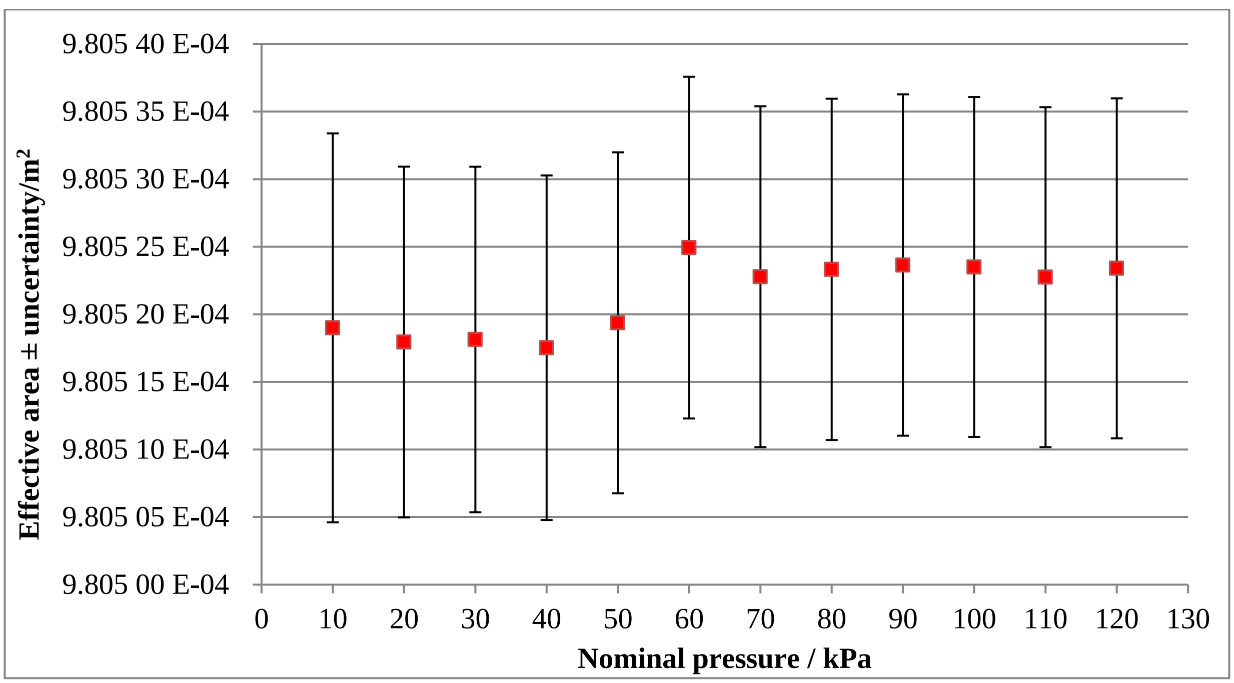
Start of Measurement date and Participant
August 1st, 2008. CENAM, TS initial calibration
October 1st, 2008. NIST
November 25th, 2008. NRC
January 10th, 2009. CENAM, TS intermediate check
February 15th, 2009. BSJ
April 1st, 2009. CENAMEP
May 15th, 2009. LACOMET
July 1st, 2009. CENAM, TS intermediate 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. As shown in graph 2, CENAM used for the comparison the last calibration performed.

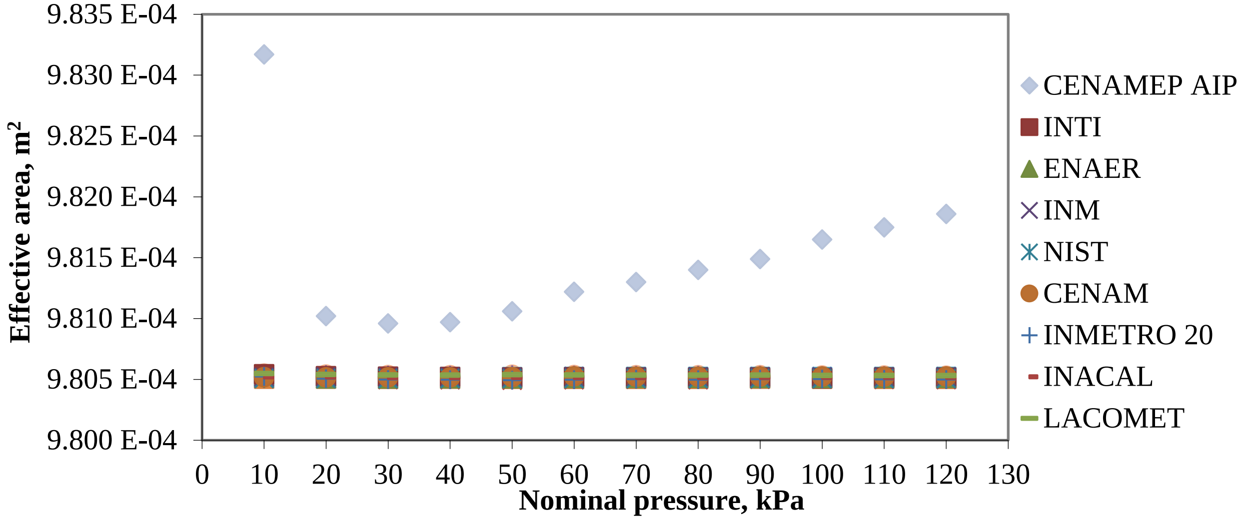


Graph 1. TS effective area and uncertainty as obtained by CENAM, first and last calibrations (at the beginning and at the end of the comparison), m².



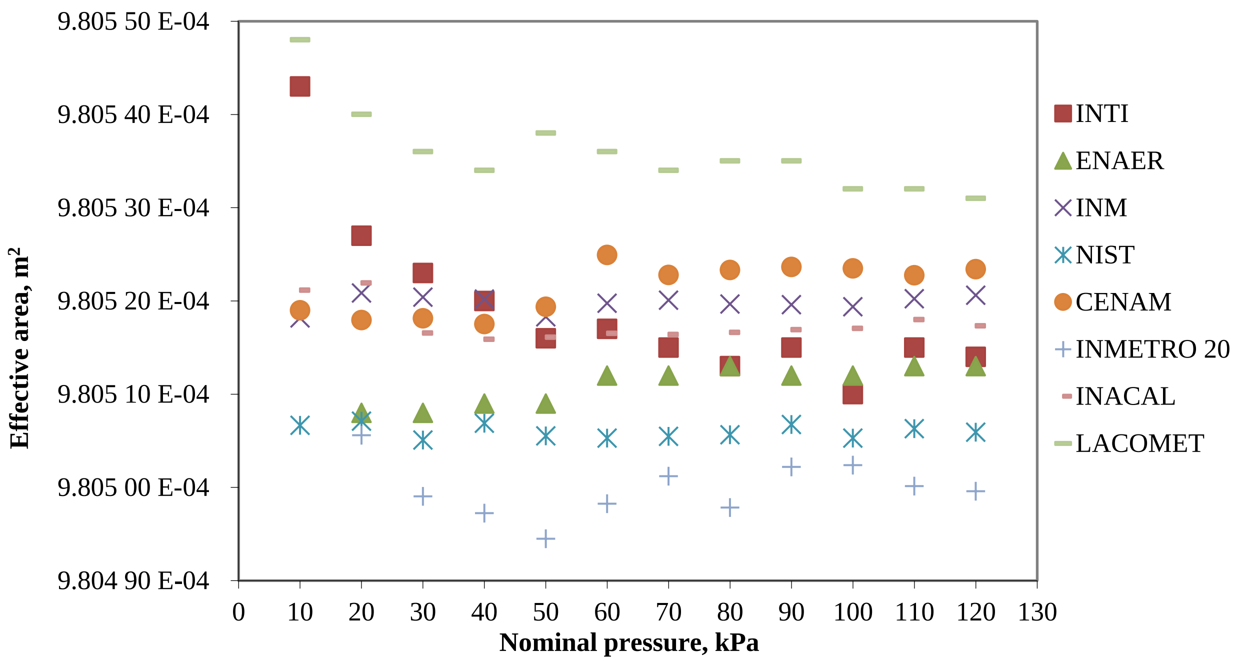
Graph 2. TS effective area and uncertainty used by CENAM, m².

Graph 3 shows the TS effective area as obtained by each NMI (in m^2).

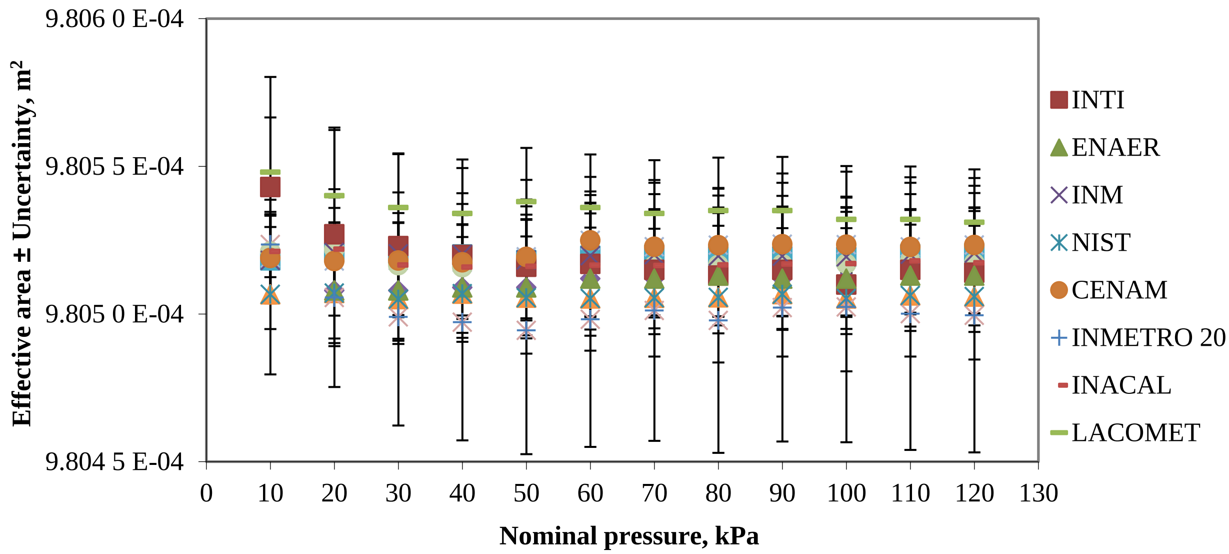


Graph 3. TS effective area as obtained by each NMI, m^2.

Graph 4 presents the effective area of the TS without CENAMEP AIP and graph 5 shows the effective area of the TS and its corresponding expanded uncertainty for each NMI, also without CENAMEP AIP. The values obtained by each participating laboratory are included in tables 5 and 6, effective area and its corresponding uncertainty.



Graph 4. TS effective area as obtained by each NMI without CENAMEP AIP, m^2.



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

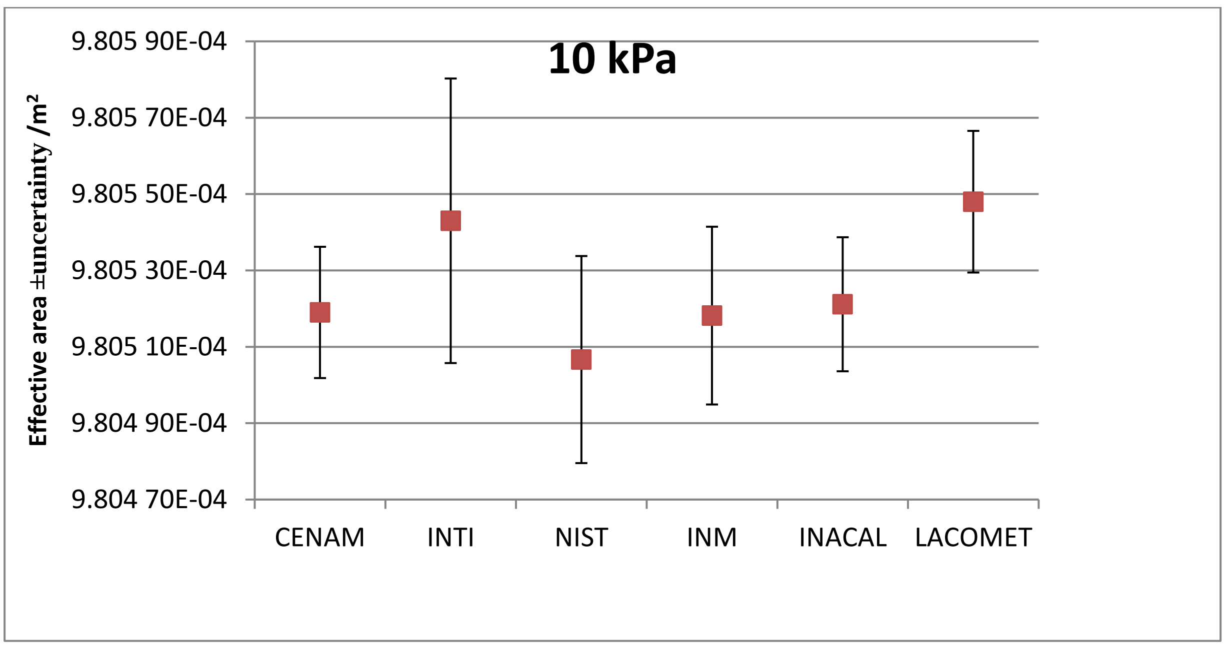
Table 5. TS effective area and its uncertainty as obtained by each NMI, m^2.

Nominal Pressure	**CENAM**		**INTI**		**NIST**		**INMETRO**		**INM**	
	Area	*U*	Area	*U*	Area	*U*	Area	*U*	Area	*U*
kPa	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2
10	9.805 19 E-04	1.7E-08	9.805 43 E-04	3.7E-08	9.805 07 E-04	2.7E-08			9.805 18 E-04	2.3E-08
20	9.805 18 E-04	1.6E-08	9.805 27 E-04	3.5E-08	9.805 07 E-04	1.8E-08	9.805 06 E-04	3.0E-08	9.805 21 E-04	2.1E-08
30	9.805 18 E-04	1.6E-08	9.805 23 E-04	3.1E-08	9.805 05 E-04	1.5E-08	9.804 99 E-04	3.7E-08	9.805 20 E-04	2.1E-08
40	9.805 18 E-04	1.6E-08	9.805 20 E-04	2.9E-08	9.805 07 E-04	1.3E-08	9.804 97 E-04	4.0E-08	9.805 20 E-04	2.1E-08
50	9.805 19 E-04	1.6E-08	9.805 16 E-04	2.9E-08	9.805 06 E-04	1.3E-08	9.804 94 E-04	4.2E-08	9.805 18 E-04	2.0E-08
60	9.805 25 E-04	1.6E-08	9.805 17 E-04	2.9E-08	9.805 05 E-04	1.3E-08	9.804 98 E-04	4.3E-08	9.805 20 E-04	2.1E-08
70	9.805 23 E-04	1.6E-08	9.805 15 E-04	2.9E-08	9.805 05 E-04	1.2E-08	9.805 01 E-04	4.4E-08	9.805 20 E-04	2.1E-08
80	9.805 23 E-04	1.6E-08	9.805 13 E-04	2.9E-08	9.805 06 E-04	1.2E-08	9.804 98 E-04	4.5E-08	9.805 20 E-04	2.0E-08
90	9.805 24 E-04	1.6E-08	9.805 15 E-04	2.9E-08	9.805 07 E-04	1.2E-08	9.805 02 E-04	4.5E-08	9.805 20 E-04	2.0E-08
100	9.805 24 E-04	1.6E-08	9.805 10 E-04	2.9E-08	9.805 05 E-04	1.2E-08	9.805 02 E-04	4.6E-08	9.805 19 E-04	2.0E-08
110	9.805 23 E-04	1.6E-08	9.805 15 E-04	2.9E-08	9.805 06 E-04	1.2E-08	9.805 00 E-04	4.6E-08	9.805 20 E-04	2.0E-08
120	9.805 23 E-04	1.6E-08	9.805 14 E-04	2.9E-08	9.805 06 E-04	1.2E-08	9.805 00 E-04	4.6E-08	9.805 21 E-04	2.0E-08

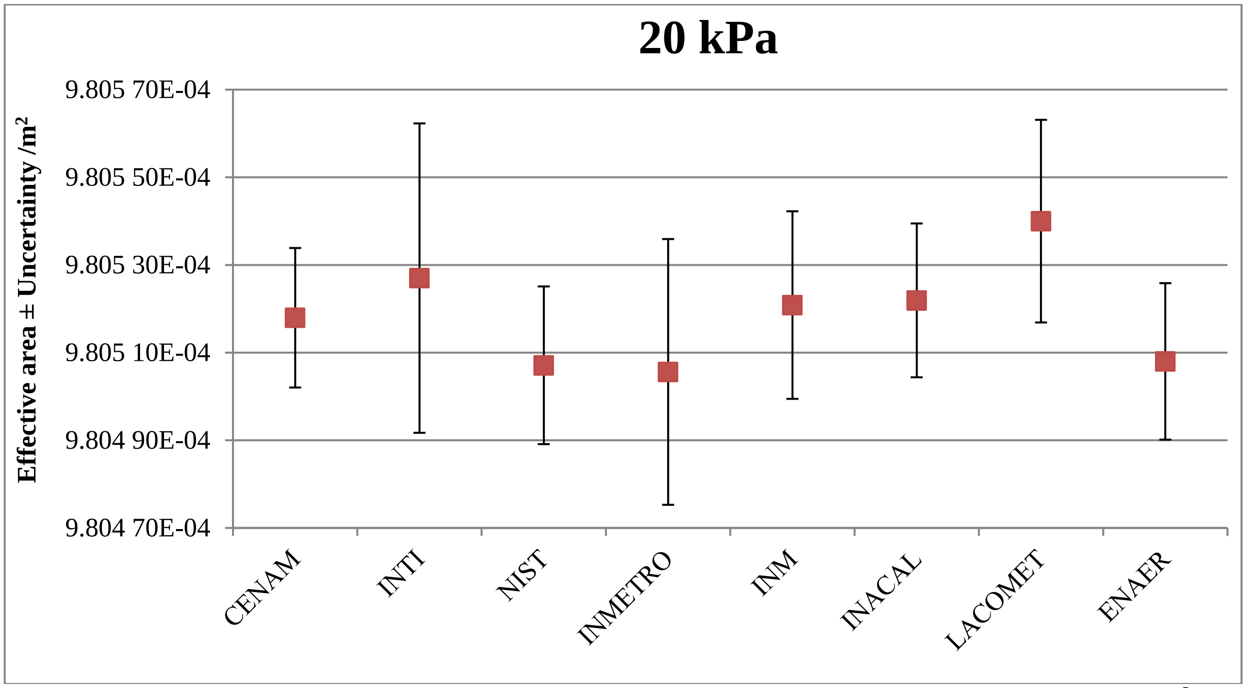
Table 6. Continued. TS effective area and its uncertainty as obtained by each NMI, m^2.

Nominal Pressure	INACAL		LACOMET		ENAER		CENAMEP AIP	
	Area	*U*	Area	*U*	Area	*U*	Area	*U*
kPa	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2
10	9.805 21E-04	1.8E-08	9.805 48E-04	1.9E-08			9.831 70E-04	4.8E-10
20	9.805 22E-04	1.8E-08	9.805 40E-04	2.3E-08	9.805 08E-04	1.8E-08	9.810 20E-04	4.8E-10
30	9.805 17E-04	1.8E-08	9.805 36E-04	1.8E-08	9.805 08E-04	1.7E-08	9.809 60E-04	4.8E-10
40	9.805 16E-04	1.8E-08	9.805 34E-04	1.8E-08	9.805 09E-04	1.7E-08	9.809 70E-04	4.8E-10
50	9.805 16E-04	1.8E-08	9.805 38E-04	1.8E-08	9.805 09E-04	1.7E-08	9.810 60E-04	4.8E-10
60	9.805 17E-04	1.8E-08	9.805 36E-04	1.8E-08	9.805 12E-04	1.7E-08	9.812 20E-04	4.8E-10
70	9.805 16E-04	1.8E-08	9.805 34E-04	1.8E-08	9.805 12E-04	1.7E-08	9.813 00E-04	4.8E-10
80	9.805 17E-04	1.8E-08	9.805 35E-04	1.8E-08	9.805 13E-04	1.7E-08	9.814 00E-04	4.8E-10
90	9.805 17E-04	1.8E-08	9.805 35E-04	1.8E-08	9.805 12E-04	1.7E-08	9.814 90E-04	4.8E-10
100	9.805 17E-04	1.8E-08	9.805 32E-04	1.8E-08	9.805 12E-04	1.7E-08	9.816 50E-04	4.8E-10
110	9.805 18E-04	1.8E-08	9.805 32E-04	1.8E-08	9.805 13E-04	1.7E-08	9.817 50E-04	4.8E-10
120	9.805 17E-04	1.8E-08	9.805 31E-04	1.8E-08	9.805 13E-04	1.7E-08	9.818 60E-04	4.8E-10

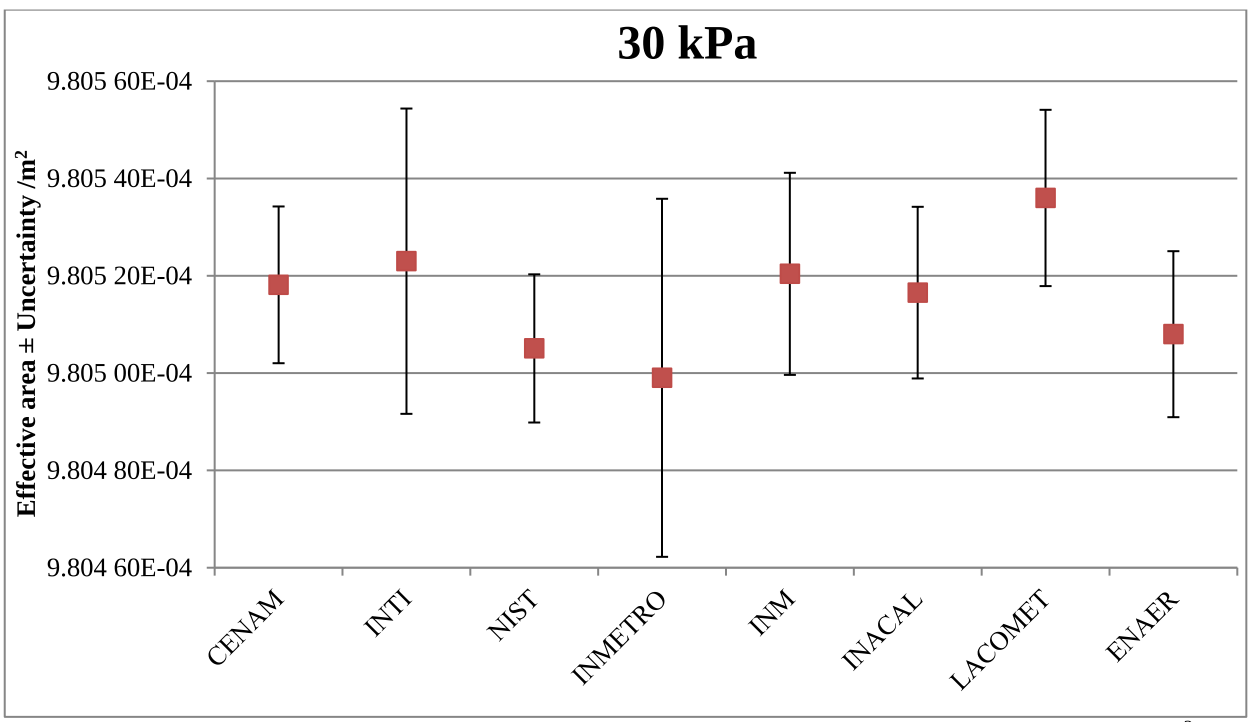
Graph 6 to graph 17, show the effective area and its corresponding expanded uncertainty as calculated by each NMI for each applied pressure. In these graphs, CENAMEP is not included to keep resolution and clarity.



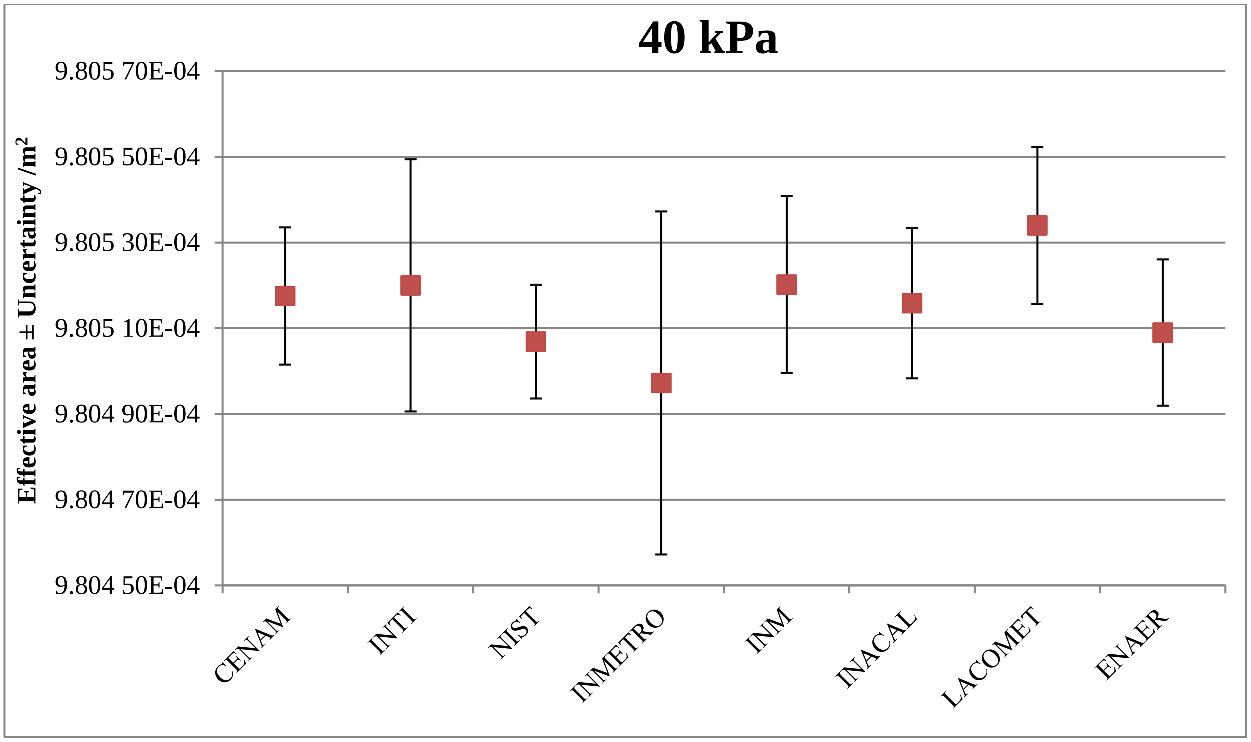
Graph 6. TS effective area and its expanded uncertainty as obtained by each NMI, for 10 kPa, m^2.



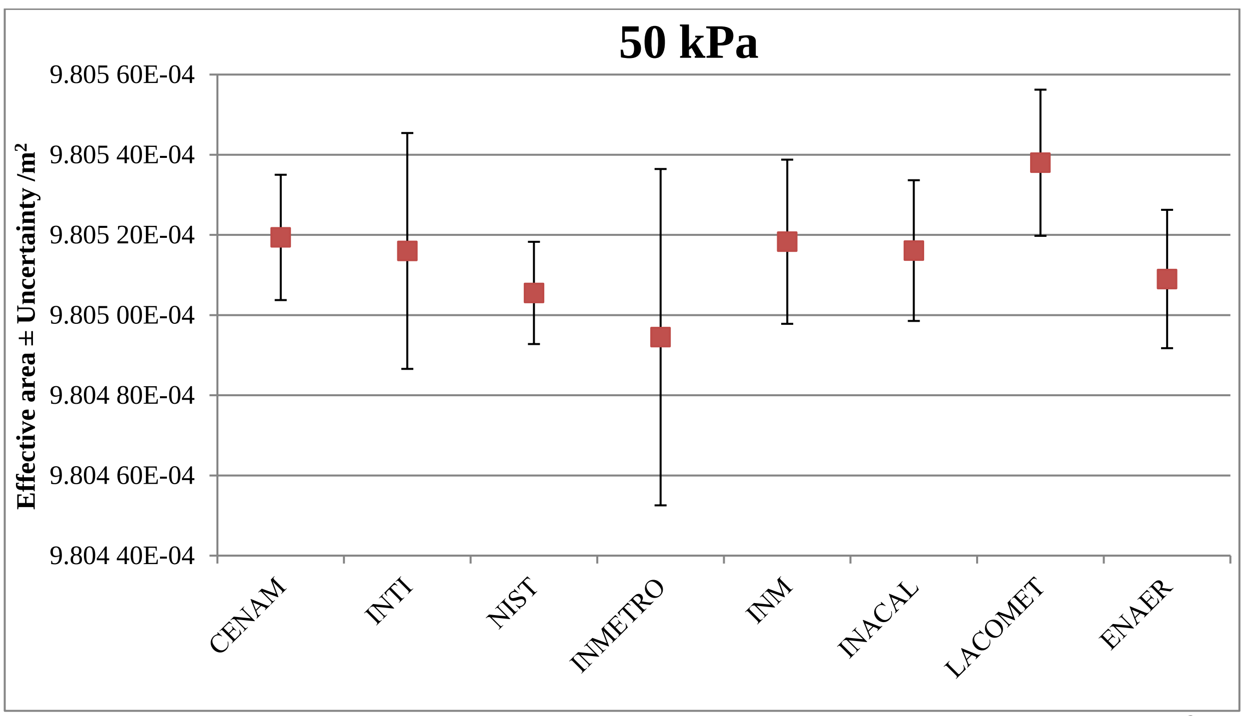
Graph 7. TS effective area and its expanded uncertainty as obtained by each NMI, for 20 kPa, m^2.



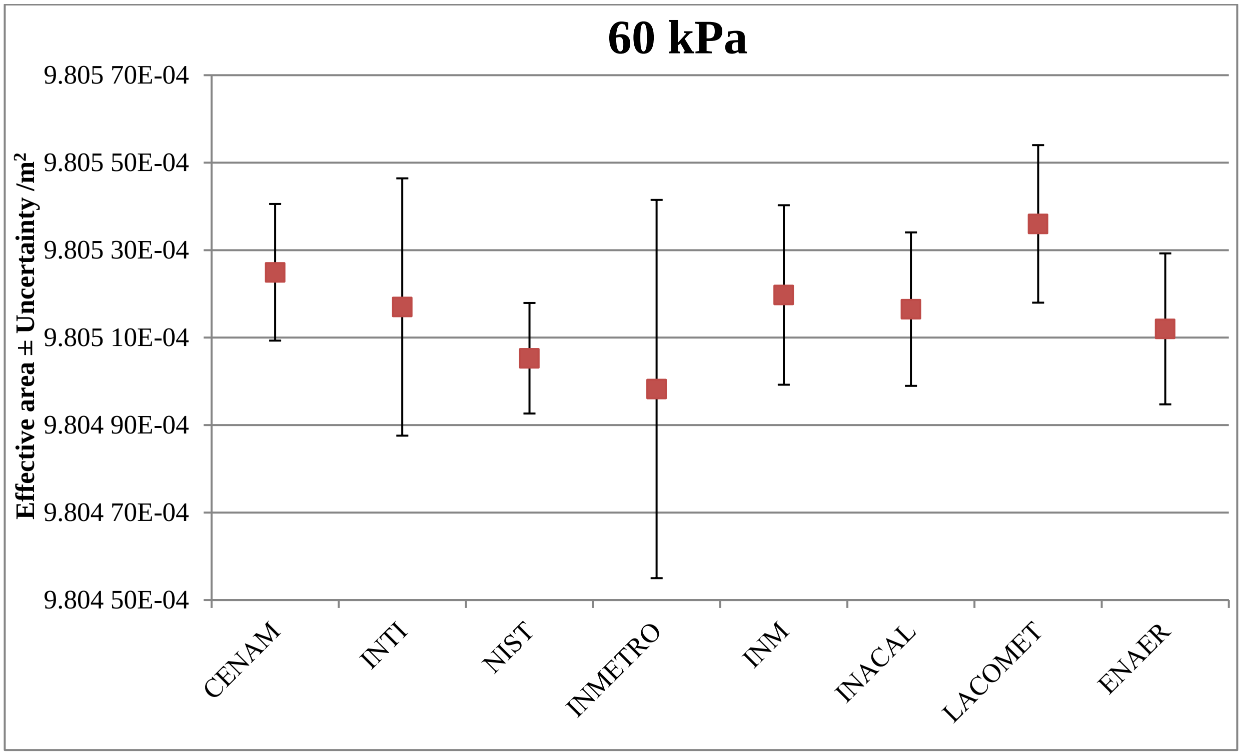
Graph 8. TS effective area and its expanded uncertainty as obtained by each NMI, for 30 kPa, m^2.



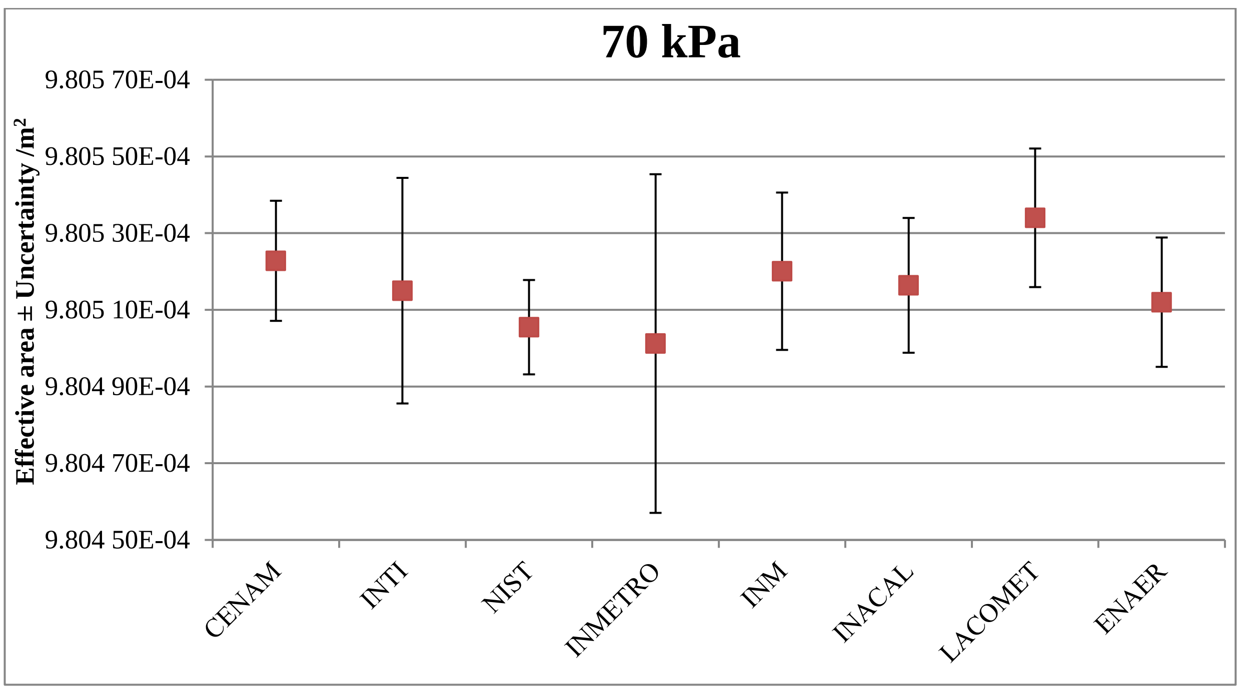
Graph 9. TS effective area and its expanded uncertainty as obtained by each NMI, for 40 kPa, m^2.



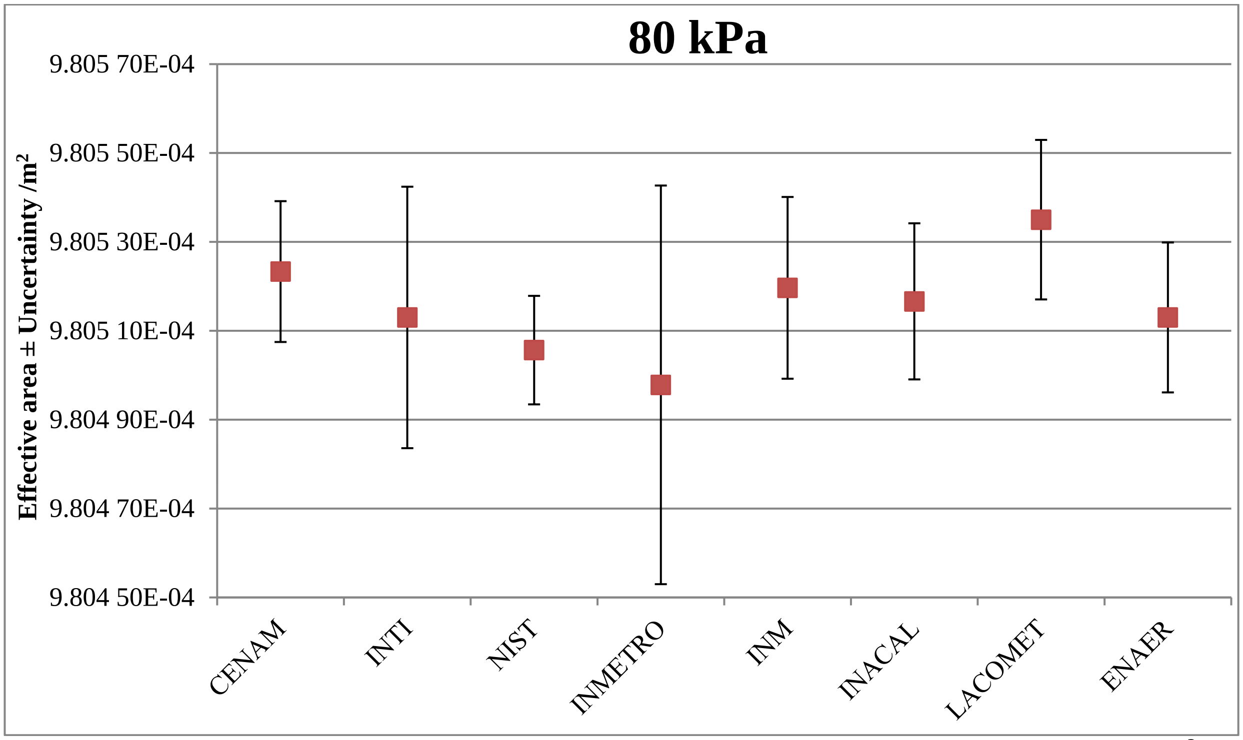
Graph 10. TS effective area and its expanded uncertainty as obtained by each NMI, for 50 kPa, m^2.



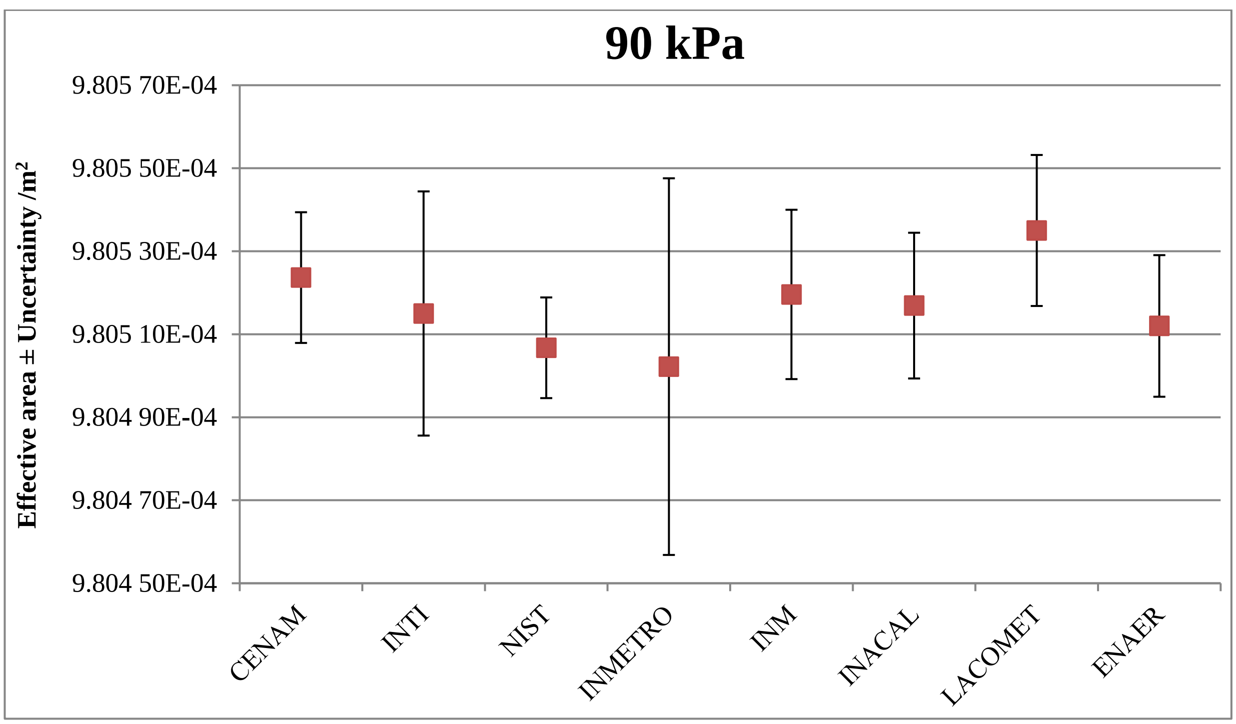
Graph 11. TS effective area and its expanded uncertainty as obtained by each NMI, for 60 kPa, m^2.



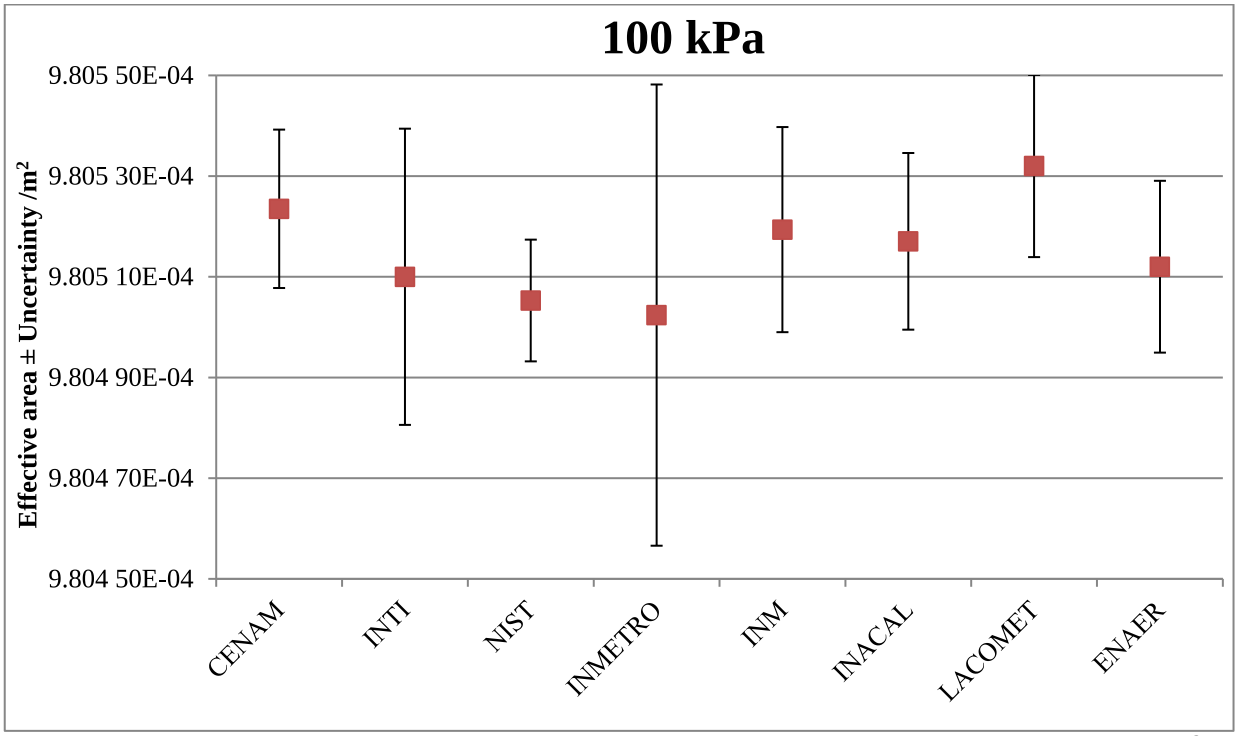
Graph 12. TS effective area and its expanded uncertainty as obtained by each NMI, for 70 kPa, m^2.



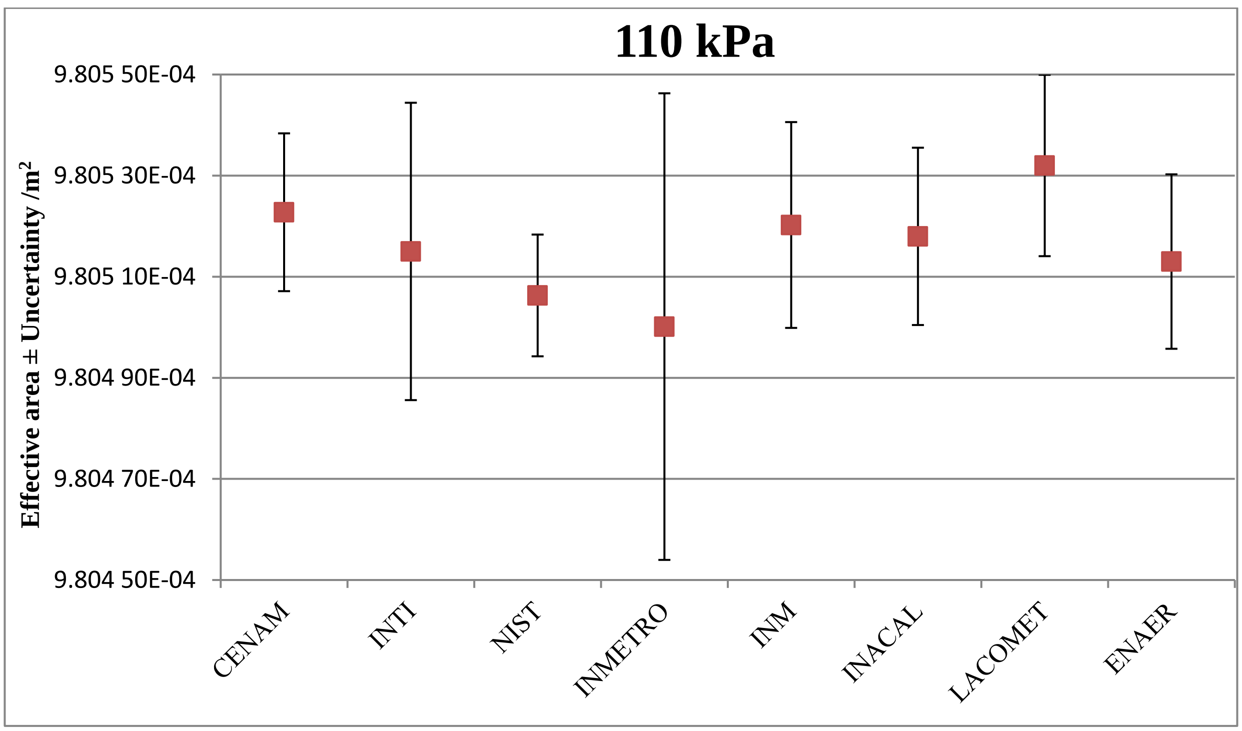
Graph 13. TS effective area and its expanded uncertainty as obtained by each NMI, for 80 kPa, m^2.



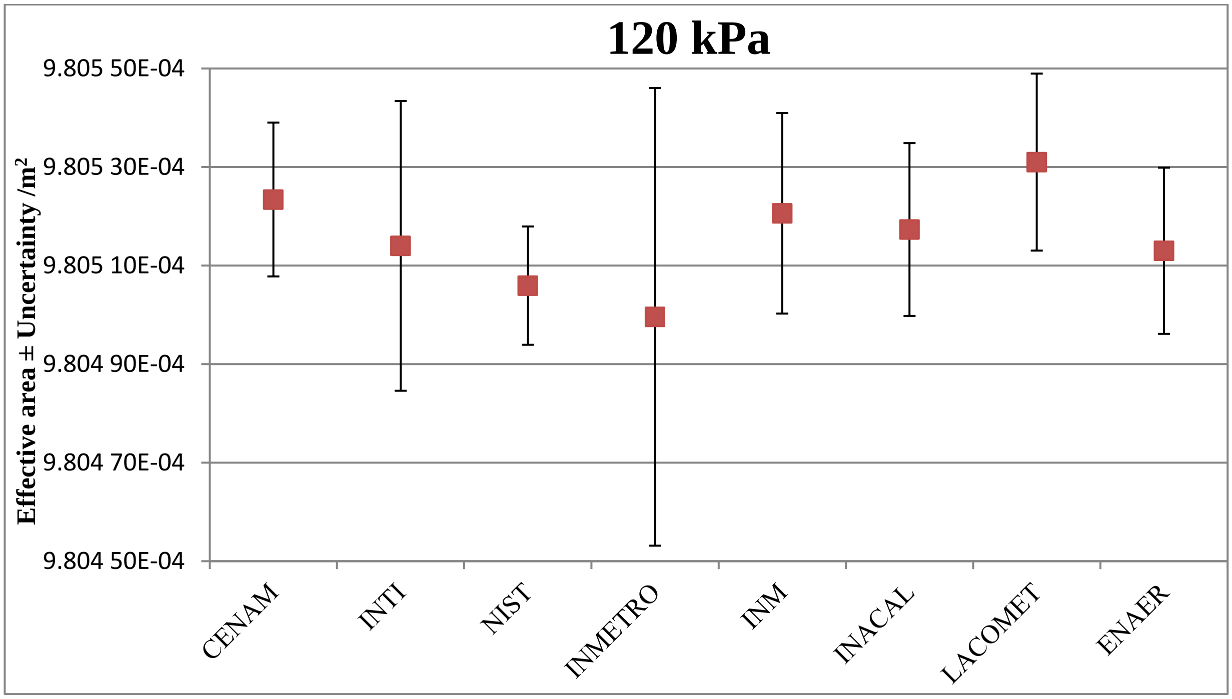
Graph 14. TS effective area and its expanded uncertainty as obtained by each NMI, for 90 kPa, m^2.



Graph 15. TS effective area and its expanded uncertainty as obtained by each NMI, for 100 kPa, m^2.



Graph 16. TS effective area and its expanded uncertainty as obtained by each NMI, for 110 kPa, m^2.



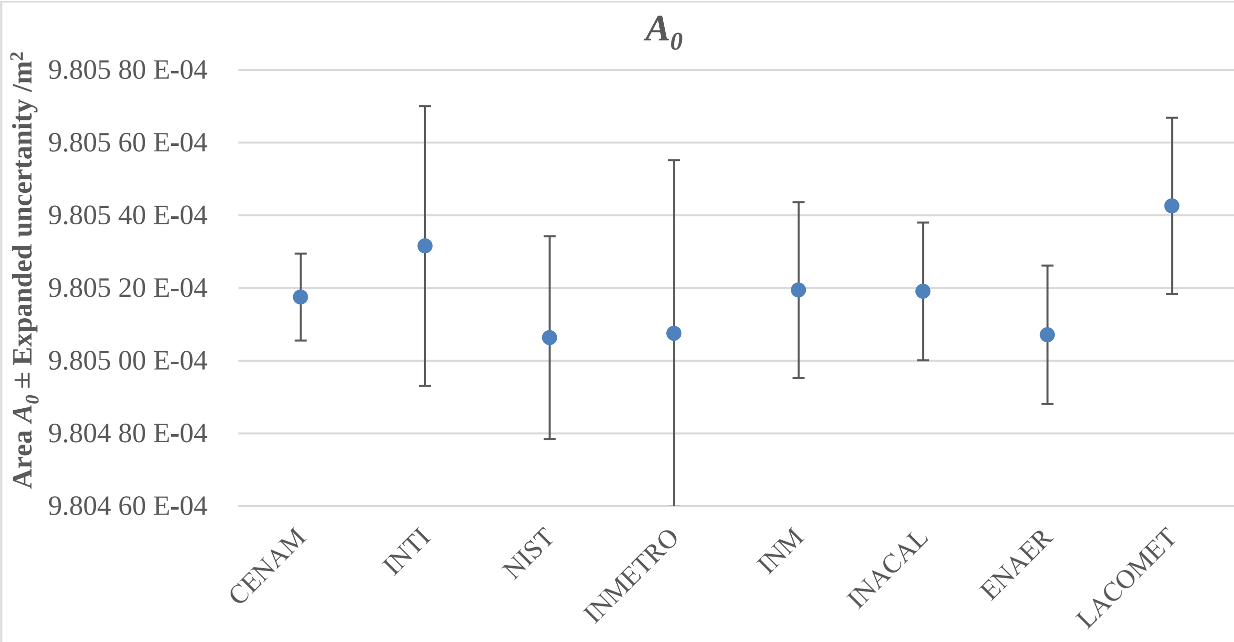
Graph 17. TS effective area and its expanded uncertainty as obtained by each NMI, for 120 kPa, m^2.

Table 7 and graph 18 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.

INMETRO used 23 °C as reference temperature. To better compared, results for this laboratory, a temperature correction was used to transfer their results to 20 °C reference temperature, as outlined in the Comparison Protocol.

Table 7. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2.

	A_0 / m^2	UA_0 / m^2	b / 1/Pa	Ub / 1/Pa
CENAM	9.805 18 E-04	1.2E-08	6.1E-11	2.7E-11
INTI	9.805 32 E-04	3.8E-08	-2.0E-10	9.7E-11
NIST	9.805 06 E-04	2.8E-08	0.0E+00	1.12E-12
INMETRO	9.805 07 E-04	4.8E-08	-9.0E-11	1.2E-10
INM	9.805 19 E-04	2.4E-08	5.5E-12	1.5E-11
INACAL	9.805 19 E-04	1.9E-08	-2.4E-14	3.2E-11
ENAER	9.805 07 E-04	1.9E-08	5.7E-11	1.9E-11
LACOMET	9.805 43 E-04	2.4E-08	-1.0E-07	4.8E-08
CENAMEP AIP	9.814 72 E-04	7.9E-07	2.4E-13	1.1E-08



Graph 18. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2.
For clarity, CENAMEP 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).

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

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 *effective 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 as criteria the following:

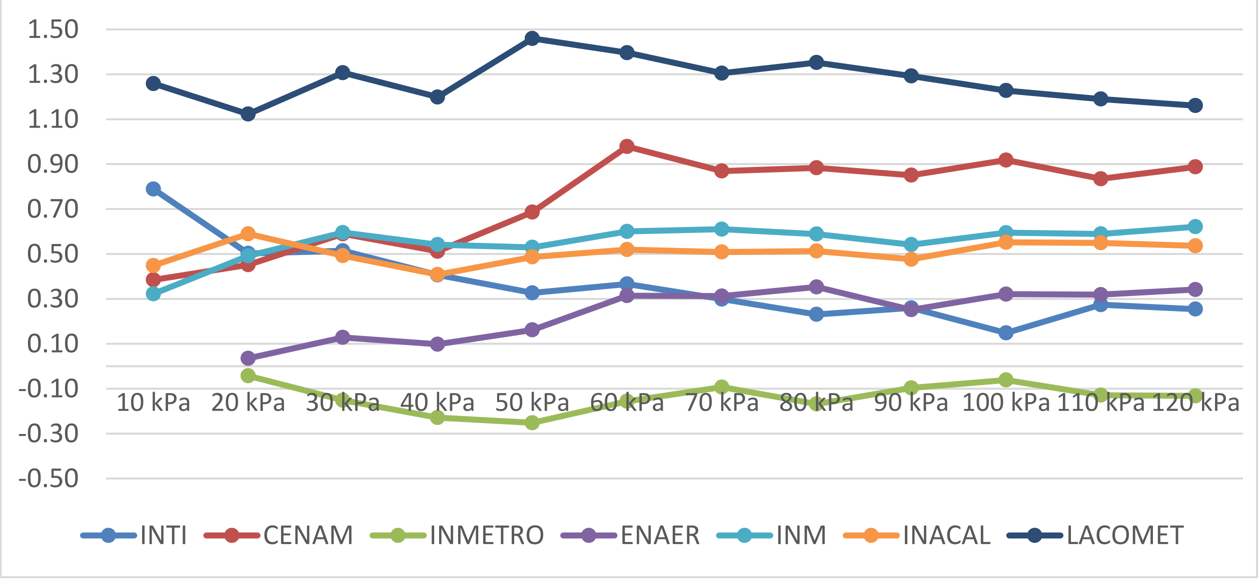
$|E_n| \leq 1.0$ Satisfactory result

$|E_n| > 1.0$ Non-satisfactory result

Table 8 and graph 19 present the results from equation 1.

Table 8. Normalized error (E_n) according to the equation (1) of participating NMIs with respect to the reference laboratory (NIST) for effective area.

NMI	10 kPa	20 kPa	30 kPa	40 kPa	50 kPa	60 kPa	70 kPa	80 kPa	90 kPa	100 kPa	110 kPa	120 kPa
INTI	0.79	0.50	0.51	0.41	0.33	0.37	0.30	0.23	0.26	0.15	0.27	0.25
CENAM	0.38	0.45	0.59	0.51	0.69	0.98	0.87	0.88	0.85	0.92	0.83	0.89
INMETRO	---	-0.04	-0.15	-0.23	-0.25	-0.16	-0.09	-0.17	-0.10	-0.06	-0.13	-0.13
ENAER	---	0.04	0.13	0.10	0.16	0.31	0.31	0.35	0.25	0.32	0.32	0.34
INM	0.32	0.49	0.60	0.54	0.53	0.60	0.61	0.59	0.54	0.59	0.59	0.62
INACAL	0.45	0.59	0.49	0.41	0.49	0.52	0.51	0.51	0.48	0.55	0.55	0.54
LACOMET	1.3	1.1	1.3	1.2	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.2
CENAMEP	98	28	29	34	43	56	64	730	81	94	103	112



Graph 19. Participating laboratories normalized error (E_n) according to the equation (1) with respect to NIST's reference values.
For clarity, CENAMEP is not included.

In this SIM comparison, 11 laboratories participated. From those, two did not sent their measurement results (NRC/Canada and BSJ/ Jamaica). From the eight laboratories which sent their results, six laboratories have compatibility of their results with the references values provided by NIST, as it can be seen in graphs from 6 to 19 as well as in table 8. One laboratory (LACOMET) is just out of the compatibility zone (between 1 and 1.5) and one laboratory (CENAMEP) has no compatibility with the reference values or with those results of the other participating laboratories.

B) SIM.M.P-K6 with CCM.P-K6

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 (1).

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

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:

$|E_n| \leq 1.0$ Satisfactory result.

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

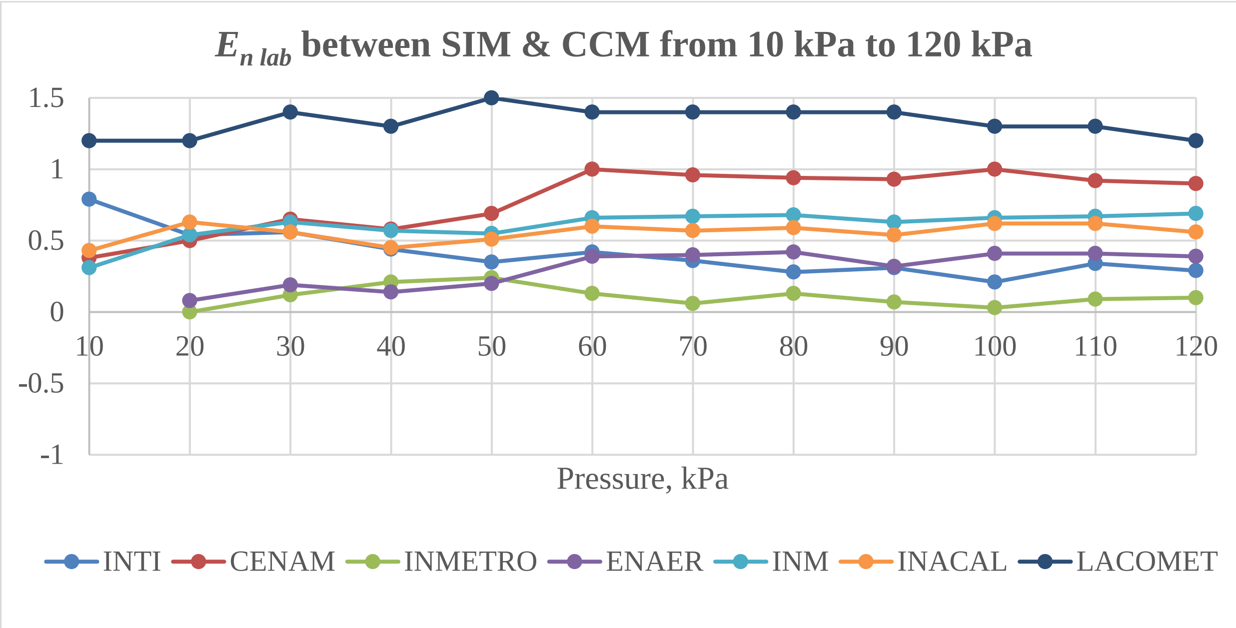
Table 9. TS effective area of the TS as obtained by NIST, TS reference area in SIM, effective area of the TS as obtained by NIST, TS reference area in CIPM & reference value for de piston-cylinder in de CCM.P-K6, m^2.

	NIST / SIM.M.P-K6		**NIST / CCM.P-K6**		**Reference Value CCM.P-K6**	
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
10	9.805 07E-04	2.7E-08	3.357 44E-04	2.1E-09	3.357 442 E-04	3.0E-09
20	9.805 07E-04	1.8E-08	3.357 44E-04	2.1E-09	3.357 444 E-04	1.4E-09
30	9.805 05E-04	1.5E-08	3.357 43E-04	2.0E-09	3.357 442 E-04	2.0E-09
40	9.805 07E-04	1.3E-08	3.357 43E-04	2.0E-09	3.357 441 E-04	1.8E-09
50	9.805 06E-04	1.3E-08	3.357 43E-04	2.1E-09	3.357 443 E-04	1.6E-09
60	9.805 05E-04	1.3E-08	3.357 43E-04	2.1E-09	3.357 443 E-04	1.0E-09
70	9.805 05E-04	1.2E-08	3.357 43E-04	2.1E-09	3.357 443 E-04	1.6E-09
80	9.805 06E-04	1.2E-08	3.357 43E-04	2.1E-09	3.357 445 E-04	1.2E-09
90	9.805 07E-04	1.2E-08	3.357 43E-04	2.0E-09	3.357 445 E-04	1.4E-09
100	9.805 05E-04	1.2E-08	3.357 43E-04	2.0E-09	3.357 445 E-04	1.8E-09
110	9.805 06E-04	1.2E-08	3.357 43E-04	2.0E-09	3.357 444 E-04	1.4E-09
120	9.805 06E-04	1.2E-08	3.357 43E-04	2.0E-09	3.357 441 E-04	2.0E-09

Table 10. Normalized error ($E_{n\ lab}$) according to the equation (2) of participating NMIs with respect to the reference CIPM for effective area.

NMI	**10 kPa**	**20 kPa**	**30 kPa**	**40 kPa**	**50 kPa**	**60 kPa**	**70 kPa**	**80 kPa**	**90 kPa**	**100 kPa**	**110 kPa**	**120 kPa**
INTI	0.79	0.54	0.56	0.44	0.35	0.42	0.36	0.28	0.31	0.21	0.34	0.29
CENAM	0.38	0.50	0.65	0.58	0.69	1.0	0.96	0.94	0.93	1.0	0.92	0.90
INMETRO	-------	0.00	0.12	0.21	0.24	0.13	0.06	0.13	0.07	0.03	0.09	0.10
ENAER	-------	0.08	0.19	0.14	0.20	0.39	0.40	0.42	0.32	0.41	0.41	0.39
INM	0.31	0.54	0.63	0.57	0.55	0.66	0.67	0.68	0.63	0.66	0.67	0.69
INACAL	0.43	0.63	0.56	0.45	0.51	0.60	0.57	0.59	0.54	0.62	0.62	0.56
LACOMET	1.2	1.2	1.4	1.3	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.2
CENAMEP	98	28	30	35	42	54	65	73	80	93	102	110

In this SIM comparison, 11 laboratories participated. From those, two did not sent their measurement results (NRC/Canada and BSJ/Jamaica). As it can be seen in graphs from 6 to 17 as well as for the normalized error results shown in table 10 and graph 20, from the 8 laboratories which sent their results, six laboratories have compatibility of their results with those of the references values provided by NIST. Two laboratories (CENAMEP and LACOMET) have no compatibility with the reference values or with those results of the other participating laboratories.



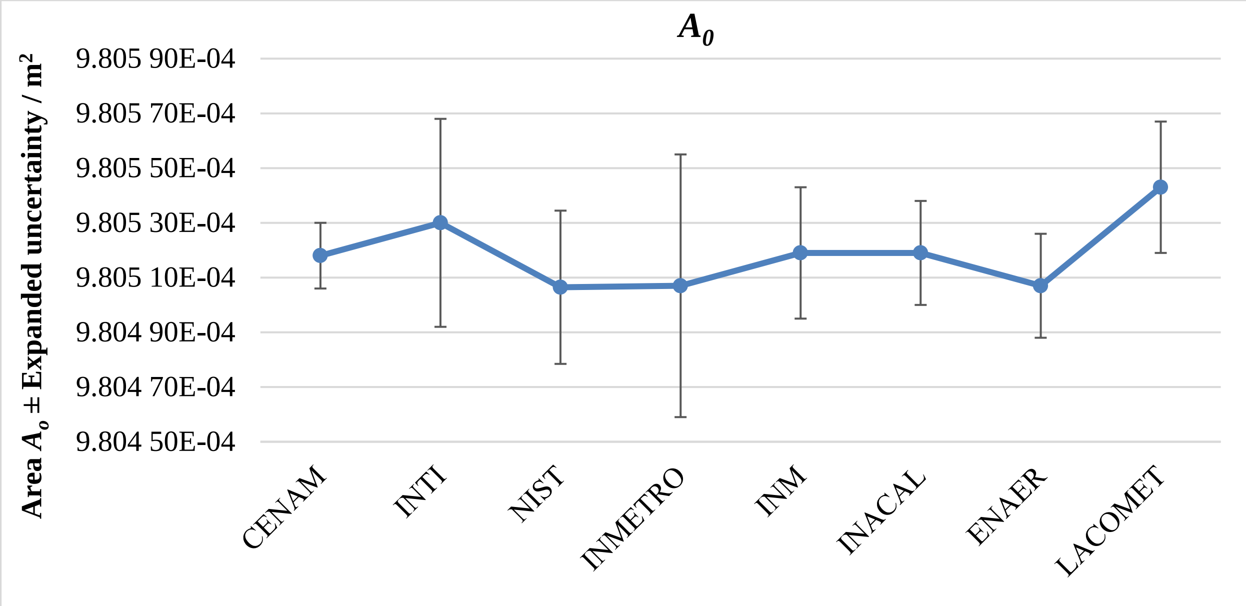
Graph 20. Effective area normalized error ($E_{n\ lab}$) equation values of participating laboratories.

As it can be seen in table 10 and graph 20, CENAMEP had no equivalence with the reference values (and has been left out of the graph 20 for clarity on the graph), LACOMET had all its points between 1 and 1.5, CENAM had 2 points equal to 1 in the E_n values. These are since CENAM had a very low uncertainty entered for its standard on the relative expanded uncertainty of A_0 as well as for the expanded uncertainty of b. Even though the distortion coefficient, b, relative significance is small, it is big enough to alter the E_n values. The uncertainty for b will be studied by CENAM. Nevertheless, the most important value in a cross-float calibration is the value of A_0.

The corresponding values of A_0 corrected by the NIST values on the CIPM comparison are here compared and the compatibility of each laboratory with NIST is presented through the E_n values.

Table 11. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2.

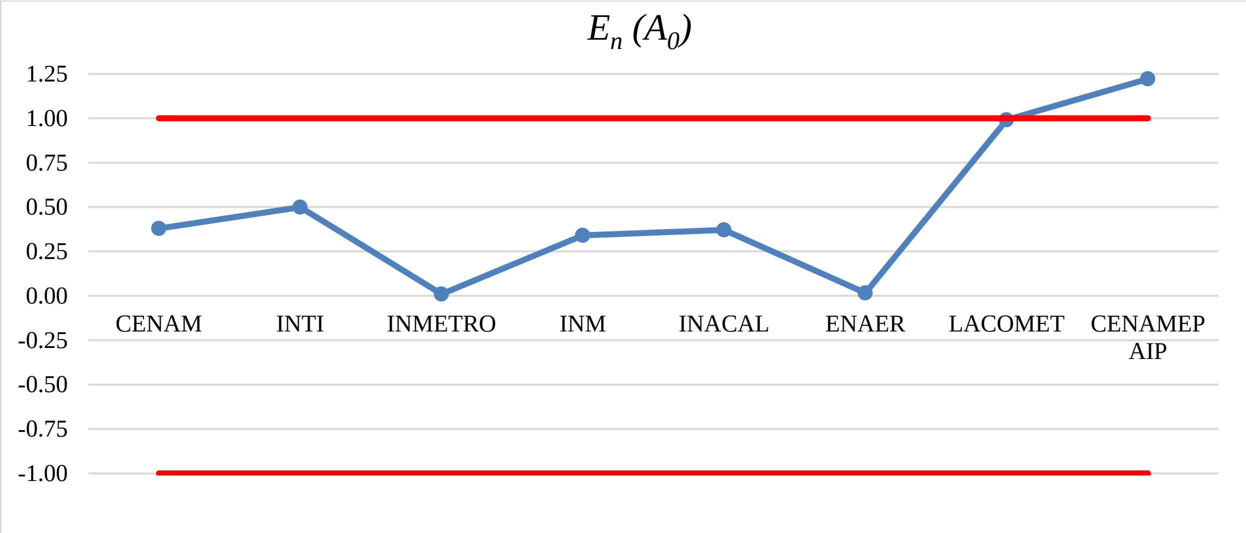
	A_0 / m^2	UA_0 / m^2	b / 1/Pa	Ub / 1/Pa
CENAM	9.805 18E-04	1.2E-08	6.1E-11	2.7E-11
INTI	9.805 32E-04	3.8E-08	-2.0E-10	9.7E-11
NIST	9.805 065E-04	2.8E-08	0.0E+00	1.12E-12
INMETRO	9.805 07E-04	4.8E-08	-9.0E-11	1.2E-10
INM	9.805 19E-04	2.4E-08	5.5E-12	1.5E-11
INACAL	9.805 19E-04	1.9E-08	-2.4E-14	3.2E-11
ENAER	9.805 07E-04	1.9E-08	5.7E-11	1.9E-11
LACOMET	9.805 43E-04	2.4E-08	-1.0E-07	4.8E-08
CENAMEP AIP	9.814 72E-04	7.9E-07	2.4E-13	1.1E-08



Graph 21. TS A_0 and its corresponding expanded uncertainty as obtained by each NMI, m^2.
For clarity, CENAMEP is not included.

Table 12. Normalized error equation values of participating NMIs for area at zero pressure (A_0).

NMI	CENAM	INTI	INMETRO	INM	INACAL	ENAER	LACOMET	CENAMEP
$E_n (A_o)$	0.38	0.50	0.01	0.34	0.37	0.02	0.99	1.2



Graph 22. Normalized error equation values of participating laboratories for area at zero pressure (A_0).

As it can be seen from table 12 and graph 22, all laboratories have equivalence except CENAMEP.

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