Proficiency Testing for Pressure Calibration at the National Voluntary Laboratory Accreditation Program (NVLAP)*

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Learning Objectives

- Learn how NVLAP conducts proficiency tests in pressure
- Understand collective performance of pressure at NVLAP accredited labs

Outline

- PT: What and Why
- Introduction to Pressure
- High Level PT
- Standard Level PT
- Summary
- Lunch

Proficiency Testing: What and Why?

- "Proficiency testing…(is the) evaluation of participant performance against pre-established criteria by means of interlaboratory comparisons" ISO/IEC 17043:2010
- "Proficiency testing, along with document review and on-site assessment, is an integral part of the NVLAP accreditation process" NVLAP LB-63-2011
- "NVLAP-accredited calibration laboratories are required to develop suitable plans to participate in relevant proficiency testing schemes than demonstrate technical competence" NVLAP LB-63-2011, as per ILAC-P9: 11/2010
- Proficiency testing is not the only means by which performance can be assessed and monitored

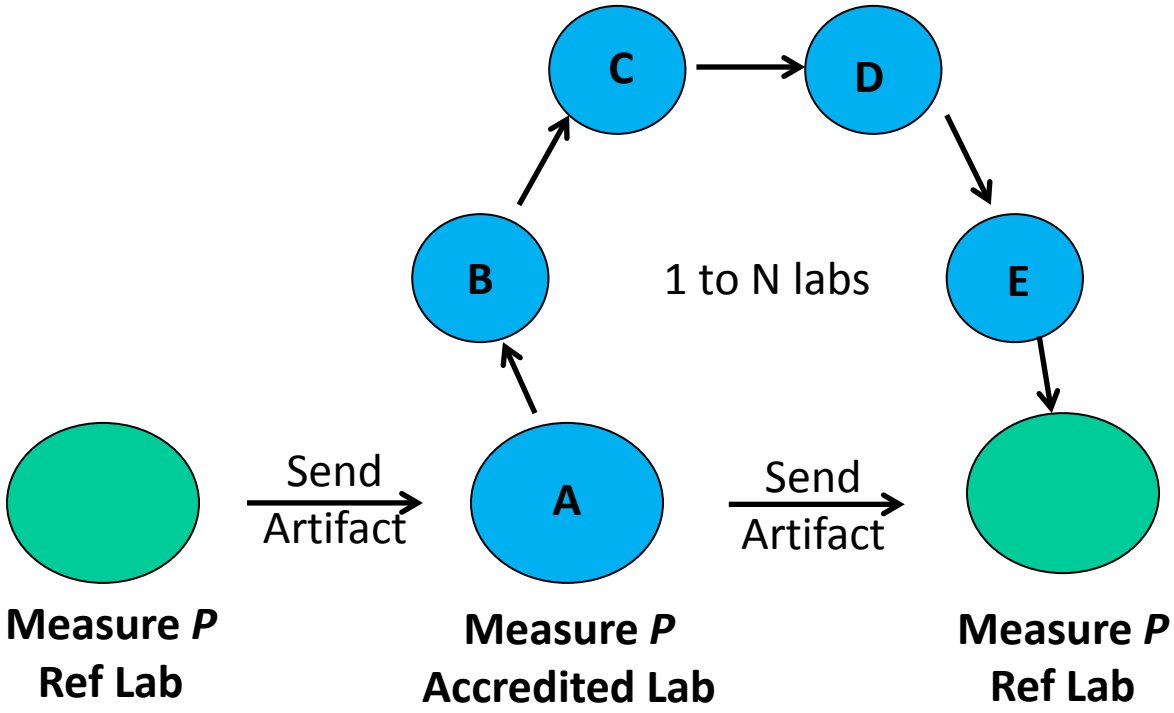
Proficiency Testing: Benefits to Lab, Customer, NVLAP/NIST

- Full-fills accreditation requirements
- Identifies problems for corrective actions
- Establishes effectiveness of measurement methods and uncertainty claims
- Educating staff, improving performance

- Provide confidence to customers
- Identifies differences in laboratories providing similar service

- Helps validate accrediting body assessment process
- Helps dissemination of SI (pressure) unit

Proficiency Testing Concept



Compare Lab *P* to Reference *P*.
If agreement is within uncertainty, proficiency demonstrated

Proficiency Testing vs. Key Comparisons (KC)

Characteristic	PT	KC
Participants	Accredited Labs	NMIs
Traveling Artifact	Yes	Yes
Protocol, circulation scheme, measurement points	Yes	Yes
Use of Result	Validate Scope (CMCs)	Validate CMCs
Confidential Results?	Yes	No, Public
Source of Ref. Value	Ref. Lab	Compute from NMIs
When Results Available	Immediate	Years

Brief Introduction to Pressure

- Important for: human health, weather, air travel, transportation, manufacturing
- A derived SI unit (from length, mass, time)
- Measured in both liquid and gas, gauge and absolute modes
- Primary pressure standards from 10 kPa to 500 MPa utilize piston gauges
  - Are commercially available, stable
  - Relative uncertainties on the order of 10^{-5} (10 ppm)
- The best electronic pressure transducers have uncertainties on the order of 10^{-4} (100 ppm)

Pressure from a Piston Gauge

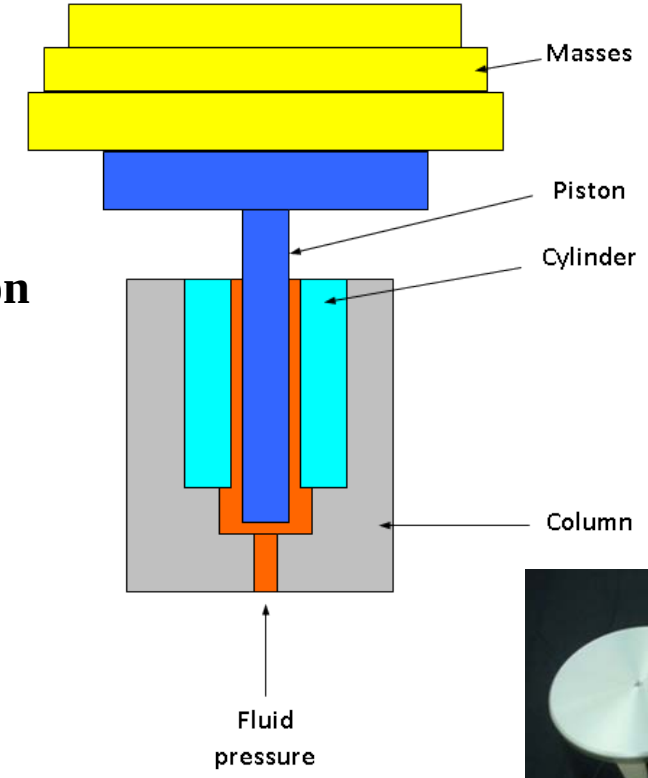
Gravity forces from masses (buoyancy-corrected) + surface tension

$$pA = Mg + \text{Surface Tension}$$

$$A = \frac{Mg + \text{ST}}{p}$$

Vertical fluid pressure forces acting on piston

effective area



NVLAP Proficiency Testing for Pressure

- No formal program prior to 2011
- 27 accredited labs for pressure in 2011 (35 in 2014)
- Utilizes NIST as ref. lab (direct traceability to SI, approved CMCs, participant in KCs)
- Pressure range of labs: few kPa to 10s of MPa
- Accredited labs calibrate both piston gauges and transducers
- NVLAP PTs for standard PRTs, gage blocks, mass, air kerma

NVLAP code 20/T05 (pressure), circa 2011
Assessment of Lab capabilities

- Effective area and pressure: 5 labs (1 dropped prior to PT start)
  - Liquid and gas. All capable of gas to 6.9 MPa
  - Government and private cal. labs
- Pressure only: 22 labs
  - 21 labs gas
  - 16 labs gas and liquid
  - 1 lab liquid only
  - Government labs, gov. contractors, private cal. labs, private industry
- P range of 21 gas labs
  - 18: 3.5 MPa or higher
  - 2: 1 MPa maximum
  - 1: 137 kPa maximum

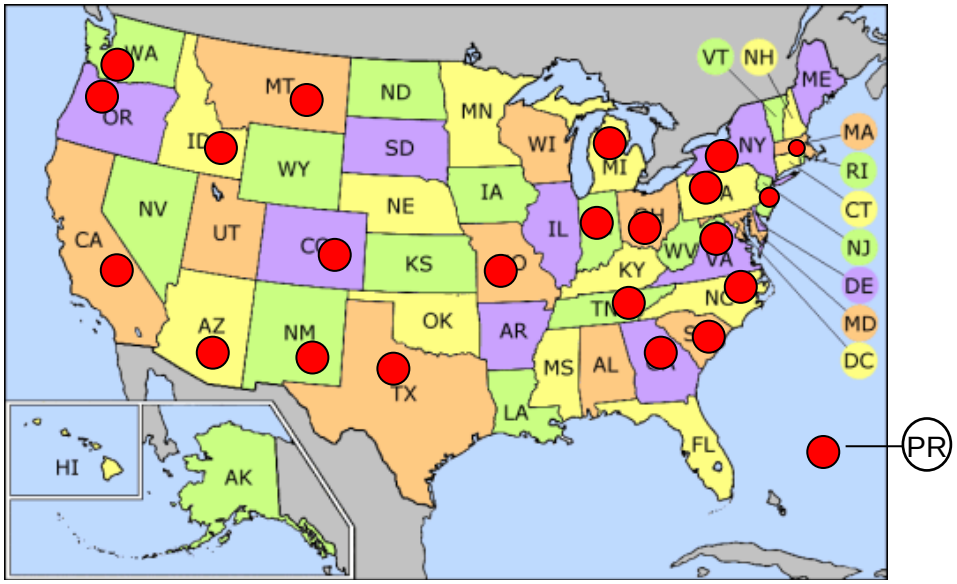
2 NVLAP PTs to match Lab capabilities:

- **High Level PT: effective area, gas, 6.9 MPa**
- **Standard Level PT: pressure, gas, 3.5 MPa and 1 MPa**

NVLAP Pressure Labs in 2014

Capabilities
- **6 Pressure and effective area**
- **29 pressure only**
- **35 Total**

Type of Lab
- **US DoE**
- **US military cal labs**
- **Government contractor cal labs**
- **Private Cal Labs**
- **Private industry**

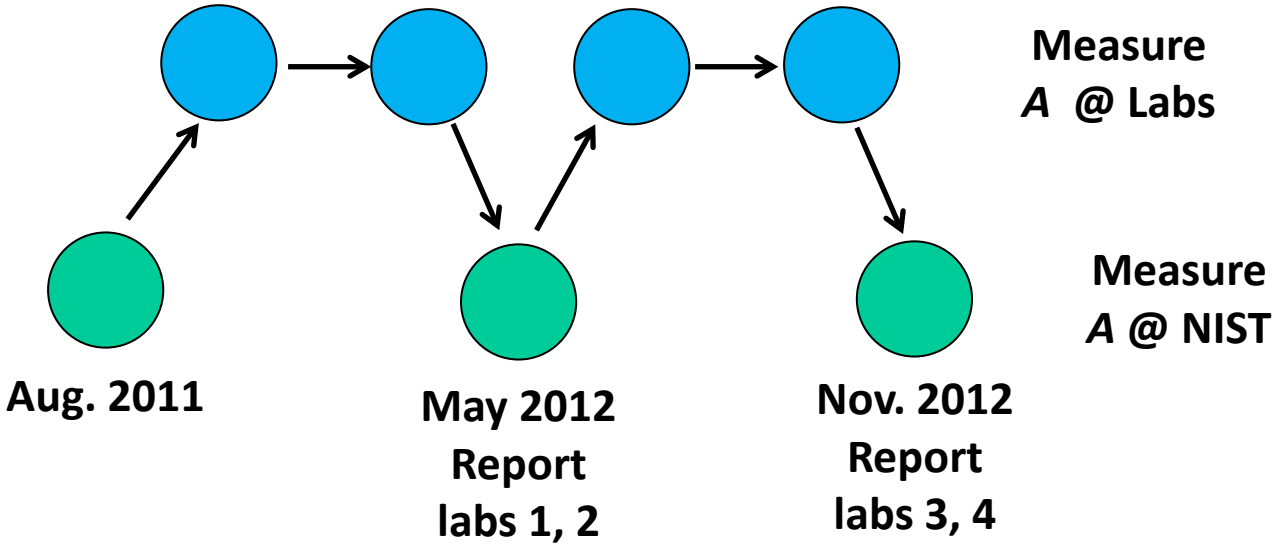


Locations of P labs
23 states, 1 Canada

Characteristics of NVLAP Pressure PTs

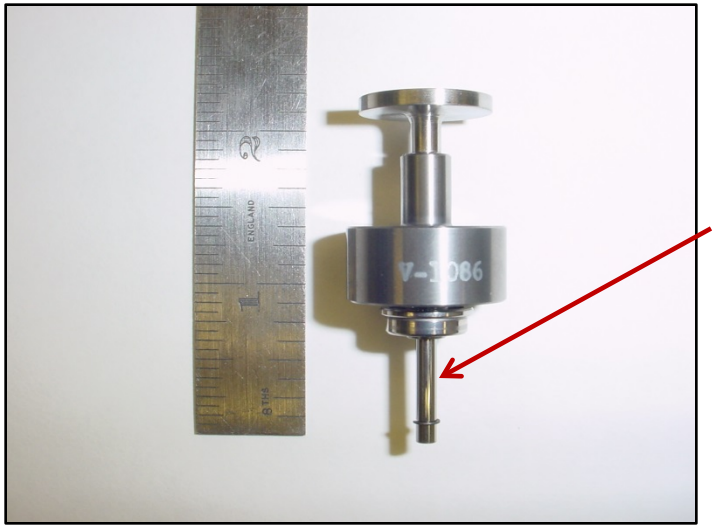
	High Level (HLPT)	Standard Level (SLPT)
Participants	4 (+1)	20
Pressure Range	6.9 MPa	3.5 MPa, 1 MPa
No. of points	11	10
Traveling Artifact	Ruska 2465, S/N V-1086	RPM4
Comparison Parameter	Effective Area	Pressure
Medium	Nitrogen	Nitrogen
Mode	Gauge	Absolute
NIST Ref Std	PG13	PG13, PG37

High Level PT: circulation pattern



- Two loops chosen due to geography and artifact stability
- 11 Pressure points: 358, 703, 1392, 2082, 2771, 3460, 4149, 4839, 5528, 6217, 6907 kPa
- Lab Standards: Fluke PG7601, Ruska 2465 piston gauges

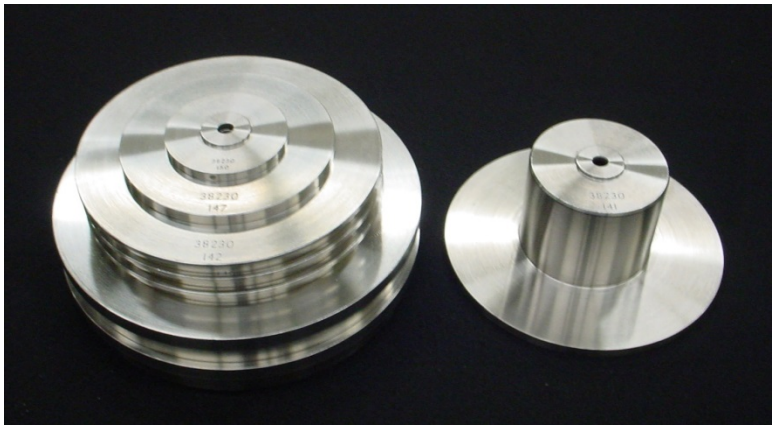
High Level PT: Traveling Artifact



- **Piston-cylinder unit, V-1086, 8.39 mm^2 nominal area**
- **358 kPa to 7 MPa range**
- **Tungsten carbide**

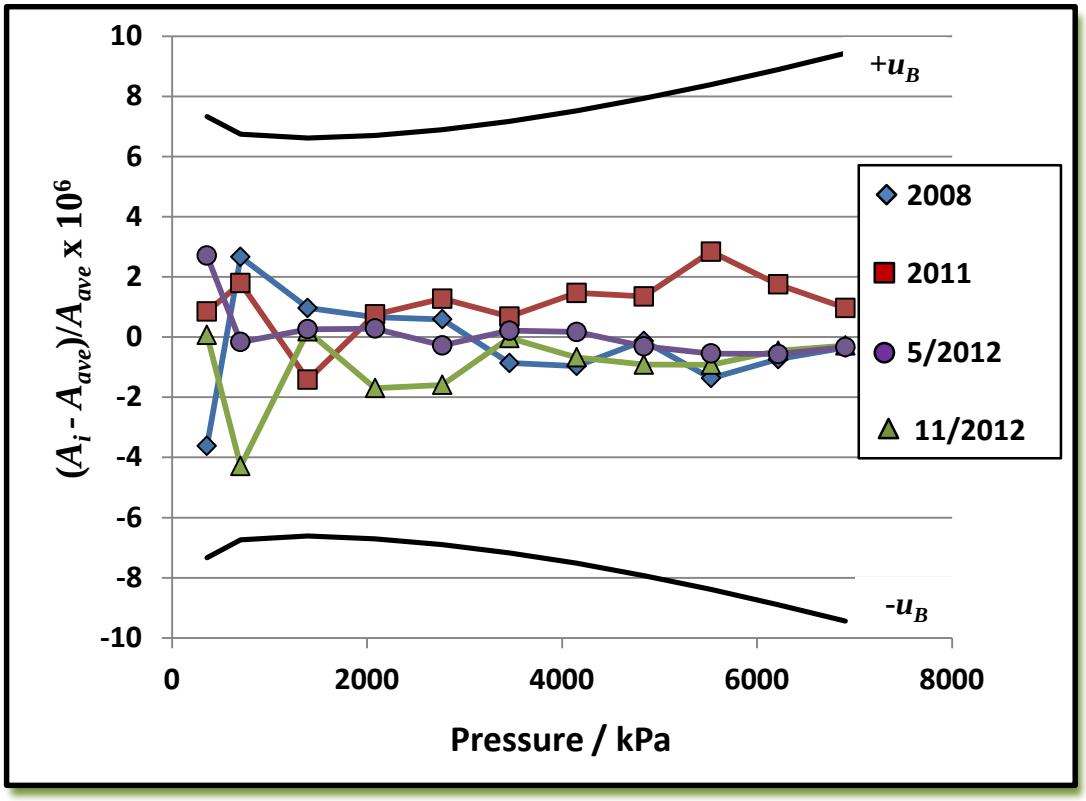
2 of 4 labs used their own base and mass sets.

Ruska (Fluke) 2465 base unit and cover



Masses used on base

High Level PT: Stability of Traveling Artifact



NIST calibration results of V-1086 against PG13. Deviations from average of 4 calibrations, 2008 to 2012. Type B standard uncertainty shown.

Long-term stability uncertainty: 3×10^{-6}, k=1, relative (3 ppm)
No systematic drift over time

High Level PT: Evaluation of Proficiency

$$E = \frac{d}{k \cdot u(d)},\ d = A_L - A_{NIST} \qquad u(d) = \left[u^2(A_L) + u^2(A_{NIST}) + u^2_{LTS} \right]^{1/2}$$

Determine *E* at each pressure for *k*=2:
If $|E| \leq 1.0$, satisfies proficiency
If $|E| > 1.0$, does not satisfy

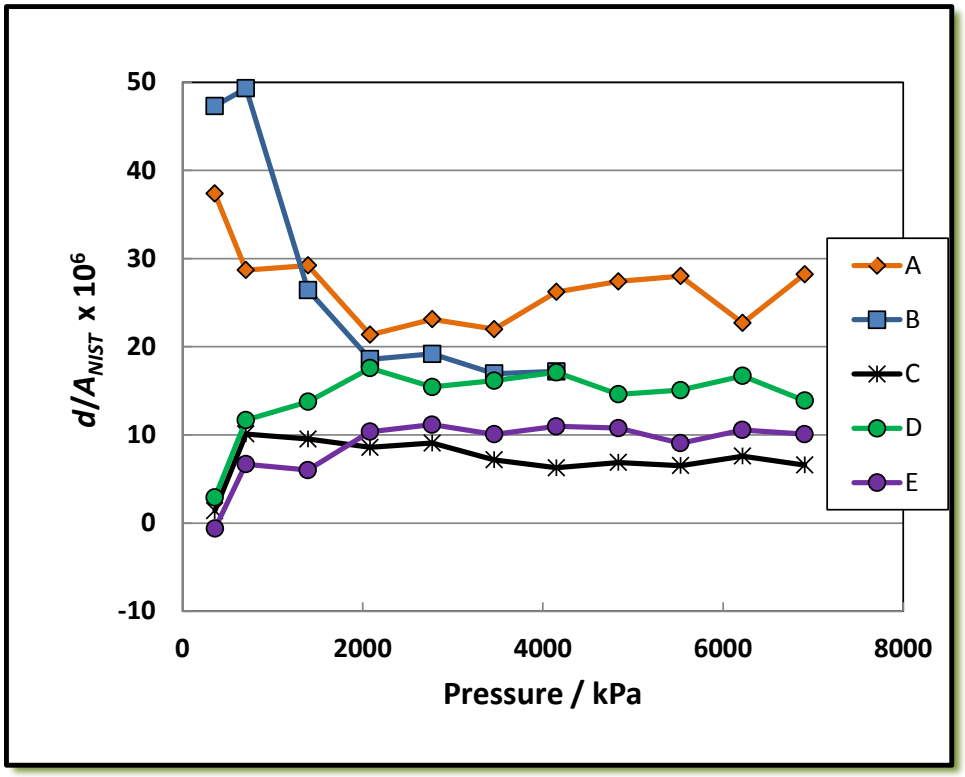
Overall proficiency test:
If $|E| \leq 1.0$ at 10 or 11 pressures: satisfactory PT
If $|E| \leq 1.0$ at 9 or less pressures: unsatisfactory PT

Range of lab relative standard uncertainties, $u(A_L)$:

8 ppm
13 ppm
18 ppm
30 ppm

NIST, $u(A_{NIST})$: 6.7 ppm to 9.5 ppm

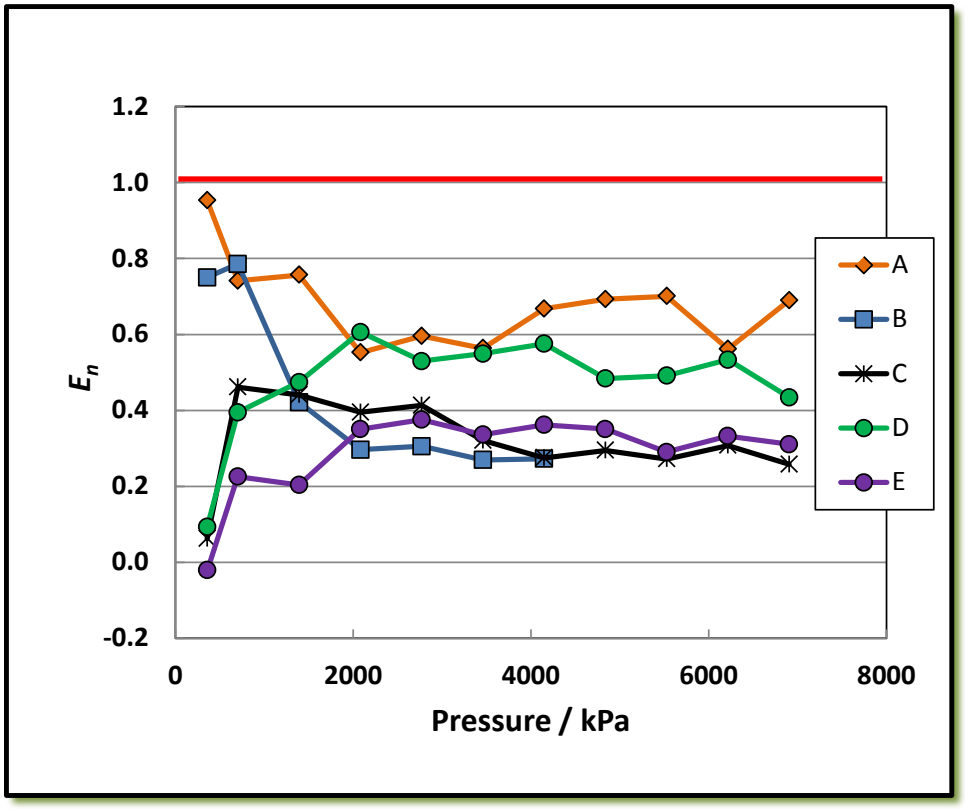
High Level PT: Lab Results *d*
As reported



Note:
Labs A to E are not chronological!!

- Positive *d* means lab areas are larger than reference value (NIST)
- 5th lab included from 2008 one-time PT

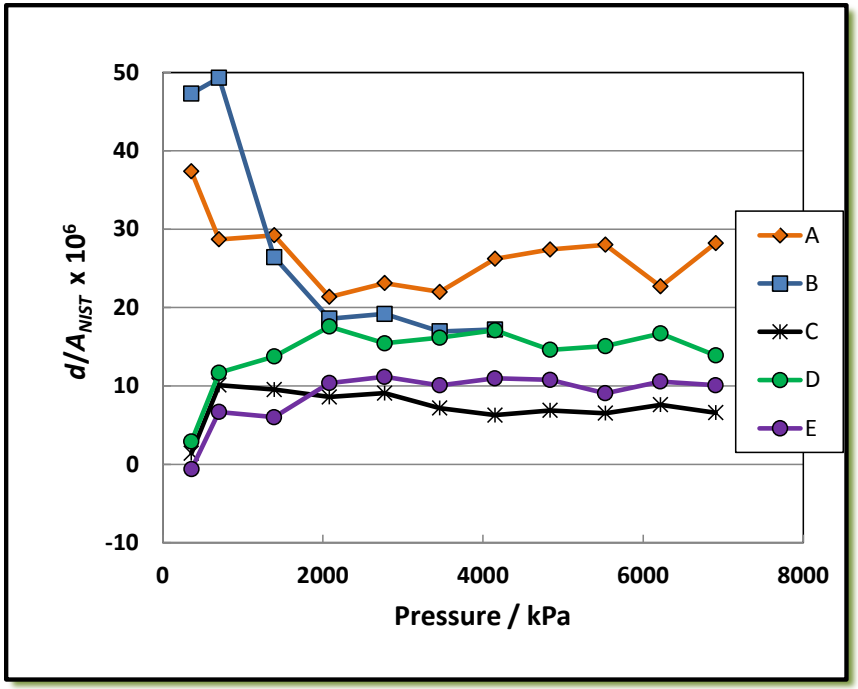
High Level PT: Lab Results E_n



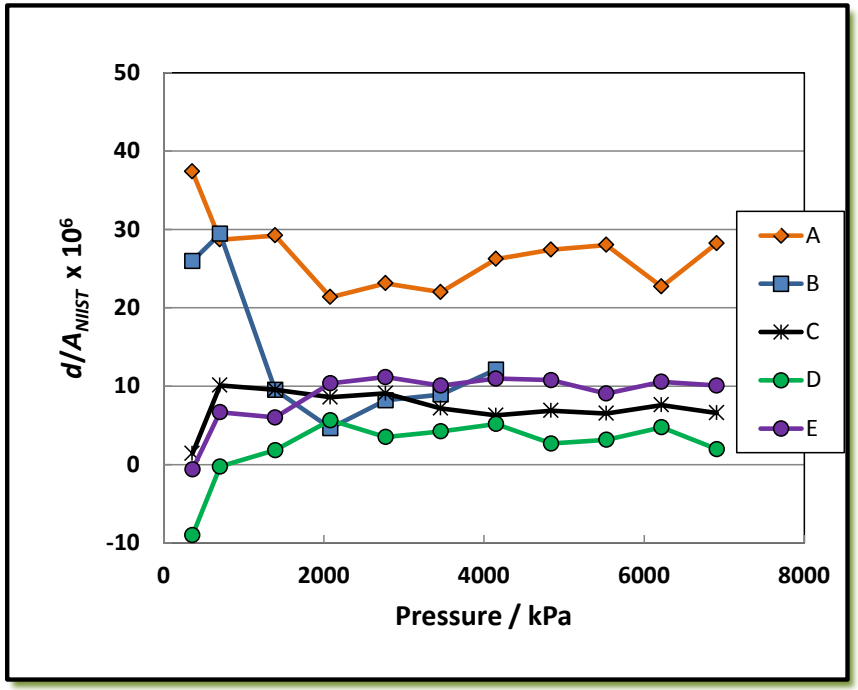
- All labs demonstrate proficiency at all points
- Labs B and D re-examined traceability based on result

High Level PT: Lab Results *d*

As submitted

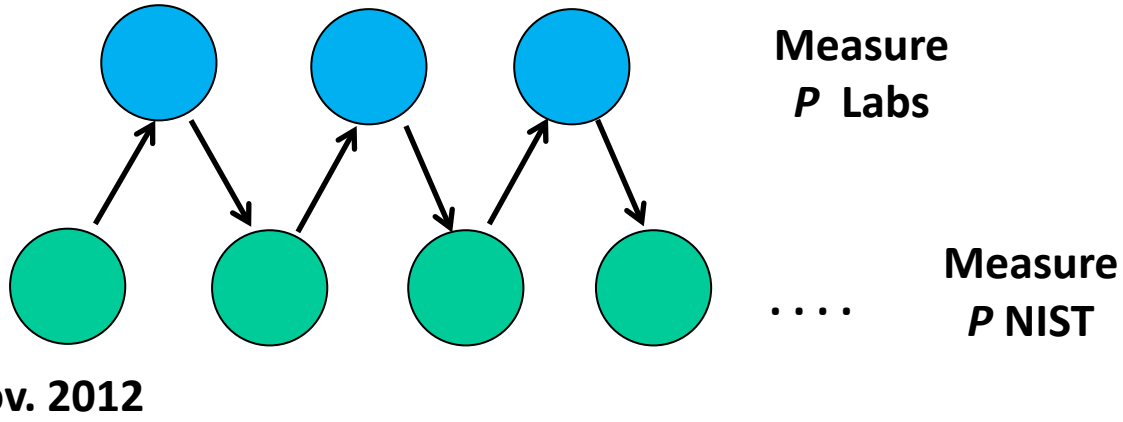


Revised B and D labs



- With revised traceability, most points within 10 ppm of reference value, except for lab A and lab B < 1 MPa

Standard Level PT: 3.5 MPa PT



- Nov. 2012: start. July 2014: artifact at lab 9
- Traveling Artifact: Fluke RPM4
- Star circulation pattern
  - Accounts for artifact stability
  - Lab *I* proficiency determined after NIST closing measurements
- 10 Pressure points: 358, 700, 1050, 1400, 1750, 2100, 2450, 2800, 3150, 3500 kPa
- Lab standards: Fluke PG7601, Ruska 2465, Fluke PPC3, Fluke RPM4

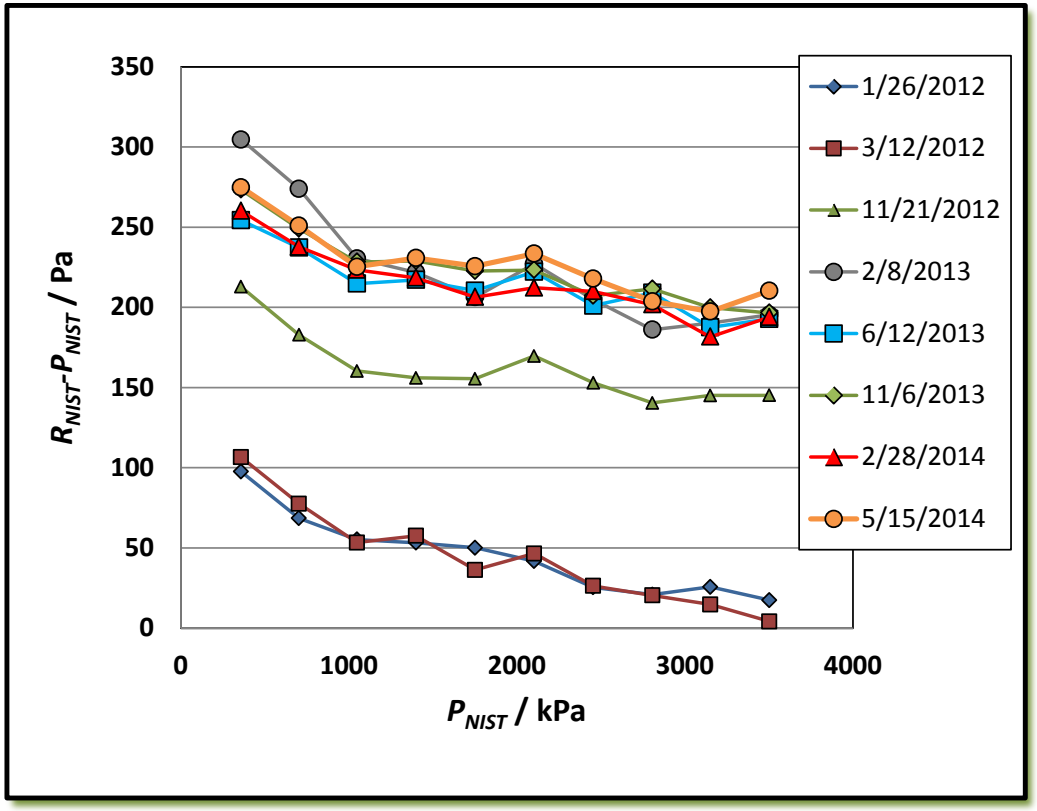
Standard Level PT: Traveling Artifact

Front View of RPM4

Back View of RPM4

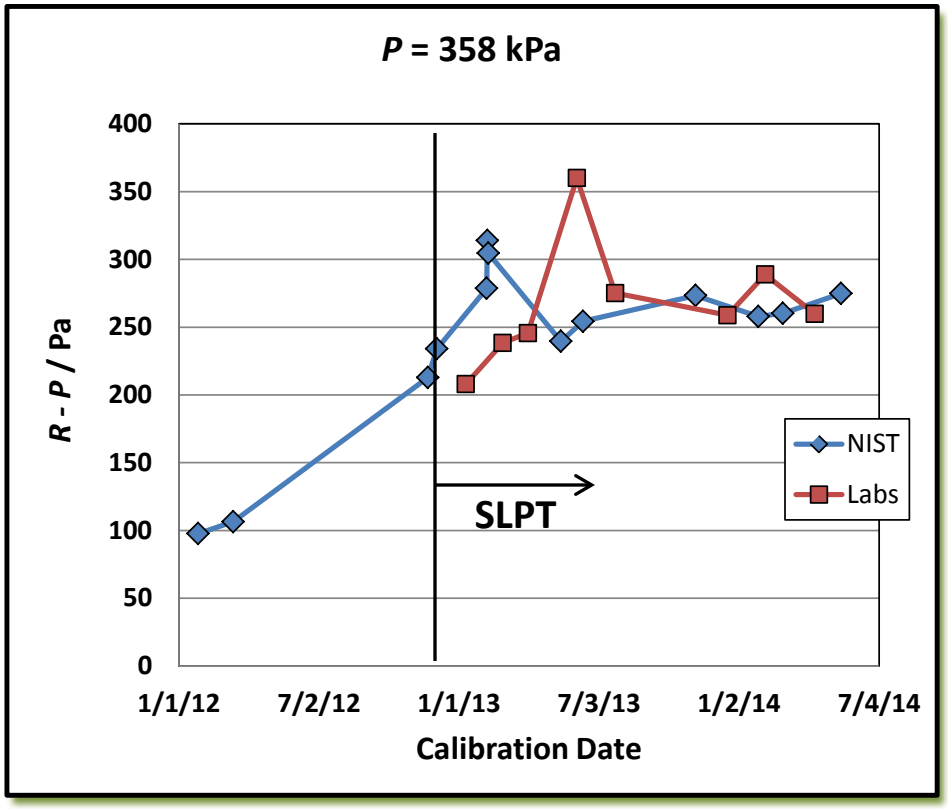
- Premium version RPM4, dual ranges, absolute mode: 7 MPa and 1.4 MPa
- Stated expanded (k=2) uncertainty, 7 MPa range:
  - P < 2.1 MPa: 168 Pa. P > 2.1 MPa: 0.008 % of reading
  - Additional 355 Pa/year due to zero drift
- Purchased by NVLAP in August 2011
- Repeat Cals at NIST (Jan 2012 to present) to monitor performance
- Opening and closing NIST measurements (prior to lab) remove most of RPM4 drift

Standard Level PT: Traveling Artifact performance at NIST from Jan. 2012 to May 2014



Offset, $R_{NIST} - p_{NIST}$, from 358 kPa to 3.5 Mpa
RPM4 drifts up with time. Drift is independent of pressure level

Standard Level PT: Traveling artifact performance at NIST and Labs over time, 358 kPa

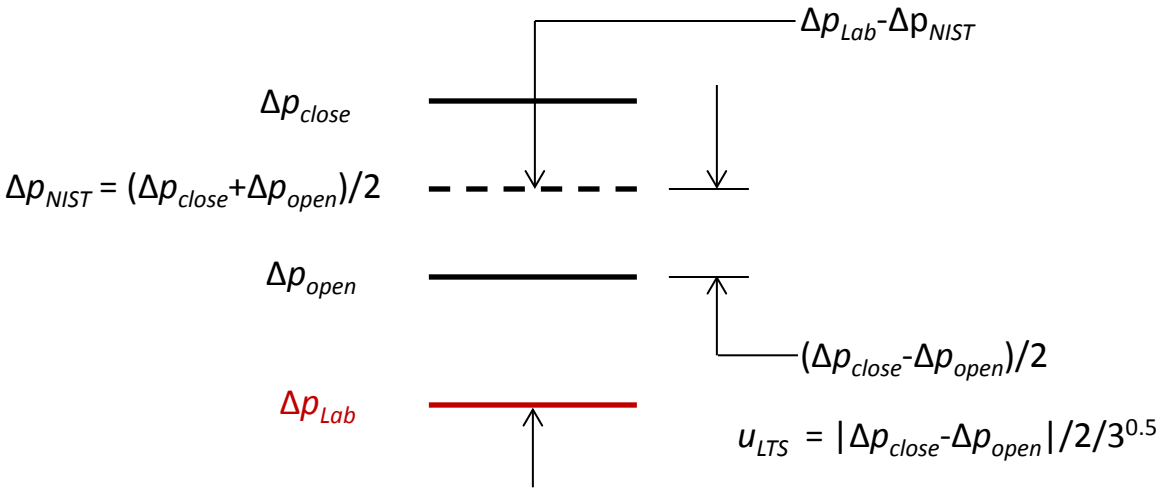


RPM4 drifts up mostly with time, more stable since May 2013

NIST value average of opening & closing measurements

u_{LTS} (k=1) based on ½ change / $3^{1/2}$. u_{LTS} : 10 Pa to 20 Pa

SLPT: Long term stability uncertainty, u_{LTS}



Typical Values	
Δp_{close}	227 Pa
Δp_{open}	160 Pa
$(\Delta p_{close}-\Delta p_{open})/2$	34 Pa
u_{LTS} (k=1)	19 Pa
Nominal P	2.1 MPa

Manufacturer's standard uncertainty: 84 Pa + 178 Pa/yr drift
Absolute u_{LTS} is constant with p, relative u_{LTS} decreases with increasing p

Standard Level PT: Evaluation of Proficiency
Compare offset between Lab and NIST

$$E = \frac{d}{k \cdot u(d)},\ d = \Delta p_L - \Delta p_{NIST}$$

$$u(d) = \left[u^2(\Delta p_L) + u^2(\Delta p_{NIST}) + u^2_{LTS} \right]^{1/2}$$

$$\Delta p_L = R_L - p_L$$

$$\Delta p_{NIST} = R_{NIST} - p_{NIST}$$

R is the RPM4 reading
p is the lab or NIST pressure
Δp = Offset = *R* - *p*

Determine *E* at each pressure for *k*=2:
If $|E| \leq 1.0$, satisfies proficiency
If $|E| > 1.0$, does not satisfy

Overall proficiency test:
If $|E| \leq 1.0$ at 9 or 10 pressures: satisfactory PT
If $|E| \leq 1.0$ at 8 or less pressures: unsatisfactory PT

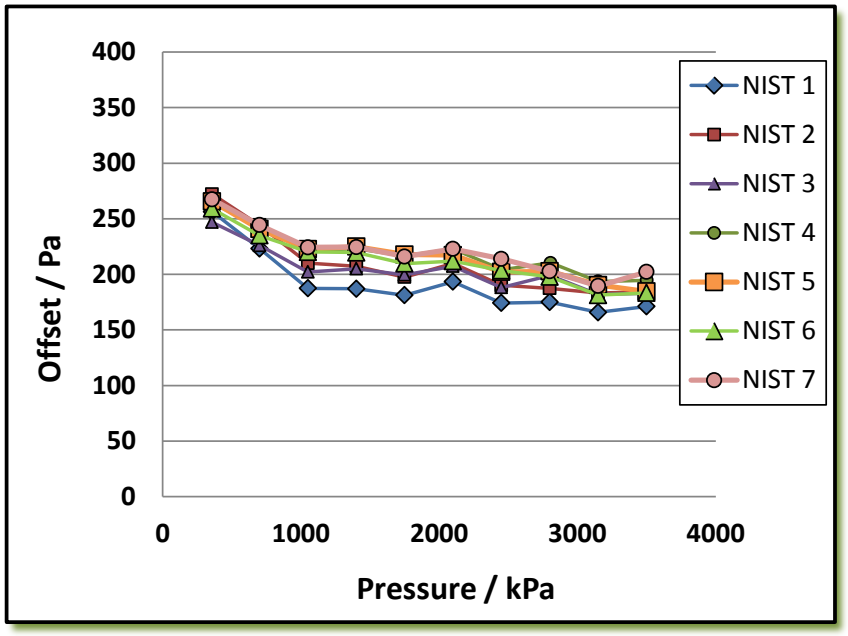
Typical lab $u(\Delta p_L)$:

- **8 Pa to 35 Pa: piston gauge standard**
- **53 Pa to 175 Pa: electronic pressure standard**

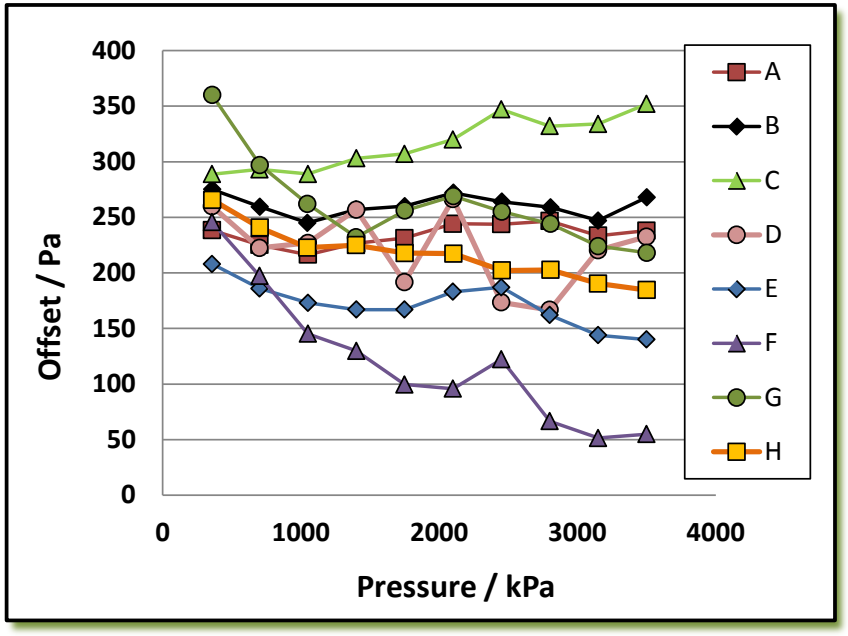
NIST, $u(\Delta p_{NIST})$: 2 Pa to 28 Pa

Standard Level PT: NIST and Lab Offsets

NIST Offset



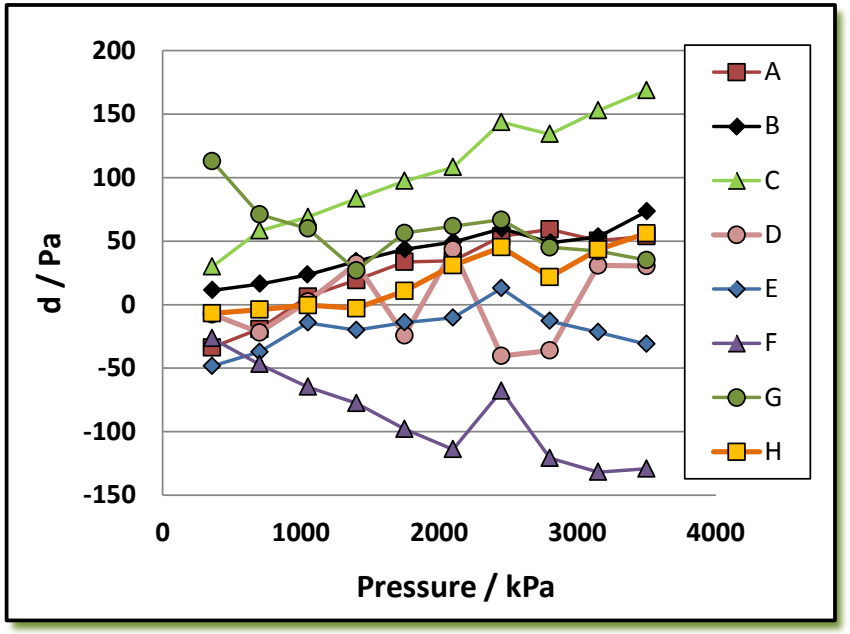
Lab Offset



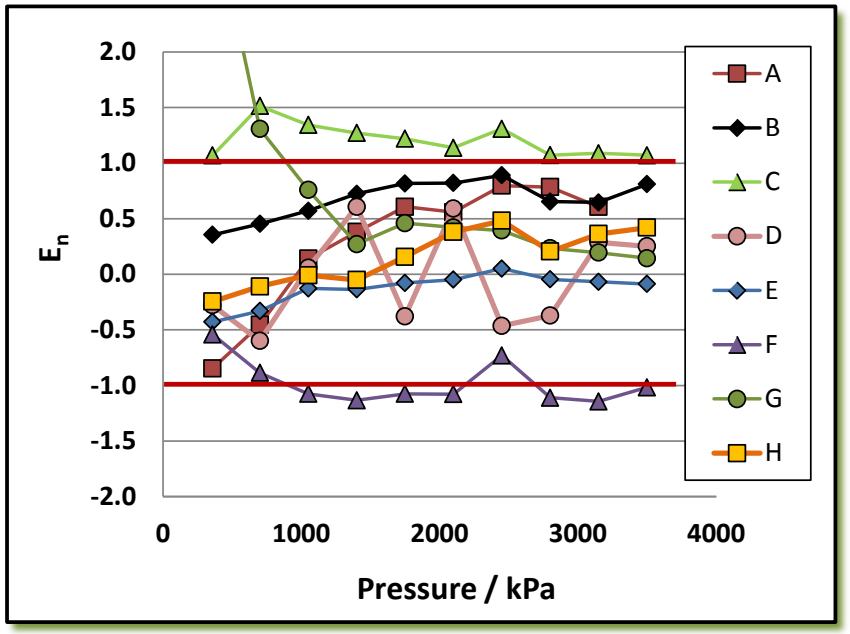
- Lab to Lab variation in offset much larger than variation in NIST Offset.
- Variation in NIST offset due to drift of artifact.
- Labs A to H are not chronological

Standard Level PT: Offset difference and E_n

Offset diff, Lab - NIST



E_n



Accounting for artifact drift, $d = p_{NIST} - p_L$

5 of 8 labs show proficiency at all pressures.

3 labs have unsatisfactory result ($E_n > 1$ at 2 or more pressure)

Summary

- NVLAP offers proficiency tests in pressure and piston gauge effective area (since 2011)
  - Full-fills accreditation requirements
  - Utilizes NIST pressure standards as ref lab, traceable to the SI
  - Tested range to 3.5 MPa and 6.9 MPa
  - 1 MPa test will be next
- 14 participating labs (to date) include US gov. cal labs, gov. contractors, private cal labs, private industry
- Collective data set shows capabilities of NVLAP accredited labs
  - 10 pass, 3 unsatisfactory, 1 waiting to report
  - Results guide improvements in traceability, procedures, and methods
- Thank you for your attention!!