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.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PT</th>
<th>KC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>Accredited Labs</td>
<td>NMI's</td>
</tr>
<tr>
<td>Traveling Artifact</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Protocol, circulation scheme, measurement points</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Use of Result</td>
<td>Validate Scope (CMCs)</td>
<td>Validate CMCs</td>
</tr>
<tr>
<td>Confidential Results?</td>
<td>Yes</td>
<td>No, Public</td>
</tr>
<tr>
<td>Source of Ref. Value</td>
<td>Ref. Lab</td>
<td>Compute from NMI's</td>
</tr>
<tr>
<td>When Results Available</td>
<td>Immediate</td>
<td>Years</td>
</tr>
</tbody>
</table>
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

\[ pA = Mg + \text{Surface Tension} \]

Vertical fluid pressure forces acting on piston effective area

\[ A = \frac{Mg + ST}{p} \]
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High Level (HLPT)</th>
<th>Standard Level (SLPT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>4 (+1)</td>
<td>20</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>6.9 MPa</td>
<td>3.5 MPa, 1 MPa</td>
</tr>
<tr>
<td>No. of points</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Traveling Artifact</td>
<td>Ruska 2465, S/N V-1086</td>
<td>RPM4</td>
</tr>
<tr>
<td>Comparison Parameter</td>
<td>Effective Area</td>
<td>Pressure</td>
</tr>
<tr>
<td>Medium</td>
<td>Nitrogen</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Mode</td>
<td>Gauge</td>
<td>Absolute</td>
</tr>
<tr>
<td>NIST Ref Std</td>
<td>PG13</td>
<td>PG13, PG37</td>
</tr>
</tbody>
</table>
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 mm² nominal area
- 358 kPa to 7 MPa range
- Tungsten carbide

2 of 4 labs used their own base and mass sets.
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: 3x10^{-6}, k=1, relative (3 ppm)
No systematic drift over time
High Level PT: Evaluation of Proficiency

\[ E = \frac{d}{k \cdot u(d)}, \quad d = A_L - A_{NIST} \]

\[ u(d) = \left[ u^2(A_L) + u^2(A_{NIST}) + u^2_{LTS} \right]^{1/2} \]

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

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

Note:
Labs A to E are not chronological!!
All labs demonstrate proficiency at all points
Labs B and D re-examined traceability based on result
• 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

- Traveling Artifact: Fluke RPM4
- Star circulation pattern
  - Accounts for artifact stability
  - Lab / 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

- 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 $\frac{1}{2}$ change / $3^{1/2}$. $u_{LTS}$: 10 Pa to 20 Pa
SLPT: Long term stability uncertainty, $u_{LTS}$

$$\Delta p_{NIST} = (\Delta p_{close} + \Delta p_{open})/2$$

$$\Delta p_{close}$$

$$\Delta p_{open}$$

$$\Delta p_{Lab}$$

$$\Delta p_{Lab} - \Delta p_{NIST}$$

$$\Delta p_{close}$$

$$\Delta p_{open}$$

$$\Delta p_{close} - \Delta p_{open}/2$$

$$u_{LTS} = |\Delta p_{close} - \Delta p_{open}|/2^{3/2}$$

Typical Values

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>$\Delta p_{close}$</td>
<td>227 Pa</td>
</tr>
<tr>
<td>$\Delta p_{open}$</td>
<td>160 Pa</td>
</tr>
<tr>
<td>$(\Delta p_{close} - \Delta p_{open})/2$</td>
<td>34 Pa</td>
</tr>
<tr>
<td>$u_{LTS}$ ($k=1$)</td>
<td>19 Pa</td>
</tr>
<tr>
<td>Nominal P</td>
<td>2.1 MPa</td>
</tr>
</tbody>
</table>

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**

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

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

**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

\[ \Delta p_L = R_L - p_L \]
\[ \Delta p_{NIST} = R_{NIST} - p_{NIST} \]

\( R \) is the RPM4 reading
\( p \) is the lab or NIST pressure
\( \Delta p = \) Offset = \( R - p \)
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 $E_n$

Accounting for artifact drift, $d = \rho_{NIST} - \rho_L$

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!!