Best Calibration Practices

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Best Calibration Practices
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Quasi-Disclaimer

This presentation merely skims the surface of metrology by covering a few more common methods of calibrating. Covering temperature calibrations alone would take more time than is provided. We hope to cover relevant material, but encourage you to research practices particular to your own processes.

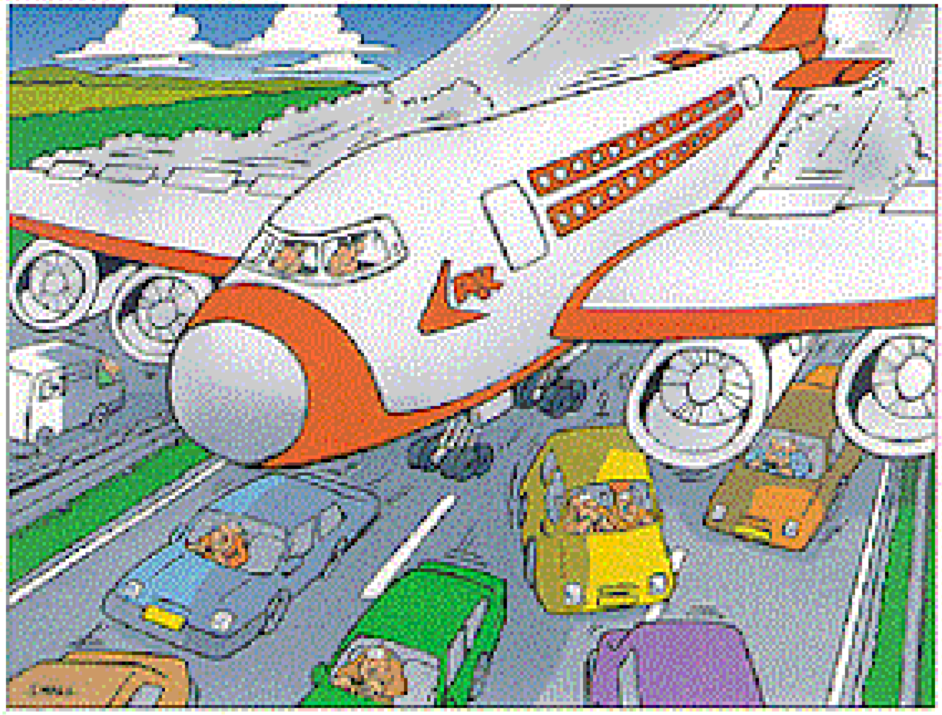
Introduction

- What is a calibration?
  - **The process of comparing one instrument's unit of measure to another device of greater accuracy for the purpose of obtaining a certain level of accuracy and confidence which is traceable to a higher standard**
  - **This chain of ever tightening comparisons is tied to a national or international standard (NIST/NRC or BIPM)**

Introduction

- Why do we calibrate?
  - **Instruments lose accuracy over time due to normal use and the environmental conditions they are exposed to**
  - **Calibrations are required to maintain the accuracy of a device**
  - **Ensure traceability to a standard**

Introduction



"Looks like someone forgot to calibrate the 'Instrument Landing System', captain."

Introduction

"Honestly officer, battery-powered milk trucks can't do 75 miles per hour.... even downhill."

Introduction

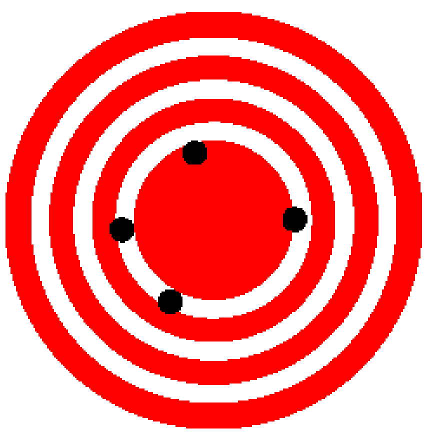
- Calibration Terms:
  - **Metrology**
    - The science and practice of measurement
  - **Traceability**
    - The ability to relate a measured value to a standard reference, usually a National or International standard, through an unbroken chain of comparisons
  - **Tolerance**
    - Can be defined as a value or percent deviation from the target value. (ie. ±0.2°F or ±0.1%)
  - **Uncertainty**
    - The range of probable values likely to enclose the true value of a particular measurement

Introduction

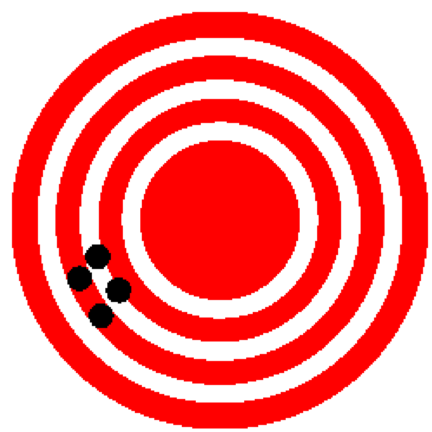
- Calibration terms continued:
  - **Repeatability**
    - **The ability to obtain like results from one device by one operator under one set of conditions (ie. location, procedures, standards, etc.)**
  - **Reproduceability**
    - **The ability to obtain like results from the same device by a different operator under different conditions**
  - **Accuracy**
    - **The degree of conformity of the measured or calculated quantity to its actual (true) value**

Introduction

- Calibration terms continued:
  - **Precision**
    - **Characterises the degree of mutual agreement among a series of individual measurements**



High accuracy
Low precision



Low accuracy
High precision

History of Calibrating

Terasen Gas

- Calibration standards can be traced as far back as ancient Egypt during the building of the pyramids
- The Egyptians used the Royal Cubit (20.6”) as the standard measure of length
- Royal Cubit Master was carved out of granite and transferred to wooden lengths used by the workers

History of Calibrating

- The royal architect or foreman was responsible for transferring the unit of length to the workers
- Failure to compare your cubit stick every full moon was punishable by death
- With this standardization the builders of the pyramids were able to achieve an accuracy of 0.05% which equates to 2” in 328’ (or the length of a football field)

Standards History

- In 1875 after a 20 country conference in France the International Bureau of Weights and Measurements was formed
- This organization was mandated to establish new metric standards and ensure uniformity of measure throughout the world

Standards

- The International System of Units used today is comprised of seven fundamental units, which are:

SI Unit	**Physical quantity**
– **meter**	**Length**
– **kilogram**	**Mass**
– **Kelvin**	**Temperature**
– **Ampere**	**Electric current**
– **second**	**Time**
– **Candela**	**Luminous intensity**
– **mole**	**Amount of substance**

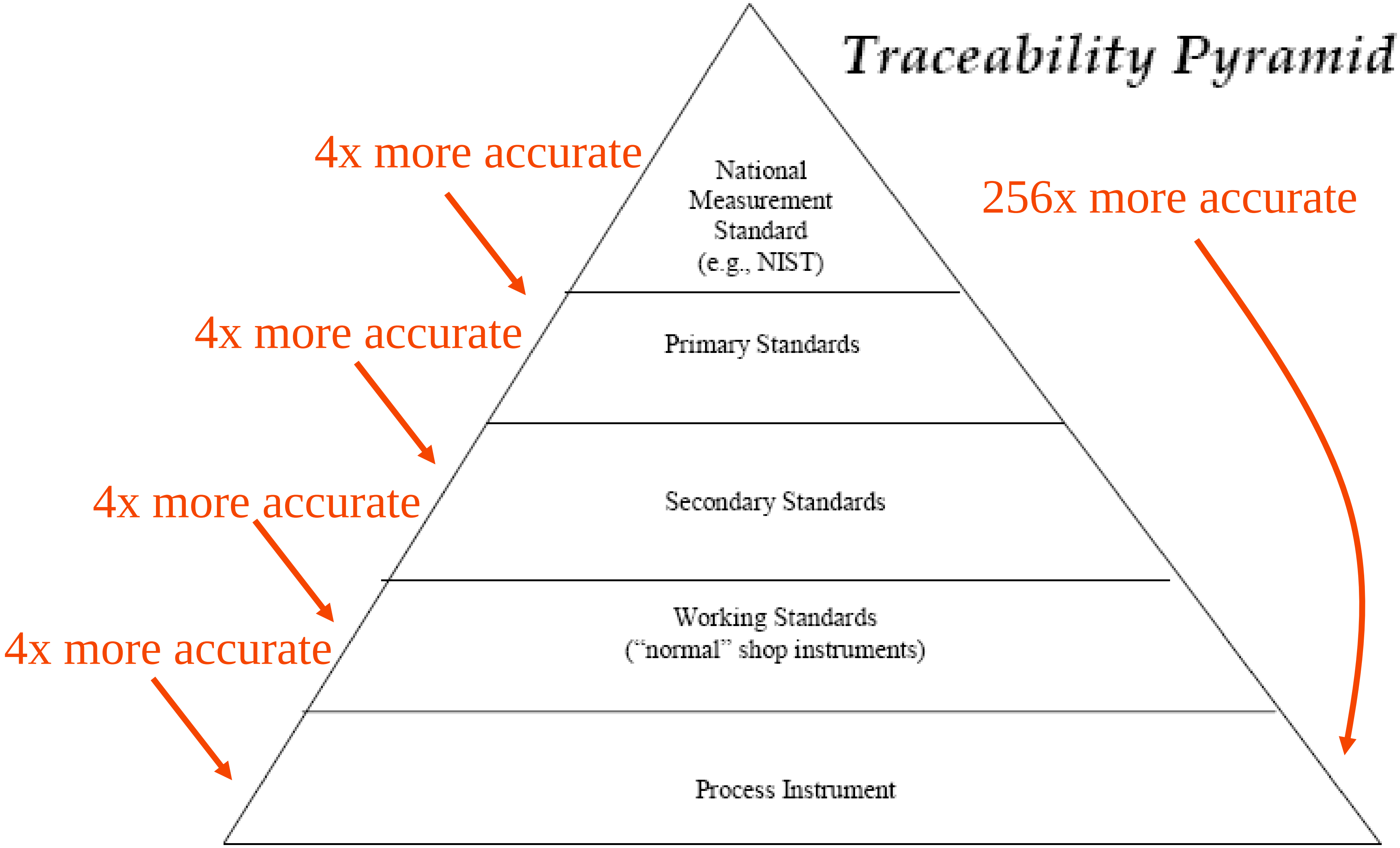
Standards

- National Laboratories such as National Research Council in Canada and National Institute of Standards and Technology in the USA have the responsibility of transferring the physical units of SI to their respective countries
- These Laboratories provide Measurements with a very low level of uncertainty and are considered the national standard
- The national laboratories then transfer accuracy through the chain of calibration to reference level and then to transfer level standards

Standards

- This chain of traceability of standards provides evidence that the measurement is correct. This is an essential element for:
  - **Quality Control Systems (ie. ISO)**
  - **International trade measurements**
  - **International manufacturing standards**

Standards


Traceability Pyramid
4x more accurate
4x more accurate
4x more accurate
4x more accurate
256x more accurate
National Measurement Standard (e.g., NIST)
Primary Standards
Secondary Standards
Working Standards ("normal" shop instruments)
Process Instrument

Standards

- Standard-creating organizations
  - ISO: International Organization for Standards
    - Writes standards for international community
  - ANSI: American National Standard Institute
    - Writes North American standards and also presents them to ISO for consideration as international standards
  - Measurement Canada:
    - Writes standards for the metrology portion of Canadian gas and electric utilities (ie. S-G-01)
  - AGA: American Gas Association
    - Writes standards for metrology/manufacturing portion of American gas industry
    - Largely adhered to by other nations

Standards

- 17025 Approved Calibration Certificate
  - **Title**
  - **Name and Address of the Calibration Location**
  - **Certificate number**
  - **Name and Address of the Client**
  - **Test method used**
  - **Description of the item being Calibrated**
  - **Date of Calibration**
  - **Calibration results**
  - **Name and Signature of the person performing the calibration**
  - **Environmental conditions at the time of test**
  - **Statement of uncertainty for the calibration**
  - **Evidence the measurements are traceable**

Measurement Methods

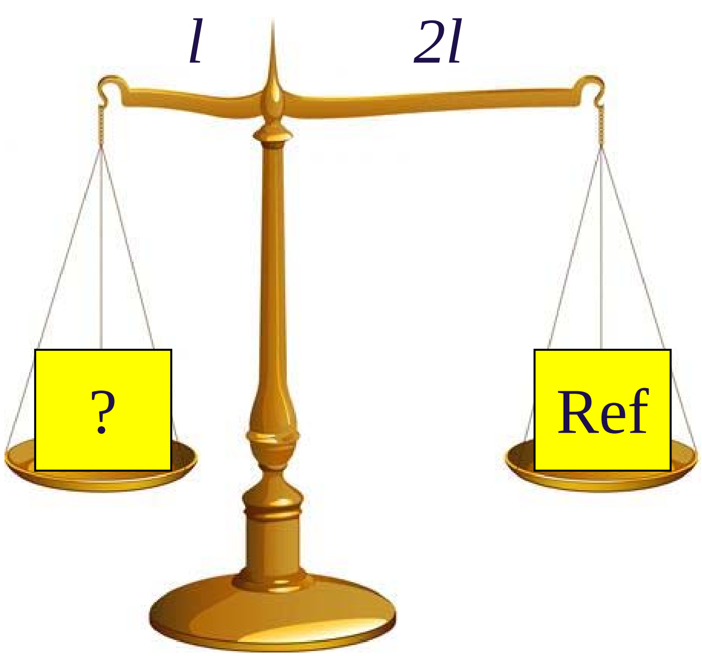
- 7 ways to measure
  - **Direct**
    - **Measurement in direct contact with the measurand and provides a value representative of the measurand as read from an indicating device**
    - **Measuring length with a ruler**

Measurement Methods

– **Differential**
  - **Measurement made by comparing an unknown measurand with a known quantity (standard) such that when their values are equal, a difference indication of zero (null) is given**
  - **Measuring the length of a gage block using a gage block comparator**

Measurement Methods

– **Ratio**
  - **Measurement made by comparing an unknown measurand with known quantity (standard) in order to determine how many divisions of the unknown measurand can be comprised of within the known quantity**
  - **Off-center scale balance**



Measurement Methods

- Reciprocity
  - Measurement that makes use of a transfer function(s) (relationship) in comparing two or more measurement devices subject to the same measurand
  - Verify the reading of one pressure transmitter by comparing it to the reading of another similar pressure transmitter
- Transfer
  - Measurement employing an intermediate device used for conveying (transferring) a known measurand value to an unknown measurement device or artifact
  - Correlation process

Measurement Methods

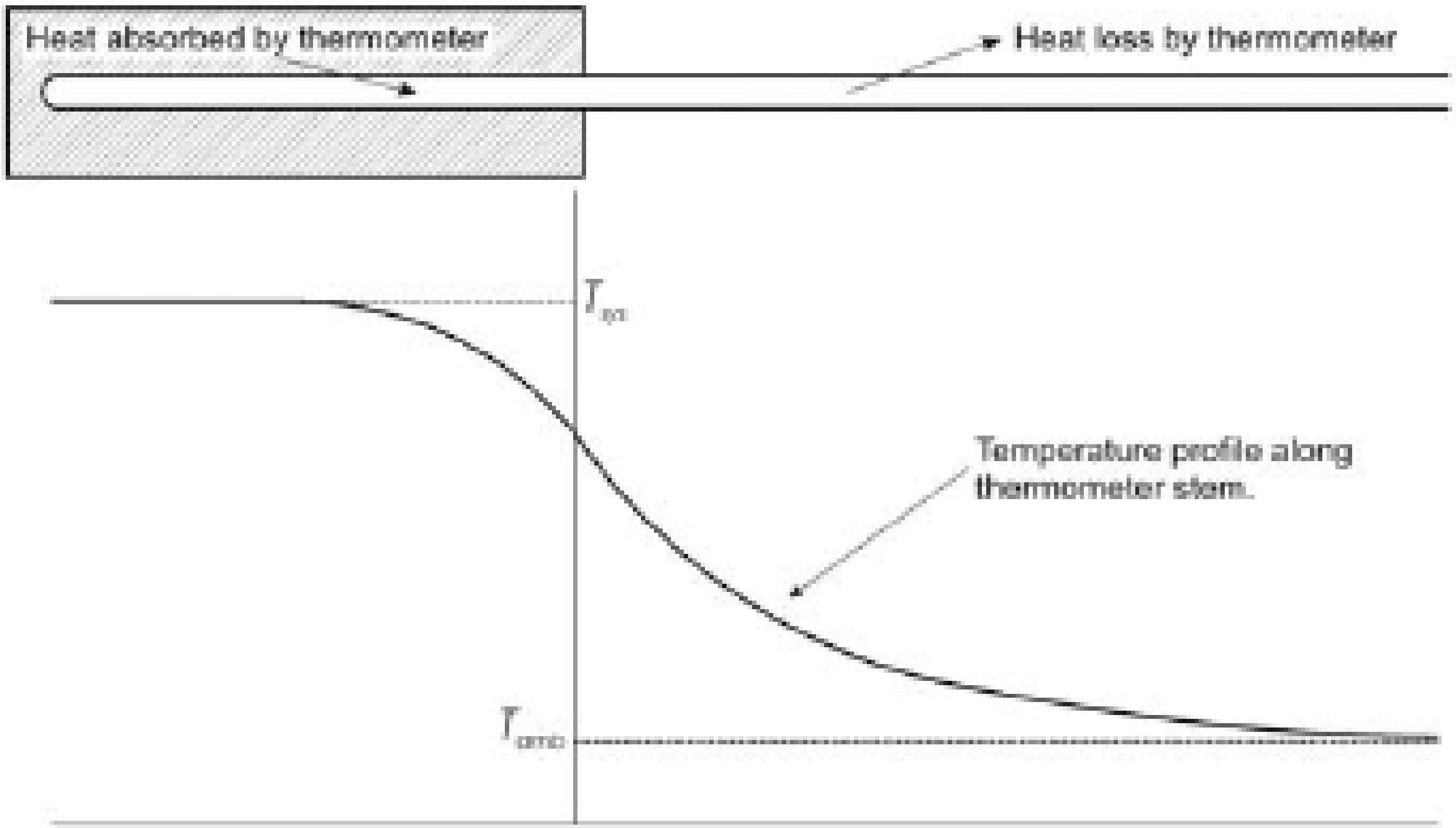
- **Substitution**
  - **Measurement using a known measurement device or artifact (standard) to establish a measurand value after which the known measurement device or artifact is removed and an unknown measurement device (unit under test) is inserted in its place so that its response to the measurand can be determined**
  - **Using a certified voltmeter to set a voltage, disconnecting the certified voltmeter, then connecting another voltmeter and obtaining a reading**
- **Indirect**
  - **Measurement made of a non-targeted measurand that is used to determine value of targeted measurand**
  - **Determining temperature by measuring resistance of RTD**

Temperature Calibration - Adversaries

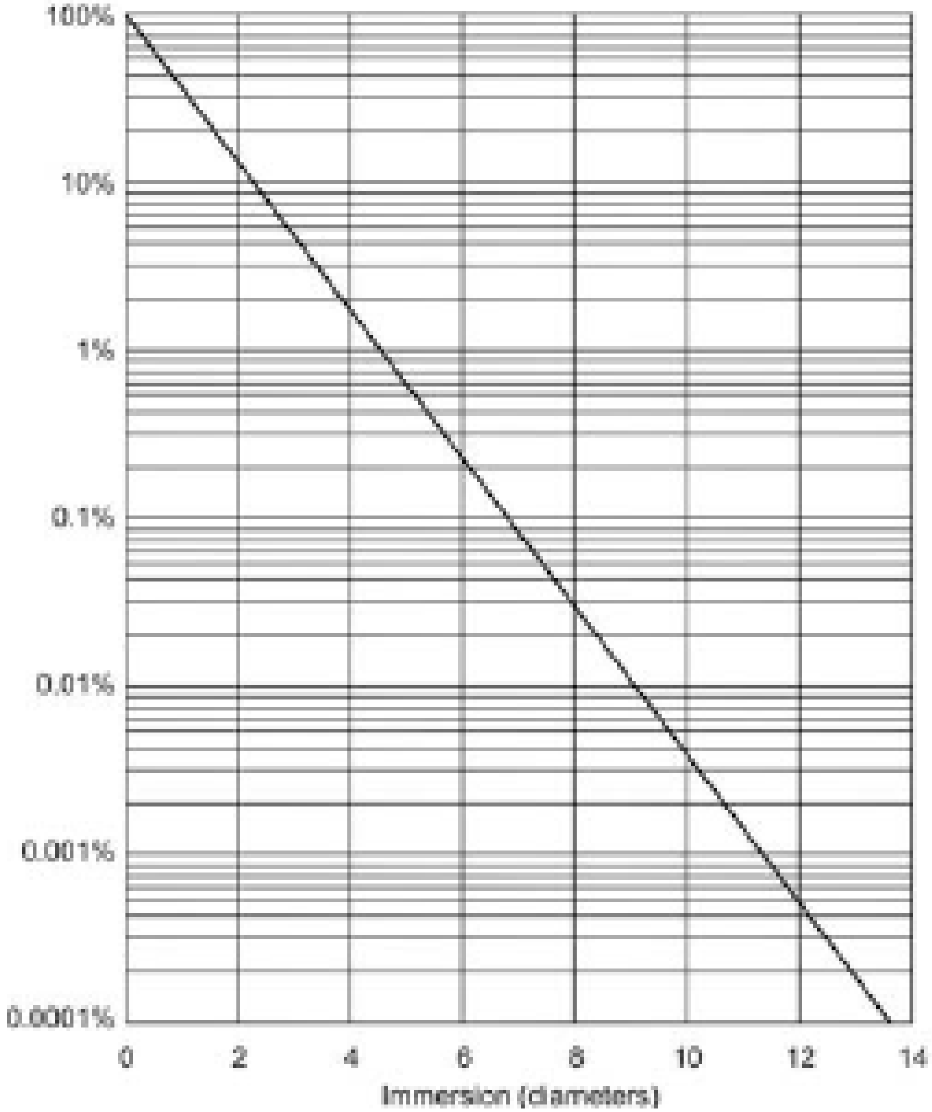
- Stratification
  - **Difference in temperatures between two locations**
  - **Hot fluids rise, cool fluids fall**
  - **Occurs anywhere (room, liquid bath, etc)**
- Energy loss due to evaporation
  - **Occurs primarily when using liquid baths**
  - **Could also affect moisture on probe in air**
  - **Cooling effect from air trying to absorb moisture**

Temperature Calibration - Remedies

- Keep sensing point away from the surface



Temperature Calibration – Remedies



- 1% - 5 diameters
- 0.01% – 10 diameters
- 0.0001% - 15 diameters

Eg. For a ¼” probe in a bath the temperature element should be immersed to about 2 ½” past the sensing part of the probe for an accuracy of 0.01%

Temperature Calibration - Remedies

- Close proximity
  - **Don't place arbitrarily in bath**
  - **Prefer to have sensing points touching**
  - **Use solid mass or combination of solid mass in temperature bath**

Pressure Calibration - Adversaries

- Leaks
  - **Hard to verify value when constantly moving**
- Temperature
  - **Charles' Law**
- Compressible tubing
  - **Moving compressible tubes changes dimensions → volume**

Pressure Calibration - Remedies

- Remove the leak (or at least its effects)
  - **Constantly adjust for leak (not ideal, but practical)**
  - **Control built-in to high end pressure calibrators**
- Try not to handle pressure line
  - **Body heat could affect pressure**
  - **0.3°C results in 0.1% change in pressure reading**

Pressure Calibration - Remedies

- Use semi-rigid tubing if possible
  - **If machine has compressible tubing, don't move it**
- Modify hose length to suit your needs
  - **Longer hose sometimes easier to control manually**
  - **Some instruments measure attached volume**
  - **Do not use longer tubing than required: even semi-rigid tubing can affect reading if moved while calibrating**

Volumetric Verification

- Explanation of actual and standard volume
- Explanation of actual and stated volume on badges

Volumetric Verification

- Actual volume
  - **Volume under the conditions of the device by which it was measured**
- Standard volume
  - **Actual volume converted to an equivalent volume under the conditions of the device that is being compared (typically meter under test) or some standard set of conditions (ie. Base conditions of 14.7 psi @ 60°F)**
  - **Converted using Boyle's law and Charles' law**

    (see also equation of state, ideal gas law)

Volumetric Verification

- To convert actual volume to standard volume we will declare the following:
  - **Actual volume = V_a**
  - **Actual temperature = T_a**
  - **Actual pressure = P_a**
  - **Standard volume = V_s**
  - **Standard temperature = T_s**
  - **Standard pressure = P_s**
- **Key point**
  - **All values NEED to be in absolute terms**
    You WILL get an incorrect answer if not

Volumetric Verification

- Boyle's law

$$V_1 \times P_1 = V_2 \times P_2$$

- Charles' law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- Combining and substituting a for 1 and s for 2

$$\frac{V_a \times P_a}{T_a} = \frac{V_s \times P_s}{T_s}$$

- So to get the volume at standard conditions (Vs)

$$V_s = V_a \times \frac{P_a}{P_s} \times \frac{T_s}{T_a}$$

Volumetric Verification

- For example, a reference meter registers $3m^3$ at 20.1°C and 15psia
- The meter under test registers $3m^3$ at 20.3°C and 14.7psia
- At this point we cannot say that $3m^3 = 3m^3$ therefore the MUT has 0% error
- We must convert the volume registered by the reference meter to the conditions of the MUT

Volumetric Verification

- We can state the following:
  - **V_a=3m³**
  - **P_a=15psia**
  - **T_a=20.1°C + 273.15 = 293.25K**
  - **P_s=14.7psia**
  - **T_s=20.3°C + 273.15 = 293.45K**
  - **V_s=?**

Volumetric Verification

$$3m^3 \times \frac{15\,psia}{14.7\,psia} \times \frac{293.45K}{293.25K} = 3.063m^3$$

$$\frac{3m^3 - 3.063m^3}{3.063m^3} * 100\% = -2.06\%$$

Volumetric Verification

- Volume per tangent revolution of diaphragm meter

$$\text{revs per dial rotation} = \frac{\text{dial volume}}{\text{stated volume per rev}}$$

$$\text{round}(\text{revs per dial rotation})$$

$$\text{actual volume per rev} = \frac{\text{dial volume}}{\text{revs per dial rotation}}$$

Volumetric Verification

- Example: AC-250
  - **2ft³ dial**
  - **Stated volume per tangent revolution of 0.111ft³**

$$\frac{2\text{ft}^3}{0.111\text{ft}^3} = 18.018$$

$$\text{round}(18.018) = 18$$

$$\frac{2\text{ft}^3}{18} = 0.1111\text{ft}^3$$

NOTE

Using 0.111ft³ would result in an error of approximately 0.1%

Types of Error

- Random error
  - **Makes up part of uncertainty**
  - **Somewhat quantifiable**
    - **Manufacturers spec ±0.1% of reading, etc.**
  - **Not able to predict**
  - **Not able to correct for**

Types of Error

- Systematic error
  - **Bias**
  - **Quantifiable through R&R testing (round robin)**
  - **Can eliminate or adjust for**
  - **Example: scale or ruler readings between operators**

Another good definition

References

- “The Metrology Handbook” - ASQ
- Wikipedia – see hyperlinks throughout
- ISO’s GUM
- Cameron Instruments website
  - **www.cameroninstruments.com**
- Isotech website
  - **www.isotechna.com**
- Hart Scientific website
  - **www.hartscientific.com (articles)**
  - **www.hartscientific.com (news)**

Questions?