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Chapter 3 - (Measurement Requirements)

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Course Outline

- Introduction – Welcome and objectives
- Chapter 1 – Background and principles
- Chapter 2 – Basic technical requirements
- Chapter 3 – Technical measurement requirements

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- Chapter 4 – Management system requirements
- Chapter 5 – Continual improvement requirements
- Chapter 6 – Monitoring and measuring the quality system

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Basic Measurement Concepts

Part 1 – Uncertainty of Measurement

Part 2 – Traceability of Measurement

Part 3 – Calibration

- Uncertainty is the **Tool** to establish Traceability
- Of these three Traceability of Measurement is the **Primary and Overriding Requirement**, and
- Calibration is how Uncertainty is **Transferred (Propagated)** down the Traceability Chain.

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17025 Measurement Requirements

1. There are 2 questions in this part of the Chapter.
2. What does the standard require?
3. Participants select their own answers.
4. The whole group is balloted for the most appropriate response.
5. Clapping indicates a correctly answered question. Buzzer indicates an incorrectly answered question.
6. The citation from the standard is displayed next to the most correct answer.
7. The quiz then advances to the next question.

Press Continue

17025 Measurement Requirements

7.2.2 Validation of methods:

Laboratories **MUST** evaluate the numerical uncertainties of measurement **DURING METHOD VALIDATION** of a quantitative method.

A. TRUE
B. FALSE
C. NOT APPLICABLE

Part 1 - Uncertainty of Measurement

ISO/IEC 17025 Clause 7.6 states that laboratories must estimate/evaluate uncertainty for all results produced and report it (when required).

- Identify and evaluate all components of uncertainty
- Account for all significant uncertainty contributions

What is Uncertainty of Measurement?

- Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measureand (the actual number) [VIM 3.9]
- The result of calibrations.
- The best indication of the quality of a test result.

“Confidence Region” Vs “Uncertainty”

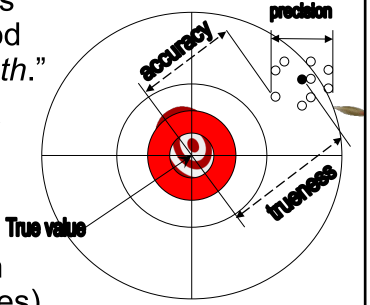
During the original drafting of the standard, we should have used the term “confidence region” instead of the term “uncertainty.”

What we really mean is…

“I have determined that 95% of all values obtained by this test will be between X and Y.”

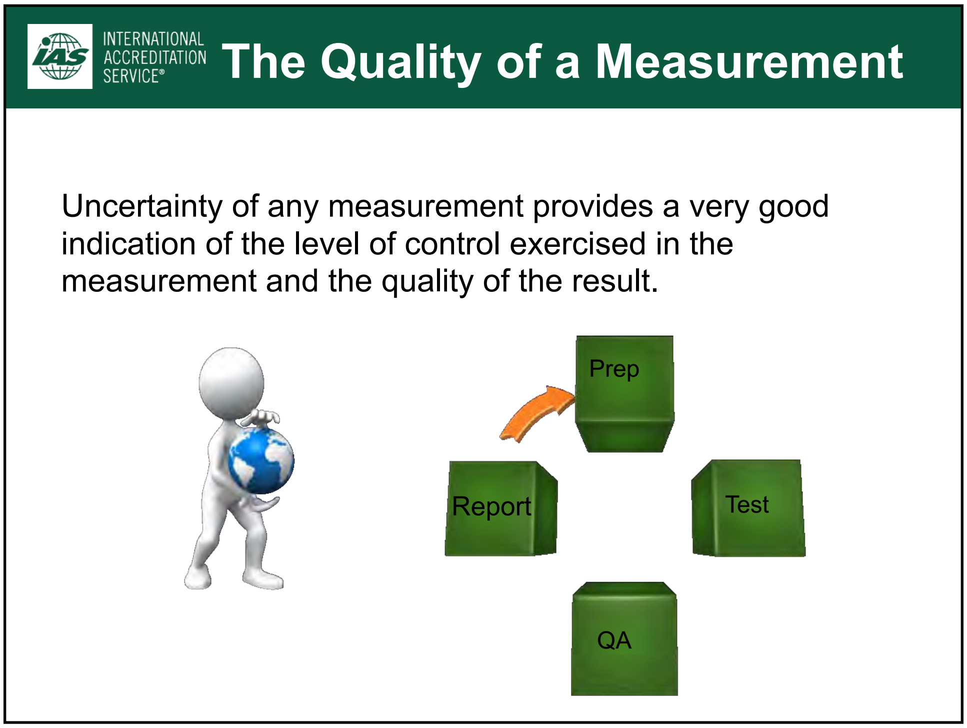
Uncertainty = Confidence Region

- Since no derived quantitative result is absolute, there must be some method of telling us how close it is to the "*truth*."
- This method is called "measurement uncertainty" or "uncertainty of measurement."
  - It is not about "not being sure"
  - It concerns establishing a region about the result (a range of values) to which we can mathematically (with some certainty) assign a level of CONFIDENCE



Confidence and Traceability

- Uncertainty of any measurement is required in order to establish the confidence that an interpreter of results can have in that measurement.
- Uncertainty is the basis for the establishment of traceability of the measurement



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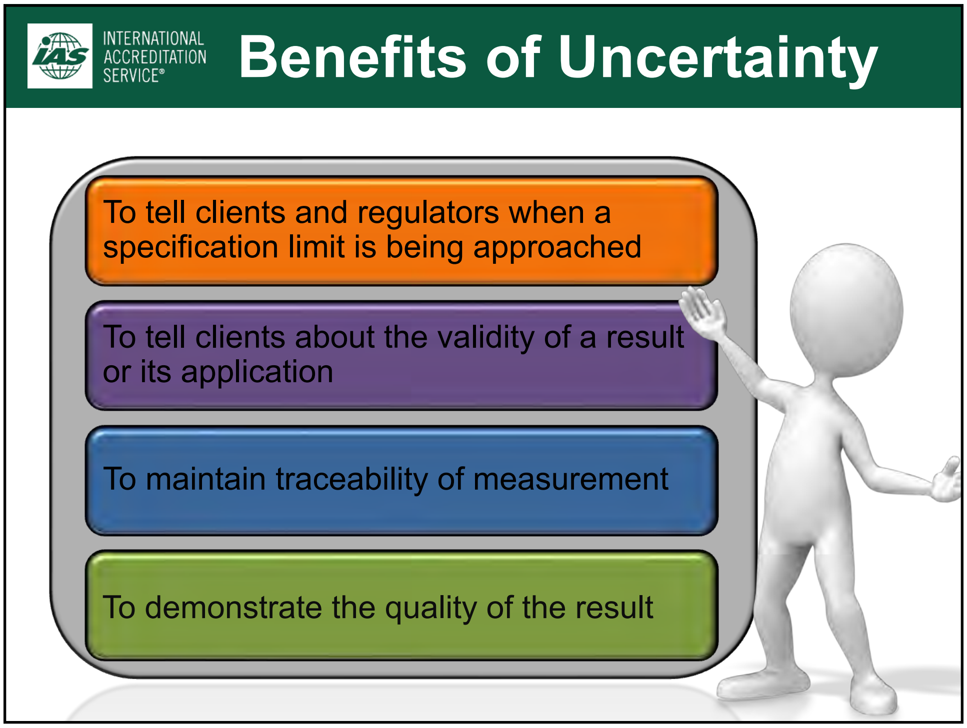
The Quality of a Measurement

Uncertainty of any measurement provides a very good indication of the level of control exercised in the measurement and the quality of the result.



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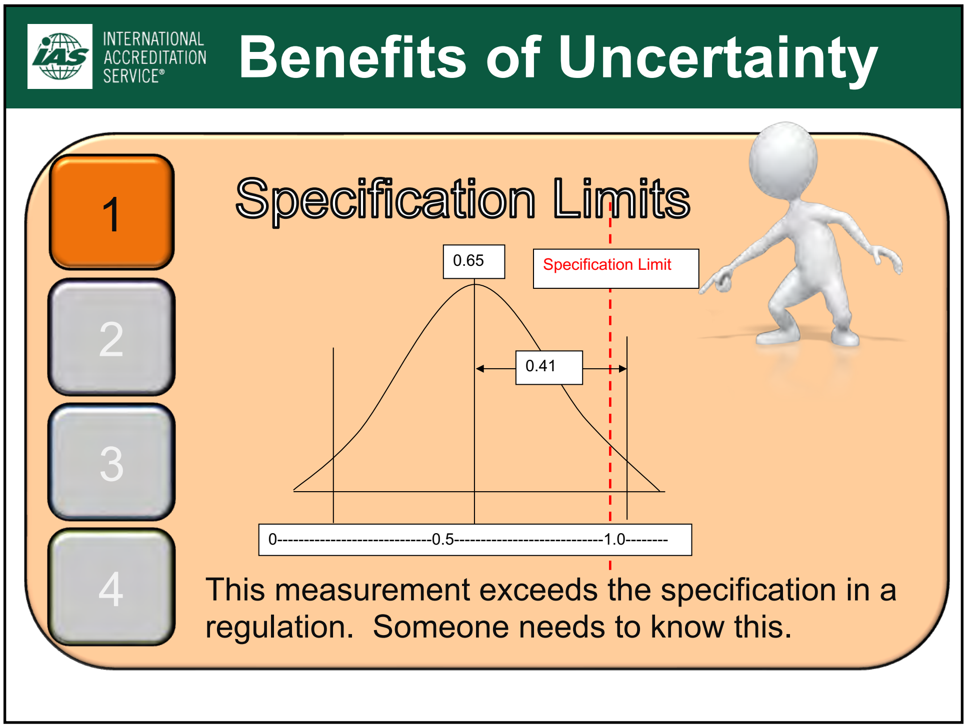
Benefits of Uncertainty

- To tell clients and regulators when a specification limit is being approached
- To tell clients about the validity of a result or its application
- To maintain traceability of measurement
- To demonstrate the quality of the result



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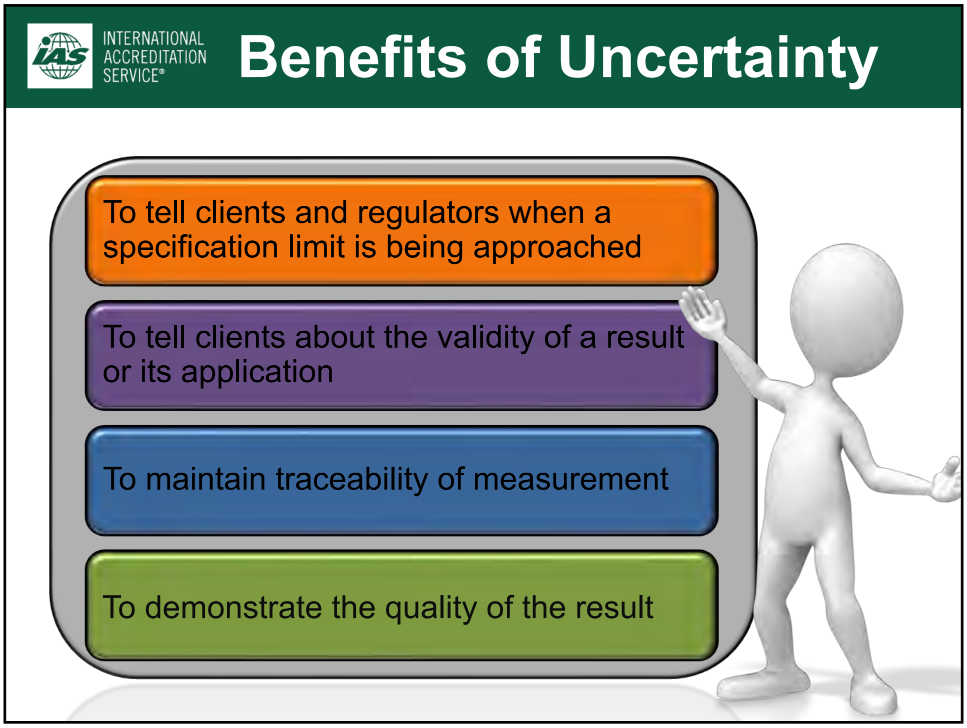
Benefits of Uncertainty

Specification Limits

This measurement exceeds the specification in a regulation. Someone needs to know this.



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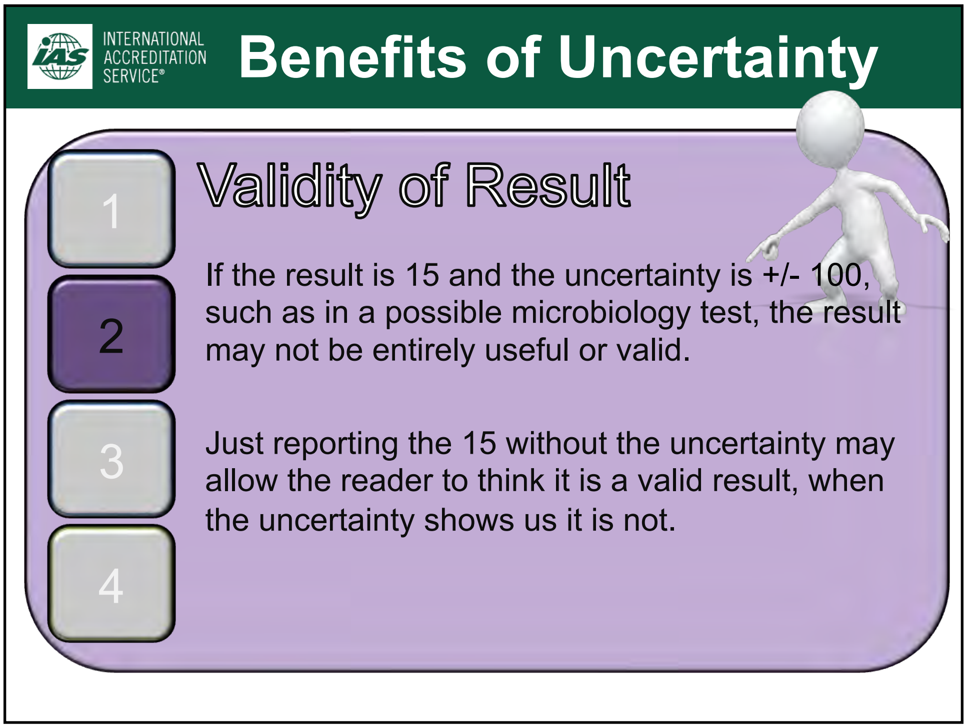

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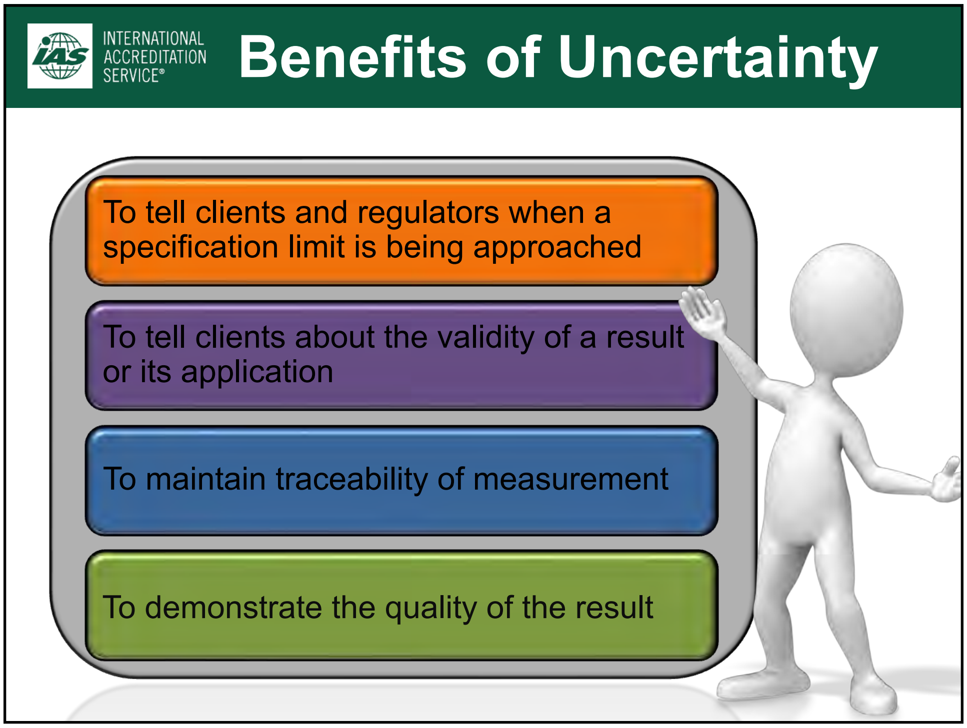
Benefits of Uncertainty

1
2
3
4

Validity of Result

If the result is 15 and the uncertainty is +/- 100, such as in a possible microbiology test, the result may not be entirely useful or valid.

Just reporting the 15 without the uncertainty may allow the reader to think it is a valid result, when the uncertainty shows us it is not.



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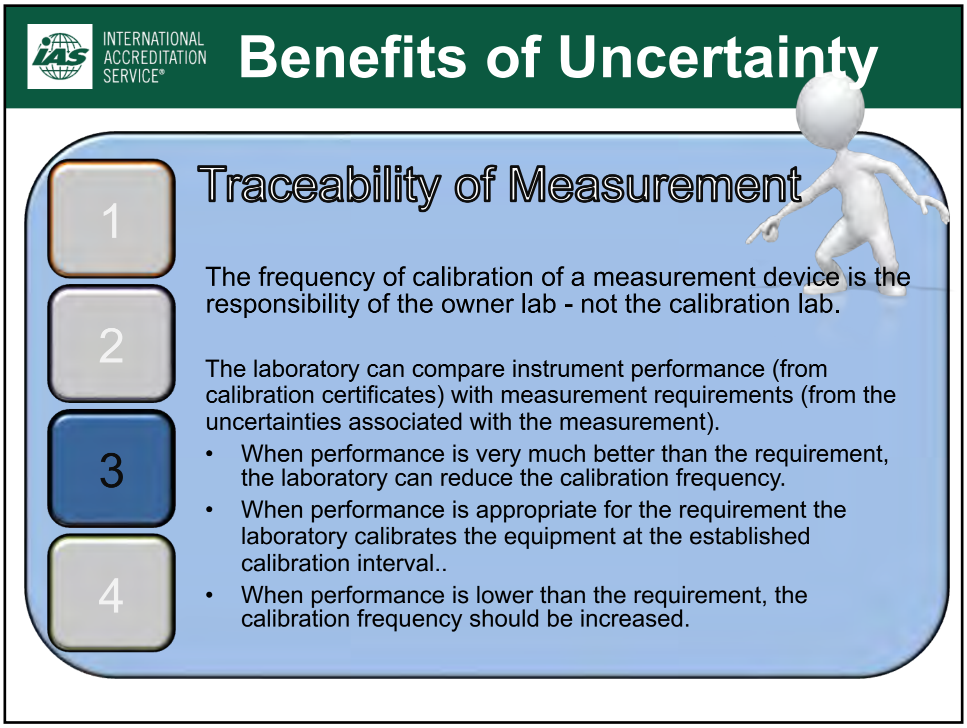
Benefits of Uncertainty

- To tell clients and regulators when a specification limit is being approached
- To tell clients about the validity of a result or its application
- To maintain traceability of measurement
- To demonstrate the quality of the result



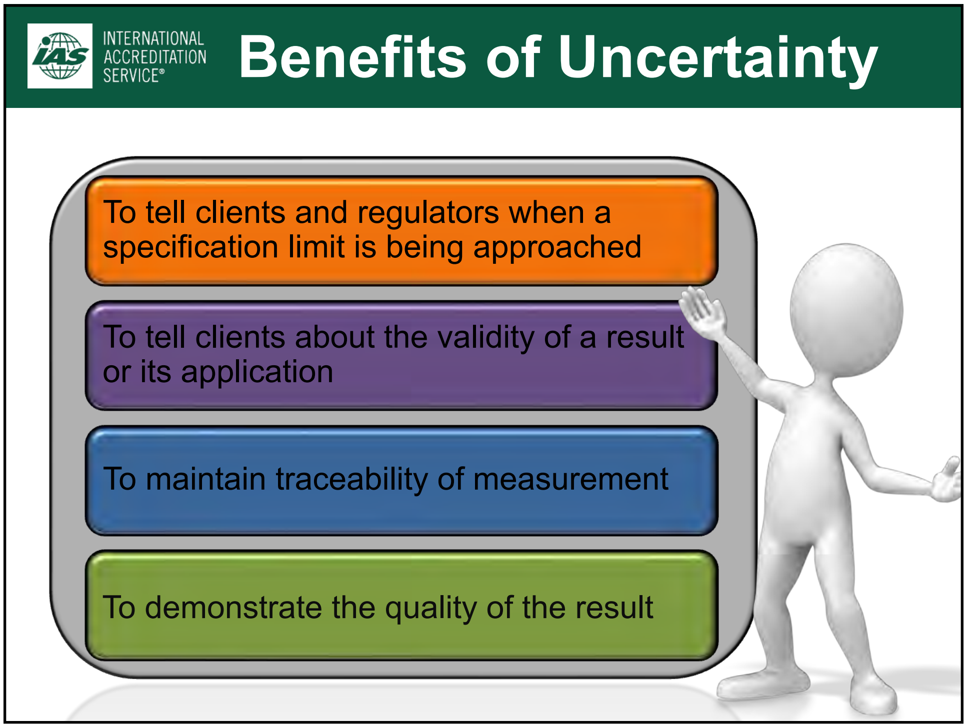
Benefits of Uncertainty

Traceability of Measurement

The frequency of calibration of a measurement device is the responsibility of the owner lab - not the calibration lab.

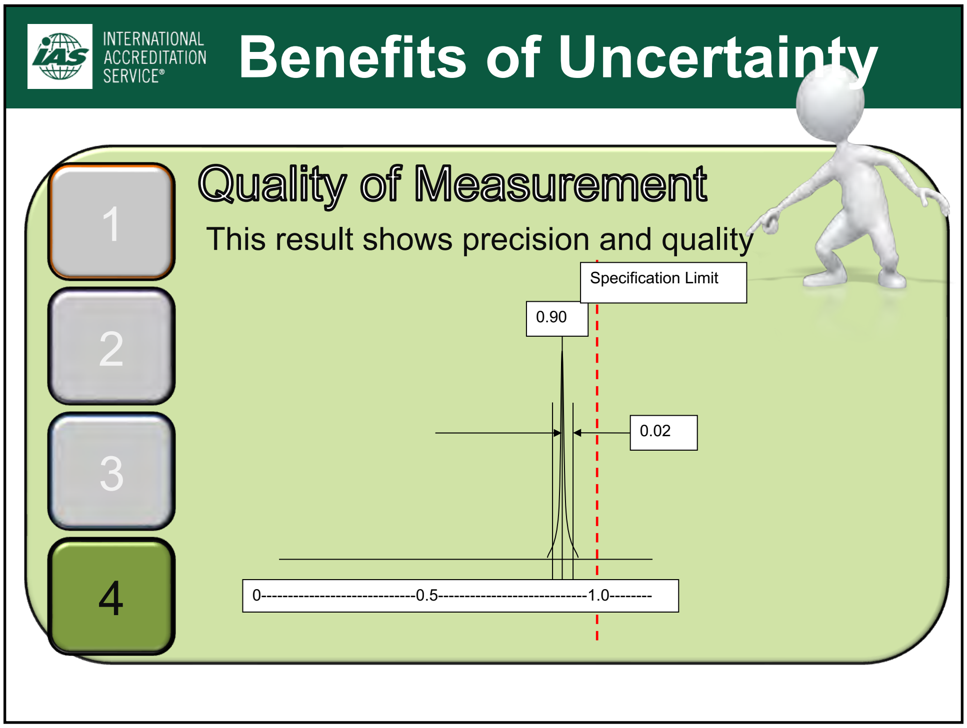
The laboratory can compare instrument performance (from calibration certificates) with measurement requirements (from the uncertainties associated with the measurement).

- When performance is very much better than the requirement, the laboratory can reduce the calibration frequency.
- When performance is appropriate for the requirement the laboratory calibrates the equipment at the established calibration interval..
- When performance is lower than the requirement, the calibration frequency should be increased.



Benefits of Uncertainty

- To tell clients and regulators when a specification limit is being approached
- To tell clients about the validity of a result or its application
- To maintain traceability of measurement
- To demonstrate the quality of the result



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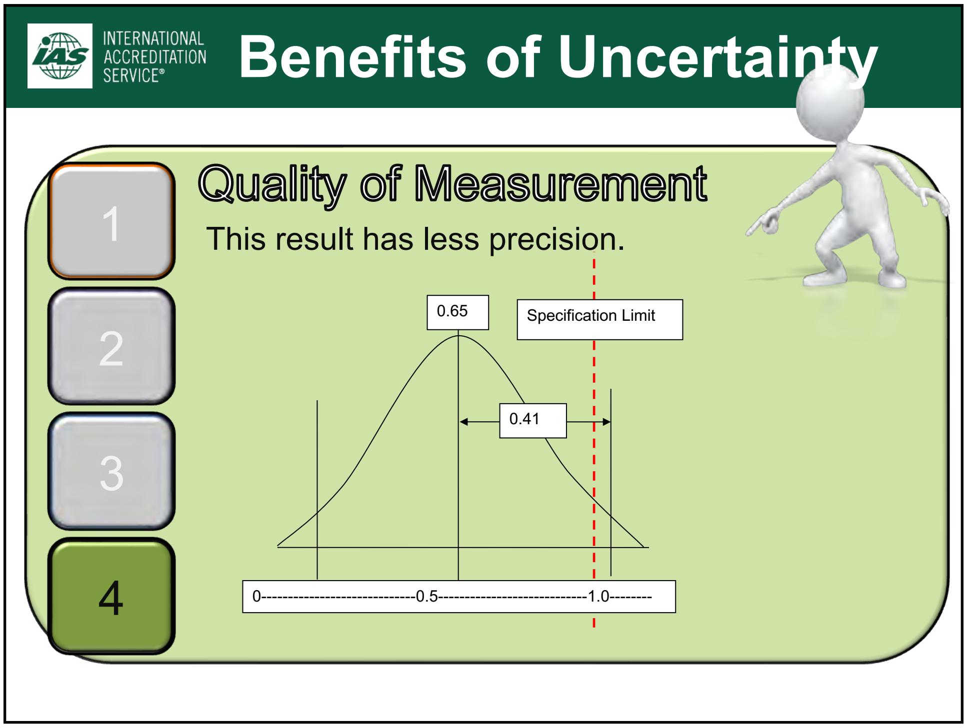
Benefits of Uncertainty

Quality of Measurement

This result shows precision and quality



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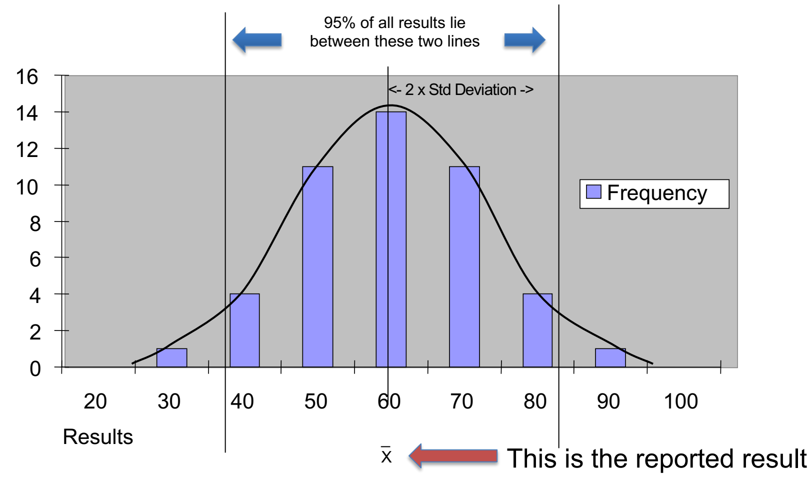
Benefits of Uncertainty

Quality of Measurement

This result has less precision.

What does Uncertainty look like?



95% of all results lie between these two lines

This is the reported result

See pages 16 and 17 of the the GUM for other types of probability distributions.
http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

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Basic GUM Method

1) Define the quantity being measured in terms of your measurement process

$$Y = f(X_1, X_2, \ldots, X_i)$$

- Y is your output, your measurand, the value you want to quantify.
- Input values X_i are your measured input quantities to be combined to determine your output quantity
- Each input value X_i has an uncertainty $u(x_i)$ associated with it

2) Determine your measurement equation in terms of your input quantities; for example, tensile strength test at break, S, is defined as load or force, F, divided by cross-sectional area A, so the above becomes

$$S = F/A$$

3) Calculate your measurement result from your input quantities

Basic GUM Method cont.

4) Determine the uncertainty contributors and obtain uncertainty estimates for each contributor $u(x_i)$.

Likely contributors: repeatability of measurement, personal bias in reading (e.g. parallax effects), inexact values in measurement standards and test equipment, environmental effects, etc.

5) Determine which uncertainty contributors are Type A and Type B

Type A evaluation of measurement uncertainty

– evaluation of a component of **measurement uncertainty** by a statistical analysis of **measured quantity values** obtained under defined measurement conditions

Type B evaluation of measurement uncertainty

– evaluation of a component of **measurement uncertainty** determined by means **other than** a Type A evaluation of measurement uncertainty

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Basic GUM Method cont.

6) Determine the “standard uncertainty” for each contributor

- “standard uncertainty” is defined as **one standard deviation**
- Evaluation of the standard uncertainty depends on whether the uncertainty contributor is Type A or Type B

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Type A Uncertainties

- Take multiple measurements under identical conditions, if possible -- (x_1, x_1, … x_n)
- Determine the mean and standard deviation of your measurements:

Mean
$$\bar{x} = \frac{1}{n}(x_1 + x_2 + ... + x_n)$$

Standard Deviation
$$s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Standard Deviation of the Mean (sometimes called standard error or standard error of the mean)
$$s_{\bar{x}} = \frac{s_x}{\sqrt{n}}$$

- *Note that the* ***standard deviation of the mean*** *is used as an estimate of the standard uncertainty of a measurement if the* ***mean value*** *is reported.*

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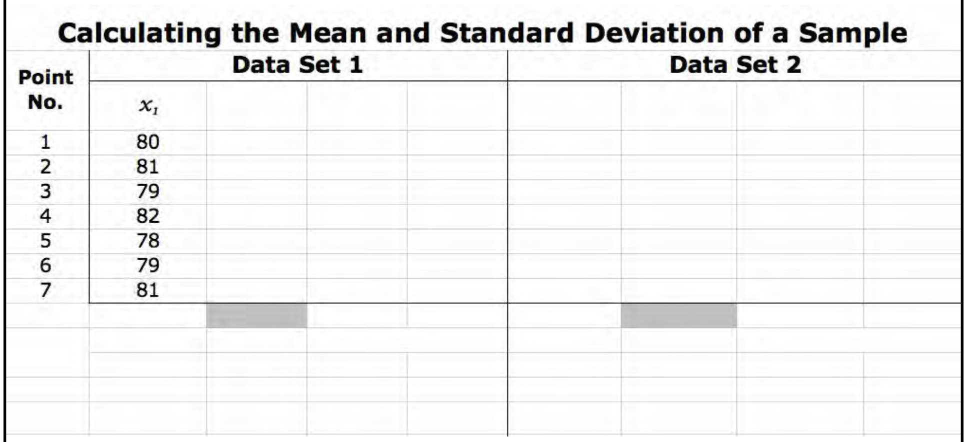
Develop a Standard Deviation



Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1							
1	80							
2	81							
3	79							
4	82							
5	78							
6	79							
7	81							

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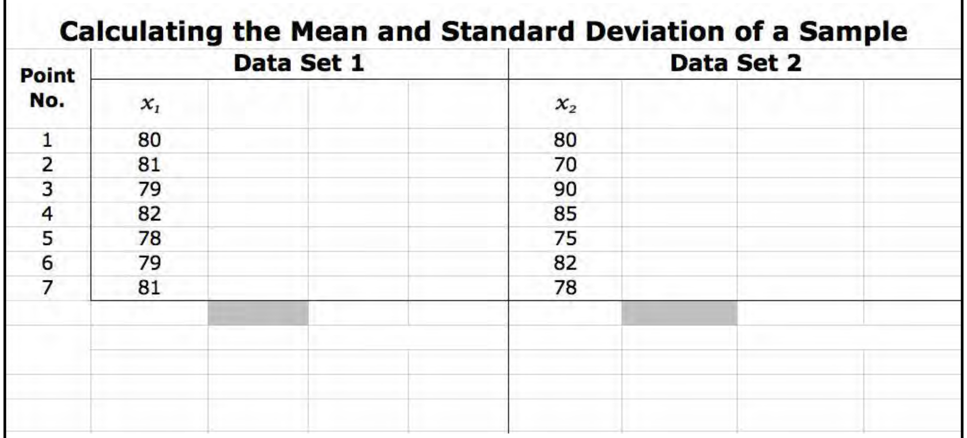
Develop a Standard Deviation



Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1				x_2			
1	80				80			
2	81				70			
3	79				90			
4	82				85			
5	78				75			
6	79				82			
7	81				78			

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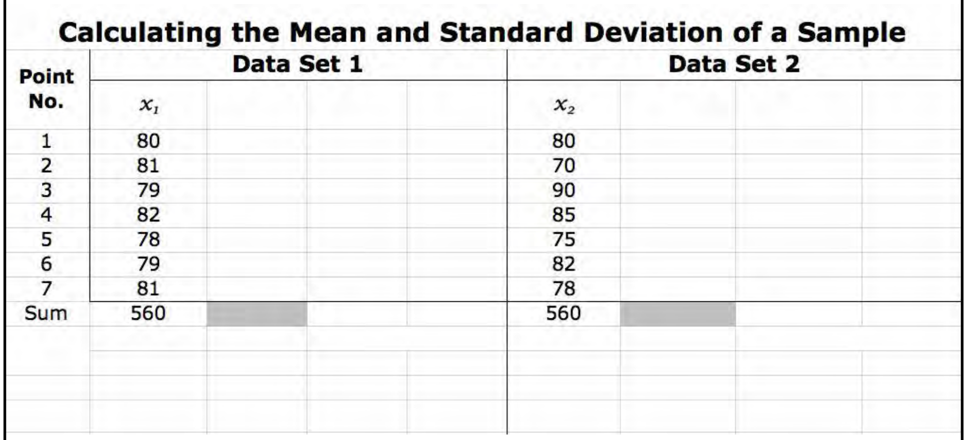
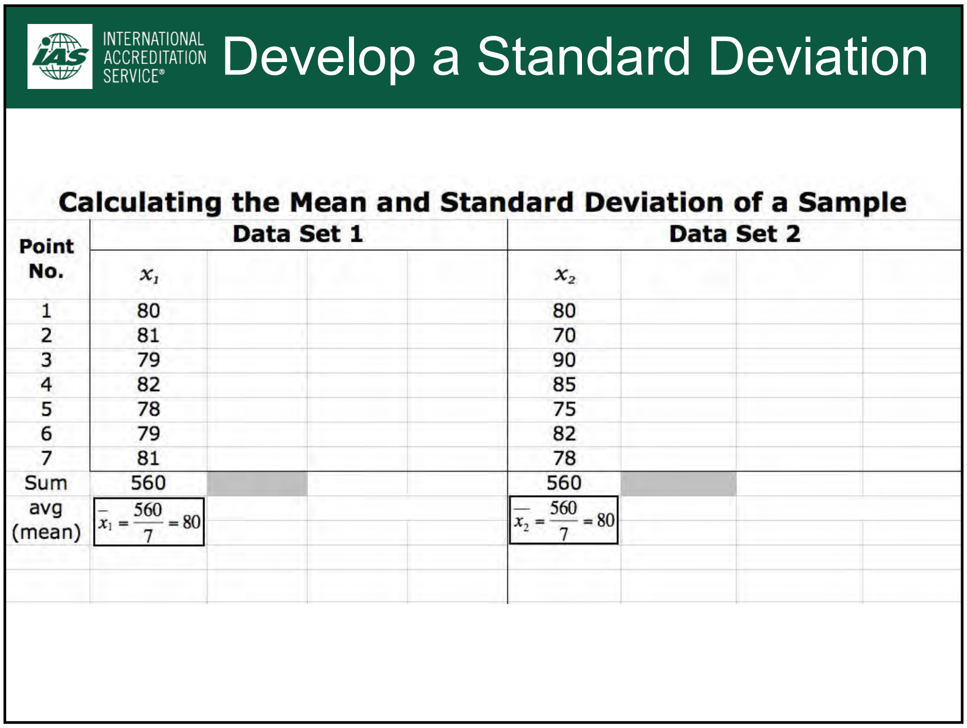
Develop a Standard Deviation



Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1				x_2			
1	80				80			
2	81				70			
3	79				90			
4	82				85			
5	78				75			
6	79				82			
7	81				78			
Sum	560				560			



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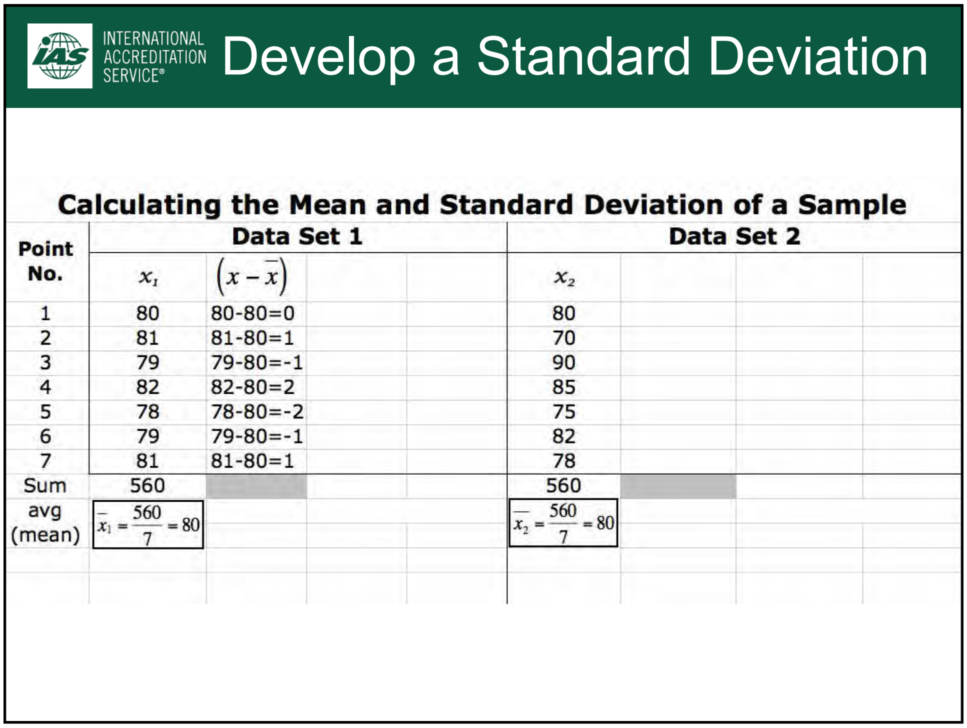
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1				x_2			
1	80				80			
2	81				70			
3	79				90			
4	82				85			
5	78				75			
6	79				82			
7	81				78			
Sum	560				560			
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$				$\bar{x}_2 = \frac{560}{7} = 80$			



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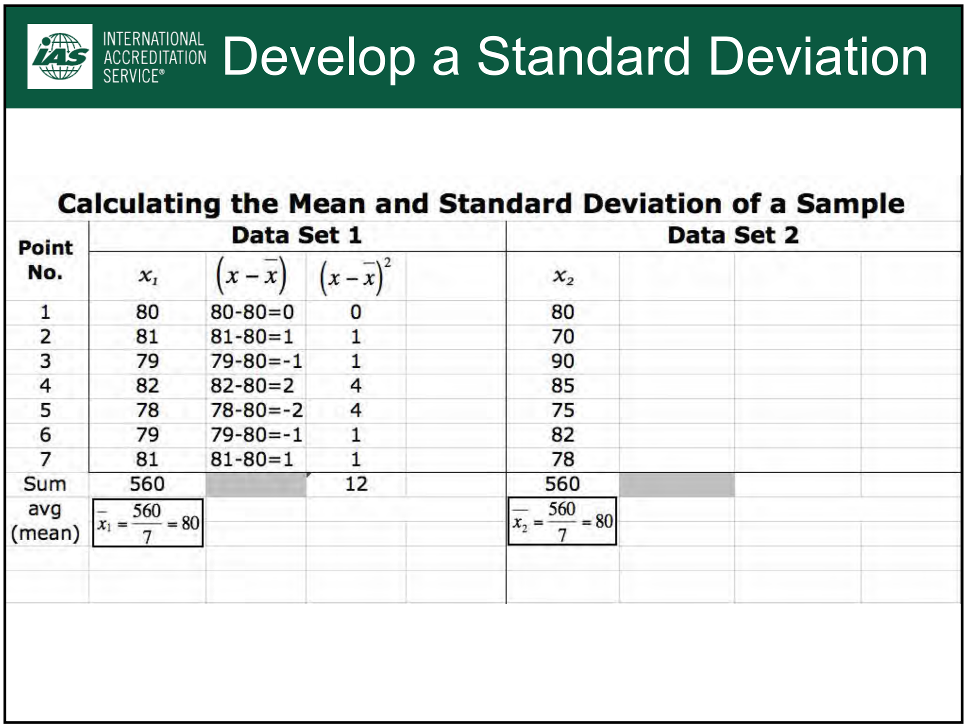
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1	$\left(x - \bar{x}\right)$			x_2			
1	80	80-80=0			80			
2	81	81-80=1			70			
3	79	79-80=-1			90			
4	82	82-80=2			85			
5	78	78-80=-2			75			
6	79	79-80=-1			82			
7	81	81-80=1			78			
Sum	560				560			
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$				$\bar{x}_2 = \frac{560}{7} = 80$			



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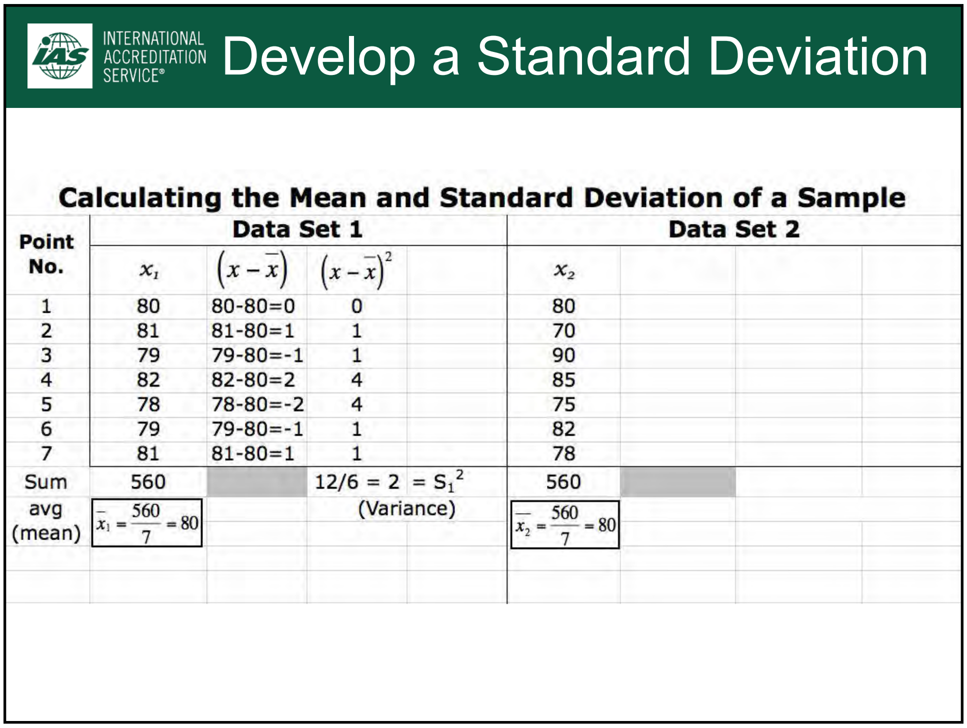
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2			
1	80	80-80=0	0		80			
2	81	81-80=1	1		70			
3	79	79-80=-1	1		90			
4	82	82-80=2	4		85			
5	78	78-80=-2	4		75			
6	79	79-80=-1	1		82			
7	81	81-80=1	1		78			
Sum	560		12		560			
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$				$\bar{x}_2 = \frac{560}{7} = 80$			



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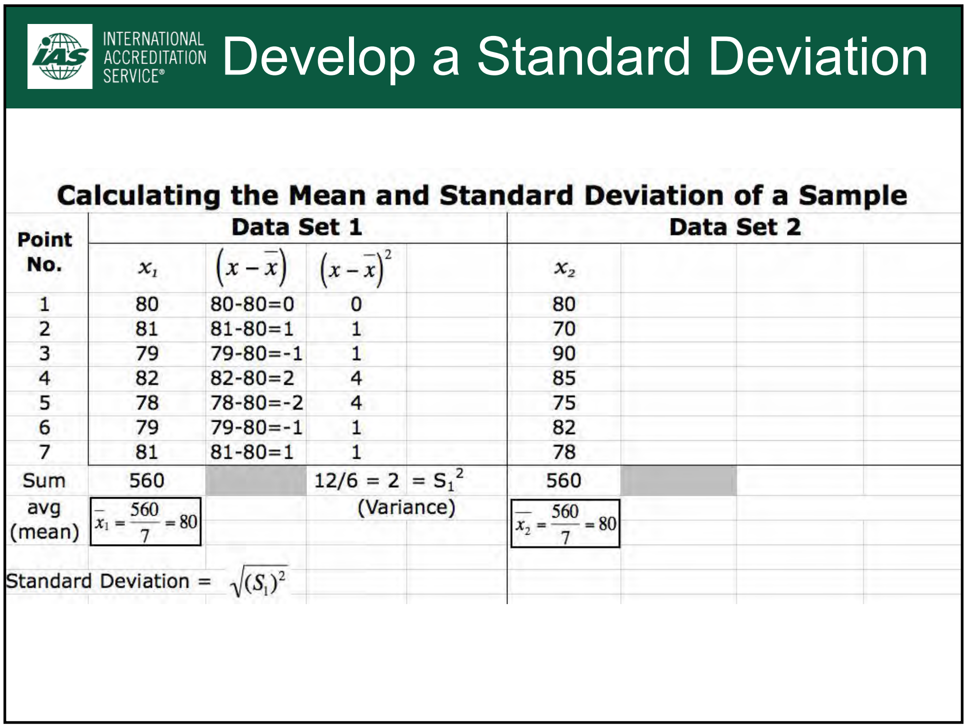
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2			
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2			
1	80	80-80=0	0		80			
2	81	81-80=1	1		70			
3	79	79-80=-1	1		90			
4	82	82-80=2	4		85			
5	78	78-80=-2	4		75			
6	79	79-80=-1	1		82			
7	81	81-80=1	1		78			
Sum	560		12/6 = 2 = S_1^2		560			
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)		$\bar{x}_2 = \frac{560}{7} = 80$			



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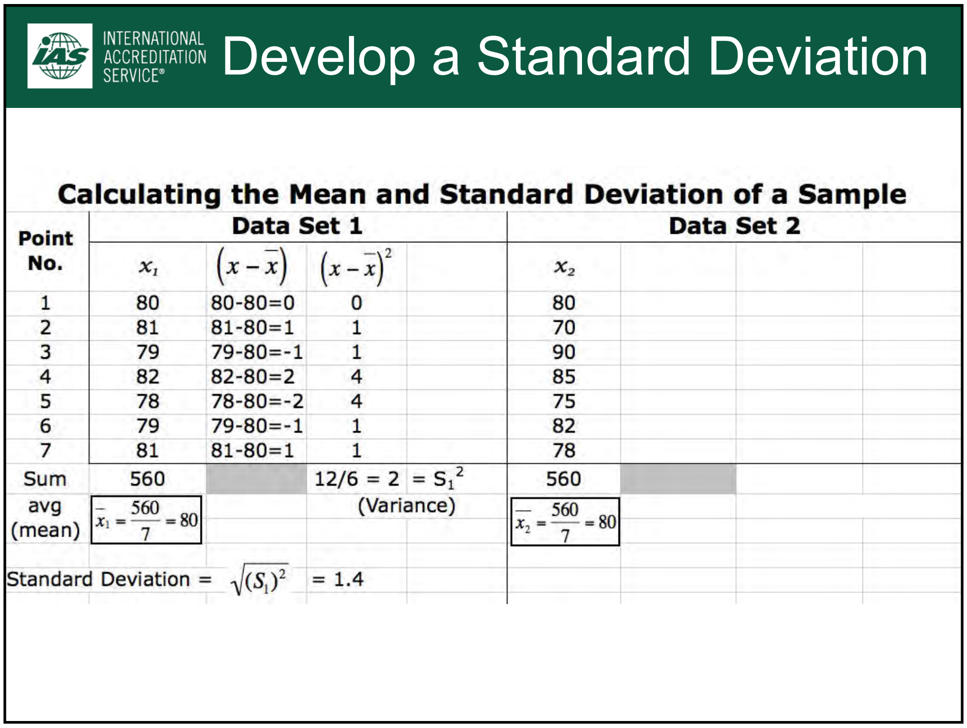
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2
1	80	80-80=0	0		80
2	81	81-80=1	1		70
3	79	79-80=-1	1		90
4	82	82-80=2	4		85
5	78	78-80=-2	4		75
6	79	79-80=-1	1		82
7	81	81-80=1	1		78
Sum	560		12/6 = 2 = S_1^2		560
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)		$\bar{x}_2 = \frac{560}{7} = 80$

Standard Deviation = $\sqrt{(S_1)^2}$



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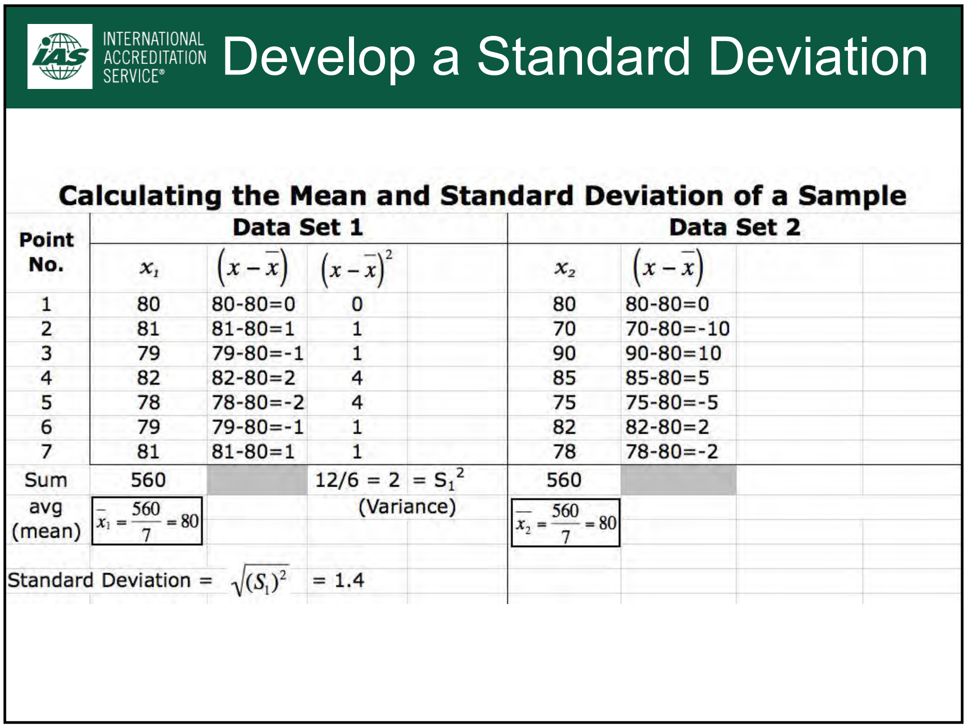
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1				Data Set 2
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2
1	80	80-80=0	0		80
2	81	81-80=1	1		70
3	79	79-80=-1	1		90
4	82	82-80=2	4		85
5	78	78-80=-2	4		75
6	79	79-80=-1	1		82
7	81	81-80=1	1		78
Sum	560		12/6 = 2 = S_1^2		560
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)		$\bar{x}_2 = \frac{560}{7} = 80$

Standard Deviation = $\sqrt{(S_1)^2}$ = 1.4



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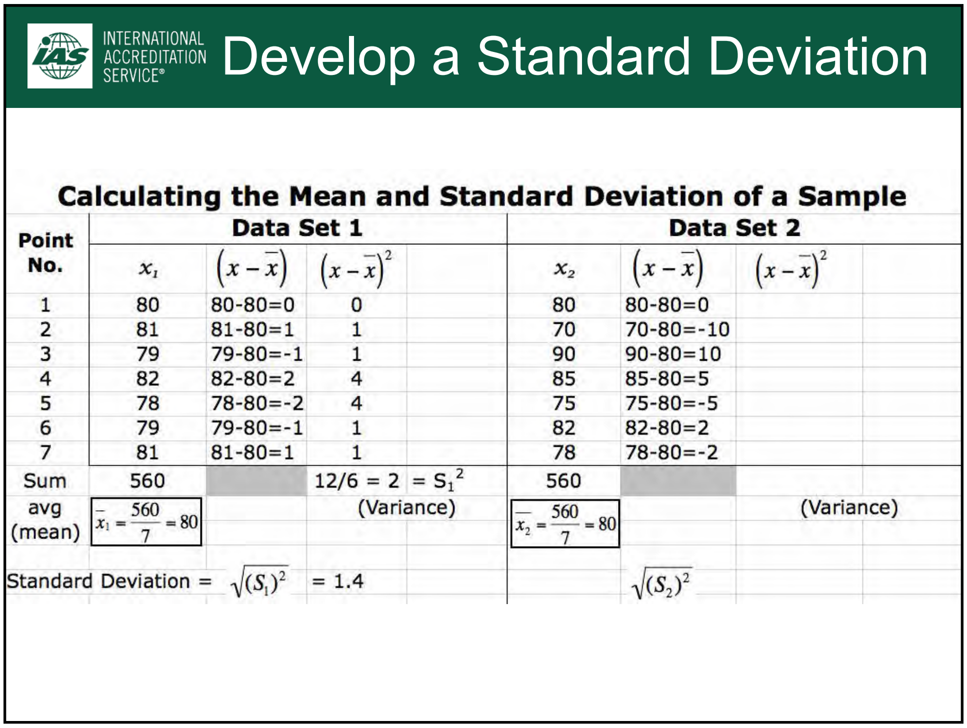
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	**Data Set 1**			**Data Set 2**	
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$	x_2	$(x-\bar{x})$
1	80	80-80=0	0	80	80-80=0
2	81	81-80=1	1	70	70-80=-10
3	79	79-80=-1	1	90	90-80=10
4	82	82-80=2	4	85	85-80=5
5	78	78-80=-2	4	75	75-80=-5
6	79	79-80=-1	1	82	82-80=2
7	81	81-80=1	1	78	78-80=-2
Sum	560		12/6 = 2 = S_1^2	560	
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)	$\bar{x}_2 = \frac{560}{7} = 80$	
Standard Deviation =		$\sqrt{(S_1)^2}$	= 1.4		



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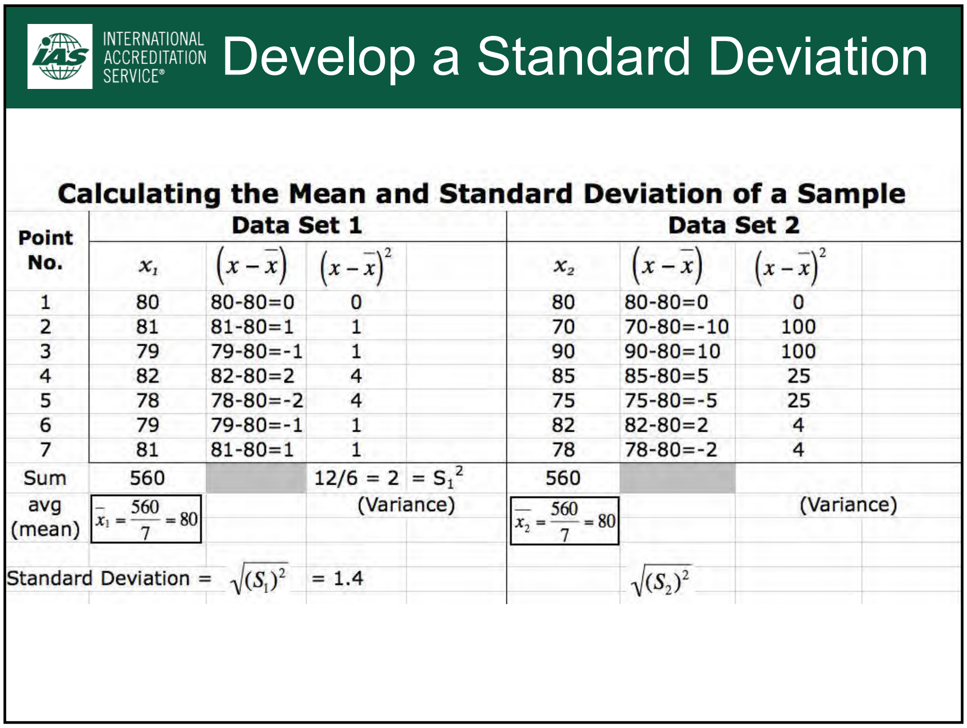
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	**Data Set 1**			**Data Set 2**		
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$	x_2	$(x-\bar{x})$	$(x-\bar{x})^2$
1	80	80-80=0	0	80	80-80=0	
2	81	81-80=1	1	70	70-80=-10	
3	79	79-80=-1	1	90	90-80=10	
4	82	82-80=2	4	85	85-80=5	
5	78	78-80=-2	4	75	75-80=-5	
6	79	79-80=-1	1	82	82-80=2	
7	81	81-80=1	1	78	78-80=-2	
Sum	560		12/6 = 2 = S_1^2	560		
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)	$\bar{x}_2 = \frac{560}{7} = 80$		(Variance)
Standard Deviation =		$\sqrt{(S_1)^2}$	= 1.4		$\sqrt{(S_2)^2}$	



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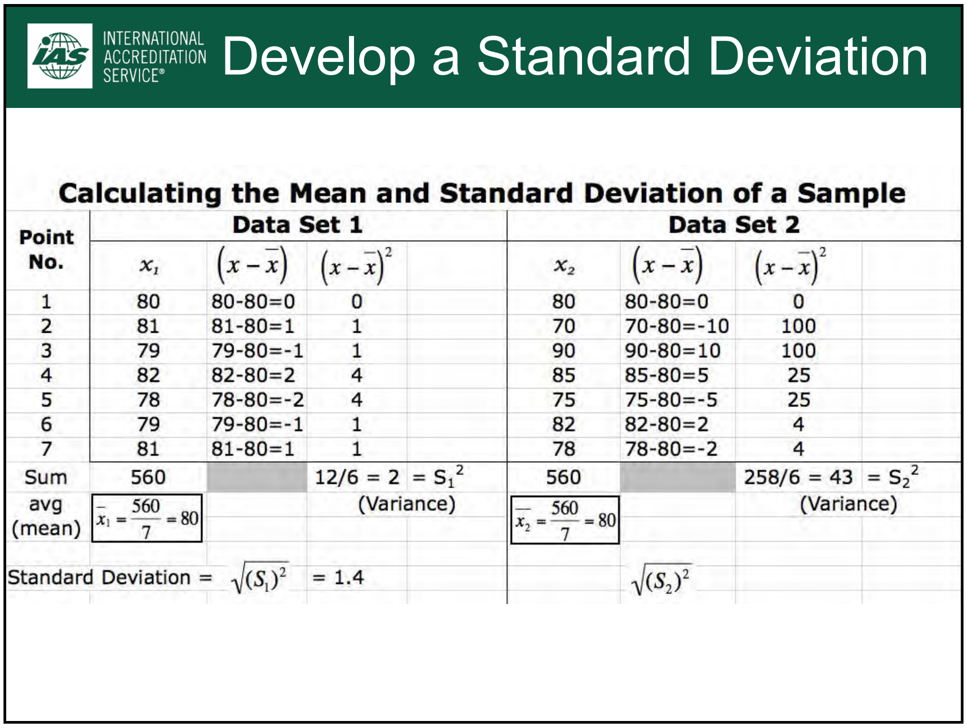
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	**Data Set 1**				**Data Set 2**			
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2	$(x-\bar{x})$	$(x-\bar{x})^2$	
1	80	80-80=0	0		80	80-80=0	0	
2	81	81-80=1	1		70	70-80=-10	100	
3	79	79-80=-1	1		90	90-80=10	100	
4	82	82-80=2	4		85	85-80=5	25	
5	78	78-80=-2	4		75	75-80=-5	25	
6	79	79-80=-1	1		82	82-80=2	4	
7	81	81-80=1	1		78	78-80=-2	4	
Sum	560		12/6 = 2 = S_1^2		560			
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)		$\bar{x}_2 = \frac{560}{7} = 80$		(Variance)	
Standard Deviation =		$\sqrt{(S_1)^2}$	= 1.4			$\sqrt{(S_2)^2}$		



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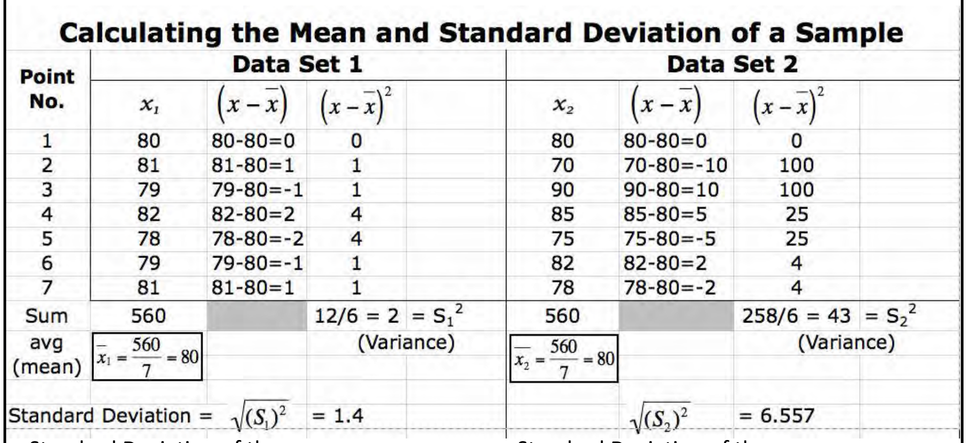
Develop a Standard Deviation

Calculating the Mean and Standard Deviation of a Sample

Point No.	**Data Set 1**				**Data Set 2**			
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$		x_2	$(x-\bar{x})$	$(x-\bar{x})^2$	
1	80	80-80=0	0		80	80-80=0	0	
2	81	81-80=1	1		70	70-80=-10	100	
3	79	79-80=-1	1		90	90-80=10	100	
4	82	82-80=2	4		85	85-80=5	25	
5	78	78-80=-2	4		75	75-80=-5	25	
6	79	79-80=-1	1		82	82-80=2	4	
7	81	81-80=1	1		78	78-80=-2	4	
Sum	560		12/6 = 2 = S_1^2		560		258/6 = 43 = S_2^2	
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)		$\bar{x}_2 = \frac{560}{7} = 80$		(Variance)	
Standard Deviation =		$\sqrt{(S_1)^2}$	= 1.4			$\sqrt{(S_2)^2}$		

Develop a Standard Deviation



Calculating the Mean and Standard Deviation of a Sample

Point No.	**Data Set 1**			**Data Set 2**		
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$	x_2	$(x-\bar{x})$	$(x-\bar{x})^2$
1	80	80-80=0	0	80	80-80=0	0
2	81	81-80=1	1	70	70-80=-10	100
3	79	79-80=-1	1	90	90-80=10	100
4	82	82-80=2	4	85	85-80=5	25
5	78	78-80=-2	4	75	75-80=-5	25
6	79	79-80=-1	1	82	82-80=2	4
7	81	81-80=1	1	78	78-80=-2	4
Sum	560		12/6 = 2 = S_1^2	560		258/6 = 43 = S_2^2
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$		(Variance)	$\bar{x}_2 = \frac{560}{7} = 80$		(Variance)
Standard Deviation =	$\sqrt{(S_1)^2}$	= 1.4			$\sqrt{(S_2)^2}$	= 6.557

Standard Deviation of the mean = 1.4/√7 = 0.53

Standard Deviation of the mean = 6.6/√7 = 2.5

Type B Uncertainties

- **Remember, these uncertainty contributors were NOT obtained through statistical methods, so how can we obtain a standard deviation for them to obtain the standard uncertainty?**
- Examples of type B uncertainty information:
  - Calibration uncertainties from calibration certificates (even if the calibration provider obtained the uncertainties by statistical methods)
  - Manufacturer's equipment specification (even if manufacturer provides confidence levels, though rare)
  - Experience with the behavior of an instrument
  - Digital resolution of an instrument
  - Values from reference books, etc.
- The GUM provides a practical answer for combining statistical (Type A) and non-statistical (Type B) uncertainties: **Treat Type B as if they were statistical with standard deviations!**

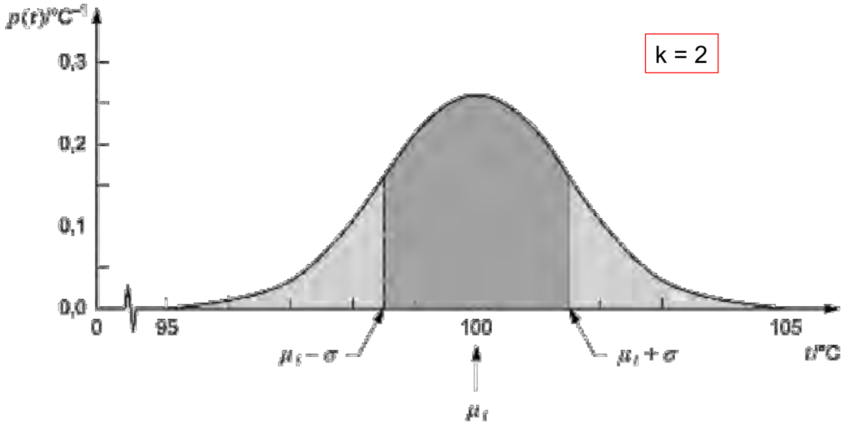
Basic GUM Method cont.

7) Assign probability distributions to type B uncertainties

Probability distribution functions were developed for common non-statistical Type B uncertainties, and the formulae can be derived to calculate the associated standard uncertainties (see GUM for derivations)

Probability distribution for Type A uncertainties

Normal Distribution



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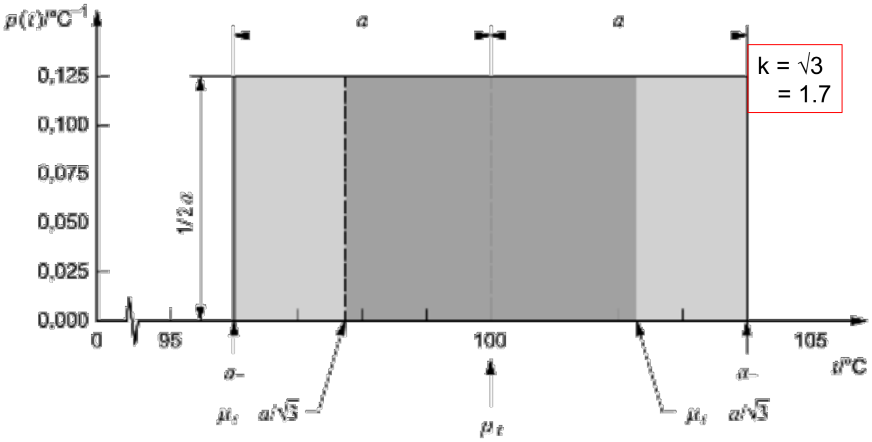
Some probability distributions for Type B uncertainties

Uniform Distribution



k = √3
= 1.7

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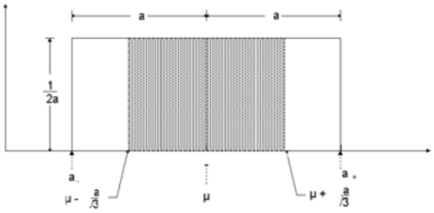
Some probability distributions for Type B uncertainties

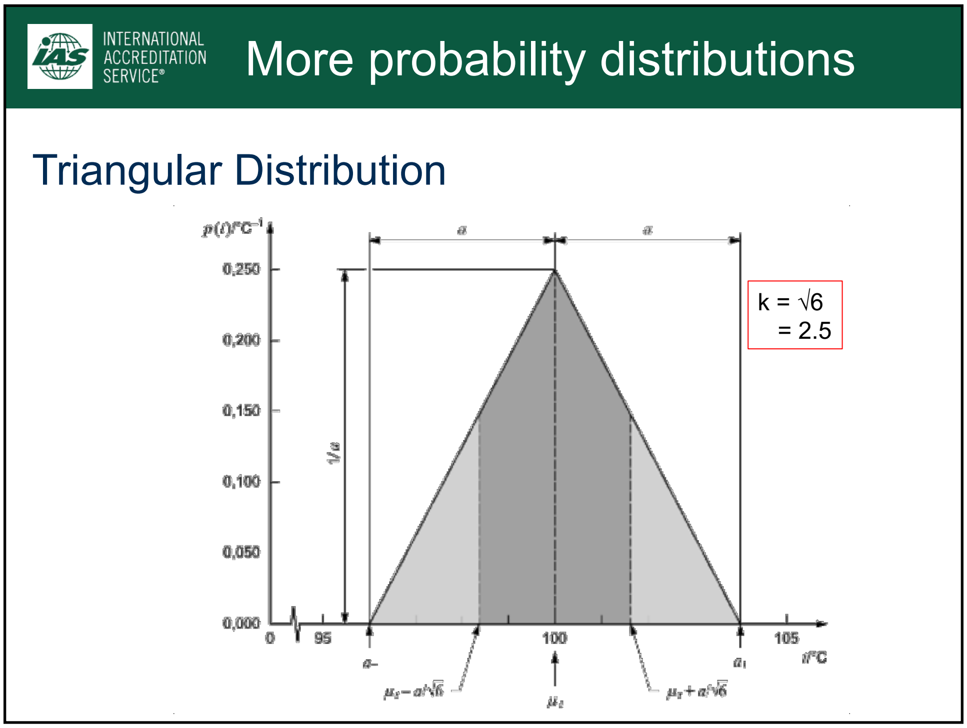
Rectangular Distribution



Used when uncertainties are given by a maximum boundary and all values are equally probable.
Standard uncertainty computed by dividing the half interval by √3
Examples: Resolution, manufacturer's specification, max. drift.

E.g. Digital voltmeter can resolve 1 mV. The standard uncertainty contribution from the resolution, u(res) is

$$u(res) = (0.5/\sqrt{3})\ \text{mV} = 0.29\ \text{mV}$$



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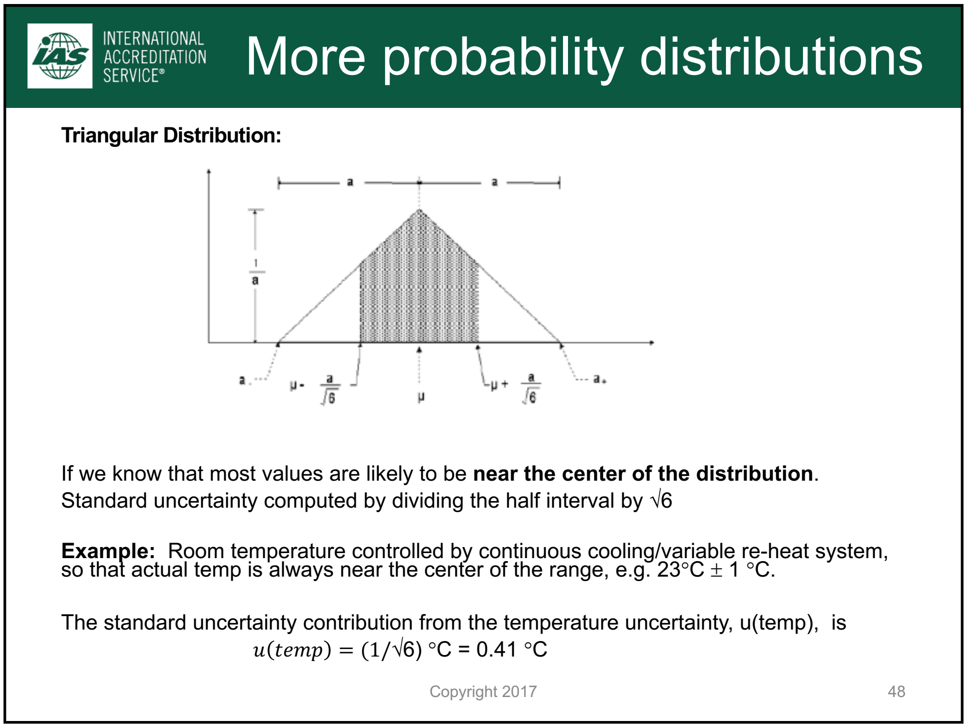
More probability distributions

Triangular Distribution

k = √6
= 2.5



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More probability distributions

Triangular Distribution:

If we know that most values are likely to be **near the center of the distribution**. Standard uncertainty computed by dividing the half interval by √6

Example: Room temperature controlled by continuous cooling/variable re-heat system, so that actual temp is always near the center of the range, e.g. 23°C ± 1 °C.

The standard uncertainty contribution from the temperature uncertainty, u(temp), is

$$u(temp) = (1/\sqrt{6})\ °C = 0.41\ °C$$

GUM Method cont.

8) Combine uncorrelated (statistically independent) uncertainties as follows:

$$u(y) = \sqrt{}[\sum_{i=1}^{N} c_i^2 u^2(x_i)] = \sqrt{}[c_1^2 u^2(x_1) + c_2^2 u^2(x_2) + \ldots + c_N^2 u^2(x_N)]$$

where the total uncertainty u(y) is assumed to have uncertainty contributors $u(x_1)$, $u(x_2)$,…$u(x_N)$ and

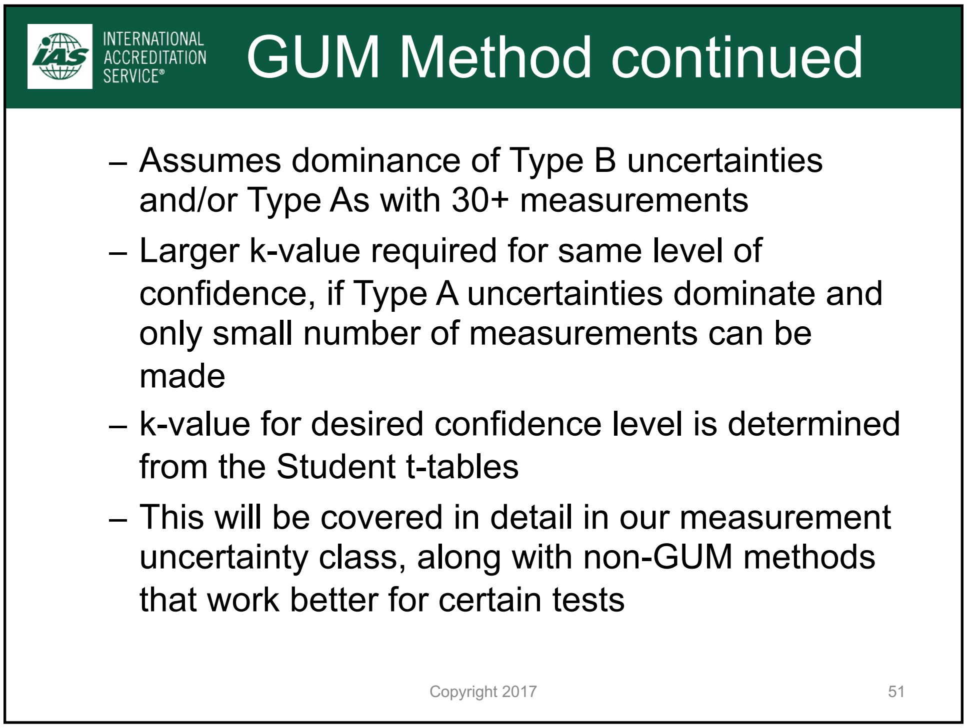
c_i are **sensitivity coefficients (**note that they always equal 1 if the uncertainty is represented as a fraction)

This is called the root-sum-square method or RSS

GUM Method cont.

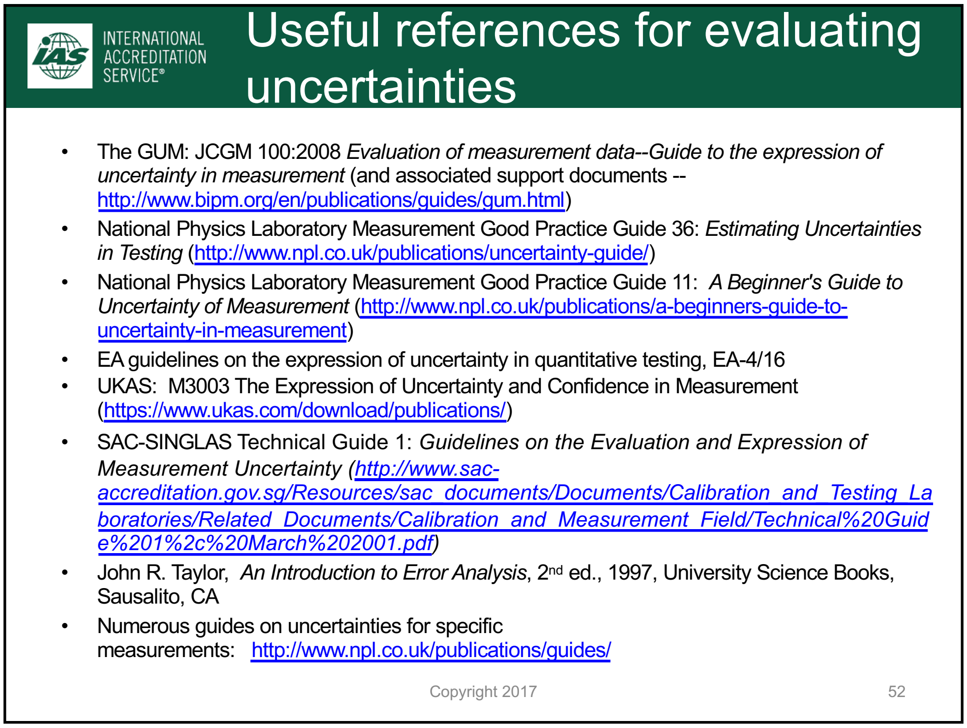
10)Expand the combined uncertainty by multiplying by desired coverage factor to obtain desired level of confidence

- In the case of a standard deviation, multiples of the **standard deviation** of a normal distribution population provide the probabilities that a value lies within the specified range.
- **Coverage factor k** is the equivalent multiplier for the combined **standard uncertainty** to ensure the measured value lies within the provided uncertainty range at a specified confidence level
- K=1,2,3 – 68.27%, 95.45%, 99.73% confidence level, respectively, assuming infinite degrees of freedom



GUM Method continued

- Assumes dominance of Type B uncertainties and/or Type As with 30+ measurements
- Larger k-value required for same level of confidence, if Type A uncertainties dominate and only small number of measurements can be made
- k-value for desired confidence level is determined from the Student t-tables
- This will be covered in detail in our measurement uncertainty class, along with non-GUM methods that work better for certain tests



Useful references for evaluating uncertainties

- The GUM: JCGM 100:2008 *Evaluation of measurement data--Guide to the expression of uncertainty in measurement* (and associated support documents -- http://www.bipm.org/en/publications/guides/gum.html)
- National Physics Laboratory Measurement Good Practice Guide 36: *Estimating Uncertainties in Testing* (http://www.npl.co.uk/publications/uncertainty-guide/)
- National Physics Laboratory Measurement Good Practice Guide 11: *A Beginner's Guide to Uncertainty of Measurement* (http://www.npl.co.uk/publications/a-beginners-guide-to-uncertainty-in-measurement)
- EA guidelines on the expression of uncertainty in quantitative testing, EA-4/16
- UKAS: M3003 The Expression of Uncertainty and Confidence in Measurement (https://www.ukas.com/download/publications/)
- SAC-SINGLAS Technical Guide 1: *Guidelines on the Evaluation and Expression of Measurement Uncertainty (http://www.sac-accreditation.gov.sg/Resources/sac_documents/Documents/Calibration_and_Testing_Laboratories/Related_Documents/Calibration_and_Measurement_Field/Technical%20Guide%201%2c%20March%202001.pdf)*
- John R. Taylor, *An Introduction to Error Analysis*, 2nd ed., 1997, University Science Books, Sausalito, CA
- Numerous guides on uncertainties for specific measurements: http://www.npl.co.uk/publications/guides/

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Basic Measurement Concepts

Part 1 – Uncertainty of Measurement

Part 2 – Traceability of Measurement

Part 3 – Calibration

- Uncertainty is the **Tool** to establish Traceability
- Of these three Traceability of Measurement is the **Primary and Overriding Requirement**, and
- Calibration is how Uncertainty is **Transferred (Propagated)** down the Traceability Chain.

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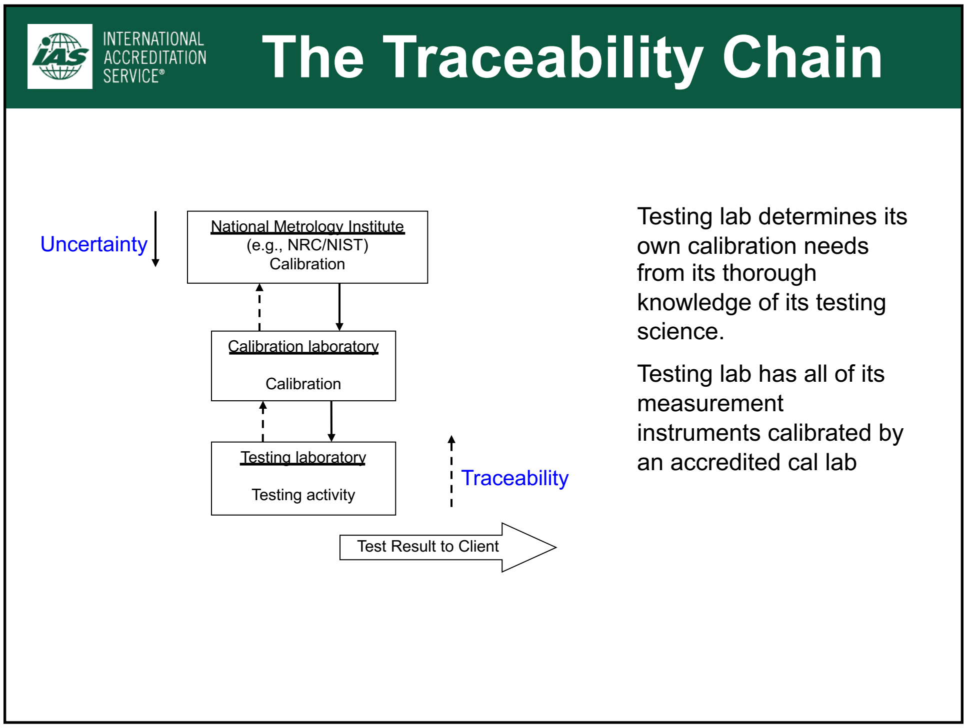
Part 2 – Traceability of Measurement

- Derived using Uncertainty
- Back to the SI through an NMI
- Uncertainty is Propagated down the chain of comparisons from National Standard to the test bench
- Provides final the contribution to the uncertainty of the method.



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The Traceability Chain

Uncertainty

National Metrology Institute
(e.g., NRC/NIST)
Calibration

Calibration laboratory
Calibration

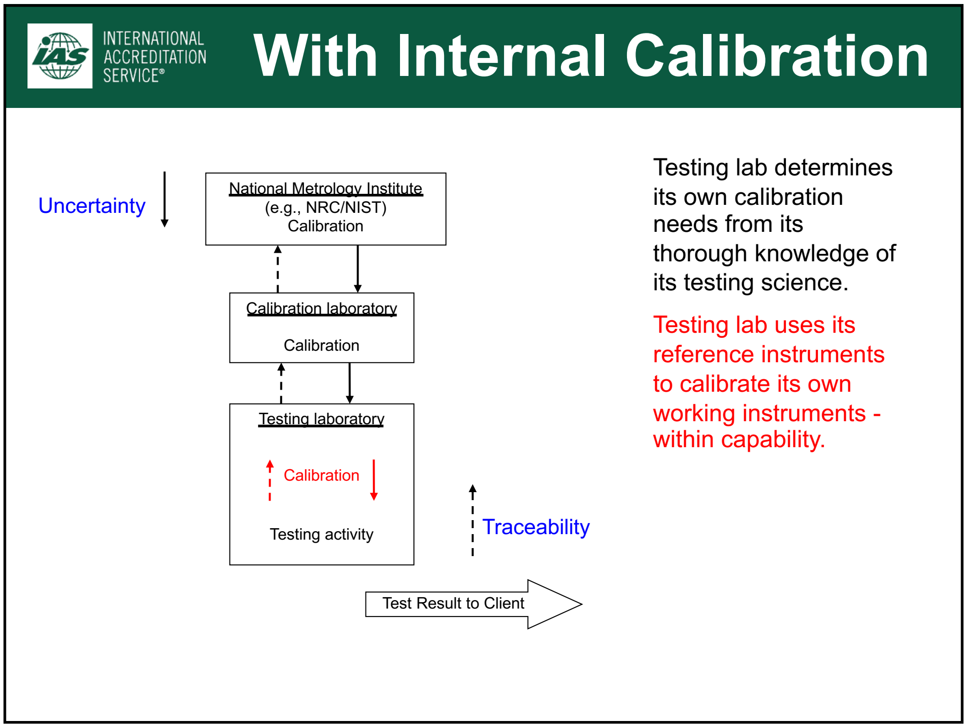
Testing laboratory
Testing activity

Traceability

Test Result to Client

Testing lab determines its own calibration needs from its thorough knowledge of its testing science.

Testing lab has all of its measurement instruments calibrated by an accredited cal lab



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With Internal Calibration

Uncertainty

National Metrology Institute
(e.g., NRC/NIST)
Calibration

Calibration laboratory
Calibration

Testing laboratory
Calibration
Testing activity

Traceability

Test Result to Client

Testing lab determines its own calibration needs from its thorough knowledge of its testing science.

Testing lab uses its reference instruments to calibrate its own working instruments - within capability.

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Part 2 – Traceability of Measurement

6.5 Metrological Traceability:

Laboratories **<u>must</u>** document their unbroken chain of calibrations, linking them to an appropriate reference such as the SI.

A. TRUE
B. FALSE
C. NOT APPLICABLE

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Defining Traceability Again

- Property of the result of a measurement or value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties.
- Key concepts:
  - Standard is an artefact or representation of a measurement parameter through a recognised universal constant.
  - The chain of comparison, called "calibrations" is unbroken
  - All comparisons contain uncertainties.

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Traceability Considerations

See Annex A to ISO/IEC 17025

- All of the individual comparisons (calibrations) that are part of the Traceability Chain, have associated uncertainties to ensure traceability.
- All of the calibrations of the Traceability Chain are done by COMPETENT people in organisations that have demonstrated COMPETENCE in this work.
- COMPETENCE in calibration is demonstrated by National Metrology Institutes that have signed the CIPM MRA and accredited calibration laboratories.
- COMPETENCE in calibration is demonstrated by calibration laboratories that are accredited by an ILAC Signatory Accreditation Body for the calibrations they perform.

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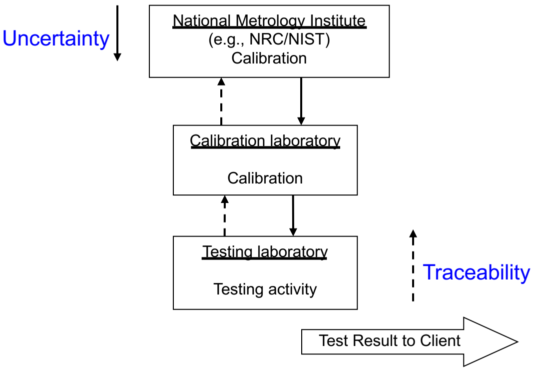
6.5 and Annex A (Traceability)

- All measuring equipment used to produce traceable results must be traceable to a national standard through an unbroken chain of comparisons. (First challenge)
- All measurements produced by the lab include the uncertainty of that measurement. (Second challenge)
- See the Components of Traceability contained in Annex A.
- Note the ILAC Policy on Traceability of Measurements.

The Traceability Chain



Testing lab determines its own calibration needs from its thorough knowledge of its testing science.

Testing lab has all of its measurement instruments calibrated by an accredited cal lab

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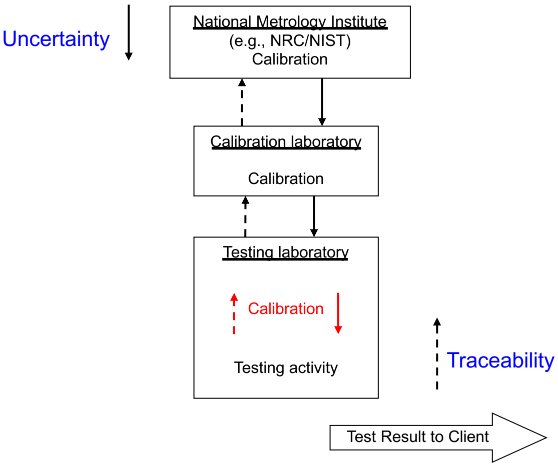
With Internal Calibration



Testing lab determines its own calibration needs from its thorough knowledge of its testing science.

Testing lab uses its reference instruments to calibrate its own working instruments - within capability.

Basic Measurement Concepts

Part 1 – Uncertainty of Measurement

Part 2 – Traceability of Measurement

Part 3 – Calibration

- Uncertainty is the **Tool** to establish Traceability,
- Of these three Traceability of Measurement is the **Primary and Overriding Requirement**, and
- Calibration is how Uncertainty is **Transferred (Propagated)** down the Traceability Chain.

Quantifying the Impact of Calibration

See pages 35-40 from the Eurachem CITAC Guide on Uncertainty
“https://www.eurachem.org/images/stories/Guides/pdf/QUAM2012_P1.pdf”

Type B - estimation based on the physical set-up of the test and other empirical data.

- Determine the process and the uncertainty contributions of each step.

This algorithm:

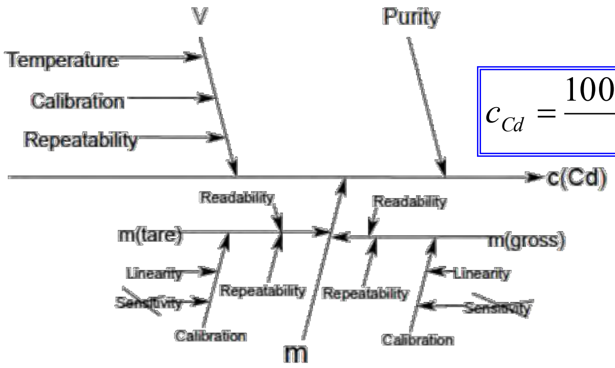
$$c_{Cd} = \frac{1000 \cdot m \cdot P}{V} (mgl^{-1})$$

…is this process…

Weigh the empty (tare) container → Weigh the container & powder → Fill the Flask with Water → Stir the powder into the water

Quantifying the Impact of Calibration

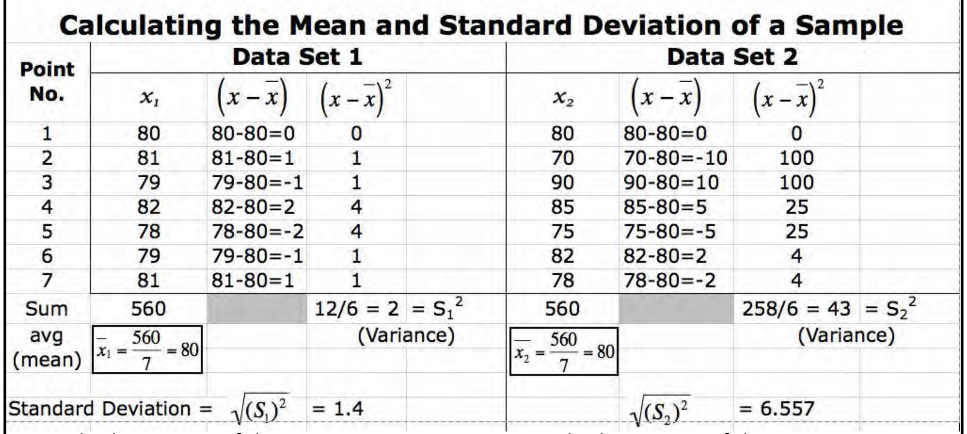
The laboratory draws up a fishbone (Ishikawa) diagram to depict its process for the measurement of the calibration standard.



$$c_{Cd} = \frac{1000 \cdot m \cdot P}{V} (mgl^{-1})$$

See page 35 from the Eurachem CITAC Guide on Uncertainty

Using Type A Evaluation Only



Calculating the Mean and Standard Deviation of a Sample

Point No.	Data Set 1			Data Set 2		
	x_1	$(x-\bar{x})$	$(x-\bar{x})^2$	x_2	$(x-\bar{x})$	$(x-\bar{x})^2$
1	80	80-80=0	0	80	80-80=0	0
2	81	81-80=1	1	70	70-80=-10	100
3	79	79-80=-1	1	90	90-80=10	100
4	82	82-80=2	4	85	85-80=5	25
5	78	78-80=-2	4	75	75-80=-5	25
6	79	79-80=-1	1	82	82-80=2	4
7	81	81-80=1	1	78	78-80=-2	4
Sum	560		12/6 = 2 = S_1^2 (Variance)	560		258/6 = 43 = S_2^2 (Variance)
avg (mean)	$\bar{x}_1 = \frac{560}{7} = 80$			$\bar{x}_2 = \frac{560}{7} = 80$		
Standard Deviation =	$\sqrt{(S_1)^2}$	= 1.4			$\sqrt{(S_2)^2}$	= 6.557

Standard Deviation of the mean =
1.4/√7 = 0.53

Standard Deviation of the mean =
6.6/√7 = 2.5

Quantifying the Impact of Calibration

- Using Type B uncertainty estimations, they would arrive at a result similar to the one from Type A.
- This algorithm: $c_{Cd} = \frac{1000 \cdot m \cdot P}{V} (mgl^{-1})$

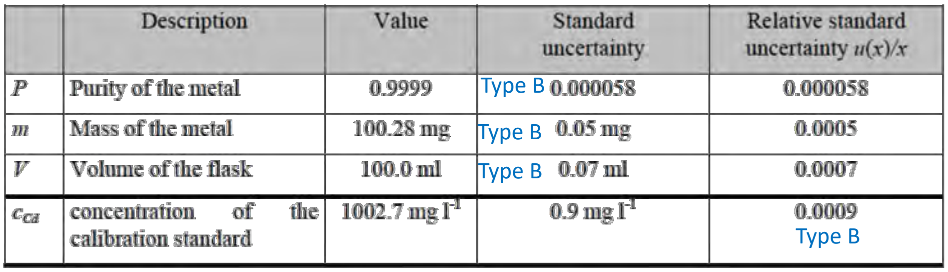
would produce this uncertainty expression:

$$u_c(c_{Cd}) = c_{Cd}\sqrt{\left(\frac{u(P)}{P}\right)^2 + \left(\frac{u(m)}{m}\right)^2 + \left(\frac{u(V)}{V}\right)^2}$$

See page 35 from the Eurachem CITAC Guide on Uncertainty

Quantifying the Impact of Calibration

Type B



	Description	Value	Standard uncertainty	Relative standard uncertainty $u(x)/x$
P	Purity of the metal	0.9999	Type B 0.000058	0.000058
m	Mass of the metal	100.28 mg	Type B 0.05 mg	0.0005
V	Volume of the flask	100.0 ml	Type B 0.07 ml	0.0007
c_{Cd}	concentration of the calibration standard	1002.7 mg l^{-1}	0.9 mg l^{-1}	0.0009 Type B

See page 35 from the Eurachem CITAC Guide on Uncertainty

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Quantifying the Impact of Calibration

Any single contribution that is less than or equal to one third of the largest contribution can tend to zero without affecting the overall uncertainty associated with the measurement.

Evaluated $u(x_1) = \sqrt{(1)^2 + (2)^2 + (3)^2} = \sqrt{14} = 3.7$

Evaluated $u(x_2) = \sqrt{(2)^2 + (3)^2} = \sqrt{13} = 3.6$

Reported $u(x) \approx 4$

$\boxed{\text{Difference} \quad = 0}$

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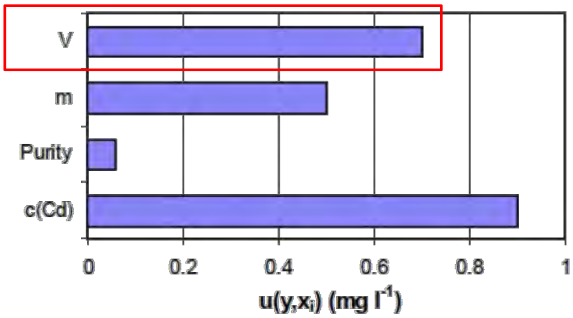
Quantifying the Impact of Calibration

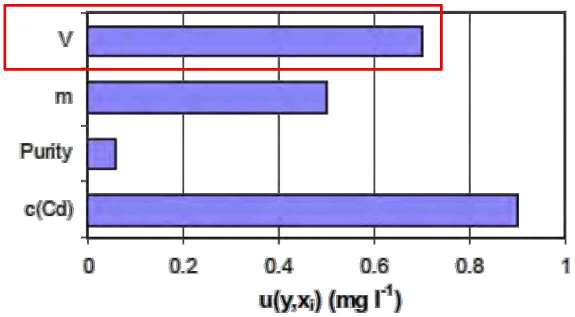
Examine the effect on the overall uncertainty caused by the use of the flask in the "Volume" consideration. It is over 70% of the overall uncertainty. It is "Significant Contribution."



See page 36 from the Eurachem CITAC Guide on Uncertainty

Quantifying the Impact of Calibration

The "Volume" contribution is 70% of the overall uncertainty. If we wish to improve (reduce) the overall uncertainty of the standard, we should improve (reduce) the uncertainty associated with Volume.



See page 36 from the Eurachem CITAC Guide on Uncertainty

Quantifying the Impact of Calibration

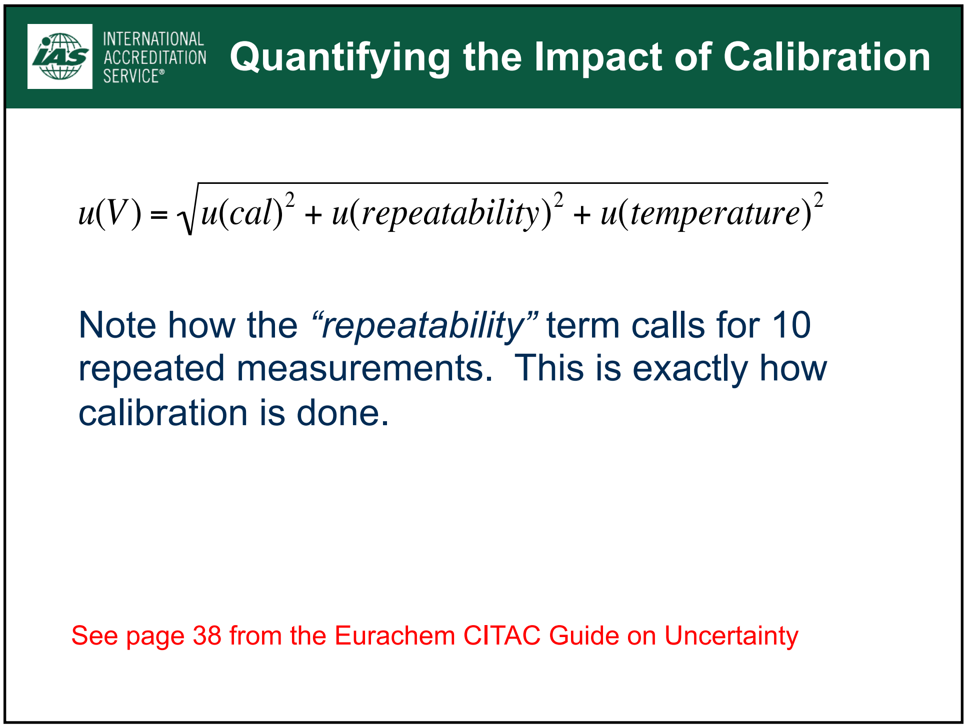
"Volume" standard uncertainty is the result of flask tolerance statement (not calibration as stated in the example), repeatability, and temperature considerations:

$$u(V) = \sqrt{u(cal)^2 + u(repeatability)^2 + u(temperature)^2}$$

The flask is not calibrated. The manufacturer "derives" calibration from "tolerance." This is the expression used.

$$u(V) = \sqrt{(0.04)^2 + (0.02)^2 + (0.05)^2} = 0.07ml$$

See page 38 from the Eurachem CITAC Guide on Uncertainty



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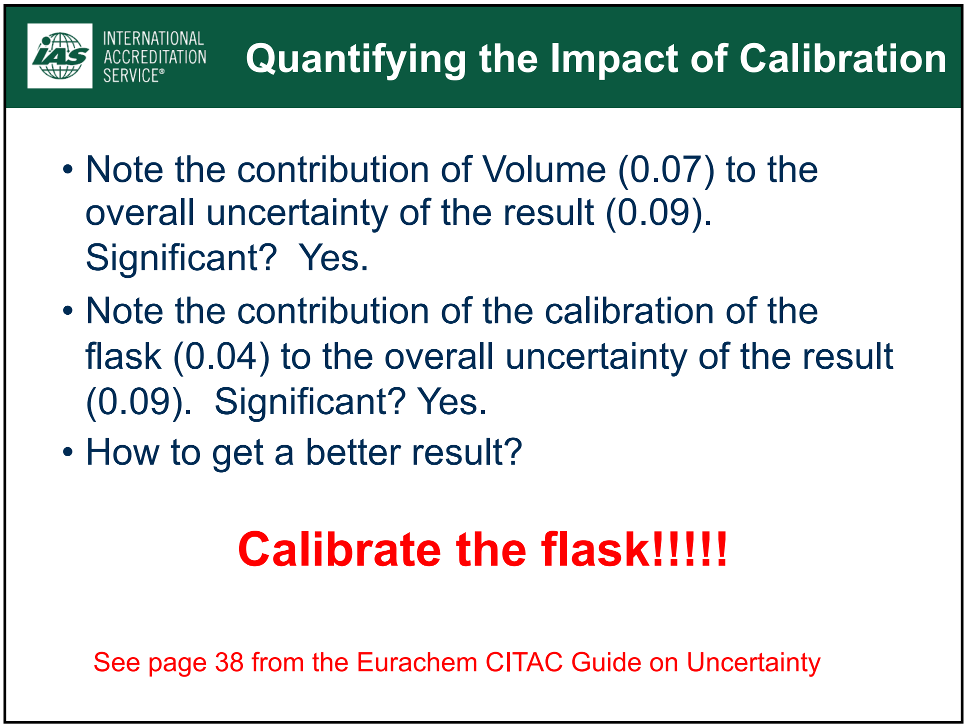
Quantifying the Impact of Calibration

$$u(V) = \sqrt{u(cal)^2 + u(repeatability)^2 + u(temperature)^2}$$

Note how the *“repeatability”* term calls for 10 repeated measurements. This is exactly how calibration is done.

See page 38 from the Eurachem CITAC Guide on Uncertainty



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Quantifying the Impact of Calibration

- Note the contribution of Volume (0.07) to the overall uncertainty of the result (0.09). Significant? Yes.
- Note the contribution of the calibration of the flask (0.04) to the overall uncertainty of the result (0.09). Significant? Yes.
- How to get a better result?

Calibrate the flask!!!!!

See page 38 from the Eurachem CITAC Guide on Uncertainty

Quantifying the Impact of Calibration

- Calibrating the flask would probably result in an uncertainty of 0.01ml instead of 0.04 ml for Volume.

$$u(V)=\sqrt{\boxed{(0.04)^2}+(0.02)^2+(0.05)^2}\boxed{=0.07ml}$$

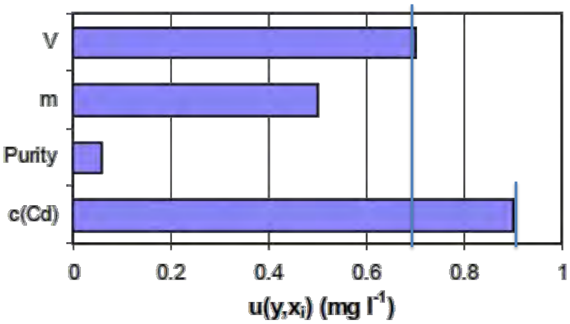
- This would reduce the uncertainty of the “Volume” consideration to 0.05 ml from 0.07 ml.
- This would reduce the overall uncertainty of the measurement to 0.7 mg/l from 0.9 mg/l, about 20%.

See page 39 from the Eurachem CITAC Guide on Uncertainty

Quantifying the Impact of Calibration

Calibrating the Flask will reduce the contribution of Volume by 20% and this will reduce the overall uncertainty of the standard by approximately 20% as well.

- The Volume consideration goes from 0.07 ml from 0.05 ml.
- The overall uncertainty of the standard goes from 0.9 mg/l to 0.7 mg/l

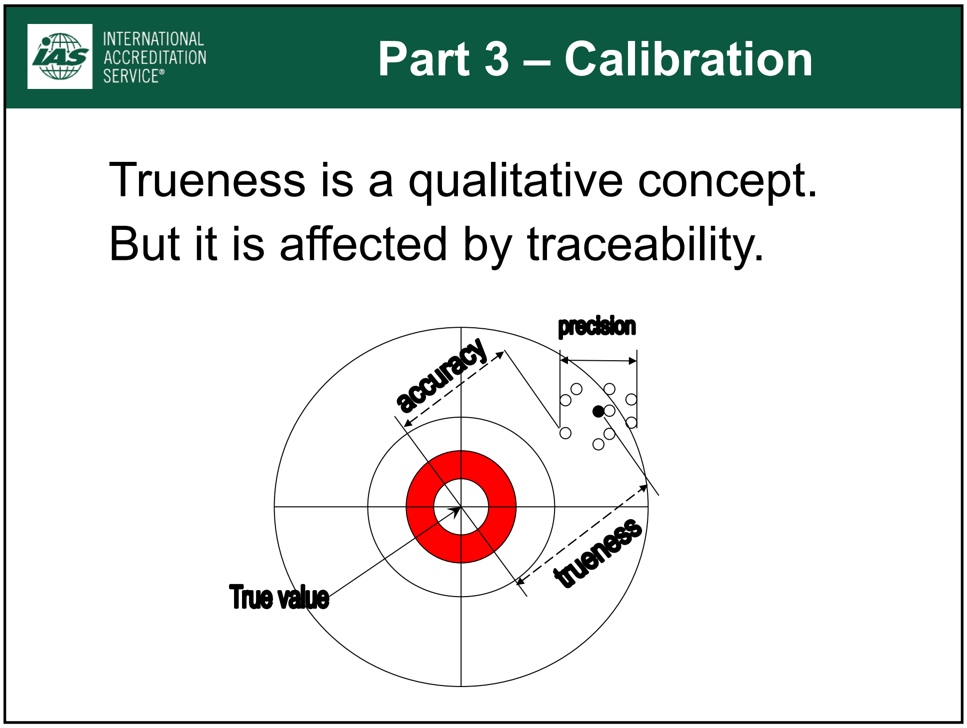


See page 40 from the Eurachem CITAC Guide on Uncertainty

Some deductions

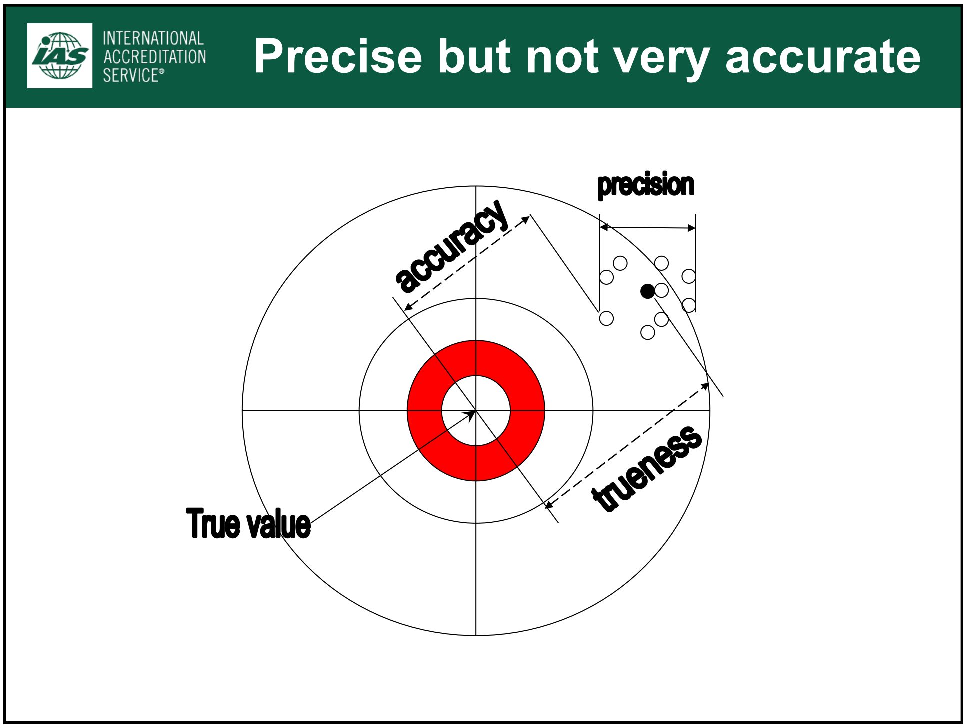
- No measurement is absolute. All measurements have some uncertainty associated with them
- No measurement can be allocated a value for “accuracy” or “trueness”.
- We can estimate/evaluate an uncertainty and thus the measurement’s quality by estimating/evaluating the various uncertainty contributors and combining them into a combined expanded uncertainty.
- “Calibration,” “Traceability,” and “Uncertainty” must all be at every stage of the traceability chain for ANY of them to exist below that stage. If one is missing - none appear below it.

NO UNCERTAINTY
= NO CALIBRATION
= NO TRACEABILITY



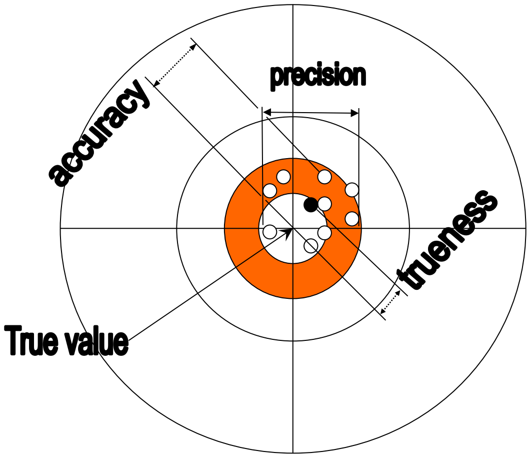
Part 3 – Calibration

Trueness is a qualitative concept.
But it is affected by traceability.



Precise but not very accurate

Precise and more accurate



Part 3 – Calibration

6.5 Metrological Traceability:

Laboratories **MUST** make use of **only** accredited calibration laboratories when establishing the traceability of their equipments.

A. TRUE
B. FALSE
C. NOT APPLICABLE

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Importance of calibration

- Calibration increases the level of confidence in equipment performance
- Calibration certificates provide important information that feeds into subsequent uncertainty analyses
- Calibration provides information on the “error” or deviation from the “true” value of a piece of equipment, and if a correction can be made, the source of uncertainty is reduced
- Calibration uncertainty itself is propagated down the traceability chain

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Competence in Calibration

- Calibration laboratories are accredited against ISO/IEC 17025 in the same manner as testing laboratories.
- Accredited calibration laboratories can only be accredited when they can demonstrate the competence required to conduct calibrations (including the competent propagation of uncertainties).

Competence in Calibration

- Accredited calibration laboratories are deemed to be able to demonstrate “traceability” of their measurements.
- Equipment owners can have “confidence” (or “certainty”) about the traceability of accredited calibration labs producing uncertainties on calibration certificates.
- A calibration result without uncertainty is not complete

Test Instrument Performance

- Measurement instrument **performance** can be quantified by the quantities shown on its calibration certificate, i.e. the error (deviation) from the nominal quantity provided by a standard, and the associated uncertainty.
- Measurement instrument **requirements** are given based on the uncertainty requirements of the test.
- When setting calibration intervals for measurement instruments used in calibration or testing, the owner should take into account
  - the historical performance of the instrument, particularly any drift between calibrations
  - the instrument’s impact on the uncertainty of the test

Test Instrument Performance

- Calibration intervals may be longer or shorter than the manufacturer’s or other published recommendations for a particular category of instruments, depending on the end user’s needs.

- If no historical calibration data is being analyzed, the owner
  - may be calibrating more frequently than needed, or
  - calibrating not frequently enough to achieve the required instrument performance for a particular test