



# Specs, Certs, Errors & UoM! Tutorial

John Wilson





# Instructor

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**Comtest (Pty) Ltd**

**National Lab Association**

**Fluke Certified Trainer**





# Agenda

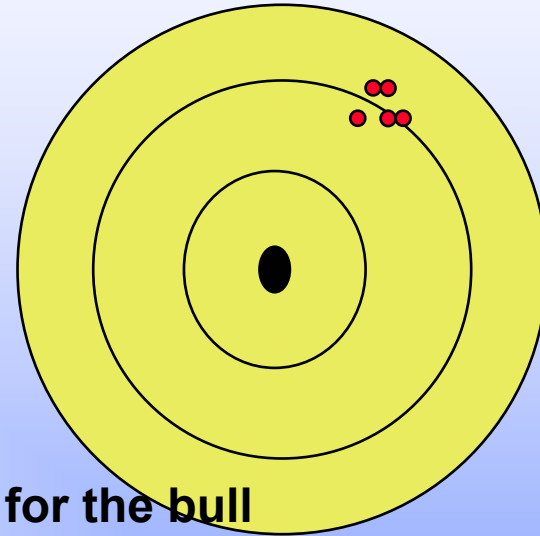
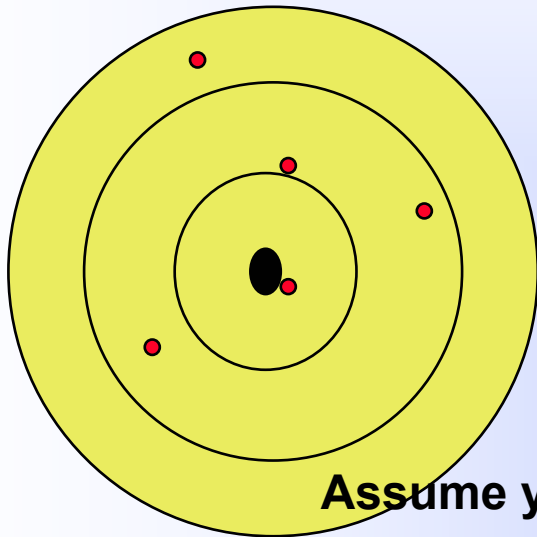
- Measurement Principles & Definitions
- Specifications
- Errors
- Certificate statements
- Practical examples
- What to do with what
- Share experiences and lessons learnt



# Accuracy etc

- On the target –
  - Which is more accurate
  - Which is more repeatable
  - Which is calibrated
  - Where is the average
  - What is the spread of the readings
  - How does this equate to uncertainty

# Accuracy

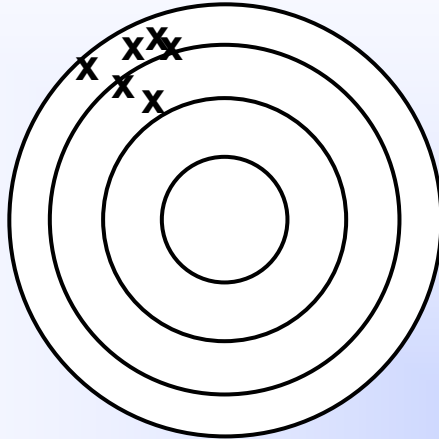


Assume you are aiming for the bull

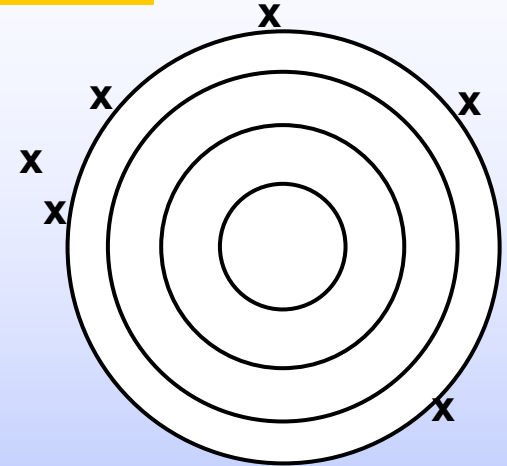
- Which is more accurate?
- Which is more repeatable?
- Which is calibrated?



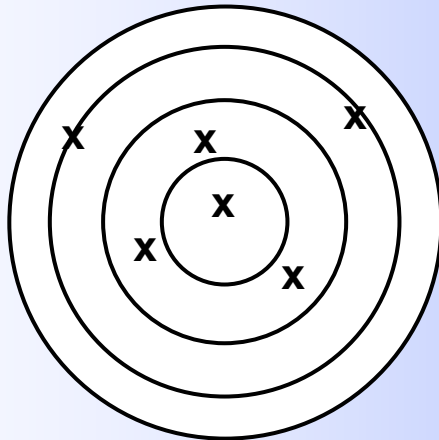
# Accuracy & Repeatability



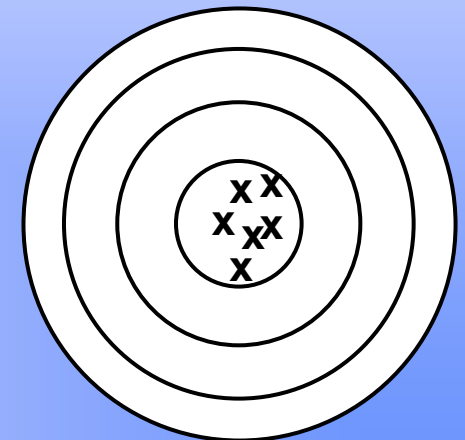
**Repeatable but not Accurate**



**Not Repeatable not Accurate**



**Accurate but not Repeatable**

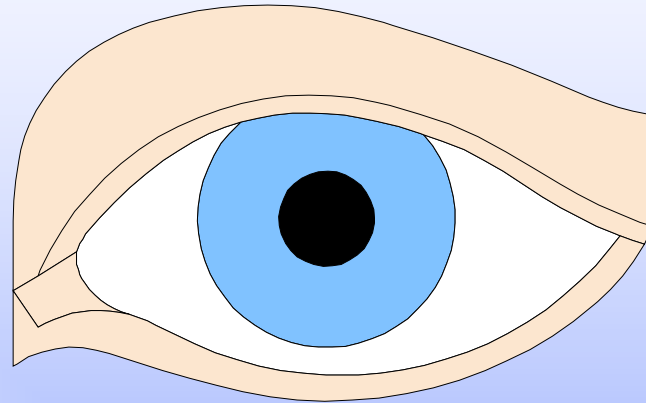


**Repeatable & Accurate**



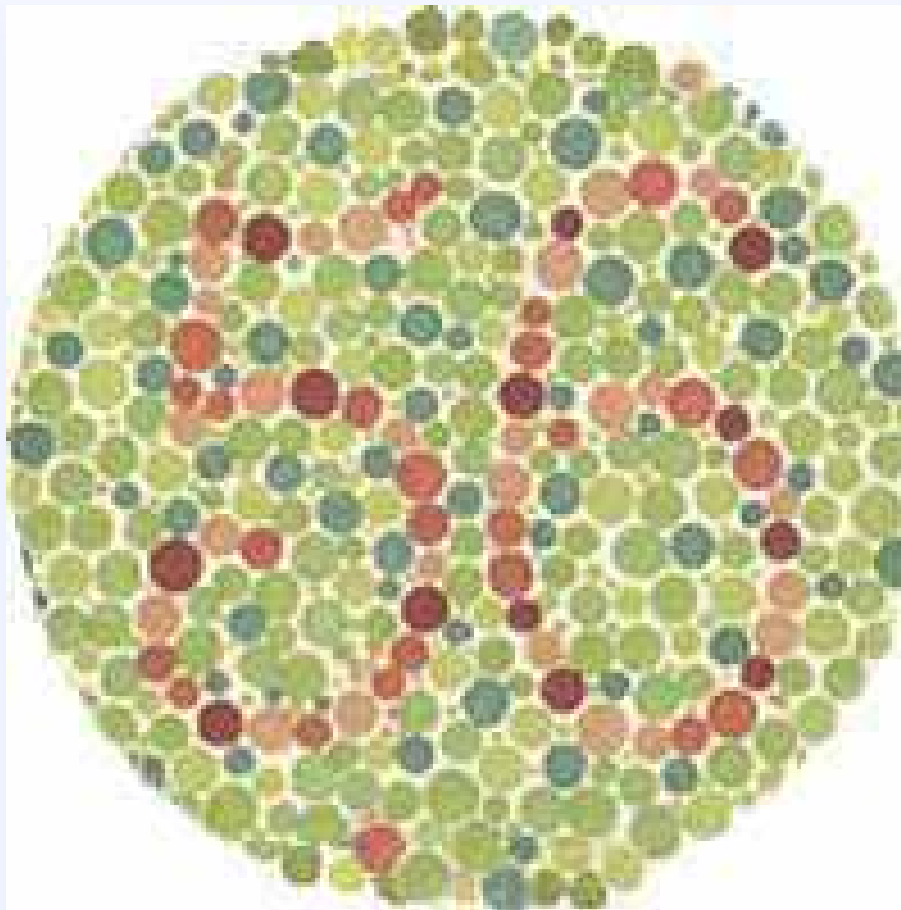
# Seeing is believing

- True or false?
  - Sports referee
  - TV/3 umpire
  - Magician
  - Card tricks
- 
- The eye and the especially the interpretation can be easily deceived as we see what we want to see or what is easy to see!





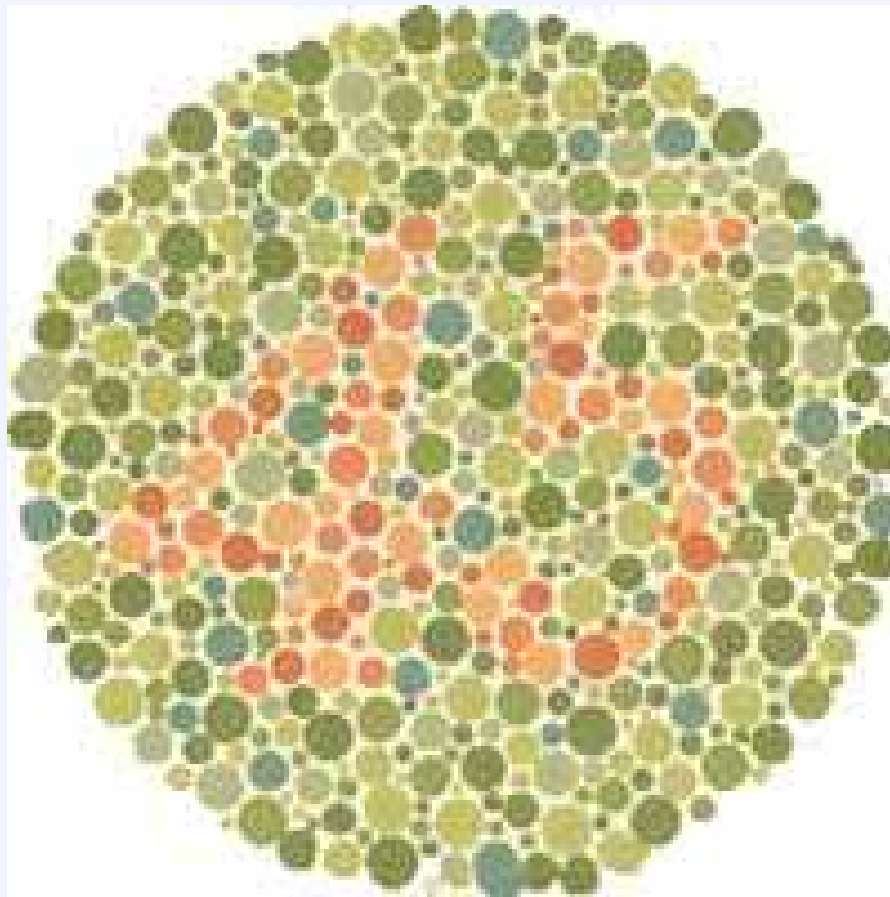
# What can you see in the circle?



**Number 56**



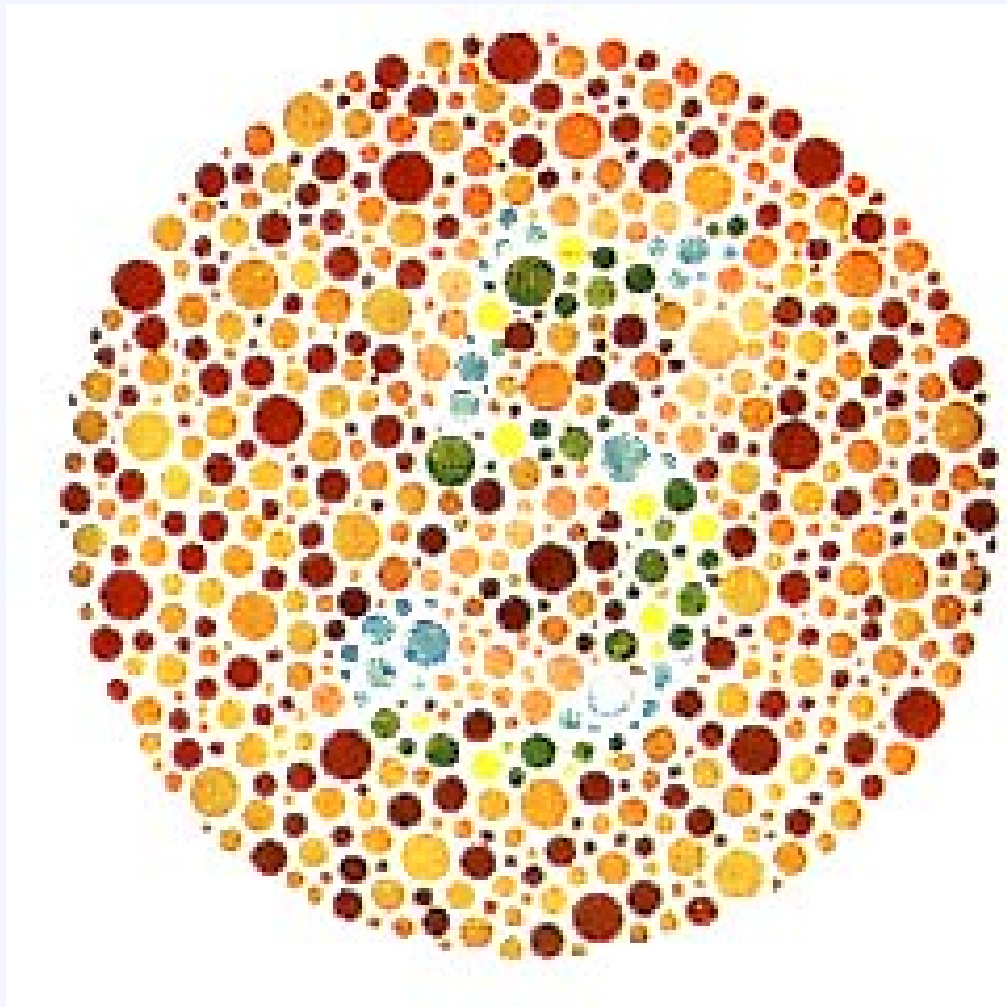
# What can you see in the circle?



Number 45



# What can you see in the circle?



Normal – no 5

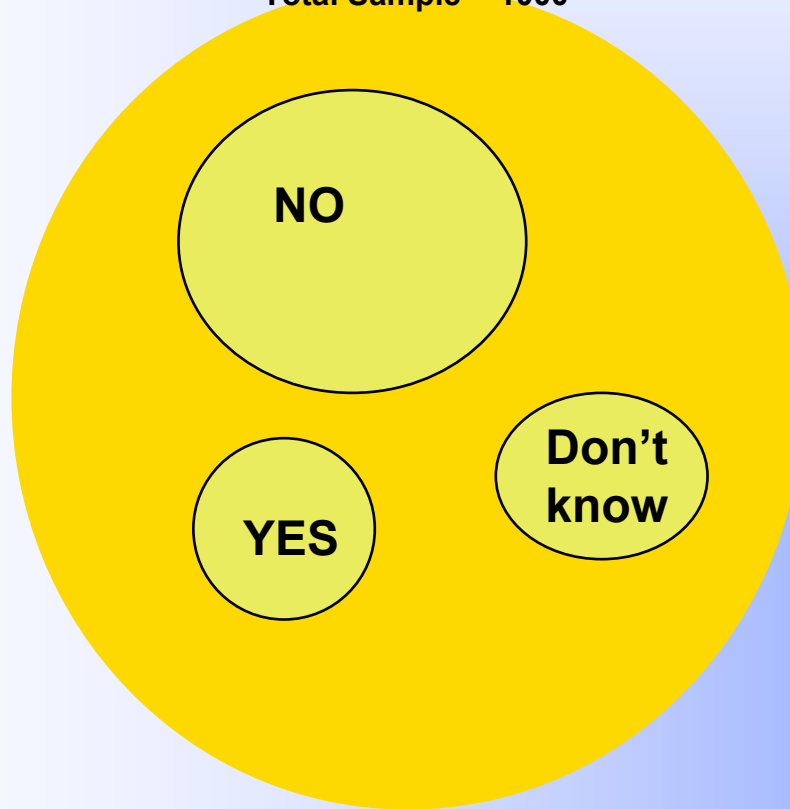
Others – no 2



# Pumpkin Survey

Do you like pumpkin?

Total Sample = 1000



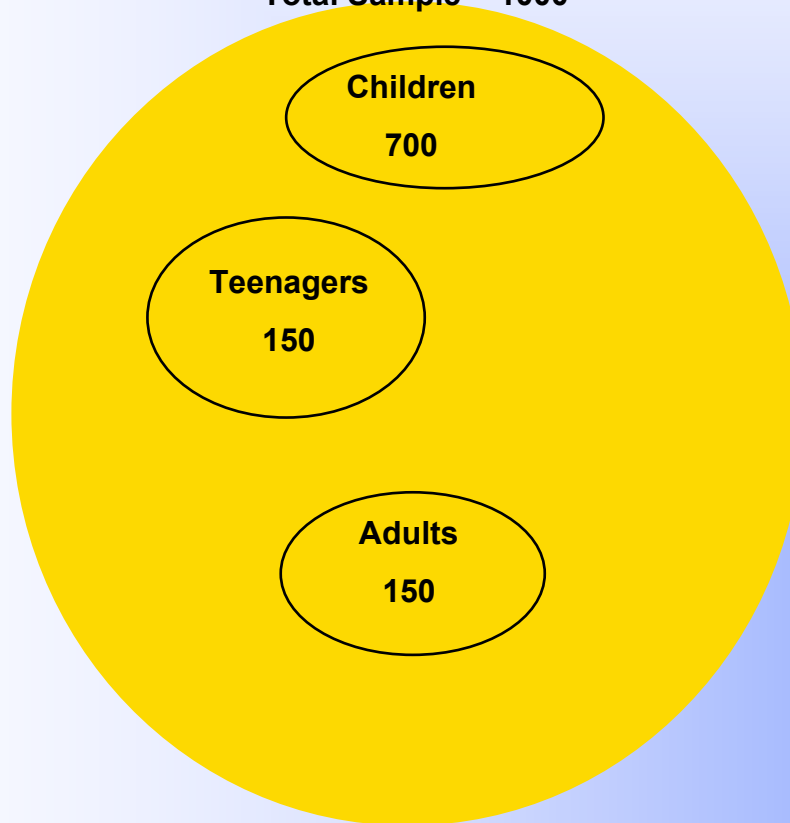
- Sample 1000 people
  - No – 800
  - Yes – 150
  - Don't know – 50
- 
- only 15% of people like pumpkin 😊



# Pumpkin Survey

## Manipulate the sample

Total Sample = 1000



• Analysing the total group surveyed, we find the following breakdown

• 700 children & 150 teenagers – the bulk of this group did not like pumpkin

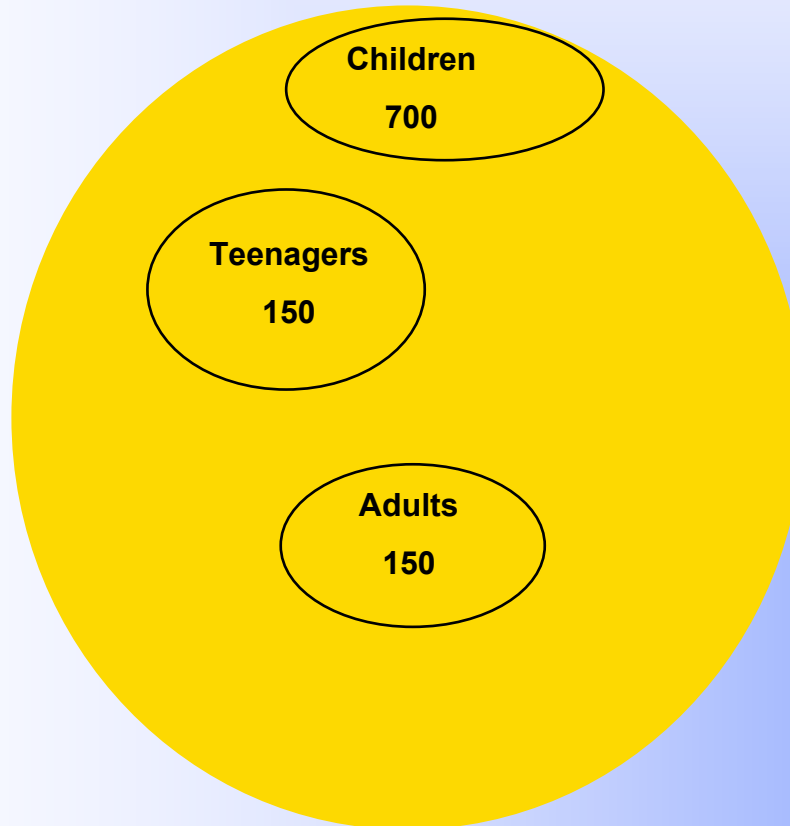
• So if we excluded them from the sample group then we would get the following



# Pumpkin Survey

## Adult sample only

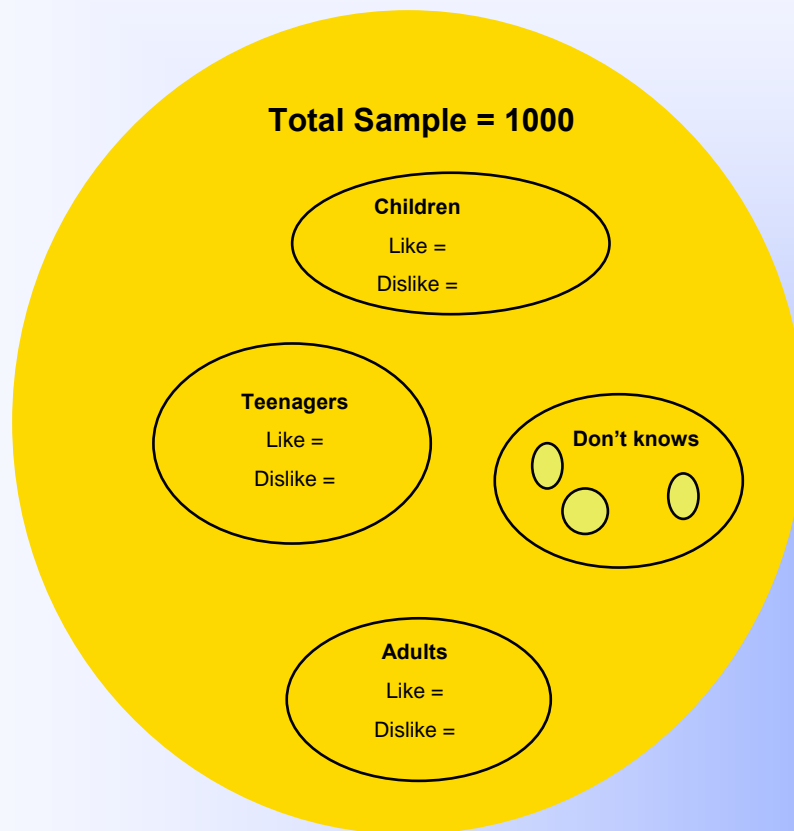
Total Sample = 1000



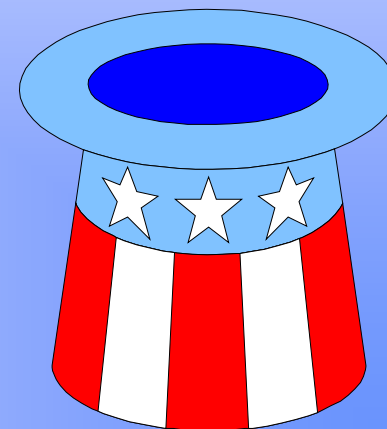
- Of the adults 129 said yes they liked pumpkin
- Then we can say 86% liked pumpkin
- In addition 10 of the don't know's were adults
- So lets remove the don't knows and the sample reduces to 140
- Now we could say 92% of the sample group liked pumpkin !



# Pumpkin Survey



By careful selection of sub groups and manipulation of the data and the words used, you can “prove” just about anything with statistics.





# Playing with words

- We all know how words can be twisted – here are some examples –
  - Parasites : What you see from the Eiffel Tower
  - Bernadette : Burning your debts
  - Subdued : A guy who works on submarines
- Product lable on a drain cleaner
  - If you do not understand, or cannot read, all the directions, cautions and warnings, do not use this product
- Product lable on a snow sledge
  - Beware: Sledge may develop high speed under certain snow conditions



# Analog or Digital accuracy

- **What is more accurate**

- Analog Watch or Digital Watch?
- Analog Scale or Digital Scale?
- A or D Micrometer
- A or D Vernier
- A or D Thermometer
- A or D Meter

- **Beware**

- Digital is not necessarily more accurate than analog
- Just as imported is not necessarily better

# Analog Meter Accuracy

- Normally specified as
  - %FS (% full scale)
  - Is only @ shown spec when the reading is at full scale
  - Degrades as the input level drops
- Example on 2.5V range
  - 2% at 2.5V
  - 3.3% at 1.5V
  - 10% at 0.5V



- Not linear scale
- Changing input impedance
- Mechanically and Electrically weak
- Limited ranges



# Digital Multimeter example

- When evaluating a DMM specification there are several points to consider but lets start with the basic specification normally, dcV.

0.1%

0.1% of Reading

0.1% of Reading + 1 digit

0.1% of Reading + 0.1% of Range

etc.

- What do these really mean?



# DMM Specification

- 0.1% (is generally of Reading but....)
- 0.1% of Reading (is what it says but.... where is the “floor spec” or the “noise spec” ...)
- 0.1% of Reading + 1 digit (What does this mean?)



# Spec conversion - dcV

- 0.1% of Reading + 1 digit is a two part spec that needs to be converted to a Total Instrument Accuracy Specification.
- This requires more information –
- What is the instrument's display (dynamic range or a/d count)
- What is the expected reading (input)
- On what range is the reading being taken



# Spec conversion - dcV

- 0.1% of Reading + 1 digit is a two part spec that needs to be converted to a Total Instrument Accuracy Specification. **mV dc**
- This requires more information –
- What is the instrument's display (dynamic range or a/d count) **3½ digit 2000 count**
- What is the expected reading (input) **180mV**
- On what range is the reading being taken **200mV**



# The Instrument's Display

- It is called a 3½ digit instrument.
- The maximum display on the 200mV range is
  - **199.9mV**
- So 1 digit represents how many millivolts?
  - **0.1mV**
- The input voltage (reading) is expected to be?
  - **180.0mV**
- What does 1 digit now represent as proportion of the reading?



# Convert the digit portion

- It is 0.1mV as a proportion of 180.0mV
- $(0.1 / 180.0) * 100 = 0.0555\%$
- Now add this to the basic spec of 0.1%
- $0.1\% + 0.056\% = 0.156\%$
- This is not the same as 0.1% !



# Convert the digit portion

- If we were now measuring 18mV on the same range and function what would you expect the total instrument accuracy to be ?
  - $0.156\%$  ?
  - No, because now the proportional part (digit) is
  - $100 * (0.1 / 18.0) = 0.555\%$
  - Thus the total instrument specification is ?
  - $0.1\% + 0.56\% = 0.66\%$
  - Very different from 0.1% !



# Proportional part of Spec

- It is thus very important to note that as with the analog meter, the digital meters also degrade the further down the scale you go. The “digit” portion of the spec has a much greater influence.
- If the spec was 0.1% + 3 digits, you might previously have ignored the 3 digits. What is the effect at 18mV?
- **Total spec is 1.77%**



# Proportional part of Spec

- Now if the spec was 0.1% + 12 digits, what does that mean at 18mV?
- **6.77%**
- But lets look at the display of the instrument again at 18mV input
- **--18.0**
- 12 digits means you cannot even resolve the 1mv digit as it is part of the 12 digits.
- The reading can be anywhere between **16.78** and **19.22mV** and **STILL BE IN SPECIFICATION**



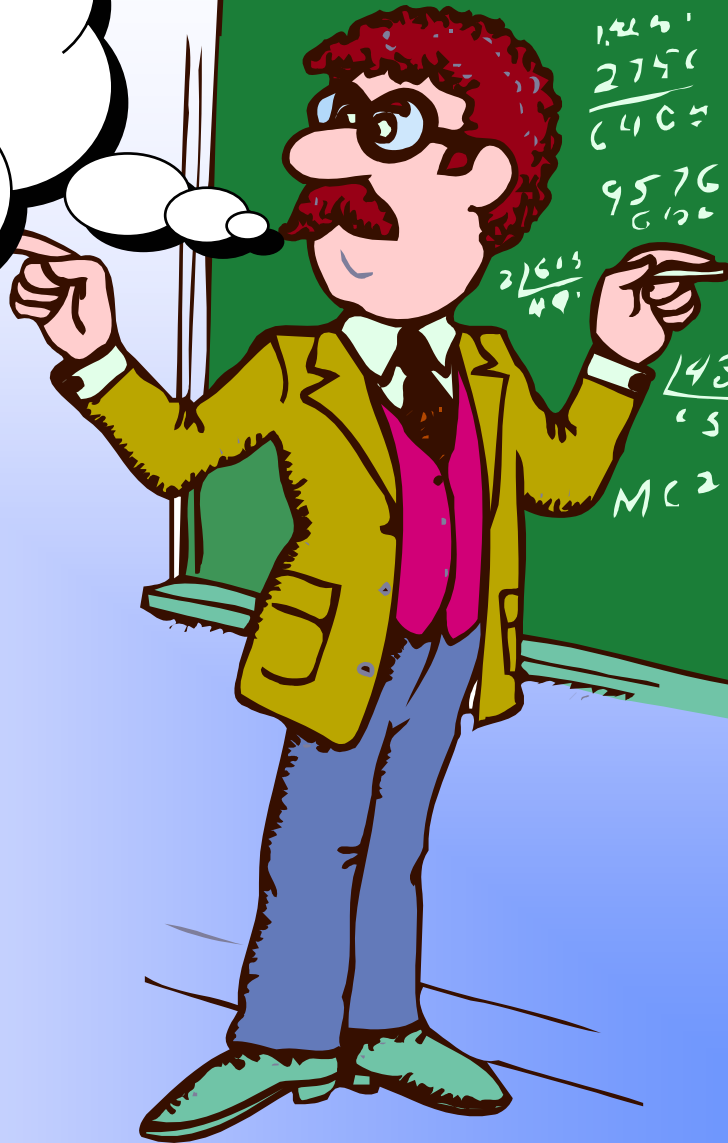
# Basic dcV spec vs others

- The basic dcV (normally the mV range) spec is generally the most accurate that the meter can be as it is the “shortest path” to the A/D converter.
- All other signals have to go through the divider and other signal conditioning circuits before they can follow the same path as the dc mV signal to the A/D converter.
- All the extra signal paths introduce more errors.



# Other Instruments

- Whilst this example was worked out using a DMM, the principle is exactly the same for all instruments, you need to understand what is being said and meant in the specification then calculate the actual specification at the point that you are making the measurement.
- The point is that the result may be FAR worse than the general specification of the instrument.





# Certificates

- SANAS Accredited Laboratories SHALL put key information on the certificate
- This is an attempt to normalize certificates and to ensure that they have “at least” the key information
- However, it cannot cover all that SHOULD be on the certificate
- And then there are reading errors and misunderstandings of what the certificate means
- Eg Thermometer (with probe) certificate states that the system is  $+0.5^{\circ}\text{C}$ . What does that mean – add 0.5 or subtract 0.5
- Very easy to get it wrong



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# Certificates

- During the presentation of the NLA's "Introduction to Estimation of Uncertainty of Measurement" Courses, many examples of inadequate calibration are discovered .
- Accurate measurements are becoming more and more important in modern manufacturing due to tighter tolerances
- The risks associated with a "bad" measurement are no longer acceptable (loss of export contracts, lawsuits due to personal injury etc)
- Customers are becoming better educated and are demanding improved service from calibration and testing laboratories alike



# Certificates

- **Customers shopping for calibration service provision have certain reasonable delivery expectations**
- **Calibration laboratories are at increased risk of losing business if they continue to ignore the technical requirements of their customers.**
- **A simple calibration result with a large uncertainty is just no longer acceptable!!**



# Some Calibration Myths

- A calibration certificate implies that an instrument meets its accuracy specification,
- Calibration means that the instrument was adjusted to ensure it meets its accuracy specification,
- It is sometimes more expensive to have an instrument calibrated than to replace it every year with a new one,
- Only instruments which can be adjusted require calibration; therefore e.g. LIG thermometers don't need periodic calibration,
- Re-calibration of an instrument only applies to instruments where the manufacturer has specified a calibration interval,
- Calibration interval is dictated by the calibration service provider and the user is bound by this,
- Safety regulations stipulate 1 year cal intervals



# Bottom Line.....

- Excessive cost – zero risk
- Zero cost – excessive risk
- Reasonable cost – acceptable risk
  - What risk are you prepared to take?
  - How much are you prepared to pay?



# Examples of unsatisfactory calibrations

- **Example 1**
- **Scenario**
- The calibration laboratory performs the calibration, but reports an uncertainty of measurement larger than the instrument's accuracy specification.
- **e.g.** dc Voltmeter with an accuracy of  $2 \mu\text{V}$  but an uncertainty of  $\pm 5 \mu\text{V}$  is reported.
- **Correct Approach**
- The uncertainty reported should always be smaller than the manufacturer's accuracy specifications.



# Examples of unsatisfactory calibrations

- **Example 2**
- **Scenario**
- The manufacturer's recommended performance verification procedure is not followed by the calibration laboratory when calibrating the instrument. That is to say the instrument is calibrated at arbitrary points.
- **e.g.** Manufacturer recommends calibration checking the linearity of the balance at 10% of full scale steps, but the calibration lab decides to save time and only performs measurements at 20% steps.
- **Correct Approach**
- The manufacturer's recommended performance verification procedure should always be followed since the manufacturer knows the functioning and design of the instrument. Calibration points are therefore very specifically selected in order that if they are within spec, there is a good probability that the instrument will perform within the manufacturer's accuracy specifications throughout its operating ranges.



# Examples of unsatisfactory calibrations

- **Example 3**
- **Scenario**
- The calibration procedure is not adequately described on the calibration certificate.
- **e.g.** The calibration certificate merely states the instrument was calibrated in terms of typical specifications. Or, the calibration certificate lists 10 or more standards which were used during the calibration to transfer traceability, but it is unclear which ones were used for which measurements.
- **Correct Approach**
- The calibration procedure, as referred to on the calibration certificate should either contain sufficient detail to repeat the measurements in exactly the same way if a second Metrologist calibrates the instrument, or alternatively should refer to some controlled document by date and revision number such as an internally generated procedure, or the manufacturer's recommended procedure in the manual.



# Examples of unsatisfactory calibrations

- **Example 4**
- **Scenario**
- The calibration certificate reports an uncertainty, but it cannot be applied to the measurement result/s due to resolution.
- **e.g.** The temperature was found to be  $102,3^{\circ}\text{C} \pm 0,05^{\circ}\text{C}$ .
- **Correct Approach**
- If the uncertainty is estimated according to the principles of the GUM, and is rounded accordingly, the uncertainty will always be applicable to the measurement result (same resolution).



# Examples of unsatisfactory calibrations

- **Scenario**
- The instrument is calibrated by simply comparing against a standard, and reporting the results even if they are clearly outside the manufacturer's accuracy specification, without bringing this to the express attention of the end user.

Range	Applied RPM	Lower Limit	Reading	Upper Limit
100	20	18	23	22
1000	800	796	795	804

- **Correct Approach**
- Any measurement results which fall outside the limits should be highlighted on the certificate to expressly draw the end-user attention to the fact that the instrument is outside specification and should be used with full knowledge of the consequences



# Examples of unsatisfactory calibrations

The calibration certificate contains a statement of compliance, however if the uncertainty is taken into account, the result could fall outside the specification limits.

Range	Applied	Lower Limit	Reading	Upper Limit
200mA	100mA	97.25mA	102.50mA	102.75mA

Uncertainty of Measurement:

$\pm 0,5 \text{ mA}$



# Examples of unsatisfactory calibrations

- **Correct Approach**
- Such measurement results should be dealt with in one of the following ways:-
  - - Do not include a compliance statement on the certificate,
  - - Mark these results and indicate that, “Conformance with the manufacturer’s accuracy specification could not be proven due to the uncertainty of measurement.”
  - - The instrument should be adjusted to bring the measurement result closer to the nominal value.



# Examples of unsatisfactory calibrations

- **Example 7**
  - No accreditation body logo on the certificate
- **Example 8**
  - No signature of an “authorised technical signatory”.
- **Example 9**
  - No units on measurement results



# On what basis do I select my calibration service provider?

- Is the selected lab capable of performing the calibration technically?
  - Does the lab have the competent staff?
  - Does the lab have a suitable method?
  - Does the lab have the equipment called for in the method?
  - Can the laboratory perform the measurements over the ranges and at the uncertainties required?
  - Does the lab have SANAS accreditation ***FOR THE MEASUREMENT RANGES AND UNCERTAINTIES REQUIRED?***



# On what basis do I select my calibration service provider? (2)

- Can the lab, and are they willing to, provide the calibration service I require?
  - Calibration may only be part of the service required.
  - Will they check for conformance to a technical specification?
  - Will they perform an adjustment if the instrument is found to perform outside the required accuracy specifications?
  - Can they calibrate the instrument according to the manufacturer's recommended performance verification procedure?
- What is the promised turnaround time?
- Where are they located?
- Are they prepared, and are they accredited, to perform the calibration on-site if required?
- **What will they charge?**



# What issues should be discussed & agreed upon during the contract review?

- What method will be used to perform the calibration?
  - Is there a requirement that an international method such as “ISO” or “BS” or “EA” be followed?
- Adjustment of the instrument if required
  - Measurement results reported for before & after adjustment
  - Do they have the technical know-how to perform the adjustment?
  - Do they have access to the manufacturer’s adjustment procedure?
  - What will they do if they cannot perform the adjustments and find the instrument performs outside the required accuracy limits?
- Do you want to know whether the instrument performs within specified accuracy limits?
  - The uncertainty must be taken into account
  - Can the lab interpret the accuracy specifications?



# Taking the uncertainty of measurement into account for conformance testing

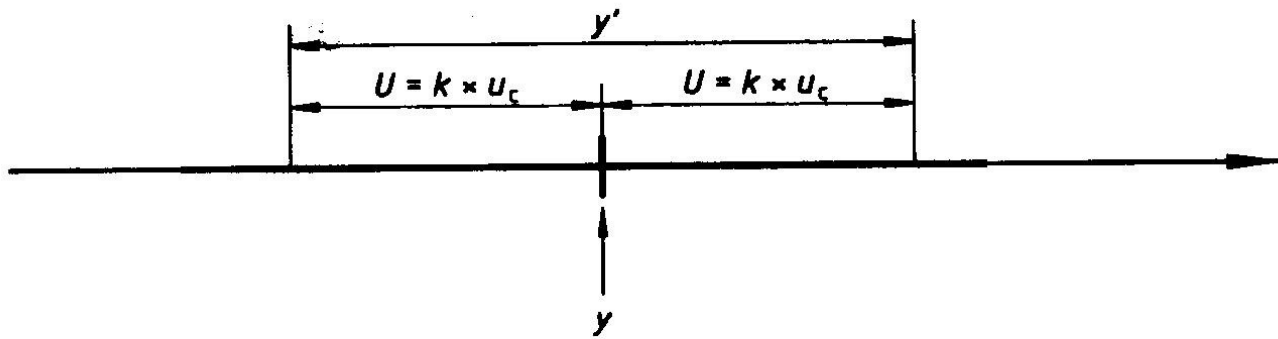
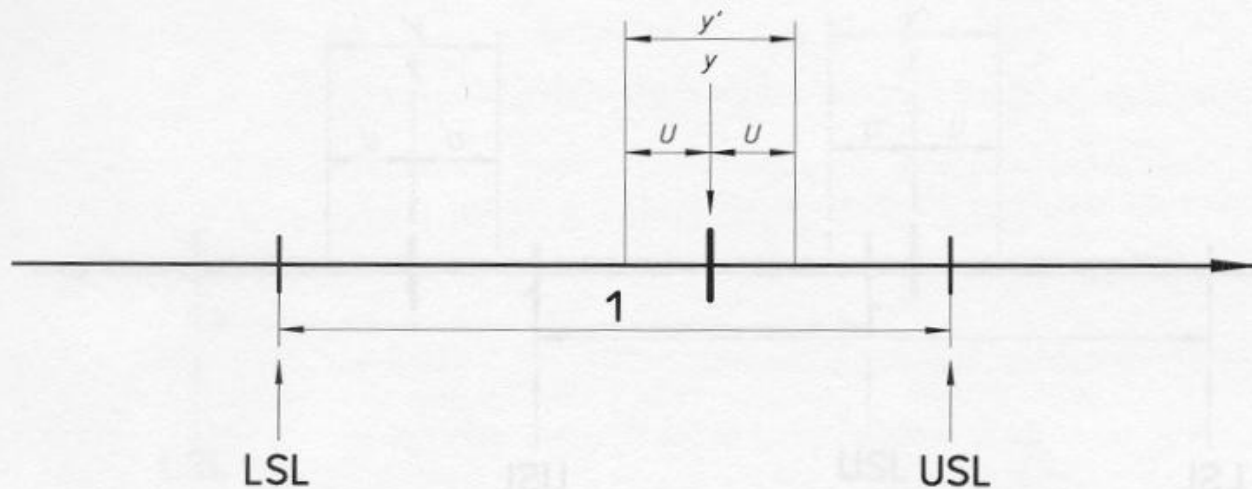


Figure 4 — Result of a measurement,  $y$ , and result of measurement, complete statement,  $y'$



# Taking the uncertainty of measurement into account for conformance testing (2)

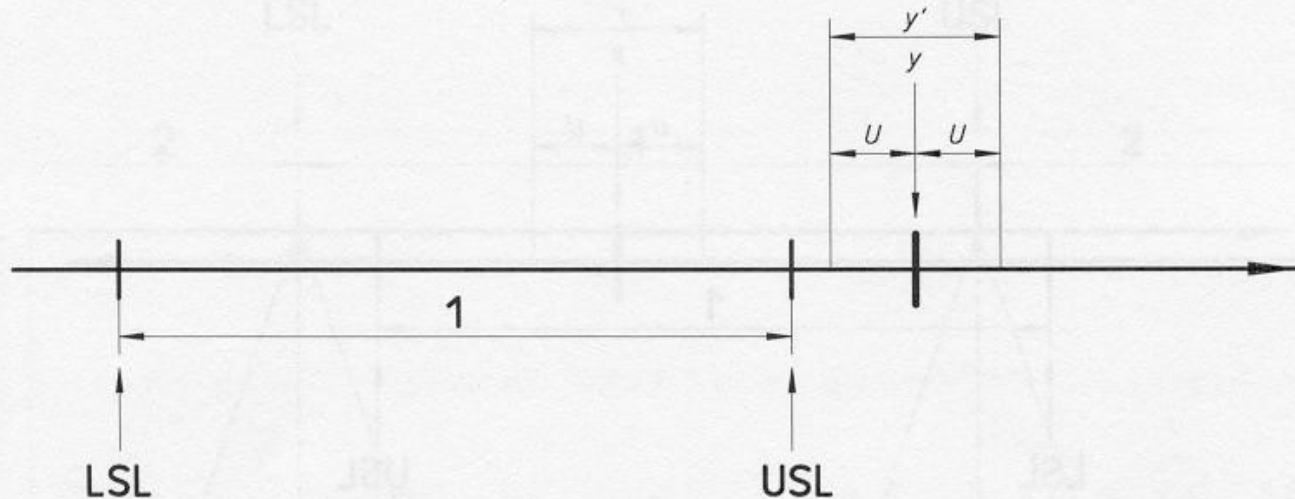


Key

1 Specification zone

Figure 6 — Conformance with specification is proved

# Taking the uncertainty of measurement into account for conformance testing (3)



**Key**

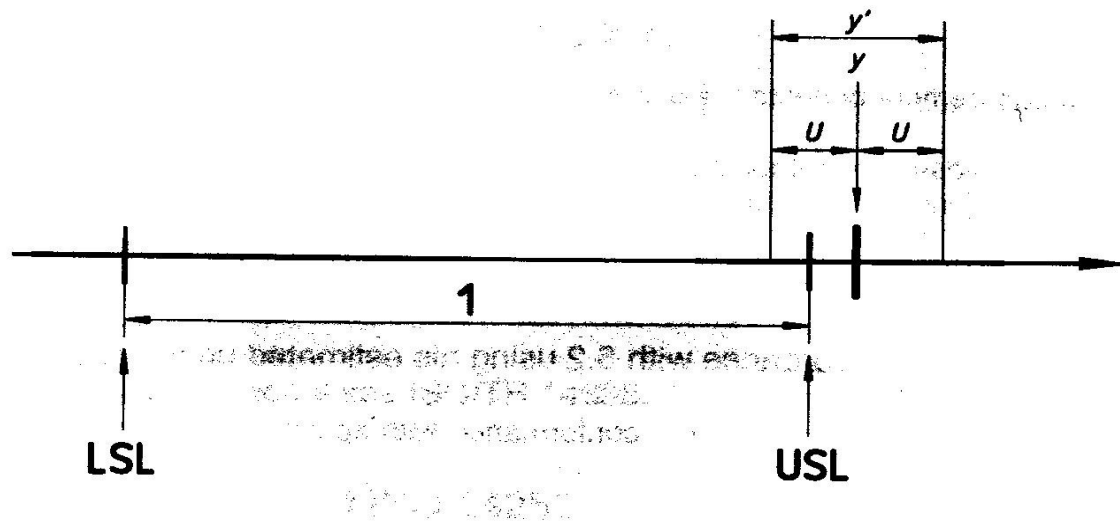
1 Specification zone

**Figure 8 — Non-conformance with specification is proved ( $USL < y - U$ )**



# Taking the uncertainty of measurement into account for conformance testing (4)

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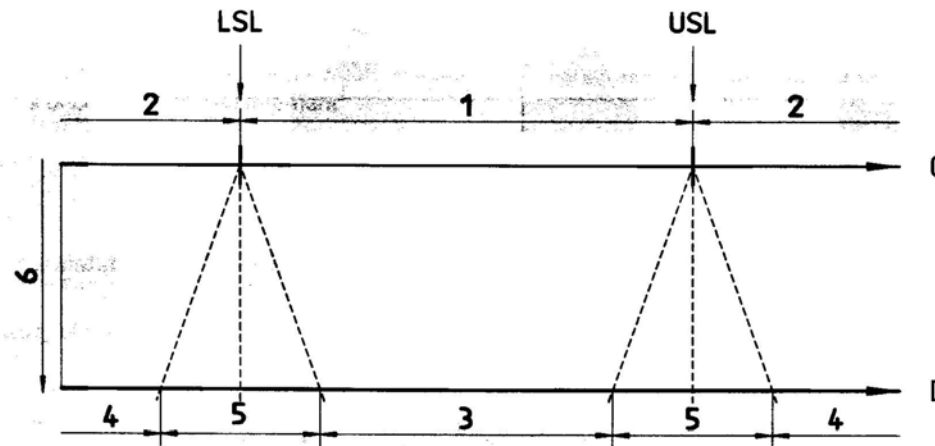


Key

1 Specification zone

Figure 10 — Neither conformance nor non-conformance with specification can be proved  
( $y - U < USL < y + U$ )

# Taking the uncertainty of measurement into account for conformance testing (5)

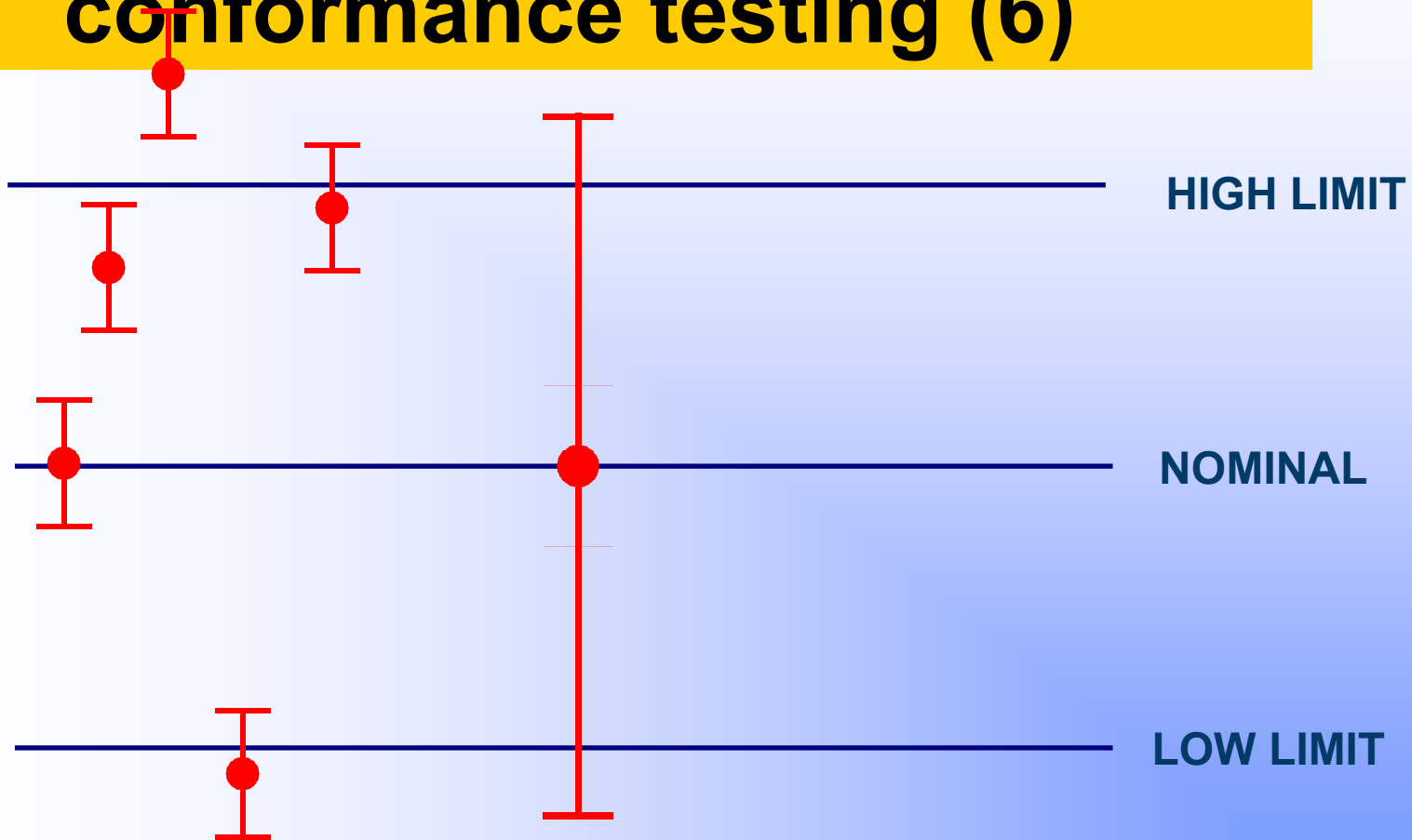


**Key**

- C Design/specification phase
- D Verification phase
- 1 Specification zone (in specification)
- 2 Out of specification
- 3 Conformance zone
- 4 Non-conformance zone
- 5 Uncertainty range
- 6 Increasing measurement uncertainty,  $U$

**Figure 5 — Uncertainty of measurement: the uncertainty range reduces the conformance and non-conformance zones**

# Taking the uncertainty of measurement into account for conformance testing (6)





# What issues should be discussed & agreed upon during the contract review? (2)

- What measurement points are to be calibrated?
- What uncertainties will be reported?
- Ensure that a SANAS calibration certificate is issued – i.e. bearing the SANAS logo
- Scheduled completion date
- Cost



# How do I best calibrate my instrument to ensure it is fit for purpose?

- The accuracy requirement of the instrument's application **must** be known.
- How will the instrument be used?
  - Will the instrument be used only at fixed measurement points or will it be used arbitrarily at any measurement point within its range?
  - Is the instrument used for a specific, dedicated application or is there a possibility it may be shared between applications?
  - Is the instrument user prepared to, or capable of, applying corrections from the calibration certificate?
  - Was the instrument originally purchased with a specified accuracy specification in order to meet the requirements of the application?
  - Will the long term stability of the instrument be analysed or is it preferable to assume the stability will be as specified by the manufacturer?



# How do I best calibrate my instrument to ensure it is fit for purpose? (2)

- How will the instrument be used (continued)?
  - Does the application necessitate the instruments use to an accuracy better than specified by the manufacturer?
  - Is the instrument a “passive” artefact, or an “active” electronic or mechanical device?



# How do I best calibrate my instrument to ensure it is fit for purpose? (3)

- In cases where the instrument is an “active” multi-range instrument calibrating it to confirm compliance with the manufacturer’s accuracy specifications has the following advantages:-
  - Corrections need not be applied,
  - Accuracy is known at any measurement point, (no complex interpolation)
  - Uncertainty analysis is dramatically simplified,
  - Instrument can be “shared” for different applications,
  - Instrument should be fit-for-purpose if the accuracy spec dictated its purchase in the first place,
  - Environmental affects on the calibration are minimised,
- How regularly do I wish to calibrate my instrument?
- Can it be calibrated by an industry SANAS accredited lab or must it be calibrated by the NML?



# How often should I be re-calibrating my instrument?

- What is a calibration interval?
  - It is the interval between calibrations, chosen to ensure the test or measuring instrument *continues to perform* at the required level of accuracy
  - At the end of the interval an accuracy must be predictable with a certain level of confidence
- What is a calibration interval not?
  - It is NOT an interval dictated by the calibration service provider
  - It is NOT an interval determined by the freq of quality audits
  - It is NOT an interval determined by budgetary considerations
  - It is NOT an interval determined by the availability of the instrument (taken out of service for cal)



# How often should I be re-calibrating my instrument? (2)

- A calibration interval should form part of an integrated calibration plan (not be arbitrarily chosen)
- If managed correctly it can reduce the costs of calibration
- What factors influence a calibration interval?
  - The type (quality/stability) of instrument
  - The accuracy required
  - The calibration service provider
  - Historical performance of the instrument
  - The use/*abuse* of the instrument
  - The *risk* associated with an out-of-tolerance measurement



# How often should I be re-calibrating my instrument? (3)

- Who is responsible for determining the calibration interval?
  - The **“user”**, in conjunction with the calibration service provider
  - This responsibility **CANNOT** be delegated to the calibration service provider without careful consideration and contract review
  - This **CANNOT** be made the responsibility of the quality department
  - This, by necessity, implies that instrument “users” must be more intimately involved with their instruments
  - Financial constraints **should not** influence the determination of calibration intervals
  - Calibration intervals **should** however be technically optimised to reduce costs to the **minimum required** to maintain the desired level of accuracy



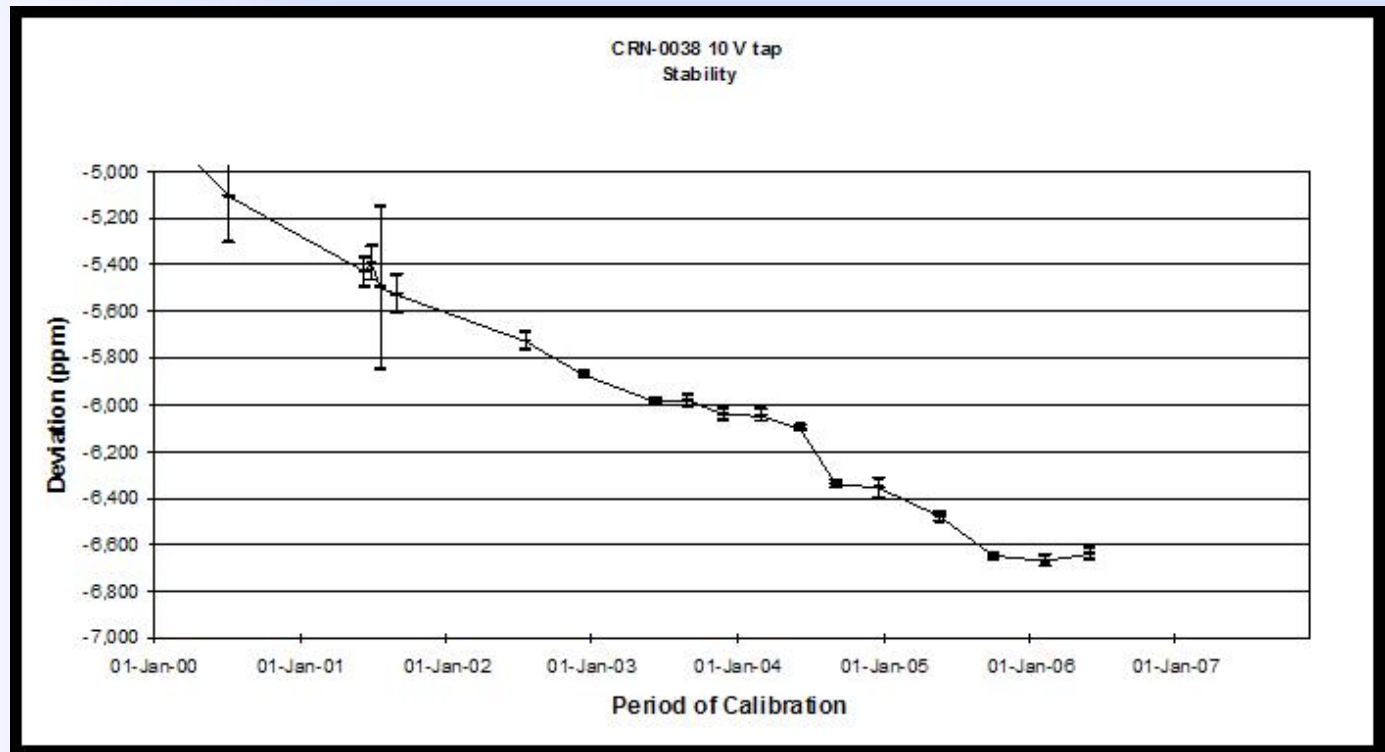
# Tracking the performance of my instrument

- Suggested ways of determining calibration intervals:-
  - **Industry – instruments on the factory floor**
    - \* Each calibration, check for conformance to the manufacturer’s accuracy specifications
    - \* Ensure calibration service providers adjust instruments, if necessary, to ensure they conform
    - \* Calibration service providers must record “before” and “after” adjustment values in order for the user to take remedial action if required
    - \* This method assumes the accuracy of the instrument, as purchased, is fit for the intended purpose
    - \* Track when adjustment is required – if no adjustment required lengthen interval, if adjustment required shorten the calibration interval
    - \* This method should however not exceed a predetermined appropriate maximum interval even if no adjustment is required as this increases risk



# Tracking the performance of my instrument (2)

- Suggested ways of determining calibration intervals continued:-
  - Test Labs – instruments used within a laboratory
    - \* Calibration intervals can be determined based on actual drift





# Periodically conducting confidence checks on my instrument

- Even a calibration interval selected on one of the two methods discussed is meaningless when:-
  - The instrument fails but the fault is not instantly noticeable,
  - The instrument is abused unknowingly,
  - The instrument is adjusted without prior knowledge
- “In-between” checks can reduce the risk associated with these scenarios
- Frequency and thoroughness of check depends on the risks associated and to some degree on available resources
- Confidence checks are **NOT** a substitute for calibration or “cheap do-it-yourself” calibration
- Confidence checks do **NOT** lengthen calibration intervals
- Confidence checks **REDUCE** risk!



# Summary

- **Let the buyer beware!**
- **Know what you are buying**
- **Know what you want**
- **Do what is right**
- **Check again and again**
- **Use common sense**



# Thanks

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# Specs, Certs, Errors & UoM! Tutorial

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