Animal & Plant Health Agency

Uncertainty of Measurement

What is it? Why do we need it? How do we use it?

David Galsworthy

What is Measurement Uncertainty?

- All measurements are made because somebody, somewhere, needs information. This information is often used to enable decisions to be made. In order to minimise risk, these decisions must be reliable.

- The reliability of decisions based on measurements depends on knowing the ‘uncertainty’ of such results.

- If the uncertainty of measurement is underestimated, erroneous decisions may be made that can have significant financial, reputational and other consequences.

What is Measurement Uncertainty?

Uncertainty and Confidence

- These go hand in hand together. For example, take a guess at the temperature of this room.
- How close to the "true" temperature do you think you might be?

What is Measurement Uncertainty?

- +/- 1 degree? H’mm… pushing it a bit, maybe.
- +/- 3 degrees? A bit more likely.
- +/- 10 degrees? Certainly (almost)!

What is Measurement Uncertainty?

- So far, our estimate of the room temperature has been based on a subjective evaluation. This is not entirely a guess, as we may have experience of exposure to similar and known environments.

- However, in order to make a more objective measurement it is necessary to make use of a measuring instrument of some kind; in this case we can use a thermometer.

What is Measurement Uncertainty?

Even if we use a measuring instrument, there will still be some doubt, or uncertainty, about the result. For example we could ask:

- “Is the thermometer accurate?”
- “How well can I read it?”
- “Is the reading changing?”

Is the Thermometer accurate?

- In order to find out, it will be necessary to compare it with a thermometer whose accuracy is better known. This thermometer, in turn, will have to be compared with an even better characterised one, and so on. This leads to the concept of *traceability of measurements*, whereby measurements at all levels can be traced back to agreed references.
- These agreed references are usually based on the SI system of units.

Is the Thermometer accurate?

- In other words, we need a *traceable calibration*. This calibration itself will provide a source of uncertainty, as the calibrating laboratory will assign a calibration uncertainty to the reported values.
- When used in a subsequent evaluation of uncertainty, this is often referred to as the *imported uncertainty*.

Is the Thermometer accurate?

- There are other possible influences relating to the thermometer accuracy. For example, suppose we have a traceable calibration, but only at 15ºC, 20ºC and 25ºC.

- What does this tell us about its indication error at 23ºC?

Is the Thermometer accurate?

- In such cases we will have to make an estimate of the error, perhaps using interpolation between points where calibration data is available. This is not always possible as it depends on the measured data being such that accurate interpolation is practical.

- It may then be necessary to use other information, such as the manufacturer's specification, to evaluate the additional uncertainty that arises when the reading is not directly at a point that has been calibrated.

How well can I read it?

How well can I read it?

- There will inevitably be a limit to which we can resolve the reading we observe on the thermometer.

- If it is a liquid-in-glass thermometer, this limit will often be imposed by our ability to interpolate between the scale graduations.

- If it is a thermometer with a digital readout, the finite number of digits in the display will define the limit.

How well can I read it?

- It can be seen that there will always be an uncertainty of ± half of the change represented by one increment of the last displayed digit.
- This does not only apply to digital displays; it applies *every time a number is recorded*.
- If we write down a rounded result of 123.456, we are imposing an identical effect by the fact that we have recorded this result to three decimal places, and an uncertainty of ± 0.0005 will arise.

Is the reading changing?

- Yes, it probably is!
- Such changes may be due to variations in the room temperature itself, variations in the performance of the thermometer and variations in other influence quantities, such as the way we are holding the thermometer.
- So what can be done about this?

Is the reading changing?

- The only information we have is a series of readings and a calculated average, or mean, value. We therefore have to use a statistical approach to determine how far our calculated mean could be away from the "true" mean.
- These statistics give us the uncertainty associated with the repeatability (or, more correctly, non-repeatability) of our measurements.

Environmental effects

•The following environmental effects are amongst the most likely to contribute to measurement uncertainty:

- Temperature
- Relative humidity
- Barometric pressure
- Electric or magnetic fields
- Gravity
- Electrical supplies to measuring equipment
- Air movement
- Vibration
- Light and optical reflections

Understanding the system

- It can be seen by now that understanding of a measurement system is important in order to identify and quantify the various uncertainties that can arise in a measurement situation.

- Conversely, analysis of uncertainty can often yield a deeper understanding of the system and reveal ways in which the measurement process can be improved. This leads on to the next question…

What are we measuring?

- Such questions have to be asked, and answered, in order that we can devise an appropriate measurement method that gives us the information we require.
- Until we know the details of the method, we are not in a position to evaluate the uncertainties that will arise from that method.

What are we measuring?

- This leads to what is perhaps the most important question of all, one that should be asked before we even start with our evaluation of uncertainty:

- *“What exactly is it that I am trying to measure?”*

What are we measuring?

- Until this question is answered, we are not in a position to carry out a proper evaluation of the uncertainty.
- The particular quantity subject to measurement is known as the *measurand*.
- In order to evaluate the uncertainty in a measurement system, we must define the measurand otherwise we are not in a position to know how a particular influence quantity affects the value we obtain for it.

What are we measuring?

- The implication of this is that there has to be a defined relationship between the influence quantities and the measurand.
- This relationship is known as the *mathematical model*.
- This is an equation that describes how each influence quantity affects the value assigned to the measurand. In effect, it is a description of the measurement process. A proper analysis of this process also gives the answer to another important question:

Measuring Uncertainty

- Our normal process for uncertainty analysis is based on something called *frequentist inference* – that is, a statistical sampling process that tells us how often events occur.
- A good example is when we evaluate repeatability - we conduct a series of measurements and then do some number crunching with the results. This is generally termed the “top-down” approach or Type A evaluation of uncertainty.
- A “bottom-up” approach or Type B evaluation is different but the uncertainties obtained are treated in the same way when they are combined.

Measuring Uncertainty

•Which approach is best for Pathology Laboratories and what key concepts do we need to consider in implementing that approach?

- Determine the measurand
- Understand the measurement procedure/process (end to end) and identify all possible sources of uncertainty
- Determine method precision
- Determine method bias / accuracy
- Evaluate the uncertainty of the method using the precision and bias estimates using applicable statistical rules
- Combine uncertainties to provide the required level of confidence in the methodology/technique

Measuring Uncertainty

•Determine method performance data from the entire measurement procedure (“top-down” approach) :

- Method Validation Studies
- Internal Quality Control
- Replicate Testing
- External Quality Assurance Data
- Within and between run (or plate) Variation

Accreditation Requirements

- **ISO 15189, 5.5.1.4**
- The laboratory shall determine measurement uncertainty for each measurement procedure in the examination phase used to report measured quantity values on patients' samples. The laboratory shall define the performance requirements for the measurement uncertainty of each measurement procedure and regularly review estimates of measurement uncertainty.

Accreditation Requirements

- **ISO 17025**
- **5.4.6.1** A calibration laboratory, or a testing laboratory performing its own calibrations, shall have and shall apply a procedure to estimate the uncertainty of measurement for all calibrations and types of calibrations.
- **5.4.6.2** Testing laboratories shall have and shall apply procedures for estimating uncertainty of measurement…

Further Information

- BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, JCGM 100:2008, *Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement.* Joint Committee for Guides in Metrology, First Edition, September 2008.
- EURACHEM/CITAC Guide CG 4: *Quantifying Uncertainty in Analytical Measurement*, QUAM:2012.P1, Third Edition, 2012. ISBN 978-0-948926-30-3.
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- United Kingdom Accreditation Service, M3003, *The Expression of Uncertainty and Confidence in Measurement*, Edition 3, September 2012.
- Eurachem/EUROLAB/CITAC/Nordtest/AMC Guide: *Measurement uncertainty arising from sampling: a guide to methods and approaches Eurachem* (2007). ISBN 978 0 948926 26 6

Exercise for Workshop Session

- Working in groups, select a particular test or analysis that is familiar to most of the group members.
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    - What is the most significant source of uncertainty for this analysis?
    - How is it evaluated?
    - Is it likely to affect the validity of the results?
    - What, if anything, can be done to reduce this source of uncertainty?
- Nominate a spokesperson for your group to present your conclusions to the other delegates when we reconvene.