

Topics in Metrology

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I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.

Lord Kelvin (William Thomson) London 1883.

Measurement is where theory and practice meet. Science, engineering and industry would have little use for mathematics or arithmetic were it not for measurement. Measurement provides a major component of the interface between theory and the real world.

This site discusses potentially controversial issues in fundamental aspects of metrology and associated fields. Most of the topics stem from our experience with calibration labs and their customers.

We welcome discussion and comment related to these articles. If you disagree with anything or would like to suggest corrections, additions or a new topic, or write a short article for this site, please contact us at: mjturner at biccard.com.

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1 Why calibrate? Why do we need ISO 17025?

1.1 Introduction

Question: *How do we know when we can truly believe a measurement?*

Short answer: *We can never have 100% confidence in a measurement.*

Longer answer:

- No measurement is ever correct. There is always an unknown, finite, non-zero difference between a measured value and the corresponding true value.
- Most instruments have specified or implied tolerance limits within which the true value of the measurand should lie if the instrument is functioning correctly
- One can never be 100% sure that an instrument is operating within its specified tolerance limits

BUT ...

- there are steps we can take to *minimise the probability of a measurement falling outside specified tolerance or uncertainty bands.*

Regular *traceable calibration* is a method for gaining quantifiable confidence in a measurement system. In this topic we discuss some fundamental aspects of calibration, why it is necessary at all, and why it is so important that a special standard is required to govern the calibration process.

1.2 Example

Consider the measurement of the gauge pressure of air in a ventilation duct. In this hypothetical example we happen to know in advance that the pressure is typically a constant 4 kPa and should lie in the range 2 – 4.5 kPa. To prevent irreversible damage to the duct the manufacturer specifies pressure may not exceed 5 kPa. In this example we use two different instruments for the measurement – a water-filled U-tube and an electronic manometer with digital display.

1. **Water-filled U-tube manometer.** We half-fill a clean glass U-tube with distilled water, connect one end of the U-tube to the duct and leave the other end open to atmosphere. All our connecting tubes are transparent and the U-tube is marked in millimetres. The pressure in the duct moves the water in the U-tube and we measure the difference in the heights of the columns with a resolution of approximately 0.5 mm. We can check for factors which we know might affect the measurement, such as leaks, blockages, air bubbles and air flow across the open end of the tube. We can also check the millimetre markings against a metre rule or vernier and measure the water temperature for density calculation. The result of the measurement is a pressure value in mm of water (503 mm in this case) which we convert to kPa, using the equation $p = \rho gh$ where ρ is the density of water ($\rho = 997.77 \text{ kg}\cdot\text{m}^{-3}$ at 22°C, Australian Standard AS 2849), and $g = 9.81 \text{ m}\cdot\text{s}^{-2}$ is the nominal acceleration due to gravity. Our calculated gauge pressure is $p = 4.92 \text{ kPa}$. Without doing any formal uncertainty analysis we intuitively believe that the true pressure is likely to be within about 1 mm of water or approximately 0.01 kPa of our measurement. therefore we feel confident that the pressure does not exceed the safe upper limit.
2. **Electronic manometer.** This manometer has a pneumatic connection to an internal temperature-compensated piezoresistive strain gauge pressure transducer, and a digital display in kPa with a resolution of 0.01 kPa. We connect the electronic manometer to the duct, wait for the display to settle and read a pressure of 4.95 kPa from the digital display. The ‘accuracy’ of the manometer is specified by the manufacturer as $\pm(0.5\% \text{ of reading} + 1 \text{ digit})$, so, if we believe the instrument, we have no option but to assume that the true pressure is within approximately 0.04 kPa of our reading, i.e., between 4.91 and 4.99 kPa. How confident can we be that the true pressure is below 5 kPa?

1.3 Comment

The U-tube manometer uses fundamental physical principles in its operation. Unless there is an unseen fault (such as a transparent blockage) the only mechanism that can hold the two menisci at different levels is a pressure difference. There are a limited number of modes of failure and an experienced technician who understands a little of the physics of fluids can easily verify the absence of faults with a high level of confidence and gain an intuitive, qualitative feel for the uncertainty in the measurement. Instruments such as

the fluid manometer based on fundamental principles can be used by experienced technicians with confidence in many applications without reference to a second instrument or standard. The trend, however, is away from this type of instrument which is cumbersome and usually requires a skilled operator, towards instruments that are more compact, portable and simple to operate.

If we require greater confidence in the U-tube measurement and the associated uncertainty, or an uncertainty substantially lower than (0.01 kPa), then it is possible to analyse and in some cases correct quantitatively the potential systematic errors that might be caused by surface tension effects at the menisci, the angle of the U-tube, the millimetre markings on the glass of the tube, parallax errors, variations in the local value of g , etc.

The electronic manometer indicates a pressure that might be very close to the upper safe limit. This example encourages us to think about the confidence we have in our manometer and in its specified tolerance bands. At what level of confidence can we say that the pressure does not exceed the safe upper limit?

The number of modes in which the pressure transducer, the electronic circuitry and the digital display can fail or malfunction is large. Most of the faults and malfunctions would not be visible to an operator therefore it is impossible to verify the absence of faults and electronic drift by simple inspection. We cannot tell by inspection if the instrument has recently been dropped, subjected to an over-range pressure or otherwise mistreated. When we make a measurement in the field we are forced to trust the instrument. The only way we can gain confidence in the electronic manometer is by regularly comparing its response with another similar or preferably superior instrument in which we have a high level of confidence. A quantitative comparison or verification of the performance of an instrument is called a *calibration*.

1.4 Calibration

To calibrate our electronic manometer we could borrow, purchase or hire a similar or superior manometer and a pressure source, and perform a comparison of the two manometers over the pressure range of interest. Our recent experience in measuring a pressure that appears to be very close to a safety limit motivates us to attempt to estimate at each calibration point the range within which the true pressure is likely to lie. This estimate is called an *uncertainty estimate*. In this case quantitative analysis of the uncertainty associated with the comparison, however, is immediately frustrated by our

lack of confidence in the output of the manometer we are using as a reference, and the unknown uncertainty associated with that instrument. If we attempt a more complete uncertainty analysis we may come across other factors that are not controlled or monitored during the comparison, e.g. fluctuations in the source pressure, environmental temperature, humidity and barometric pressure. If we are honest with ourselves we soon appreciate that to truly gain confidence in our electronic manometer we require at least the following conditions:

1. we should have a high level of confidence in the reference manometer:
 - it should have been calibrated recently against a superior instrument we trust by technicians we trust
 - it should have a well known uncertainty
2. the conditions under which the comparisons are performed should be well controlled and monitored.
3. the technician doing the comparison should have the technical competence and experience to enable him/her to identify and control external factors that might affect the comparisons.
4. The calibration process should deliver one of:
 - assurance that the manometer is performing within the manufacturer's specifications
 - uncertainty estimates associated with each calibration point indicating the range within which the true pressure lies with an appropriate level of confidence.

VIM³ defines calibration as:

a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realised by standards.

A product of a formal calibration is usually a calibration report including a table containing a set of reference values in which the calibration lab has

a high level of confidence, and the corresponding values indicated by the device under test (in this case our electronic manometer). To confirm that our manometer delivers measurements within its specified tolerance bands, at least at the time of the calibration, we need to verify that the true pressure is unlikely to lie outside the tolerance bands at each calibration point. This verification process requires quantitative estimates of the uncertainty associated with the comparison and the reference instrument.

1.5 Obtaining a calibration in which we have confidence

To calibrate our manometer in a manner that fulfills our requirements as enumerated above we have two options.

1. Perform the calibration ourselves. In this way we have full control over all the technical and quality aspects of the calibration process.
2. Request an independent laboratory to perform the calibration but audit that laboratory thoroughly to ensure that they have reference instruments in which we have confidence, a controlled environment in which to perform the calibration, competent technicians who understand our requirements well, and procedures for producing error-free calibration reports.

Options (1) and (2) above are feasible under limited circumstances. Maintaining our own dedicated calibration lab, however, is time-consuming and costly. We also soon discover that if we calibrate our instruments ourselves that our customers start auditing us to verify that we are competent, doing the job properly and keeping proper records etc. We are likely to find that managing audits of our labs and regularly auditing other laboratories we use is time consuming and costly.

After a little honest thought we come to the conclusion that we (and probably many other organisations who regularly make measurements in which a high level of confidence is required) would benefit from a national or international system which would give us confidence in calibration laboratory services. A system that provides confidence intervals around our critical measurements would be extremely valuable.

1.6 ISO 17025

ISO 17025 is an international standard governing most of the important aspects of calibration processes. Laboratories who meet this standard should operate a quality control system, be technically competent and be capable of producing technically valid results. The intention of ISO 17025 is to provide a functional system or hierarchy of calibration laboratories in which we can have confidence. Any calibration performed by an ISO 17025 accredited lab should:

- be performed by competent technicians in a controlled environment
- use reference instruments or materials in which we can have confidence
- operate an administrative quality system similar to ISO 9001.

ISO 17025 maximises confidence in reference instrument and materials by requiring that they are traceable to SI (System Internationale) units defined by international agreements at the BIPM[8] in Paris.

Mutual recognition agreements (MRA's) between accrediting authorities in different countries extend the hierarchy of trusted laboratories to a world-wide pyramid-shaped structure which has BIPM[8] in Paris at the apex. Traceability to SI units also ensures that measurements that we make in Sydney, Australia can be compared with similar traceable measurements made in many other countries. For example, if the ventilation duct in the example in section 1.2 above is made in Holland then we can have confidence that the Dutch kPa is the same as an Australian kPa.

1.7 Calibration intervals

Once our manometer has been calibrated how long can we trust its performance? The manometer is exposed to vibration, varying temperatures, humidity etc during storage and transport. After the initial calibration (which in some cases is performed by the manufacturer) have no information concerning its drift and response to normal handling. Only after the second and (preferably) subsequent calibrations do we have information from which we can deduce whether or not the performance of the instrument *between calibrations* is adequate.

Calibration interval is an aspect of calibration that can be critically important to the validity of measurements and confidence intervals, but is

highly instrument-specific and hence is not covered by a general standard like ISO 17025. Many manufacturers recommend calibration intervals (often one year) for their instruments. In practice, however, the user should determine the calibration interval based on analyses of successive calibration reports, the costs of calibration, the manner in which the instrument is stored and treated during normal use, and the consequences of out-of specification measurements.

1.8 Discussion

Making a measurement is simple. Anyone can do it. We have all done it. Making measurements in which we have a *quantifiable level of confidence*, however, is not a trivial task. Achievement of a measurement that can be compared with confidence with other measurements, possibly made in a different country, is even more difficult. Confidence and trust are critical in serious measurements. While it is feasible for small groups of individuals or organisations to audit each other, the development of mutual trust and confidence among larger groups of organisations and between nations is not feasible without some type of standard to which everyone agrees. To facilitate measurement comparisons between organisations in different countries this standard has to be international.

If a standard is to govern a world-wide activity successfully it should be unique, a genuine industry standard. Therefore there can be no alternative standards for calibration laboratories or users of calibrated measurement systems. A calibration is either performed by an ISO 17025 accredited laboratory and hence has documented confidence intervals and is traceable, or it is not. If the system is to work there can be no grey areas. If you don't like ISO 17025 your only recourse is to participate in the system and change it from within.

The fluid-filled manometer can be thought of as an instrument that realises a pressure unit based on a fundamental physical law ($p = \rho gh$) and constants (ρ , g). Instruments based on fundamental physical principles, such as the fluid-filled manometer, can deliver performance acceptable for many applications in skilled hands under controlled conditions. With a few exceptions these instruments tend to be bulky, costly and/or difficult to operate and the modern trend is towards instruments that are more compact and easier to use. To improve or verify confidence in instruments such as the fluid-filled manometer, or to fulfill contemporary ISO 17025 traceability requirements, these instruments are often formally calibrated.

It is of interest to note that at present all the base SI units with the exception of mass are defined in terms of fundamental physical constants and hence can be reproduced in any laboratory by skilled technicians with the appropriate equipment. Many national measurement laboratories reproduce a number of the base units using these instruments and compare their realisations with the BIPM[8] or other national labs.

1.8.1 Guarantees and probabilities

No standard can *guarantee* that a calibrated instrument performs within specified limits or according to the calibration certificate. Immediately after a calibration in an ISO 17025 accredited lab an instrument should perform within defined tolerances with a specified probability. To maintain that performance until the next calibration it is the user's responsibility to ensure that the instrument is not mishandled, subjected to environmental extremes, and to select an appropriate calibration interval.

1.9 Conclusions

The original question: *How do we know when we can truly believe a measurement result?*

Answer:

If we wish to make a measurement and estimate a range of values within which the true value is likely to lie with a quantifiable level of confidence, then our instrument has to be calibrated regularly by an ISO 17025 accredited laboratory. In our example in section 1.2 a traceable calibration would either confirm that our electronic manometer operates within specifications, or include uncertainty estimates at each calibration point. Uncertainty estimates would enable us to estimate a range of values within which the true pressure lay, and hence facilitate the determination at a specified confidence level, of whether or not the pressure exceeded the upper safety limit.

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2 ISO 9001, ISO 17025, calibration and traceability

If you can not measure it, you can not improve it.

Lord Kelvin (William Thomson)

2.1 Summary

ISO 9001 certified organisations have to make decisions regarding where to send their measuring instruments for calibration. Many calibration laboratories are accredited to ISO 17025 but some are not. Many accredited laboratories are not accredited for all the services they offer. The use of non-accredited calibration labs, or non accredited services of partially accredited labs, may reduce operating costs in the short term, but could turn out to be costly in the long term. Examination of ISO 9001 (2000) and ISO 17025 suggests that ISO 9001 certified organisations should select their calibration labs carefully and make sure that the labs they use are properly accredited for the services they provide.

2.2 Introduction

Organisations certified to ISO 9001 are required to calibrate all measurement equipment used to verify or control quality, and all such calibrations are required to be traceable to national or international standards (ISO 9001 1994 section 4.11, ISO 9001 2000 section 7.6). Records of calibrations are required to be kept and corrective action taken when measurement equipment is found to be out of specification.

In this topic we discuss some of the implications of calibration and traceability requirements for ISO 9001 certified organisations and for calibration and test laboratories. We investigate the meaning and components of the term ‘traceable’ and show that ISO 9001 certified organisations should use laboratories accredited to ISO 17025 for the calibration of all test and measurement equipment used to verify or control quality.

2.3 ISO 17025 (1999)

Many calibration laboratories claim accreditation to ISO 17025[2]. In Australia NATA[1] is the accrediting body, and accredited Australian labs are en-

titled to use the NATA logo on their documents and web pages. Accrediting bodies in some other countries are listed below[7]. ISO 17025 is an international standard that specifies quality and technical competence requirements for testing and calibration laboratories. ISO 17025 replaced ISO Guide 25 in 1999.

2.4 ISO 17025 accreditation

In Australia the ISO 17025 accreditation process includes an initial on-site visit by NATA officials and NATA-appointed technical experts who assess the calibration environment and the qualifications and competence of the technical staff. The assessment includes discussions with technical laboratory staff to allow them to demonstrate their knowledge and expertise. A measurement audit may also be carried out in which the lab is asked to calibrate a well characterised instrument or artifact. These activities are designed to bring to light any deficiencies in the technicians' understanding of the calibration processes. Subsequent to the initial assessment, the laboratory's performance is regularly assessed through proficiency testing[6]. Proficiency testing involves regular round-robin calibration or testing of pre-prepared artifacts, instruments or samples, and comparison of individual lab results with either the group result or a reference lab result.

An ISO 17025 accredited lab is required to perform internal audits (section 4.13) to verify that its operations continue to comply with the requirements of its quality system. Labs are also encouraged to maintain in-house quality checks on their calibration standards so that departure from specified performance is detected early (ISO 17025 section 5.9). For example, a voltage calibration lab might calibrate a stable in-house voltmeter regularly and statistically evaluate deviations from mean values to warn of possible problems with their voltage calibrator.

2.4.1 Costs

Services from ISO 17025 accredited labs are usually a little more costly than apparently identical services from non-accredited labs. Calibration labs that are not accredited to ISO 17025 have reduced costs and hence can deliver lower cost calibration services. In an era when share prices and quarterly returns rule, it is very tempting to shop around and simply use the cheapest service. This article attempts to show that this approach may not be optimal in the long term.

2.4.2 Errors

Hiring and keeping competent technical staff, internal audits, maintenance of in-house quality checks and participation in proficiency testing programs improves the likelihood of an error-free service but can never guarantee complete absence of calibration or other errors. However, customers of reputable ISO 17025 accredited labs can expect to be informed promptly and fully of errors when they are discovered, and of the particular consequences related to the calibration of their equipment (sections 4.9, 4.10).

2.5 Calibration, uncertainty and traceability

The ISO 9001 requirement for traceable calibration of test and measurement equipment raises questions concerning the term ‘traceable’. We examine definitions and components of traceability extracted from ISO 9001, ISO 17025 and other documents, and discuss the implications.

2.5.1 Traceability

VIM[3] defines traceability as *the property of the result of a measurement or the 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 The unbroken chain of comparisons is called a ‘traceability chain’.*

An unbroken chain of comparisons is a logical and easily understood component of traceability. In its simplest form a traceability chain can be thought of as a pedigree or list of makes, models and serial numbers of instruments or artifacts in the chain. The manager of a non-accredited lab might claim that his/her calibrations are traceable because he/she is able to trace the calibration pedigree of the references and standards he/she uses. However, there is more to traceability than a simple list of hardware.

2.5.2 Competence as an essential component of traceability

We discuss this aspect by example. Assume we keep a set of weights which we use to check balances in a chemical laboratory. If we can show that our weights are calibrated against weights which have a traceability chain that leads to the standard kilogram in Paris can we claim that our weights are traceably calibrated? Consider briefly the process of using a balance to

compare our weights with a set of calibrated weights. The balance should have a resolution and repeatability necessary for the uncertainty required in the final result. It must be properly serviced and maintained, mounted on an appropriately rigid and vibration-free bench in a temperature controlled environment, and not abused in any way. Air movement around the balance may need to be restricted. If the weights to be compared are of different densities compensation for buoyancy might be necessary. Buoyancy compensation might require measurements of air temperature, humidity and barometric pressure. If the lab provides other calibration services then the presence of other equipment nearby may alter the environment in the vicinity of the balance, e.g. a temperature calibration oven might alter the mean radiant temperature in the vicinity of the balance.

If we appreciate the potential complexity of the calibration process then we should require that the lab calibrating our weights employ a technician with sufficient competence and training to appreciate all the potential sources of error in the calibration. He/she should be capable of setting up the equipment properly and deciding which errors are significant and which can be ignored for a particular calibration.

Competence as a component of traceability is addressed in ISO 17025 section 5.6. Section 5.6.2.1.1 states that *... traceability of measurement shall be assured by the use of calibration services from laboratories that can demonstrate competence, measurement capability and traceability*. The use of the word ‘shall’ in a standard usually means that there is no other way to achieve compliance. ISO 17025 further notes that:

- *Calibration laboratories fulfilling the requirements of this International Standard are considered to be competent.*
- *A calibration certificate ... from a calibration laboratory accredited to this International Standard for the calibration concerned is sufficient evidence of traceability.*

Hence traceability as defined by VIM[3] and ISO 17025[2] contains a recursive element that requires ISO 17025 accreditation at each step.

2.5.3 Uncertainty as an essential component of traceability

No measurement is ever true. There is always a difference between the true value of a measurand and the output of an instrument. Measurement uncertainty is an quantitative statistical estimate of the limits of that difference.

VIM[3] defines measurement uncertainty as *a parameter associated with the results of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand.*

There are a number of reasons for the inclusion of uncertainty estimates as essential components of traceability. We discuss two below.

1. An uncertainty estimate and the procedure used to derive it document essential aspects of the calibration process. It is not logical to compare arbitrarily two measurement systems of widely disparate capabilities. Uncertainty estimates document the rationality and consistency of the comparisons. A traceability chain is a documented set of comparisons between consecutive pairs of instruments or measurement systems: A–B, B–C, C–D, etc. Usually instrument A is compared with instrument or standard B for the purposes of calibrating A, and the uncertainty estimated is that associated with that calibration process. The contribution of instrument or standard B to the overall calibration uncertainty is typically 4–10 times smaller than the contribution of A. Properly calculated and documented uncertainty estimates in a calibration chain indicate the ‘direction’ of traceability. As a corollary, uncertainty estimates should prevent inadvertent recursive or re-entrant calibration, in which, for example, instrument A is calibrated against B, B against C, and C against A.

More than one calibration lab has commented to us that many of their customers do not appear to be interested in uncertainties associated with the calibration of their instruments. The customer should view uncertainty estimates as confirmation that his/her instrument was calibrated against a reference of adequate performance and that all potential sources of error were under control during the calibration process.

2. Calibration often involves the use of more than one standard or reference measurement. For example, calibration of a volume flowmeter by comparison with a mass flowmeter requires simultaneous measurement of gas density to facilitate inter-conversions between mass and volume. If the gas is ambient air the density may be calculated from measurements of barometric pressure, temperature and humidity. When a calibration involves multiple measurements or comparisons the traceability chain develops multiple branches at that point. The uncertainty analysis documents the branches of the traceability chain and indicates the relative contribution of each of the associated measurements to the uncertainty in the final result.

2.5.4 Summary: Essential components of traceability

1. Traceable calibration involves comparisons with traceable standards or reference materials
2. Traceable calibrations can be performed only by laboratories that demonstrate their competence by accreditation to ISO 17025
3. A traceable calibration certificate must contain an estimate of the uncertainty associated with the calibration.

2.6 Discussion

The authors have seen evidence that instruments from ISO 9001 certified top-100 Australian companies are being calibrated in laboratories that are not NATA accredited. These organisations might be making small savings in the short term by using non-accredited labs. If, however, inadequately calibrated instruments are used to verify or control quality, then those organisations may find themselves in an embarrassing situation if their products are subsequently found to be out of specification. In extreme cases it may be necessary to recall all products manufactured since the last time the instrument was traceably calibrated. Organisations using non-accredited calibration labs do not conform to ISO 9001 and should not claim conformance.

Some calibration laboratories offer a wide range of calibration services but are accredited for only a subset of those services. In some cases labs claim 'ISO 17025 accreditation' but are vague about exactly which services are accredited and which are not. ISO 9001 organisations should be careful to select calibration labs that are explicitly accredited for the services they are using. In Australia NATA[1] keeps an up-to-date publicly available list of accredited labs with details of the calibration services for which they are accredited and their least uncertainties of measurement.

In a manufacturing environment it is often the case that more than one measurement system is used to monitor or control the quality of the product, and inevitably some measurements contribute more than others to uncertainty in product quality. ISO 9001 does not require all measurement systems to be calibrated – only those that contribute significantly to the control or verification of the quality of the product. One approach to this problem might be to perform uncertainty analyses on quality-related measurements using techniques similar to those outlined in the ISO GUM[4] to determine which measurement systems require calibration and the maximum associated uncertainties.

2.7 Conclusions

ISO 9001 certified organisations should analyse the measurement systems they use to verify or control quality, make informed decisions on which instruments require calibration, and have these instruments calibrated by selected ISO 17025 accredited labs.

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3 Calibration and adjustment

3.1 Introduction

A perusal of the archives of the ISO 17025 international email discussion list[5] suggests that there is substantial disagreement amongst the experts concerning the components of calibration. Much of the disagreement concerns *adjustment*. Some instruments and reference materials, e.g. mercury-in-glass thermometers, gauge blocks, standard resistors, cannot be adjusted if they are found to be out of spec at calibration. Many instruments, however, can be adjusted to make the indicated value equal to the standard value, within the uncertainty of the instrument. In this topic we discuss pros and cons of adjustment as part of a calibration process.

3.2 Adjustable instruments

Various circumstances may be associated with a given calibration.

- The customer might be monitoring the long-term stability of the instrument (e.g. as part of a process for determining calibration intervals) and adjustment might confound the stability analysis. In this case an acceptable outcome might simply comprise a calibration certificate with a table of indicated vs standard values or corrections.
- The customer might simply want the instrument returned ‘in specification’ and leave any adjustment decision up to the calibration lab. ISO 17025 (section 5.10.4.3) advises that if an instrument is adjusted the lab should report ‘as found’ or ‘before adjustment’ values, and ‘as left’ or ‘after adjustment’ values on the calibration certificate. This information should allow some analysis of stability to be performed post-calibration, but might increase the costs of calibration.
- An adjustable instrument might deviate from the reference by a large proportion (e.g. 80–90%) of the instrument’s specified uncertainty. This instrument is technically within specification, but if left unadjusted, might drift out of specification soon after the calibration, resulting in problems for the user that may be detected only one year later. Customers who are aware of this possibility sometimes request adjustment only if the indicated value deviates from the standard value

by more than a pre-determined proportion of the tolerance. Some calibration labs have standard procedures which specify the conditions under which in-tolerance adjustments should be made.

3.3 Non-adjustable instruments

For completeness we briefly discuss non-adjustable instruments. The calibration certificate of non-adjustable items may contain various items of information depending on the calibration lab operating procedures and the customer's requests.

- A simple 'in specification' or 'out of specification' report may be given. In this case the user is not able to analyse the stability of the instrument or reference material. ISO 17025 accredited labs, however, are obliged to keep detailed records of all such calibrations (section 5.10.4.2), so clients should be able to obtain those details after the event.
- The calibration certificate may contain a table of indicated values vs standard values, or corrections vs indicated values, or both.

3.4 Conclusion

It is important that the customer discuss with the calibration laboratory, before work commences, the details of any adjustment procedure to be followed during the calibration.

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4 ISO 9001 certified calibration labs

4.1 Introduction

It might seem reasonable that an ISO 9001 certified calibration laboratory should be capable of calibrating instruments for an ISO 9001 certified organisation. In this short article we examine ISO 9001 and ISO 17025 for evidence for and against this possibility.

4.2 ISO 9001 and ISO 17025

ISO 17025 section 1.6 states that laboratories that *comply with the requirements of this International Standard ... will operate a quality system for their testing and calibration activities that also meets the requirements of ISO 9001 ... and ISO 9002*. In the same section, however, we read that *ISO 17025 covers several technical competence requirements that are not covered by ISO 9001 and ISO 9002*. The technical competence requirements of ISO 17025 are found in section 5.

4.3 Discussion

A lab that operates an ISO 9001 system may have certain quality systems in place but they do not necessarily have accredited technical competence for performing calibration services. In the metrology environment ISO 17025 can be considered to be a superset of ISO 9001. Appendix A of ISO 17025 provides a cross-reference between ISO 17025 and ISO 9001/2.

4.3.1 ISO 17025 revision

ISO 17025 (1999) is presently undergoing minor revision so the sections relating to quality systems maintain compatibility with the recently revised ISO 9001 (2000).

4.4 Conclusions

ISO 9001 certification can be considered to be a necessary but not sufficient condition for the provision of calibration services. Potential customers should

select labs that are accredited to ISO 17025 for their specific calibration requirements.

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5 Uncertainty and proficiency testing

5.1 Commercial reality

Most calibration labs are commercial concerns and need to attract enough customers to cover costs and make a profit. If a lab can lower its ‘least uncertainty of measurement’, it is in a position to increase the charge for its service. In addition, a lower uncertainty enables a lab to calibrate a wider range of instruments and hence it should be able to attract more customers.

5.2 ISO 17025 and NATA requirements for proficiency testing

All ISO 17025 accredited labs are required (section 5.9) to *have quality control procedures for monitoring the validity of tests and calibrations undertaken. . . . This monitoring . . . may include . . . participation in interlaboratory comparisons or proficiency-testing programs.* Australian ISO 17025 accredited labs, however, are *normally required to participate in all NATA proficiency testing programs*[6] unless no suitable program is available.

5.3 Evaluation of proficiency tests

Calibration labs participating in a proficiency test are requested to calibrate an instrument or artefact that has been calibrated by a reference laboratory. NATA presently analyses each lab’s results by calculating a normalised error E_n as follows[6]:

$$E_n = \frac{LAB - REF}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad (1)$$

where:

LAB and U_{ref} are the participating laboratory’s result and uncertainty respectively.

REF and U_{ref} are the reference laboratory’s result and uncertainty respectively.

5.4 Discussion

If both reference and participating labs produce measurements with zero mean bias (no systematic errors) then we expect that on average $E_n = 0$. Typically U_{lab} and U_{ref} are based on a 95% level of confidence, hence the range $-\sqrt{U_{lab}^2 + U_{ref}^2}$ to $+\sqrt{U_{lab}^2 + U_{ref}^2}$ is an estimate of the 95% confidence interval for $LAB - REF$, taking both labs' uncertainties into account. If the observed deviation of E_n from zero is truly random then E_n should lie in the interval -1 to $+1$ in 95% of cases. In proficiency tests E_n values that lie outside this interval are considered unsatisfactory and labs are asked to investigate and explain their result.

The participating lab's uncertainty estimate appears in the denominator of equation 1. Therefore, all other things being equal, a lab with a large uncertainty (U_{lab}) is less likely to be asked to explain a large E_n than a lab with a small uncertainty.

Calibration laboratories are therefore faced with conflicting motives when they develop procedures for estimating uncertainties. On the one hand low uncertainty estimates may increase revenue. On the other hand high uncertainties decrease the probability of failing a proficiency test. During participation in proficiency tests calibration labs can expect to be asked to calibrate an instrument or artefact with a specification that is close to its best measurement capability, and hence contributes little to the overall uncertainty of the result. In other words, usually $U_{ref} \ll U_{lab}$.

5.5 Conclusions

Proficiency testing can be viewed as an evaluation of both calibration ability and uncertainty estimates. As far as we are aware proficiency tests are the only occasions when uncertainty estimates are evaluated quantitatively.

Calibration labs should take care to develop procedures for estimating unbiased, realistic uncertainty values for their calibration processes.

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6 Errors, corrections and uncertainty

6.1 Summary

Errors can be divided broadly into two types – systematic and random. Systematic errors are repeatable and can usually be predicted and hence corrected. Errors caused by processes that are either truly random or too difficult or too costly to predict are usually classified as random errors and treated statistically. An uncertainty value associated with a measurement or a calibration is conventionally interpreted as the scatter or spread of a random process. Conventional practice is to correct a measurement for all known systematic errors, and estimate an uncertainty associated with only the random components of the error. Corrections are seldom perfect and uncertainties associated with corrections are included in the overall uncertainty estimate. Uncorrected systematic errors should not be included in an uncertainty estimate.

6.2 Introduction

No measurement is ever correct. Every measurement has an associated error. The true value of a measurand is *never* known. Measurement error is the difference between the (unknown) true value and the measured value. The value of the error is never known. If we know the error in magnitude and sign we can correct the measurement to obtain the true value of the measurand. In practice the best we can do is correct known systematic errors to the extent that is possible or practical and estimate a range of values within which the random component of the error is likely to lie. Such an estimate is termed the *uncertainty* of the measurement.

This topic examines the classification of measurement errors into systematic and random, and how the two types of errors are treated in the estimation of uncertainty.

This topic is incomplete.

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7 References and web links

1. National Association of Testing Authorities (Australia)
<http://www.nata.asn.au>.
2. ISO 17025 – 1999. General requirements for the competence of testing and calibration laboratories. International Standards Organisation. Switzerland 1999.
3. VIM: Vocabulaire International des Termes Fondamentaux et Généraux de Métrologie. (International Vocabulary of Basic and General Terms in Metrology). International Standards Organisation. Switzerland 1993. Published in Australia as AS 3807-1998 : Vocabulary of basic and general terms in metrology.
4. ISO GUM: Guide to the expression of uncertainty in measurement. International Standards Organisation. Switzerland 1995.
5. ISO 17025 discussion group list server can be found at
<http://www.fasor.com/iso25/>.
Archives can be found at <ftp://ftp.fasor.com/pub/iso25/archive/>. To find discussion on the definition of calibration open the October 1999 file with a text editor or word processor and search for the text string ‘definition of calibration’.
6. National Association of Testing Authorities. Guide To Nata Proficiency Testing. Sydney 2002.
7. Some ISO 17025 accrediting bodies:
 - UK: <http://www.ukas.com>
 - Canada: <http://www.scc.ca>
 - New Zealand: <http://www.ianz.govt.nz>
 - USA: <http://www.a2la2.net>
 - South Africa: <http://www.sanas.co.za>

A more comprehensive list of accreditation bodies can be found at <http://www.bipm.org/links/>.

8. Other useful links:

- BIPM (Bureau International des Poids et Mesures):
<http://www.bipm.fr>
- Agilent (formerly Hewlett-Packard) Metrology Forum:
<http://metrologyforum.tm.agilent.com/>
- Microsoft Excel bugs:
<http://www.npl.co.uk/ssfm/ssfm1/validate/testing/excel.html>.
- Standards Australia (on-line sales of Australian, ISO, IEC and Japanese standards): <http://www.standards.com.au/>

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