

# The History and Current Status of Traceability

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## **6.10 traceability**

*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 definition of uncertainty has changed little since it was required in Mil Std 45662A, the only change being the addition of the final 4 words. For national level laboratories, as well as scientific work in general, the additional phrase mandating uncertainty statements was of no particular note since uncertainty statements were always considered necessary. In the industrial measurement community, however, it was a bombshell that unmoored traceability from its historical practice and set it adrift. In this paper I will try to give some historical perspective to the current state of affairs, and discuss the increasing confusion about the relation of traceability to uncertainty. Finally, I will try to show that there are no real technical issues to settle because the laboratory accreditation community has already, and properly, addressed traceability as a contractual and regulatory issue.

In a scientific sense, traceability has never been an issue. Scientists never give traceability statements. They do give estimates of uncertainty, and one source of uncertainty is that the unit might not be exactly the stated unit. In other words, if a scientist states an answer is meters, everybody assumes he is using the international meter, and any uncertainty in his meter being the SI meter is somehow handled in the uncertainty budget. For the scientist, a measurement that is not traceable is inconceivable.

For industrial metrology, traceability is a critical property of measurements. The reasons are basically historical. The gradual implementation of the idea that industrial measurements should be made like scientific measurements has taken a long and somewhat twisted path. A century ago industry got along quite well with a system that looked at a factory or company as its own little universe. As long as measurements were consistent in the little universe, it was of no major concern that the different universes used slightly different units. As industry became more linked, that is, sold parts and assemblies to each other this separate universe paradigm no longer worked. The era when different industries needed linkages between local units is quite varied. Both world wars I and II caused a flurry of standardization efforts and international agreements. Still, it was not until 1959 that a meeting of the directors of the English speaking NMIs adopted a single definition of the inch, 25.4 mm. Semiconductor factories were still separate universes with respect to details like linewidth within the memory of most readers.

## **Traceability of Standards**

The term “traceability” itself became a serious matter with the US Government adoption of quality standards in the middle of the last century. It was an age of specification writing, with detailed

specifications for everything from quality systems to doughnuts. Among these was MIL Q-9858A which stated:

***4.2 Measuring and Testing Equipment.***

*These devices shall be calibrated against certified measurement standards which have known valid relationships to national standards at established periods to assure continued accuracy.*

One thing of note is that this standard is somewhat better in its language. If the language “known relationship” had been used instead of “traceability” the system might have been closer to our current thinking on the subject.

MIL 45662A defined traceability as:

- 3.5 *Traceability. The ability to relate individual measurement results through an unbroken chain of calibrations to one or more of the following:*
  - 3.5.1 *U.S. national standards maintained by the U.S. National Bureau of Standards (NBS) and the U.S. Naval Observatory;*
  - 3.5.2 *Fundamental or natural physical constants with values assigned or accepted by the U.S. NBS;*
  - 3.5.3 *National standards of other countries which are correlated with U.S. national standards;*
  - 3.5.4 *Ratio type of calibrations;*
  - 3.5.5 *Comparison to consensus standards.*

The standard then defined the requirements for traceability in section 5.8.

*5.8 Calibration sources. M&TE and measurement standards shall be calibrated by the contractor or another calibration facility utilizing measurement standards whose calibration is traceable. All measurement standards used in the calibration system shall be supported by certificates, reports, or data sheets attesting to the description or identification of the item; the calibration source; date of calibration; calibration assigned value; statement of uncertainty and environmental or other conditions under which the calibration results were obtained.*

This “traceability” is not quite our current traceability in that it specifies only the traceability of equipment. Thus, the values expressed by the measurement standards used in calibrations, not the measurement results, needed to be traceable. It is from this point that the definition of traceability begins to shift.

The problem with traceability was the chain. In many cases the gage blocks on the floor were related to national standards by chains of 5 to 10 steps. There was simply no mechanism to actually go through the chain from the bottom to the top for all gages and measuring equipment. Into this vacuum stepped the NBS Number. MIL Handbook 52B was the guidance document for MIL C-45662A. It stated:

*6. Reports for the highest level standards of sources other than NBS or a Government laboratory must bear a statement that comparison has been made and is traceable to*

*National Standards at planned intervals. An NBS test number is one means of substantiating comparison.*

The “one means” eventually became THE MEANS when the individual standards, like the gage block standard GGG-G-15, called for specific items to be in a calibration report.

*3.9 Manufacturer’s report of calibration. A report of calibration is required (see 6.2), it shall be furnished with each gage block or set of gage blocks showing the results obtained at the manufacturer’s final inspection of each individual block and containing the following information:*

*(g) Statement on traceability of calibration to NBS shall include NBS test number and date.*

Thus the “Traceability = NBS Number” became the US norm.

Before we go on, it is important not to miss the forest for the trees, or in this case one tree. The military quality standards are an important landmark in metrology history. The entire system was designed to help assure that equipment, and in our case measurements, met a specification. MIL STD 45662A was an important step towards modern industrial metrology methods and is a direct ancestor of the current ISO 17025. Of the large requirements structure of the standard, traceability is a small part, and a rather limited part at that.

While the system might look fragile, particularly the NBS Number somehow enforcing accuracy, we are still faced with the undeniable fact that the system seemed to work. Airplanes fly, cars roll, and this laptop I am using works quite well. It was not an efficient system; some calibration labs were audited by their customers over 100 times a year. But the combination of two things seems to have been adequate for the purpose.

1. The existence of a valid NBS number on the lab calibration report was reasonable assurance that an NBS calibration was somewhere in the chain.
2. The standards used were better than what was actually needed by some significant ratio.

### **Traceability of Measurements**

Traceability, of itself, does not make measurements better. The entire structure of the MIL standards did force better measurements, or at least placed some emphasis on better measurements. Somehow, traceability became an important issue separate from the regulatory environment that started it. By the end of the 1970s there was a cottage industry of traceability paper writing, mostly at NBS. There were problems fitting statistical process control and measurement assurance practices into the industrial environment where calibration intervals and stickers were a way of life, a way of life required by MIL C-45662A. There began to be a linkage between traceability and uncertainty. Traceability was something that had a “timeline”. One system could be “more traceable” than another. These are attributes of uncertainty, not traceability. Traceability is the existence of a chain, and thus a logical variable. There is a chain or there isn’t. Still uncertainty was somehow implicitly tangled up in the picture.

The final linkage was completed in the definition in the VIM. Here, two things changed. First, traceability moved from being a property of the measurement standards to the measurement result. The second change was to demand a reported uncertainty on each calibration.

The changes in the definition of traceability, while appropriate, had the consequence of destabilizing traceability. It was now obvious that an NBS number was not adequate proof of traceability. Somehow the lab at the bottom would have to prove that all the links existed and had uncertainty statements. For a while, at least in the US, the requirement was simply ignored. The new definition of traceability was only in the International Standards system, and had not been adopted into the US Government or US voluntary standards system. This changed dramatically with the rise of laboratory accreditation in the 1990s.

### **Laboratory Accreditation**

The US calibration system abruptly joined the rest of the world in 1994 with the adoption of NCSL/ANSI Z540-1994 and the cancellation of 45662A. This standard adopted the language of ISO Guide 25 for the US calibration quality standard. It was not a complete break with the past, Guide 25 was basically a modified version of 45662A after it had passed through NATO into the European standards system. Thus, most of the quality system requirements were not much different than the one currently in use in the US. The new definition of traceability, however, was now the only definition.

During the same period that the quality standard was changing laboratory accreditation hit the US calibration system. Laboratory accreditation, like the registration to ISO 9000 movement, can be thought of as the final formalization of supply chain audits. Now, instead of each supplier being responsible for auditing their suppliers, a third party would audit them. The direct economic benefit was that a calibration lab that had been audited by 100 or more different customers each year would now be audited once, and all of the companies would accept it. This was a significant savings for the calibration system as a whole, and since most of these audits were required by and paid for by the US government it was a savings for everybody.

While the need for laboratory accreditation can be debated, one thing it did simplify was traceability. The basic premise of accreditation is that each lab need only worry about its link in the traceability chain and the accreditation organization will assure the rest of the chain. In its simplest implementation it would mean that each lab would have to use suppliers that were accredited by the same organization. In practice, the organizations have organized under the International Laboratory Accreditation Cooperation (ILAC) to allow labs to use suppliers accredited by other organizations that have reciprocity agreements. Thus the different assessment organizations assess each other on a regular basis and the web of reciprocal organizations is large. In the US there are a number of organizations that have wide reciprocity with both the European (EA) and Pacific (APLAC) mutual recognition bodies.

In order to have reciprocity, there must be essential agreement of what the standard (ISO 17025) means, and this includes traceability. Traceability has gone from being a US government contractual term to an internationally recognized regulatory term, defined in detail by ILAC.

## ILAC G2:1994 Traceability of Measurements

### 4. ELEMENTS OF TRACEABILITY

*Traceability is characterized by a number of essential elements:*

- an unbroken chain of comparisons going back to a standard acceptable to the parties, usually a national or international standard;*
- measurement uncertainty; the measurement uncertainty for each step in the traceability chain must be calculated according to defined methods and must be stated so that an overall uncertainty for the whole chain may be calculated;*
- documentation; each step in the chain must be performed according to documented and generally acknowledged procedures; the results must equally be documented;*
- competence; the laboratories or bodies performing one or more steps in the chain must supply evidence for their technical competence (e.g. by demonstrating that they are accredited);*
- reference to SI units; the “appropriate” standards must be primary standards for the realization of the SI units;*
- recalibrations; calibrations must be repeated at appropriate intervals; the length of these intervals depends on a number of variables, (e.g. uncertainty required, frequency of use, way of use, stability of the equipment).*

Widespread laboratory accreditation moves the term “traceability” completely out of the scientific arena to the international regulatory arena. The US, though a bit behind because of a late start, is catching up fast. There are over 800 accredited laboratories in the US.

It would be nice if this was the end of the story, but there are always some details to clean up. In traceability the detail is how many traceability paths must be documented when the measurement entails the measurement of a number of different quantities. To measure speed you must measure distance and time. This is not so hard. But to measure length, you must measure temperature. How well do you need to measure temperature?

If I am measuring a 1 meter piece of wood with a tape, and need an uncertainty of 1 mm, do I need a traceable temperature measurement? The worst case (across the grain) CTE wood is about  $60 \times 10^{-6}/^{\circ}\text{C}$ , and my tolerance means I need to know the temperature to about  $20^{\circ}\text{C}$ . I would maintain I can reliably guess the room temperature to much better than that, although I have never been personally calibrated.

At what point does having a calibrated thermometer become silly? There is a complete continuum of cases between the NMI measurements where millidegrees are important to the case above. Nearly any attempt to address all of the possible cases is a bottomless pit. The simplest thing is to say that any correction to a measurement result that is over some % of the total uncertainty must

come from a traceable measurement. The problem even with this is the % needed will vary by field, and in a regulatory environment, well meaning advice can have serious consequences. Currently, the decisions are left to the technical assessor. The lab can, of course, appeal any decision and have other experts weigh in on the subject.

The problem is well understood at the international level. The ILAC G16 document of 2001 states its policy on traceability and has the following requirement and note:

(a) Laboratories accredited by ILAC Member Bodies shall be able to demonstrate that calibration of *critical equipment*, and hence the calibration or test results generated by that equipment, relevant to their scopes of accreditation, is traceable to the International System of Units (SI units).

Note 3:

“Critical “ equipment used by testing and calibration laboratories is considered by ILAC to be those items of equipment necessary to perform a test or calibration from the scope of accreditation and which have a significant effect on the uncertainty of measurement of test or calibration results. ILAC member bodies have agreed to investigate this issue further and to develop guidelines to differentiate between calibrations that are critical and less critical and to indicate how in the latter case the traceability requirements may be less rigorous.

Thus the problem is being addressed. Finally, it should be recognized that refining the meaning of traceability is not a game that just anybody can play. Laboratory accreditation is a world-wide movement with very rigorous requirements for the member bodies to use standardized interpretations of terminology, traceability included. The terms must be usable in such diverse fields as chemical and environmental testing, ASTM materials tests, and gauge blocks. Given the breadth of uses and the international nature of its definition and interpretation, it few remaining details that are unsettled will remain unsettled for some time to come.

There is still a useful niche for professional and standards groups, which is to give advice on how to make up uncertainty budgets in their respective fields. Some fields, like dimensional metrology, have a reasonable number of references for metrologists to consult, although there is room for more. Traceability, however, is best left to the regulatory community that defines and enforces it.

References:

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3. MIL Handbook 52B, “Evaluation of Contractor’s Calibration System”, Feb. 1, 1989.
4. International Vocabulary of Basic and General Terms in Metrology, second edition, 1993, BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, and OIML, International Organization for Standardization, Geneva (1993).
5. National Conference of Standards Laboratories (NCSL), ANSI/NCSL Z540-1-1994, American National Standard for Calibration—Calibration Laboratories and Measuring and Test Equipment—General requirements, First Edition, August 1994, p. 7.
4. ILAC-G2:1994 “Traceability of Measurements”, 1994
5. ILAC-G16:2001, “ILAC Policy on Traceability of Measurement Results”, 2001.